NONRESIDENT
TRAINING
COURSE

Aviation Electrician's Mate 3 & 2

NAVEDTRA 14009

PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its references to useful information to be found in other publications. The well-prepared Sailor will take the time to look up the additional information.

Any errata for this course can be found at https://www.advancement.cnet.navy.mil under Products.

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CHAPTER 1

BASIC PHYSICS

This chapter has been deleted. For information on basic physics, refer to Nonresident Training Course (NRTC) *Aviation Electricity and Electronics—Maintenance Fundamentals*, NAVEDTRA 14318, chapter 3.

CHAPTER 2

ELECTRICAL MAINTENANCE AND TROUBLESHOOTING

Aircraft maintenance falls into two broad categories—scheduled maintenance and unscheduled maintenance. Scheduled maintenance is the actions taken to reduce or eliminate failure and prolong the useful life of the equipment. Unscheduled maintenance is the actions taken when a system part or component has failed, and the equipment is out of service.

In maintenance work of any kind, you use two fundamentals—knowledge and skills. As an AE, you must have specific information about the particular equipment you repair or keep in good condition. Also, you must have certain general skills and knowledge that apply to many kinds of equipment and types of work assignments.

The specific information required consists of special procedures and processes, and detailed step-by-step directions approved by proper authority. You can find this information in publications or checklists authorized by the Naval Air Systems Command, type commanders, and other authorities.

General maintenance skills and procedures are based on knowledge that is not in equipment manuals. These skills come from schools, on-the-job training, and from training manuals such as this one.

SAFETY

Learning Objective: *In addition to general safety precautions, identify safety precautions regarding aircraft, personnel, material, and tools.*

In the performance of your duties, you come across many potentially dangerous conditions and situations. You install, maintain, and repair electrical and electronic equipment in confined spaces where high voltages are present. Among the hazards of this work are injury caused by electric shock, electrical fires, and harmful gases. Also, you must include improper use of tools among these hazards. Common sense and carefully following established rules will produce an accident-free naval career.

When working, there is one rule to stress strongly—SAFETY FIRST. Whether you are working in the shop, on the line, or during a flight, you should follow prescribed safety procedures. When working on or near aircraft, there is the danger of jet blast, losing your balance, or being struck by propeller or rotor blades. Because of these dangers, you need to develop safe and intelligent work habits. You should become a safety specialist, trained in recognizing and correcting dangerous conditions and unsafe acts.

You must know how to treat burns and how to give artificial ventilation (respiration) to persons suffering from electric shock. In some cases, you may have to perform external heart compression in addition to artificial ventilation to restore the heartbeat. Artificial ventilation and external heart compression performed together are known as *cardiopulmonary resuscitation (CPR).*

You should study the CPR training section of *Basic Military Requirements,* NAVEDTRA 14325. This text provides valuable information; however, it does **not** replace training in CPR procedures. It is your responsibility to get first aid training, including CPR. Personal CPR training is available at many Navy medical facilities. Many local fire stations and Red Cross agencies also offer this type of training. It is important for you to be currently certified in the **special skills** of CPR. One final note, you must update your CPR certification annually.

WARNING

Do not perform CPR unless you have had the proper training.

The life of a shipmate could easily depend upon **your** CPR skills. This statement is not to say that knowledge of other first aid procedures is less important.

Cooperation of personnel and being vigilant prevents most accidents that occur in noncombat operations. You can learn about general aviation safety by studying *Aviation Fundamentals,* NAVEDTRA 14318. You should study and review this manual.

GENERAL PRECAUTIONS

Only authorized personnel can repair and maintain electronic and electrical equipment because of the chance of injury, the danger of fire, and possible material damage. When you work on electrical equipment, open and tag the main supply switches or cutout switches. The tag should read as follows: "This circuit is open for repairs and shall not be closed except by direct order of __________________ (usually the person directly in charge of the repairs)."

Securely cover fuse boxes and junction boxes, except when you are working on them. Don't alter or disconnect safety devices, such as interlocks, overload relays, and fuses except when replacing them. Never change or modify safety or protective devices in any way without proper authorization.

Remove and replace fuses only after the circuit is de-energized. If a fuse blows, replace it with a fuse of the same current rating only. When possible, carefully check the circuit before making the replacement since the burned-out fuse often results from a circuit fault.

You should move slowly when working around electrical equipment. Maintain good balance and **DO NOT** lunge after falling tools. **DO NOT** work on electrical equipment if you are mentally or physically exhausted. **DO NOT** touch energized electrical equipment when standing on metal, damp, or other well grounded surfaces. **DO NOT** handle energized electrical equipment when you are wet or perspiring heavily. **DO NOT TAKE UNNECESSARY RISKS.**

Some general safety precautions that you should follow are shown below:

- REPORT ANY UNSAFE CONDITION, or any equipment or material that you consider to be unsafe, to the immediate supervisor.

- WARN OTHERS you believe to be endangered because of known hazards or who fail to follow safety precautions.

- WEAR or USE APPROVED PROTECTIVE CLOTHING or EQUIPMENT for the safe performance of work or duty.

- REPORT to the supervisors ANY INJURY or evidence of impaired health occurring during work or duty.

- EXERCISE REASONABLE CAUTION during any unforeseen hazardous occurrence, as is appropriate to the situation.

The safety precautions that apply to the work of Aviation Electrician's Mates include those you should follow when working in and around aircraft. You will also work in the electrical or battery shop. In addition to these, you need to know the authorized fire-fighting methods for electrical fires, treatment of burns, and artificial respiration.

Some of the publications you should be familiar with are listed below:

1. *Airman,* NAVEDTRA 14014
2. *Navy Occupational Safety and Health (NAVOSH),* OPNAVINST 5100.23 (series)
3. *Navy Safety Precautions for Forces Afloat,* OPNAVINST 5100.19

These publications contain a variety of operations and functions in the Navy; therefore, they are basic and general in nature. Activities use these instructions as a basis for establishing specific safety instructions for their particular equipment, weapons system, or locality.

PRECAUTIONS REGARDING AIRCRAFT

As an AE, you are exposed to flight line hazards. You will be working around moving machinery, which is dangerous. Therefore, you need to be alert when working around aircraft. Always follow your activity's instructions on the application of external power. Make sure you get a thorough safety indoctrination from your supervisor.

The maintenance instructions manual (MIM) for each type of aircraft has an illustration, such as that shown in figure 2-1 for the F/A-18 aircraft. Study the illustrations for each aircraft in your operating area. Most safety instructions require the anticollision light to be operating whenever the engine or engines are operating. This gives an additional warning so you will be aware of propellers, rotors, or jet intakes and exhausts.

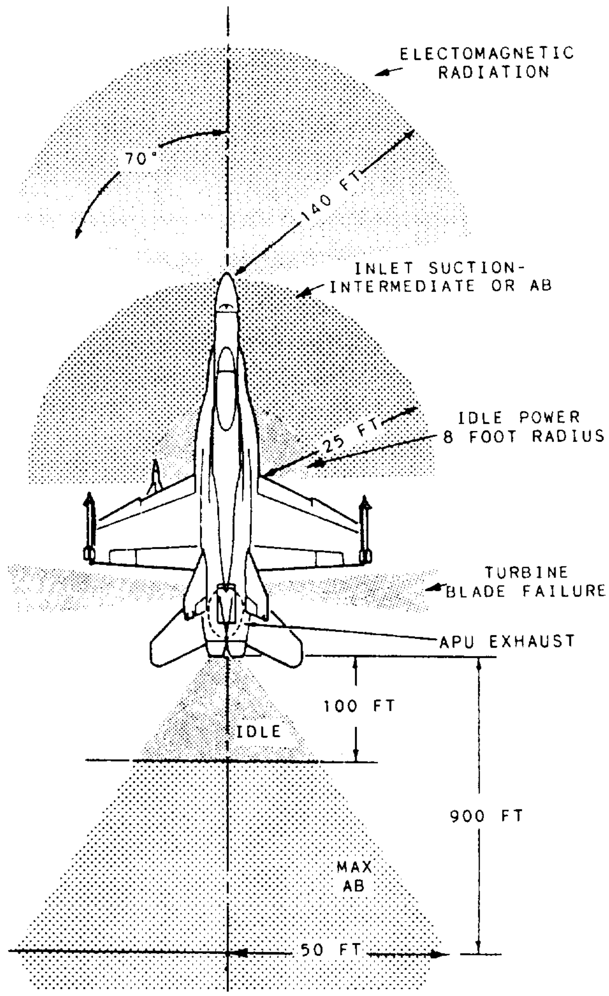

Figure 2-1.-Radiation, intake, exhaust, and turbine blade failure danger areas.

PRECAUTIONS REGARDING PERSONNEL AND MATERIALS

If possible, you shouldn't make repairs on energized circuits. When repairs on operating equipment are necessary, only experienced personnel under the supervision of a senior AE should do the work. Follow every known safety precaution carefully. Make sure there is enough light for good illumination, and there is insulation from ground, using a suitable nonconducting material. Station helpers near the main switch or the circuit breaker to de-energize the equipment immediately in case of emergency. While making the repair, someone qualified in first aid should be standing by in case of injury due to electrical shock.

High-Voltage Precautions

NEVER work alone near high-voltage equipment. Don't use tools and equipment containing metal parts within 4 feet of high-voltage circuits or any wiring having exposed surfaces. The handles of all metal tools, such as pliers and cutters, should have rubber insulating tape covers. You can't use plastic or cambric sleeving or friction tape alone for this purpose when working with circuits having a high potential voltage.

Before touching a capacitor, short-circuit the terminals to discharge the capacitor completely. Permanently attach grounded shorting prods to workbenches where electrical devices receive regular servicing.

Don't work on any type of electrical apparatus with wet hands or while wearing wet clothing. Don't wear loose or flapping clothing. Don't wear thin-soled shoes with metal plates or hobnails; wear safety shoes with nonconducting soles when available. Don't wear flammable articles, such as celluloid cap visors.

Before you work on an electrical or electronic apparatus, remove all rings, wristwatches, bracelets, and similar metal items. Make sure that your clothes do not contain exposed zippers, metal buttons, or any type of metal fastener.

Make sure warning signs and suitable guards are posted to prevent personnel from coming into accidental contact with high voltages.

Low-Voltage Precautions

Most people never realize the dangers of low-voltage electric shock. These hazards are present and dangerous. You need to be aware of their existence; you should be aware of any voltage greater than 15 volts.

DEGREE OF SHOCK. —The current that may pass through the body without causing damage depends on the individual, and the type, path, and length of contact time. The resistance of your body varies. For example, if the skin is dry and unbroken, body resistance will be quite high—on the order of 300,000 to 500,000 ohms. However, if the skin becomes moist or broken, body resistance may drop to as low as 300 ohms; a potential as low as 30 volts could cause a fatal current flow. Therefore, any circuit with a higher value potential is more dangerous. If a 60-hertz alternating current passes through the chest cavity, it has the following effects:

- At 1 milliampere (0.001 ampere), you will feel the shock.
- At 10 milliamperes (0.01 ampere), the shock paralyzes muscles, and a person may be unable to release the conductor.
- At 100 milliamperes (0.1 ampere), the shock is usually fatal if it lasts for 1 second or more. IT IS IMPORTANT TO REMEMBER THAT, FUNDAMENTALLY, CURRENT, RATHER THAN VOLTAGE, IS THE CRITERION OF SHOCK INTENSITY.

When a person is unconscious because of electrical shock, you can't tell how much current caused the condition.

BEGIN ARTIFICIAL RESPIRATION IMMEDIATELY IF BREATHING HAS STOPPED.

FIRST AID FOR ELECTRIC SHOCK. — Electric shock produces a jarring, shaking sensation. The victim usually feels like he/she just received a sudden blow. If the voltage and resulting current is high enough, the victim may become unconscious. Severe burns may appear on the skin at the place of contact. Muscular spasm may occur, causing the victim to clasp the apparatus or wire causing the shock. If this happens the victim is unable to release it.

Use the following procedures for rescuing and caring for shock victims:

1. Remove the victim from electrical contact at once. **DO NOT ENDANGER YOURSELF.** Remove the victim by throwing the switch if it is nearby, or cut the cable or wires to the apparatus, using an axe with a wooden handle. (Protect your eyes from the flash when the wires are severed.) Also, you can use a dry stick, rope, belt, coat, blanket, or any other nonconductor of electricity to drag or push the victim to safety.

2. Determine whether the victim is breathing. Keep the person lying down in a comfortable position and loosen the clothing about the neck, chest, and abdomen for easy breathing. Protect from exposure to cold, and watch closely.

3. Keep the victim from moving. In this condition, the heart is very weak. Any sudden muscular effort or activity of the patient may result in heart failure.

4. Do not give stimulants or opiates. Send for a medical doctor at once, and do not leave the patient until adequate medical care is available.

5. If the victim is not breathing, apply artificial ventilation without delay, even though the patient may be lifeless. **Do not stop artificial respiration until the victim revives, or proper authority pronounces the victim is beyond help.**

ELECTRICAL FIRES

The three general classes of fires are A, B, and C. Class A fires involve wood, paper, cotton and wool fabrics, rubbish, and the like. Class B fires involve oil, grease, gasoline and aircraft fuels, paints, and oil-soaked materials. Class C fires involve insulation and other combustible materials in electrical and electronic equipment.

Electrical or electronic equipment fires are caused by overheating, short circuits, friction (static electricity), or radio-frequency arcs. Also, equipment may ignite from exposure to nearby class A or B fires. Since class C fires involve electrical circuits, electrical shock is an added hazardous condition. Whenever possible, immediately de-energize any electrical equipments exposed to class A or class B fires, or ignited by such a fire. If the equipment cannot be de-energized completely, use protective measures to guard against electrical shock. Extinguishing agents other than gases contaminate delicate instruments, contacts, and similar electrical devices. Carbon dioxide (CO_2) is the preferred extinguishing agent for electrical fires. It does not conduct electricity, rapidly evaporates, and leaves little or no residue. It reduces the possibility of electrical shock to personnel and damage to equipment as a result of contamination.

A dry chemical extinguishing agent, composed chiefly of potassium carbonate (Purple-K), can be used on electrical fires. It is a nonconductor, which provides protection against electrical shock. However, damage to electrical or electronic parts may result from the use of this agent.

CAUTION

Never use a solid stream of water to extinguish electrical fires in energized equipment.

Water usually contains minerals that make it conductive. (The conductivity of seawater is many times greater than that of fresh water.) Pure distilled water is not a good electrical conductor, and it is suitable for emergency use on small electrical fires. If you must use fresh water or seawater, use a fog head or tip hose nozzle in electrical in electronic equipment spaces. The fog is a fine diffusion or mist of water particles, with very little conductivity. However, there is a danger of electric shock unless the equipment is completely de-energized. Also, condensation from the fog frequently damages the electrical components. Be careful when using the fire hose. Pressure at the fireplug may be as much as 100 PSI. An unrestrained fire hose may result in whiplash for the person holding it.

Do not use foam on electrical fires. Foam can damage equipment and possibly pose a shock hazard to personnel. **If necessary, you can use foam on de-energized circuits.** When a blanket of foam goes on a burning substance, the foam smothers the fire, cutting off the air supply to the burning substance. As the supply of oxygen decreases, the fire dies out.

When fighting electrical fires, you should use the following general procedures:

1. Promptly de-energize the circuit or equipment affected.
2. Sound an alarm according to station regulations or ship's fire bill. When ashore, notify the fire department; if afloat, notify the officer of the deck. Give the fire location, and state what is burning. If possible, report the extent of the fire.
3. Close compartment air vents or windows.
4. Control or extinguish the fire using a $C0_2$ fire extinguisher.
5. Avoid prolonged exposure to high concentrations of carbon dioxide in confined spaces. You can suffocate in confined spaces unless you're using special breathing apparatus.
6. Administer artificial ventilation and oxygen to a person overcome by carbon dioxide fumes, and keep the victim warm.

Even under normal conditions, fire aboard a Navy vessel at sea can kill and injure more people and cause more ship damage than happens in battle. All personnel need to know the dangers of fire. You need to know the type and location of all fire-fighting equipment and apparatus in your immediate working and berthing spaces and throughout the ship.

Volatile Liquids

Volatile liquids, such as insulating varnish, lacquer, turpentine, and kerosene, are dangerous when used near operating electrical equipment because sparks from the equipment can ignite the fumes. When these liquids are used in compartments containing nonoperating equipment, make sure there is enough ventilation to avoid an accumulation of fumes. Also, make sure the space is clear of all fumes before energizing the equipment.

Never use alcohol or gasoline for cleaning; use only an approved cleaning agent.

Today, all aviation fuels are hydrocarbons. Handling hydrocarbon products is hazardous because of their flash point. Products such as gasoline, solvents, and most crude oils begin to vaporizes at or below 80°F; their flash point is reached at 80°F. Their flash point makes them the most hazardous petroleum products to handle. Other petroleum products, such as kerosene and lubricating oils, have a flash point above 80°F, making them less hazardous.

The vapors of petroleum, gasoline, and other petroleum products cause drowsiness when inhaled. Petroleum vapors in concentrations of 0.1 percent can cause dizziness to the extent of inability to walk straight after 4 minutes of exposure. Longer exposure and/or greater concentrations may cause unconsciousness or death.

The first symptoms of exposure to toxic (poisonous) vapors are headaches, nausea, and dizziness. When working in an area where there are possible toxic vapors, stay alert. If you get a headache, become dizzy, or become nauseous, you might be exposed to toxic vapors. You should leave the area and report the condition.

You recover from early symptoms quickly when you move to an area having fresh air. If you find people overcome by vapors, get them immediate medical attention. First aid consists of the prevention of chilling, and, if breathing has stopped, artificial respiration.

If gasoline remains in contact with you skin, it may irritate the skin, particularly under soaked clothing or gloves. Remove clothing or shoes soaked with gasoline at once. Wash gasoline from the skin with soap and water. Repeated contact with gasoline removes protective oils from the skin, causing drying, roughening, chapping, and cracking, and in some cases, infection. While removing your clothes, an arc, caused by static electricity, can cause the fuel to ignite. For this reason, remove fuel soaked clothes in a running shower.

If a person swallows gasoline, give first aid immediately. You should give the victim large amounts of water or milk and 4 tablespoons of vegetable oil, if available.

DO NOT INDUCE VOMITING. GET MEDICAL ATTENTION IMMEDIATELY.

JP-4 fuel has some of the characteristics of gasoline. Due to different characteristics, such as lower vapor pressure and high aromatic content (compounds added to increase the performance number), handle this fuel very carefully.

JP-5 is a kerosene type of fuel. It has a vapor pressure close to 0 PSI. Since its tendency to vaporize is lower than the more volatile grades, the vapor-air mixture above its liquid surface is too lean to ignite. For ignition to occur, the liquid's surface must reach 140°F. Handle this fuel with care.

Take precautions to prevent personnel from breathing fumes from any fuel. Also prevent fuel from coming in contact with the skin, especially if the skin has abrasions, or sores.

Compressed Air

Compressed air, when misused, is dangerous. Injuries occur through hose or fitting failures, causing the hose to whip dangerously and propelling fitting parts through the air. Blowing dust and small particles become an eye hazard. Air under pressure may cause internal injury or even death by introducing an airstream into body tissue, usually through an existing cut or scratch. Air can rupture cell tissues and cause severe wounds through injection of minute foreign bodies into the skin. Impurities always exist in a shop's air supply. Falls can result from tripping over air lines thoughtlessly left lying on the floor.

CAUTION

Compressed air is a special tool, do not use as a substitute for a brush to clean machines, clothing, or your person. In those cases where an air hose is essential for blowing out fixtures and jigs, wear eye protection and maintain air pressure below a maximum of 30 PSI. It is also desirable to place screens around work to confine the blown particles.

The National Safety Council has published the following general safety rules for working with compressed air:

1. Use only sound, strong hose with secure couplings and connections.
2. Make sure there aren't any sharp points on metal hose parts.
3. Close the control valve in portable pneumatic tools before turning on air.
4. Turn off air at the control valve before changing pneumatic tools. Never kink a hose to stop the airflow.
5. Wear suitable goggles, mask, protective clothing, or safety devices.
6. Never use air to blow dust chips from work clothing or from workbenches.
7. Never point the hose at anyone. Practical jokes with compressed air have caused painful deaths.
8. When using compressed air, see that nearby workers are not in line of airflow.

PRECAUTIONS REGARDING TOOLS

The tools you use should conform to Navy standards as to quality and type. You should use them only for the purposes of their design. Maintain tools in good repair, and turn in all damaged or nonworking tools.

As an AE, you will use hand tools. By using them correctly, you will improve the quality of maintenance and reduce the chance of failures. All third and second class AEs should complete *Tools and Their Uses,* NAVEDTRA 14256.

Carelessness is the biggest menace in any shop. A machine doesn't inflict injury. Operator inattention is the cause of most accidents in electrical and electronics shops today. Remember, all moving machinery is dangerous. Its not safe to lean against any machine that is or may start to move. Don't start a machine until you know how to operate it. Treat a machine with respect; there is no need to fear it. Do not start a machine until you fully understand its operation.

Always follow the two basic safety precautions stated below:

1. Use the proper tool for its intended function, and use it correctly.
2. Keep all tools in working order and in a safe condition.

Sharpen or replace dulled cutting tools. Protect tools from damage while in use or in stowage. If a tool becomes worn, damaged, or broken, report it to the work center supervisor. Always clean, inspect, and account for all tools after you complete a job. Return all tools to their proper stowage place.

Nonmagnetic Tools

You can get tools made of nonmagnetic materials through normal supply channels. You will use them to maintain equipment that can be damaged if tools become magnetized. Normally, these tools are made from beryllium-copper or plastic. They aren't as rugged as steel tools, and can be damaged easily. Use them properly; they will last longer and operate properly.

NOTE: Do not etch beryllium-copper tools.

When working near compasses and other components containing permanent magnets, you always use nonmagnetic tools. Magnetic-susceptible tools could become magnetized and transfer this magnetic condition to other equipment.

Insulated Tools

Often, safety considerations require use of insulated tools. You can get many types of insulated tools directly through supply channels. If you can't get insulated tools through normal supply channels, buy these tools locally, or modify conventional tools. Put insulated sleeving on the handles of pliers and wrenches and on the shanks of screwdrivers. **Only use tools modified in this way on low-voltage circuits only because of the insulating material's limitations.** You can get special insulating handles for many common tools you use when working on equipment containing higher voltages.

Power Tools

In working as an Aviation Electrician's Mate, you will use some shop machinery, such as a power grinder or drill press. In addition to the general precautions on the use of tools, there are a few other precautions to follow when working with machinery. Some of the precautions are as follows:

1. Never operate a machine with a guard or cover removed.
2. Never operate mechanical or powered equipment unless you know how to operate them. When in doubt, consult the appropriate instruction or ask someone who knows.
3. Always make sure that everyone is clear before starting or operating mechanical equipment.
4. Cut off the source of power before trying to clear jammed machinery.
5. Always keep everyone clear when hoisting heavy machinery or equipment by a chain fall. Guide the hoist with lines attached to the equipment.
6. Never plug in electric machinery without knowing that the source voltage is the same as that called for on the nameplate of the machine.

Carefully inspect all portable power tools to be sure they are clean, well-oiled, and in working order before you use them. The switches should operate normally, and the cords should be clean and free of defects. Ground the casings of all electrically driven tools. Do not use sparking portable electric tools in any place where flammable vapors, gases, liquids, or exposed explosives are present.

Check to make sure that power cords do not come in contact with sharp objects. Don't let cords kink. Don't leave them where they might be run over. Don't let cords contact oil, grease, hot surfaces, or chemicals. When damaged, replace power cords. When unplugging power tools from receptacles, you should grasp the plug, not the cord.

Soldering Iron

The soldering iron is a potential fire hazard and a source of burns. Always assume a soldering iron is hot. Never rest the iron anywhere but on a metal surface or rack provided for that purpose. Keep the iron holder in the open to reduce the danger of fire from accumulated heat. Don't shake the iron to get rid of excess solder. The hot solder may strike someone or the equipment, causing a short circuit. Hold small soldering jobs with pliers or clamps.

When you are cleaning the iron, place the cleaning rag on a suitable surface and wipe the iron across it. Don't hold the rag in your hand. Disconnect the iron when leaving the work area, even for a short time—the delay may be longer than planned.

Grounding

A poor safety ground, or one with incorrect wiring, is more dangerous than no ground at all, A poor ground is dangerous because it doesn't offer full protection; it lulls you into a false sense of security. The incorrectly wired ground is a hazard because one of the live wires and the safety ground are transposed. When this happens the shell of the tool is *hot* the instant the plug connects into the outlet. You will get a shock unless the safety ground connects to the grounded side of the line on a single-phase grounded system, or no grounds are present on an ungrounded system. Today, a three-wire, standard, color-coded cord with a polarized plug and a ground pin is used.

In all properly connected new tools, the green wire is the safety ground. This wire attaches to the tool's metal case at one end and to the polarized grounding pin at the other end. It normally carries no current, and is in use only when the tool insulation fails. When this happens, the safety ground short-circuits the electricity around the user to ground and protects that person from shock.

To check the grounding system resistance, you use a low-reading ohmmeter to be certain the safety ground is adequate. If the resistance shows greater than 0.1 ohm, you should use a separate ground strap.

Some old installations do not have receptacles that will accept the grounding plug. If you are working on these, use one of the following adaptations:

- Use an adapter fitting.
- Use the old type plug and bring the green ground wire out separately.
- Connect an independent safety groundline.

When you use an adapter, connect the ground lead extension to a good ground. Don't use the center screw that holds the cover plate on the receptacle. Where separate safety ground leads are connected externally, connect the ground first, and then plug in the tool. Likewise, when disconnecting the tool, first remove the line plug, and then disconnect the safety ground. **ALWAYS CONNECT THE SAFETY GROUND FIRST AND REMOVE IT LAST.**

UNSCHEDULED MAINTENANCE

Unscheduled maintenance is the performance of a repair action without a set interval. Discrepancies found before, during, and after flight fall into this category. Some of the duties performed during unscheduled maintenance are shown below:

- Visually check equipment for loose leads, improper connections, damaged or broken components, etc., before applying power to the equipment. This check applies particularly to new equipment preserved or stored for long periods and equipment exposed to the weather.
- Conduct a close visual inspection on O-rings, gaskets, and other types of seals when the equipment under check is a pressurized component. A visual inspection often reveals discrepancies that you can correct at that time with minimum labor and parts. Such discrepancies, if left uncorrected, might result in loss of an aircraft or a major maintenance problem.

REVIEW SUBSET NUMBER 1

Q1. What is the ONE rule you should always follow when working on electric or electronic equipment?

Q2. When working on an electrical system, what should you do to the power supply?

Q3. Name the manual that you should refer to for an illustration of the danger areas for your aircraft.

Q4. What exterior light is required to be on during engine operation?

Q5. When working on a/an ________________ circuit, you need to have a person who is fully qualified in first aid standing by.

Q6. Before touching a capacitor, you should be sure it is discharged by ________________

____

Q7. When removing a victim from electrical contact, you should not take what action?

Q8. List the three classes of fires.

Q9. What is the preferred fire extinguishing agent for electrical fires?

Q10. What are the two basic rules you should follow when working with hand tools?

TROUBLESHOOTING TECHNIQUES

Learning Objective: *Recognize troubleshooting techniques, including how to analyze, detect, and correct faults in electrical equipment.*

You will spend most of your time troubleshooting the equipment in squadron aircraft. You maintain many components and systems that are complex and difficult to troubleshoot. However, the most difficult troubleshooting job will become simple if you break it down into the following steps:

1. Analyze the symptom.
2. Detect and isolate the trouble.
3. Correct the trouble and test the work.

ANALYZE

If you don't understand a system or component, you can't find out what's wrong with it. The following are tools that will help you analyze what's wrong with a system or component:

- Maintenance instructions manuals (MIMs)
- Schematics
- Records on the equipment

DETECT AND ISOLATE

The first thing to do when troubleshooting is to visually inspect the component. If parts are obviously not in proper condition, correct these faults before going any further. The types of things to look for include open circuit breakers, improperly placed switches, burnt equipment, loose mountings, disconnected components, and dented equipment.

If you can't find anything after visually inspecting the equipment, check the condition of fuses and circuit breakers. Sometimes, a circuit protector will open. If so, reset or replace the circuit protector and apply power. If the protector opens again, secure the power because there is a probable circuit malfunction. Don't apply power until after you correct the malfunction.

At this point, use the MIM for equipment. By using the MIM, you will know which pin in a connector is the power input to the connector. You can use the MIM to close the correct circuit breakers and locate the switches to use for testing. If there is power to the component and it still does not work, then the fault is with the component itself.

If a short, ground, or overload condition is not indicated, take power readings at the checkpoints shown in the MIMs. Common faults that interrupt power through a circuit are broken wiring, loose terminal or plug connections, faulty relays, and faulty switches. Look for these conditions when checking points along a circuit. If there is no power reaching the component, assume that the component is good, and start checking the power supply. Begin the check at the bus that supplies the power. If you find evidence of a short circuit or overload, secure the power. At this time, you need to make continuity and resistance checks.

Continuity and Resistance Checks

The process of fault detection often leads beyond visual inspection and power checks. You use a voltmeter to find out if a power circuit is delivering power to the proper place. However, the voltmeter won't identify what is wrong. An ohmmeter is a better instrument for identifying the problem. With the ohmmeter, you can find opens, shorts, grounds, or incorrect resistance values. You use the schematic to trace circuits in components, part by part and wire by wire, until you isolate the trouble. You can use the MIM for the equipment to find the proper resistance readings.

At intermediate maintenance activities, bench-test installations are used for off-equipment testing. In this type of installation, there is a complete and fully operational system with the components grouped closely together. This lets the troubleshooter remove any unit and replace it with the one for testing. Bench-testing components is used when the trouble is hard to determine. It might be used when the unit is functioning, but does not measure up to minimum standards. Bench tests are highly specialized test installations, and only specific tests can be run on specific components. Normally, AEs troubleshoot using a meter and a schematic.

Nonelectric Components

So far, you have learned about fault detection in systems using electric power. However, a group of systems and components do not use electricity. This group includes such items as mechanical instruments, direct reading gauges, and mechanisms closely associated with electrical equipment. Such mechanisms are switch actuators, mounting assemblies, mechanical linkages, and any type of hardware that is part of an electrical system. You can not check this equipment with a volt-ohmmeter, but the three basic rules for troubleshooting remain the same—analyze, detect, and correct.

CORRECT AND TEST

Many faults may occur, and for each fault you must perform a corrective action. There are rules that apply to practically all corrective actions. In some cases, the detection of a fault involves more time and labor than correcting it.

Study the job and think through each step. Form a plan of attack, and decide which tools you need. In addition to hand tools, consider equipment, such as extension lights and cooling blowers. Refer to the MIM. It lists special tools you need and also describes how to gain access to a system component or area. Ask someone who has performed that particular job before; he/she can usually offer some very good pointers.

As a troubleshooter, you should plan how to deal with special safety considerations you might meet during a job. Some of these are hydraulic oil drainage from disconnected lines, dangling and unprotected power cables, high-pressure air lines, and the handling of heavy components. Drain or bleed off gas or liquid lines, and handle heavy objects with special care.

NOTE: Only Aviation Structural Mechanics (AMEs) work on oxygen lines.

If exposed power cables are unavoidably left loose, use some means to avoid their shorting out. You can do this by covering them with a temporary insulating shield. Place a warning sign on the main power switch in the cockpit and on the external power receptacle. Another very good precautionary measure, where applicable, is to disconnect the aircraft battery. In this case, place a sign in the cockpit stating the battery is disconnected. Complete all of the safety measures mentioned here before starting work.

The nature of the job determines the procedures you will use to actually do the work. You will either repair or replace the component or system. Total job quality depends on the quality of work on smaller components/systems, such as soldering, replacing connecting devices, safety wiring, and using tools.

Learn and practice good techniques. Working under the supervision of an experienced AE is one way to learn them. Another place to look for approved methods is in *Installation Practices Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505. It contains the accepted way of performing many practical operations, and it is well illustrated.

Often, parts replacement is the best way to correct a malfunction. However, never use parts replacement as a method of troubleshooting. Each year, thousands of dollars worth of instruments and *black boxes* are returned to overhaul activities with labels stating that they are faulty. Upon completion of test and check by the overhaul activity, many have no defect. This practice is wasteful and very expensive. The replacement of an entire unit when only a small part is at fault reflects poor maintenance practices. A typical example of such a case is the replacement of an entire compass amplifier when there is only a faulty fuse. When troubleshooting, remember you are working with equipment that is both expensive and scarce. Make decisions to replace equipment only after thoroughly testing it and making sure it is faulty.

For the procedures to follow when replacing and testing equipment, refer to the removal, installation, and testing section of the MIM. Some of the topics covered in the MIMs are discussed in the following paragraphs.

Removal. Remove equipment in such a way that you don't damage it more and you don't damage nearby structures. Pay attention so you don't loose or misplace small parts. They maybe easy to replace with new ones, but small items lost in the aircraft are a very real foreign object damage (FOD) hazard. **FOD kills!**

If you can't finish installing the new part immediately, remove all tools and parts from the aircraft during the waiting period. You might forget and leave them in the aircraft. This precaution applies to any unfinished job involving a waiting period. Before you remove the defective part from the aircraft, pull and tag circuit protective devices and notify maintenance control, This prevents people from turning on fuel pumps when fuel lines are open. Also, it prevents power being applied to loose cables.

Installation. Many of the rules for removal apply to installation. However, there are a few rules that apply almost exclusively to installing new equipment. Some units have special conditions while in shipment. Look for these conditions because they often require you to remove sealing plugs, locking devices, and other special equipment from the component before you can install it. If adjustments are necessary on new equipment, you might need to make the adjustments before completing the installation. For example, often the matching of a position transmitter to the position indicator is easier to do with only the electric wiring connected to the actuator. After calibration, complete the mechanical mounting. Again, the only guide for making adjustments to any system is the MIM. In the final installation, make sure that all mounting hardware is in place and properly tightened. Also, make sure all cable and line connections are secure and connected to the proper points.

Testing. The entire process of detecting and correcting a fault means nothing unless the system operates properly. Therefore, the final step of the job is to test the equipment. This test is usually an operational test. Where possible, simply operate the new component or system to see that it is doing its job properly. When a final check shows the job is complete, you must pass this word quickly to those concerned. Officially, the aircraft is down until the proper people are notified.

REVIEW SUBSET NUMBER 2

Q1. List the three steps that will make your troubleshooting easier.

Q2. What is the best test equipment to use when looking for shorts, grounds, opens, and wrong resistances?

Q3. You should never use a ______________ as a troubleshooting method because it is expensive and does not always fix the fault.

Q4. After removing apart, you should always look for small items from the work to ensure they do not become what type of a hazard?

Q5. List the tools that help you analyze a system.

Q6. What is the first action to take when beginning to troubleshoot apiece of equipment?

Q7. What types of common faults interrupt power through a circuit?

Q8. List a reference to which you can refer for approved maintenance procedures.

Q9. You should refer to the ______________ for procedures to follow when removing and replacing equipment?

Q10. What is the purpose of testing a piece of equipment after it has been repaired?

USE OF BASIC TEST EQUIPMENT

Learning Objective: *Recognize the various types of general-purpose test equipments associated with aircraft electrical maintenance, and identify tests the AE will make using these equipment.*

Test equipment, like any other tool the AE uses, is susceptible to damage, misuse, and deterioration. Knowledge of the Navy calibration program is essential to ensure your shop or division has the most reliable test equipment. For more information on the calibration program, refer to the latest edition of *Aviation Maintenance Ratings Fundamentals,* NAVEDTRA 10342-3, and NEETS, module 16. Also, when making tests on equipment, you should adhere to the following rules:

1. Always connect an ammeter in series—never in parallel.
2. Always connect a voltmeter in parallel—never in series.
3. Never connect an ohmmeter to an energized circuit.
4. On test meters, select the highest range first, then switch to lower ranges as needed.
5. When you use an ohmmeter, select a scale that gives a near midscale reading, since midscale is where the meter is most accurate.
6. Do not leave the multimeter selector switch in a resistance position when not using the meter. The leads may short together discharging the internal battery. There is less chance of damaging the meter if the switch is on a high ac volts setting, or in the OFF position. Meters that have an OFF position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when moving the meter.
7. View the meter from directly in front to eliminate parallax error.
8. Observe polarity when measuring dc voltage or current.
9. Do not place meters in the presence of strong magnetic fields.
10. Never measure the resistance of a meter or a circuit with a meter in it. The high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-filament-current tubes and to some types of semiconductors.
11. When you are measuring high resistance, do not touch the test lead tips or the circuit. Doing so may cause body resistance to shunt the circuit, causing an erroneous reading.
12. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

CONTINUITY TESTS

In open circuits, current flow stops. The cause may be a broken wire, defective switch, etc. To detect open circuits, you perform a continuity test, which will tell if the circuit is complete or continuous.

To make a continuity test, you will use an ohmmeter. Normally, you will make this test in a circuit where the resistance is low, such as the resistance of a copper conductor. If the resistance is very high or infinite, the resistance between the two points shows an open circuit.

Look at figure 2-2. It shows a continuity test of a cable connecting two electronic units. You can see that both plugs are disconnected, and the ohmmeter is connected in series with conductor A, which is under test. The power should be off. When checking conductors A, B, and C, the current from the ohmmeter flows through plug 2 (female), conductor A, B, or C, to plug 1 (female). From plug 1, current passes through the jumper to the chassis, which is grounded to the aircraft structure. The aircraft structure serves as the return path to the chassis of unit 2 and completes the circuit through the series-connected ohmmeter. The ohmmeter shows a low resistance because no break exists in conductors A, B, or C. However, checking conductor D (shown by reading in figure) reveals an open. The ohmmeter shows maximum resistance because current cannot flow in an open circuit. With an open circuit, the ohmmeter needle is all the way to the left since it is a series-type ohmmeter (reads right to left).

If you can't use the aircraft structure as the return path, use one of the other conductors (known to be good.) This technique will also reveal the open in the circuit.

GROUNDED CIRCUIT TEST

Grounded circuits happen when some circuit part makes contact either with the aircraft metallic framework or with a metal object that is a ground. The most common cause of grounds is insulation fraying from a wire, allowing the conductor to come in contact with aircraft structure.

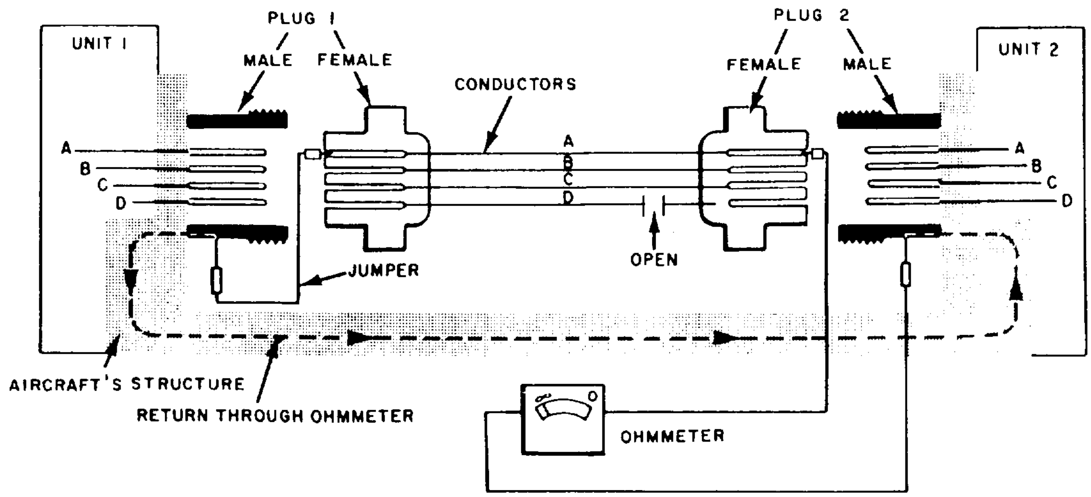

Figure 2-2.-Continuity test.

When testing for grounds, you use an ohmmeter or some other continuity tester. By measuring the resistance to ground at any point in a circuit, you can determine if the point goes to ground. Look at figure 2-2. After removing the jumper from pin A of plug 1, you can test each cable conductor for grounds. To do this, connect one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance shows that a pin is shorting to ground. For this test you remove both plugs from their units; if you remove only one plug, a false indication is possible.

SHORT TEST

A short circuit occurs when two conductors accidentally touch each other directly or through another conducting element. In a short circuit, enough current may flow to blow a fuse or open a circuit breaker. It is possible to have a short between two cables carrying signals and the short not blow the fuse.

You use an ohmmeter to check for a short. By measuring the resistance between two conductors, you may detect a short between them by a low resistance reading. Refer to figure 2-2. If you remove the jumper and disconnect both plugs, you can make a short test. You can do this by measuring the resistance between the two suspected conductors.

Shorts not only happen in cables, they occur in many components, such as transformers, motor windings, capacitors, etc. The major method for testing such components is to make a resistance measurement and compare the indicated resistance with the resistance given on schematics or in maintenance manuals.

VOLTAGE TESTS

Voltage checks are made while the power is applied; therefore, you must follow the prescribed safety precautions to prevent injury to personnel and equipment damage. Voltage tests are important. You will use them to isolate malfunctions to major components and to maintain subassemblies, units, and circuits.

The voltmeter is used to test voltages. When you use the voltmeter, make sure the meter is the correct one for the type current (ac or dc) under test. Also, make sure it has a scale with a suitable range. Since defective parts in a circuit may cause higher than normal voltages to be present at the point of test, use the **highest** voltmeter range available first. Once you get a reading, you can determine if a lower scale is possible. If so, you use the lower scale as it provides a more accurate reading.

Another consideration in the circuit voltage test is the resistance and current in the circuit. A low resistance in a high-current circuit may cause a considerable voltage drop. The same resistance in a low-current circuit may cause a minimal voltage drop. You can check abnormal resistance in part of a circuit with either an ohmmeter or a voltmeter. Where practical, use an ohmmeter because the test is then on a **dead** circuit.

Normally, you will work on low-current electronic circuits. Schematics show the voltages at various test points. If you suspect that a certain stage is defective, you may check the voltage by connecting a voltmeter from the test point to ground. If the suspected stage is good, the voltmeter readings will match the voltages given on the schematic.

Some technical manuals contain voltage charts. These charts usually show the sensitivity of the meter (e.g., 20,000 ohms/volt) you should use to take the voltage readings for the chart. To get comparable results, you must use a voltmeter of the same sensitivity (or greater) as that specified. This is to be sure the voltmeter is not loading the circuit while taking a measurement. If the meter resistance is not considerably higher than circuit resistance, the reading will be markedly lower than true circuit voltage because of the voltmeter's loading effect.

AMMETER

The ammeter connects in series with the current path. Circuits requiring frequent current readings or adjustments provide current jacks for use with a plug-in meter. Some systems have a meter installed as part of the equipment.

OHMMETER

The Navy does not have an instrument consisting solely of an ohmmeter. The ohmmeter and the voltmeter form a multimeter. Therefore, you must determine the choice of ohmmeter by the resistance ranges available in the various multimeters. Small multi meters have a high range of R x 100; larger multimeters, such as the AN/PSM-4, have a high range of R x 10,000. VTVM TS-505A/D has a high range of R x 1,000,000.

WHEATSTONE BRIDGE

Resistance measurements taken using an ohmmeter are not always accurate enough. The cause of this inaccuracy is an error in meter movement and in the reading of the meter. The Wheatstone bridge (fig. 2-3) is widely used for precise resistance measurements.

Resistors R1, R2, and R3 are precision, variable resistors. The value of Rx is an unknown value of resistance that you must determine. After properly balancing the bridge, you can find the unknown resistance by using a simple formula.

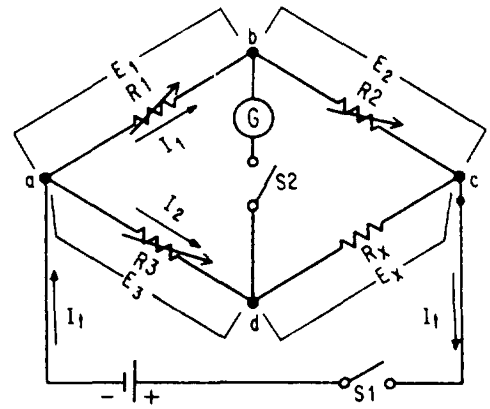

Figure 2-3.-Wheatstone bridge.

The galvanometers (an instrument that measures small amounts of current) across terminals b and d shows the condition of balance. When the bridge is in balance, no difference in potential exists across terminals b and d; when switch S2 closes, the galvanometers reading is 0.

When the battery switch (S1) closes, electrons flow from the negative terminal of the battery to point a. Here, the current divides as it would in any parallel circuit. Part of it passes through R1 and R2; the remainder passes through R3 and R_x. The two currents, I_1 and I_2, unite at point c and return to the positive terminal of the battery. The value of I_1 depends on the resistance of R1 and R2, and the value of I_2 depends on the resistances of R3 and R_x. The current is inversely proportional to the resistance.

Adjust R1, R2, and R3 so when S1 closes, and no current flows through G. When the galvanometers shows no deflection, there is no difference in potential between points b and d. All of I_1 follows the $a \rightarrow b \rightarrow c$ path, and all of I_2 follows the $a \rightarrow d \rightarrow c$ path. This means that voltage drop E_1 is the same as voltage drop E_3. Similarly, the voltage drops across R2 and R_x (E_2 and E_x) are also equal.

$$E_1 = E_3$$

$$I_1R_1 = I_2R_3, \text{ AND}$$

$$E_2 = E_x$$

$$I_1R_2 = I_2R_x.$$

With this information, you can figure the value of unknown resistor R_x. Divide the voltage drops across R1 and R3 by their respective voltage drops across R2 and R_x as follows:

$$\frac{I_1R_1}{I_1R_2} = \frac{I_2R_3}{I_2R_x}$$

Simplify this equation:

$$\frac{R_1}{R_2} = \frac{R_3}{R_x}$$

Then, multiply both sides of the expression by R_x to separate it:

$$R_x = \frac{R_2R_3}{R_1}.$$

For example, in figure 2-3, you know that R1 is 60 ohms, R2 is 100 ohms, and R3 is 200 ohms. To find the value of R_x, use the formula as follows:

$$R_x = \frac{R2R3}{R_1}$$

$$R_x = \frac{100 \times 200}{60}$$

$$R_x = \frac{20000}{60}$$

$$R_x = 333.33 \text{ ohms}$$

The Wheatstone bridge is widely used to get precise resistance measurements. You can measure capacitance, inductance, and resistance for precise accuracy by using ac bridges. These bridges consist of capacitors, inductors, and resistors in a wide variety of combinations.

DC VOLTMETER

When selecting a dc voltmeter, you should consider the sensitivity of the meter movement and its effect on the circuit under test. Navy Electricity and Electronics Training Series (NEETS), Module 16, discusses meter sensitivity.

Use a multimeter having low sensitivity for quick, rough readings where approximations are adequate. When desiring a high degree of accuracy, use a meter having high sensitivity. Such a meter has wide application in the maintenance of medium- and high-impedance electronic circuits found in aviation electrical/instrument systems.

A vacuum tube voltmeter, because of its high input impedance, is the ideal instrument for measuring low voltage in oscillators, automatic gain control, automatic frequency control, and other electronic circuits sensitive to loading, When measuring voltages of more than 500 volts, a multimeter having a sensitivity of 20,000 ohms per volt has an input impedance comparable to most vacuum tube voltmeters. The input impedance of most vacuum tube voltmeters is between 3 and 10 megohms. A 20,000-ohm-per-volt meter, when reading a voltage of 500 volts, has an input impedance of 500 x 20,000 or 10 megohms. Therefore, on the 500-volt scale, a multimeter of this sensitivity has an input impedance at least equal to the vacuum tube voltmeter. For voltage readings over 500 volts, a 20,000-ohms-per-volt multimeter offers an input impedance higher than the vacuum tube voltmeter.

You can use any multirange voltmeter, though its sensitivity may not exceed 1,000 ohms per volt, to get fairly reliable readings in a dc circuit. If you do not know the impedance of the circuit under test, a comparison of two voltage readings will show if the meter is having a loading effect on the circuit. Take the voltage readings on the lowest usable range and the on the next higher range. If the two readings are approximately the same, the meter is not causing appreciable voltage variations, and you can accept the higher reading as the true voltage. If the two readings differ considerably, the true voltage may be found by the following formula:

$$E = \frac{E2 - E1}{\frac{E_1R}{E_2} - 1} + E_2$$

where E is the true voltage

E_1 is the lower of the two voltage readings.

E_2 is the higher of the two voltage readings.

R is the ratio of the higher voltage range to the lower voltage range.

As an example of how the formula works, make the following assumptions:

1. A reading of 22 volts was obtained between two terminals with the meter on the 0-30 volt scale.
2. A reading of 82 volts was obtained from the same terminals with the meter on the 0-300 volt scale.

The true voltage is found as follows:

$$E = \frac{82 - 22}{\frac{22 \times 10}{82} - 1} + 82$$

$$E = 117.7 \text{ volts}$$

MULTIMETER

During troubleshooting, you will often measure voltage, current, and resistance. Rather than using three or more separate meters for these measurements, you can use the multimeter. The multimeter contains circuitry that allows it to be a voltmeter, an ammeter, or an ohmmeter. A multimeter is often called a volt-ohm-milliammeter (VOM).

One advantage of a VOM is that no external power source is necessary for its operation. Therefore, no warm-up is necessary. It is a portable, versatile meter that is free of calibration errors caused by aging tubes or line voltage variations.

The VOM does have two disadvantages:

1. The VOM can load the circuit under test.
2. The meter movement is easy to damage because of improper testing procedures.

The VOM (fig. 2-4) includes all the necessary switches, jacks, and additional devices arranged in a compact, portable case. It uses one meter movement. The permanent-magnet, moving-coil meter mechanism responds only to direct current. To adapt this mechanism for measuring alternating current and voltages, a rectifier or thermal converter must be used.

The use of a rectifier affects the calibration of the meter. Waveforms of various shapes have

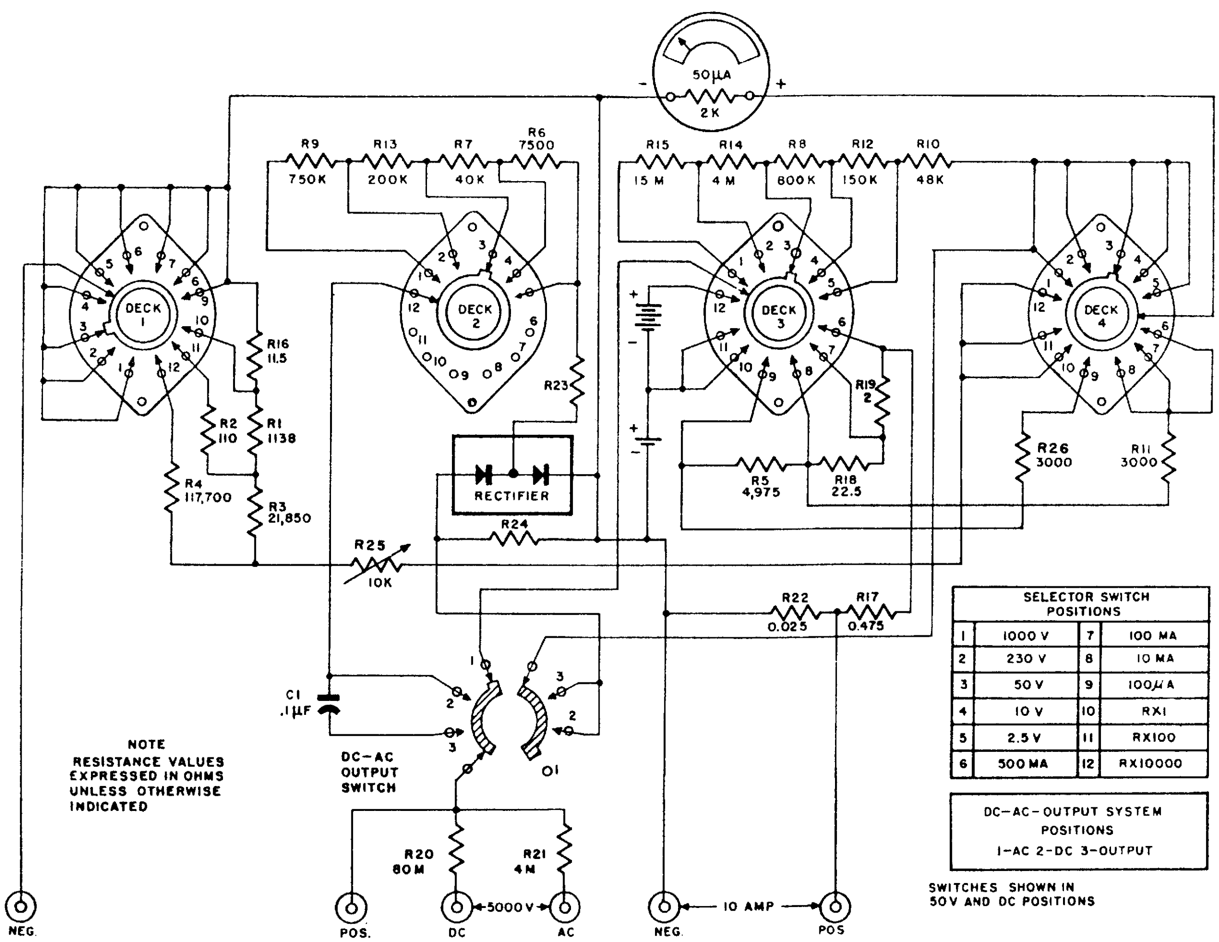

Figure 2-4.—Schematic diagram of a typical multimeter.

different average and effective values. Since this meter mechanism responds only to the average value, you must take into consideration the waveform shape when calibrating the meter for effective value. Thus, the meter reading is correct only on waveforms for which the meter is calibrated. In this respect, the instrument has a definite limitation because waveforms may vary considerably in conventional circuits. For example, the sine-wave voltage response of a half-wave rectifier is 32 percent of maximum for the average value, and 50 percent for the effective value. The full-wave rectifier response is 64 and 71 percent, respectively. In the design of the meter, these values are taken into consideration, and the scales are plotted to read in effective units when calibrated against an accurate standard.

DIGITAL MULTIMETER

The digital multimeter is an accurate, reliable measuring instrument used at the organizational, intermediate, and depot levels of maintenance. The instrument is easy to use and read. Also, some digital multimeters have a battery pack for the portable operation.

The Fluke Model 8100A (fig. 2-5) is representative of digital multimeters presently used in the fleet. It is a small, compact unit that weighs 10 pounds, including the optional battery pack. It is capable of measuring ac and dc voltages to a maximum of 1,000 volts and resistance to 10 megohms. Standard features of the Model 8100A include protection against overvoltages, a selectable input filter, autopolarity. push-button function, and range selection. Also, it has a full four-digit readout plus a *1* in a fifth digit to show overranging. The unit operates from voltages of either 115 or 230 volts at frequencies from 50 to 500 Hz. An optional rechargeable nickel-cadmium battery pack can power the unit for 8 continuous hours. Accessories and options besides the rechargeable battery pack are a high-frequency probe, a high-voltage probe, and switched ac/dc current shunts.

MEGGER

Ordinary ohmmeters cannot be used to measure multimillion ohm values of resistances, such as those in conductor insulation. To test for insulation breakdown, you use a much higher potential than that supplied by the battery of an ohmmeter. This potential is placed between the conductor and the outside of the insulation. You will use a megger (megohmmeter) for these tests.

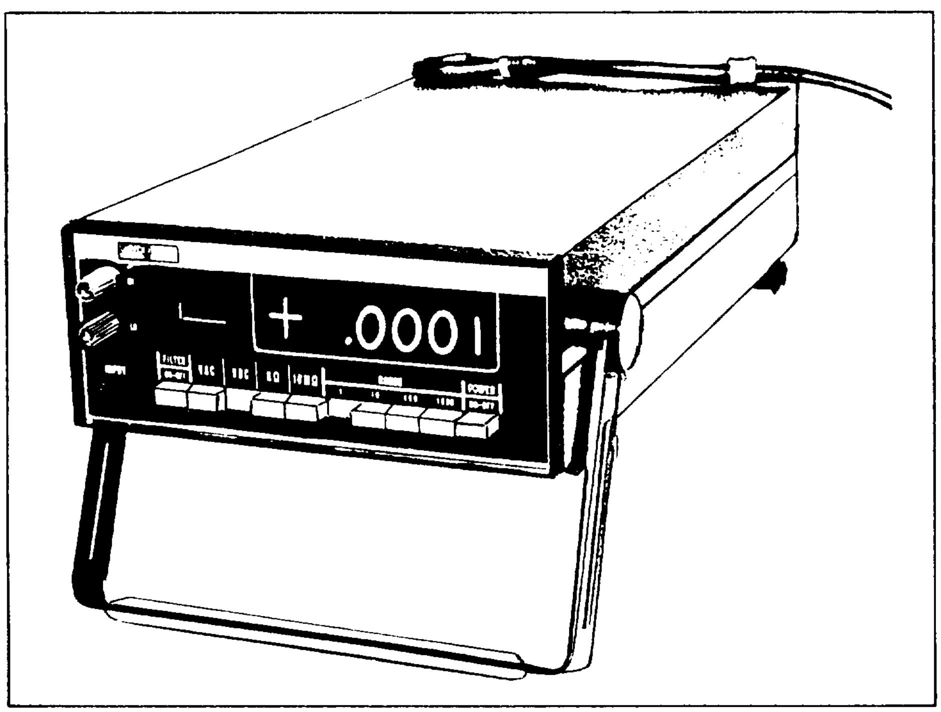

Figure 2-5.-Digital multimeter.

The megger (fig. 2-6) is a portable instrument consisting of two main elements.

1. The hand-driven dc generator, which supplies the voltage for making the measurement, and
2. the instrument portion, which shows the value of the resistance you are measuring.

The instrument portion is of the opposed-coil type, as shown in view A. Coils **a** and **b** are on movable member **c.** A fixed angular relationship exists between coils; they are free to turn as a unit in a magnetic field. Coil **b** moves the pointer counterclockwise, and coil **a** moves it clockwise.

Coil a connects in series with R3 and unknown resistance R_x. The combination of coil **a,** R3, and R_x forms a direct series path between the + and – brushes of the dc generator. Coil **b** connects in series with R2. This combination also connects across the generator. Notice that the movable member (pointer) of the instrument portion of the megger has no restoring springs. Therefore, when the generator is not operating, the pointer will float freely and may come to rest at any position on the scale.

The guard ring, shown in figure 2-6, view A, shunts any leakage currents to the negative side of the generator. This prevents such current from flowing through coil a and affecting the meter reading.

If the test leads are open, no current will flow in coil **a.** However, current will flow internally through coil **b** and deflect the pointer to infinity. This reading shows a resistance too large to measure. When you connect a resistance, such as R_x, between the test leads, current also flows in coil **a;** this moves the pointer clockwise. At the same time, coil **b** moves the pointer counterclockwise. Therefore, the moving element,

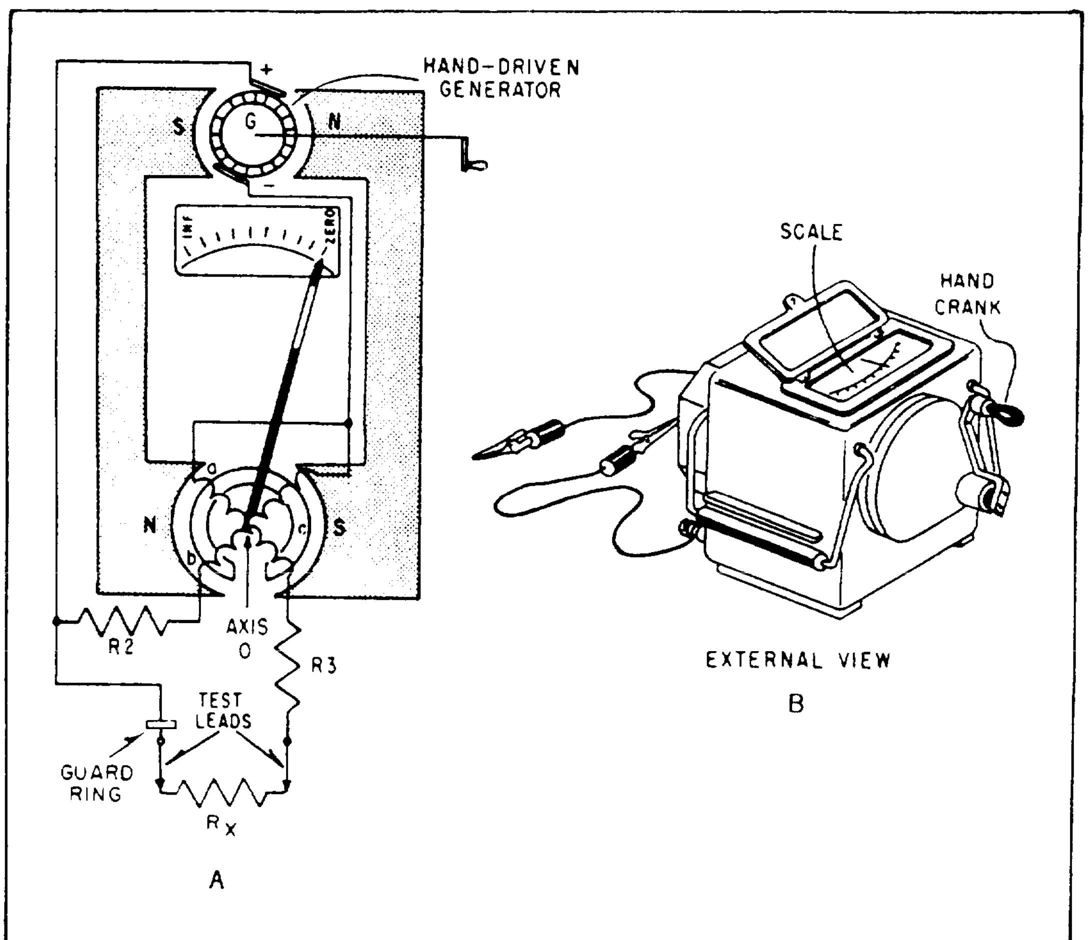

Figure 2-6.-Megger internal circuit and external view.

composed of both coils and the pointer, comes to rest at a position in which the two forces balance. This position depends upon the value of R_x, which controls the current in coil **a.** Because changes in voltage affect both coils in the same proportion, the position of the moving element is independent of the voltage. If you short the test leads together, the pointer will come to rest at zero because the current in coil **a** is relatively large. Since R3 limits the current, the instrument is not damaged under these circumstances. Figure 2-6, view B, shows the external appearance of one type of megger.

Most meggers you will use have a 500-volt rating. (Normally, meggers have friction clutches.) When you crank the generator faster than its rated speed, the clutch slips. This prevents the generator speed and output voltage from exceeding rated values. A 1,000-volt generator is available for extended ranges. When you want to measure an extremely high resistance (10,000 megohms or more), a high voltage is needed to cause enough current flow to operate the meter movement.

When you use a megger, observe the following precautions:

- When making a megger test, make sure the equipment is de-energized.
- Observe all rules for safety in preparing equipment for test and in testing, especially when testing installed high-voltage apparatus.
- Use well-insulated test leads, especially when using high-range meggers. After connecting the leads to the instrument and before connecting them to the component under test, operate the megger to make sure there is no leakage between leads. The reading should be infinity. Make certain the leads are not broken and the connections are good by touching the leads together while turning the crank slowly. The reading should be zero.
- When using high-voltage meggers, take proper precautions against electric shock. There is enough capacitance in most electrical equipment to *store up* sufficient energy from the megger to give a very disagreeable and even dangerous electric shock. The megger has a high protective resistance, and its open circuit voltage is not as dangerous, but always be careful.
- Discharge equipment having a considerable capacitance before and after making megger tests to avoid the danger of receiving a shock. You can do this by grounding or short circuiting the terminals of the equipment under test.

OSCILLOSCOPE

An oscilloscope is a versatile instrument used in viewing wave shapes of voltages or currents. It is capable of giving information concerning frequency values, phase differences, and voltage amplitudes. It can also trace signals through electronic circuits to localize sources of distortion and to isolate troubles to particular stages.

The majority of oscilloscopes used for test and other measurements contain a basic presentation unit (screen) and accessory units, such as amplifiers, synchronizing circuits, time-delay circuits, and sweep oscillators. These circuits are used to display a stationary pattern on the cathode-ray tube (CRT). The sensitivity of an oscilloscope should be adequate for the smallest signals to have sufficient amplitude for screen display.

NEETS discusses the CRT, the oscilloscope, and their operation in detail.

TIME-DOMAIN REFLECTOMETRY

Time-domain reflectometry (TDR) is a measurement concept widely used in the analysis of wideband systems. The art of determining the characteristics of electrical lines by observation of reflected waveforms is not new. For many years power-transmission engineers have located discontinuities in power-transmission systems by sending out a pulse and monitoring the reflections. *Discontinuity is any abnormal resistance or impedance that interferes with normal signal flow.*

TDR is particularly useful in analyzing coaxial cables, such as those in fuel or oxygen quantity indicating systems. The amplitude of the reflected signal corresponds directly to the impedance of the discontinuity. You can find the distance to the discontinuity by measuring the time required for the pulse to travel down the line to the reflecting impedance and back to the monitoring oscilloscope.

TDR analysis consists of inserting an energy step or pulse into a system and the subsequent observation, at the insertion point, of the energy reflected by the system. Several arrangements are possible, but the following procedure is used with the newer, specialized reflectometers (fig. 2-7). The pulse generator develops a fast (or incident) step. This step then passes through a TEE connector and goes into the system under test. The sampling oscilloscope is also attached to the TEE connector, and the incident step, along with the reflected waveform, shows on the CRT. Analysis of the magnitude, duration, and shape of the reflected waveform shows the type of impedance variation in the system under test.

When the fast-rise input pulse meets with a discontinuity or an impedance mismatch, the resultant reflections appearing at the feedpoint are compared in phase, time, and amplitude with the original pulse. Also, since distance relates to time and the amplitude of the reflected step directly relates to impedance, the comparison shows the distance to the fault, as well as an indication of its nature. Time-domain reflectometry shows both the position and the nature (resistive, inductive, or capacitive) of each line discontinuity. It also reveals the characteristic impedance of the line and shows whether losses are parallel or series losses.

PHASE ANGLE VOLTMETER

You can determine the overall accuracy of many electronic parts by measuring phase angles in computing transformers, computing amplifiers, and resolver systems. In the past, the most common method used for measuring phase shift or phase angles between signals was observing patterns on an oscilloscope. With this method, it was hard to determine small angles and difficult to translate various points into angles and sines of angles. When one of the signals contained harmonic distortion or noise, this interference limits the use of oscilloscope patterns.

In any complex waveform containing a basic frequency and harmonics, measuring phase shifts presents problems. In most applications, interest lies in the phase relationship of the basic frequencies, regardless of any harmonics that are present. One requirement of a phase measuring device is measuring the phase difference between two discrete frequencies. It must accomplish this, regardless of phase and amplitude of other components of the waveform.

The basic block diagram of a phase angle voltmeter is shown in figure 2-8. You should refer to it while reading this section. There are two inputs—the signal and the reference. Both channels contain filters that pass only the fundamental frequency. Harmonics are highly attenuated. Each channel has a variable amplitude control and amplifiers to increase the variety of signals you can check.

By placing a calibrated phase shifter into the reference channel, that channel signal can be phase shifted to correspond to the other channel. The phase detector will detect this action and it will also show on the meter.

The calibrated phase shifter connects to a switch (whose position corresponds to the 0-degree, 90-degree, 180-degree, and 270-degree phase shift) and a potentiometer (whose dial is calibrated from 0 degree to 90 degrees). The total phase shift is the sum of the two readings.

The phase detector is a balanced diode bridge-type demodulator. Its output is proportional to the signal amplitude times the cosine of the angle of phase difference between the signal input and the reference input.

If the reference input is phase shifted until it is in phase or 180 degrees out of phase with the signal input, the output from the phase detector is proportional to the signal input amplitude (the cosine of the angle is unity). If the reference input is phase shifted until it is 90 degrees out of phase

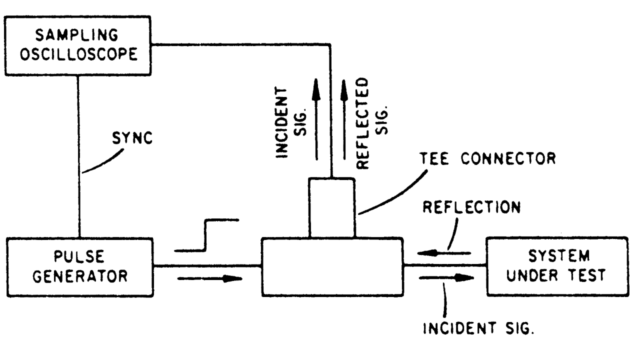

Figure 2-7.-Typical time domain reflectometer.

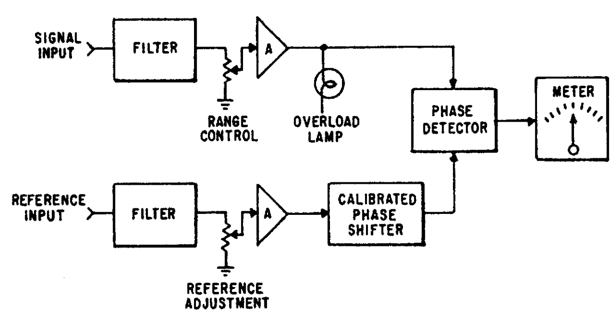

Figure 2-8.-Phase angle voltmeter, block diagram.

with the single input, the phase detector output is zero (the cosine of the angle is zero).

The point where the two signals are in phase or 180 degrees out of phase is the point of maximum deflection on the meter. The difference between the in-phase and 180 degrees out-of-phase points is in the direction of needle swing, not the distance it swings. Upon approaching the point of maximum deflection, the rate of change of the meter reading decreases. This happens because the cosine has a smaller rate of change near 0 degree. This makes it difficult to read the exact point of maximum deflection.

Most commercial voltmeters determine the point at which the signals are 90 degrees out of phase as *quadrature.* The cosine has a maximum rate of change as it approaches 90 degrees, thus it gives a better indication on the meter. When the voltmeter is setup for this point, there must be some way of converting the phase shifter reading. You have to convert the reading to show the correct amount of phase shift, rather than 90 degrees more or less than the actual amount. Some confusion exists in this area because different manufacturers have different methods of determining the signal quadrant. Manufacturers also differ on whether the final reading is a leading or a lagging phase shift. This means that you should be familiar with the type of phase angle voltmeter you are using. You can't assume that the method used to determine phase angle on one type of meter can be used on another.

DIFFERENTIAL VOLTMETER

The differential voltmeter is a reliable piece of precision test equipment that provides extremely accurate volt age measurements. Its general function is to compare an unknown voltage with a known internal reference voltage and show the difference in their values. The Model 893A, differential voltmeter (fig. 2-9) is commonly used by naval personnel.

You can use the differential voltmeter as a conventional **transistorized electronic voltmeter (TVM)** or as a **differential null voltmeter.** You can also use it to measure variations of a voltage near some known value (null detector), high resistance

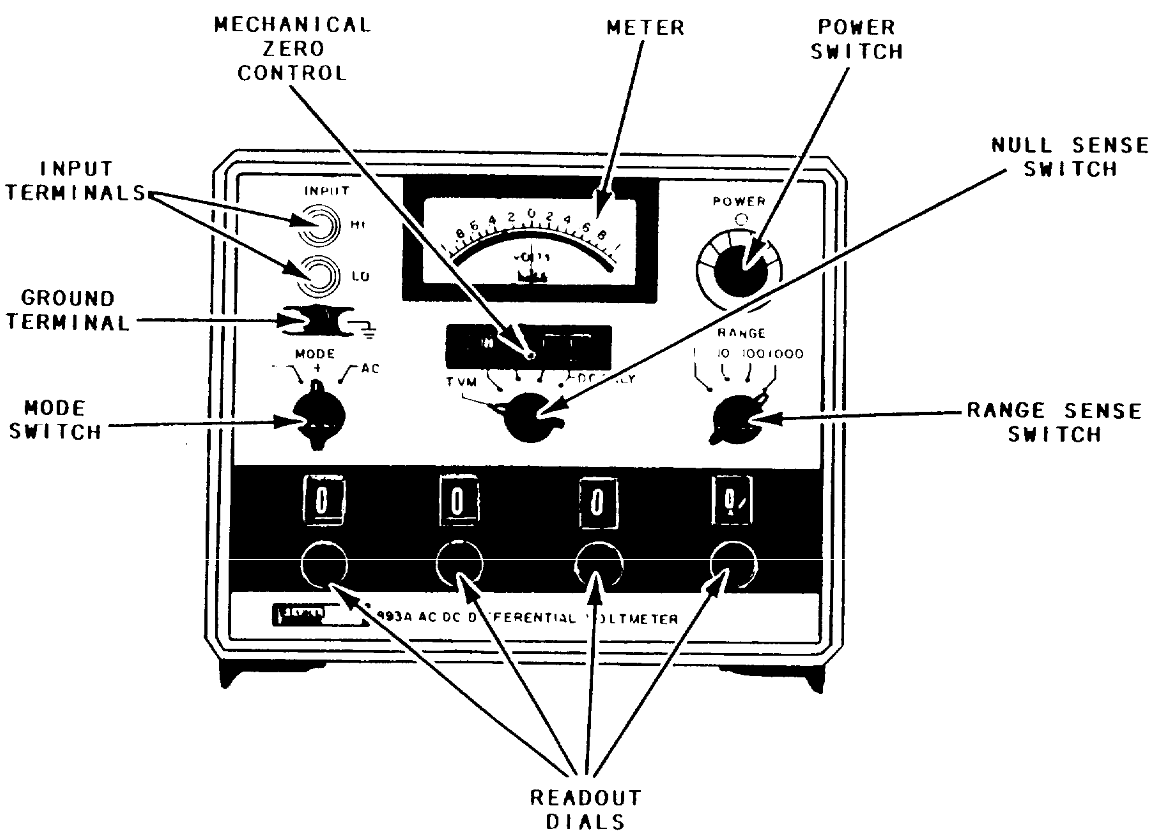

Figure 2-9.-Differential voltmeter.

values (megohmmeter), and for dBm measurements. This meter is a solid-state differential voltmeter providing the capability of making dc voltage measurements from ± 10 microvolt to ± 1,100 volts. It also measures ac voltages from 0.001 to 1,100 volts over a frequency range from 5 hertz to 100 kilohertz. You can make both of these measurements without concern of loading the circuit. It has four voltage readout dials that vary the resistance of the divider assembly as described above.

The differential voltmeter uses a built-in null detector to measure an unknown voltage. The meter circuitry compares the unknown voltage to a known, adjustable reference voltage supplied by the meter. The reference voltage is from a high-voltage dc power supply and decade resistor divider assembly strings. You use voltage readout dials to adjust the decade resistor assembly. In this way, you can divide the output from the high-voltage power supply precisely into increments as small as 10 microvolt. The readout dials adjust the meter pointer to 0, and the unknown voltage is on the voltage dials.

A primary feature of a differential voltmeter is that it does not draw current from the unknown source for dc measurements when you make the measurement. Therefore, the determination of the unknown dc potential is independent of its source.

REVIEW SUBSET NUMBER 3

Q1. Describe how you would connect a voltmeter to the circuit under test?

Q2. *When using a meter, you should start at what range?*

Q3. A circuit in which current no longer flows is known as an ____________________.

Q4. What test do you perform to find an open circuit?

Q5. Blown fuses and open circuit breakers are usually an indication of what type of fault?

Q6. List the two disadvantages of the volt-ohm-milliammeter.

Q7. What type meter should you use to test for insulation breakdown?

Q8. What test equipment shows you the wave shape of current or voltages?

Q9. What is a discontinuity?

Q10. What meter compares an unknown voltage with a known internal reference voltage and shows the difference in their values?

AIRCRAFT WIRE AND CABLES

Learning Objective: *Recognize aircraft wire and cable characteristics and various means of identifying and splicing wires and cables.*

An important part of aircraft electrical maintenance is determining the correct wire or cable (fig. 2-10) for a given job. For electrical installations, a wire is a stranded conductor, covered with an insulating material. The term *cable,* as used in aircraft electrical installation, includes the following:

- Two or more insulated conductors contained in the same jacket (multiconductor cable)
- Two or more insulated conductors twisted together
- One or more insulated conductors covered with a metallic braided shield (shielded cable)
- A single insulated center conductor with a metallic braided outer conductor (RF cable)

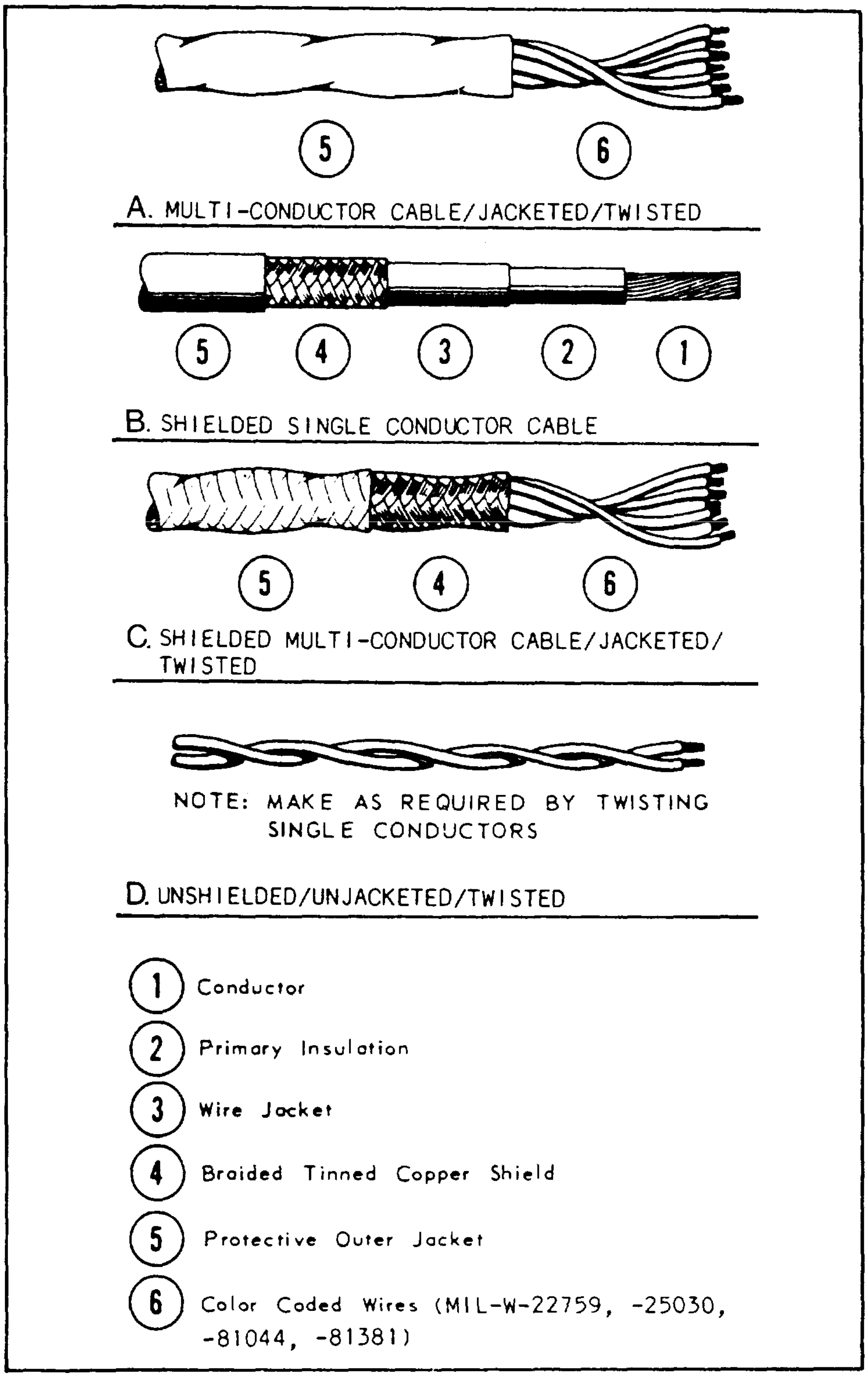

Figure 2-10.-Cables commonly used in aircraft.

WIRE REPLACEMENT

Before you can replace wiring, you need to find information about the wire. First, consult the aircraft's maintenance instructions manual (MIM) for wire replacement since it normally lists the wire used in a given aircraft. When you cannot get this information from the manual, you must select the correct size and type of wire needed. The factors in determining correct wire size are in NEETS, module 4, and *Installation Practices Aircraft Electric and Electronic Wiring, NAVAIR* 01-1A-505. The procedures specified in NAVAIR 01-1A-505 are mandatory for the maintenance of naval aircraft. The information in these publications and in the latest Military Specification MIL-W-5088 should help you select the correct replacement wire.

The data necessary to determine the correct wire for a given application is summarized below:

1. Current drawn by the load (table 2-1)
2. Length of wire required to go from the source to the load
3. Allowable voltage drop between the source or point of voltage regulation and the load
4. The maximum voltage that is applied to the wire
5. The approximate ambient air temperature of the wire installation location
6. Whether the conductor is a stranded wire in free air or one of a group of wires in a bundle or in a conduit

Wire Selection and Characteristics

After you have determined the wire size, consider insulation characteristics. The following are descriptions of the various military specifications of wires and cables. These military specification numbers are on the reel, spool, or shipping container. Always refer to NAVAIR 01-1A-505 before selecting wires and cables for weight discrepancies.

MIL-W-22759. MIL-W-22759 is a fluoropolymer-insulated single conductor electric wire. It is made of tin-coated, silver-coated, or nickel-coated wires of copper or copper alloy. You may use this specification wire in combination with other insulating materials. Temperature and voltage ratings range from 302°F to 500°F and 600 to 1,000 volts, respectively, depending on part number and application.

MIL-W-25038. MIL-W-25038 is a high-temperature, fire-resistant electrical wire. This wire is made of nickel-clad copper with insulation that will operate efficiently in ambient temperatures that exceed +500°F. Its insulation design assures emergency operation of electrical circuits subject to fires.

MIL-W-81044. MIL-W-8 1044 is a single conductor with tin, silver, and nickel-coated copper or copper alloy wires insulated with various poly materials. You may use these poly materials alone or in combinations, depending upon application and part number.

MIL-W-81381. MIL-W-81381 is a polyamide-insulated, single wire with silver and nickel-coated conductors made of copper and copper alloys. You may use polyamide insulation alone or in combinations with other insulating materials, depending on application and part number.

MIL-C-7078. MIL-C-7078 includes three types of electrical cable.

1. Unshield/unjacketed/twisted—two or more coded wires with no overall jacket or shield
2. Jacketed/twisted—two or more coded wires with no overall shield enclosed within a single jacket
3. Shielded/jacketed/twisted—one or more coded wires, twisted, with an overall shield enclosed within a single jacket

MIL-C-27500. MIL-C-27500 is electrical cable made up of two to seven-wire specifications. Cables of this type are included in the following groups:

1. Unshielded/unjacketed—color-coded wires, spirally laid without an overall jacket
2. Jacketed—color-coded wires, spirally laid with an overall jacket
3. Shielded/jacketed—one to seven color-coded wires, spirally laid with one or two shields within an overall jacket

Aluminum Wire Properties

The use of aluminum wire in aircraft is well established. Therefore, you need to know some of the unusual properties of aluminum.

Table 2-1.-Current Rating of Wires

CONDUCTOR MATERIAL	Wire Size	Continuous duty current (amperes) (2) Wires in bundles, groups or harnesses		
		Wire temperature rating		
		221 °F (105 °C)	302 °F (150 °C)	302 °F (200 °C)
COPPER OR COPPER ALLOY	26(1)	2	3	4
	24	3	4	5
	22	4	6	7
	20	5	8	10
	18	7	11	14
	16	8	12	16
	14	11	17	22
	12	15	22	29
	10	19	30	38
	8	26	39	50
	6	35	53	68
	4	48	72	93
	2	66	100	130
	1	78	115	148
	1/0	89	135	173
	2/0	106	159	203
	3/0	125	186	241
	4/0	146	220	287
ALUMINUM (2)	8	17		
	6	23		
	4	30		
	2	43		
	1	50		
	1/0	57		
	2/0	68		
	3/0	76		
	4/0	86		

NOTE:

(1) The use of these wires requires procuring activity approval.
(2) Rating is for 94 °F (70 °C) ambient, 33 or more wires in the harness with no more than 20% of harness current capacity being used, at an operating altitude of 60,000 feet.
(3) Ratings are for copper conducting size 4/0 through size 22 and copper alloy for size 24 through 26.

Aluminum is unusual because it forms an electrically resistant oxide film on all of its surfaces. It has an inherent property known as *creep,* which makes proper installation of a terminal extremely critical. *Creep is the tendency of aluminum to flow away from the point of pressure.* Aluminum is softer than copper, and chemically corrosive when in direct contact with copper.

The electrically resistant aluminum oxide film is always present. Therefore, you must either penetrate or remove it to guarantee a satisfactory electrical connection by using the specified compound to remove this film. (Refer to Avionics *Cleaning and Corrosion Prevention/Control,* NAVAIR 16-1-540.) Initially, tin-plated terminals and splices are supplied so no oxide film is present. Terminals become dirty when stored or excessively handled. You should clean them by wiping with a soft cloth. **Never use a wire brush or any abrasive method to clean a tinned aluminum surface.**

One problem found in aluminum wire is corrosion by dissimilar metals. This problem occurs frequently when aluminum and copper come in contact. As soon as moisture collects

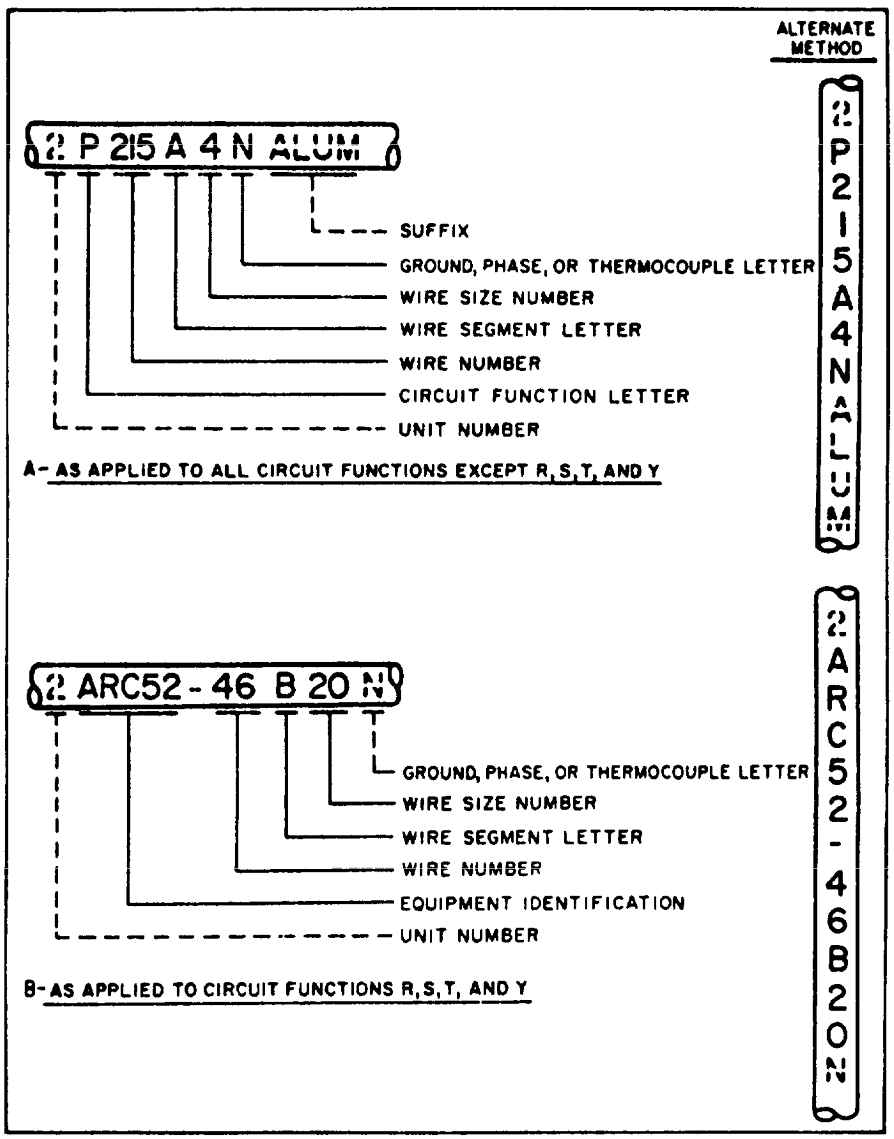

Figure 2-11.-Examples of wire identification coding.

between the two metals, an electrical differential exists, which produces a *battery effect.* This effect quickly results in corrosion.

Use the following techniques to reduce the undesirable effects caused by aluminum's softness, creep, and oxide film:

- Select the proper size of wire and terminals/splices. Terminals and splices used with aluminum wire will have an AL or ALUM stamp.
- Select the proper hand tool when crimping.
- Handle aluminum wire carefully. Use the proper assembly procedure when preparing it for an electrical connection.
- Thoroughly clean any terminals.
- Be careful not to scrape or nick the wire when stripping.

CAUTION

Never cut aluminum wire with tools that have reciprocating motion, such as a hacksaw. Reciprocating cutting action "work hardens" aluminum. This will lead to broken and torn strands.

WIRE IDENTIFICATION

Equipment contractors assign the wire identification code for wires and cables having function letters R, S, T, and Y. The block of wire numbers for each equipment starts with 1 and continues for as many numbers needed to identify all wires. For example, wires of the AN/APS-45 are identified as APS45-1A20-APS45-975C22, those of the AN/ARC-52A would be ARC52-1A22-ARC52-9C22, and the MX-94 would be the MX94-1A20, etc. If a type designation (AN nomenclature) is **not** assigned for a piece of equipment (such as commercial equipment), get a block of numbers from the procuring activity. You can get the wire identification code by using that portion of the military type designation (AN nomenclature) following the slash (/). You must exclude the hyphen and any suffix letters.

Wire Marking

You may stamp the identification code on wires either horizontally or vertically, as shown in figure 2-11. The preferred method is to stamp the identification marking directly on the wire or cable with a hot foil stamping machine. Use this method wherever possible. If the wire insulation or outer covering won't stamp easily, stamp lengths of insulating tubing (sleeves) with the identification marking. Then, install the sleeve on the wire or cable. The following types of wire usually have sleeve identification markings:

1. Unjacketed shielded wire
2. Thermocouple wires
3. Multiconductor cable
4. High-temperature wire with insulation difficult to mark, such as, TFE, fiber glass, etc.

CAUTION

Do not use metallic markers or bands for identification. Do not use any method of marking that will damage or deform the wire or cable.

Whatever method you use to mark the wire, make sure the marking is legible and the color contrasts with wire insulation or sleeving. Use black stamping for light-colored backgrounds and white on dark-colored backgrounds. Make sure that markings are dry so they don't smear. **Stamp** wires and cables at intervals of not more than 15 inches along their entire lengths (fig. 2-12). Also, stamp wires within 3 inches of each junction (except permanent splices) and at each ending

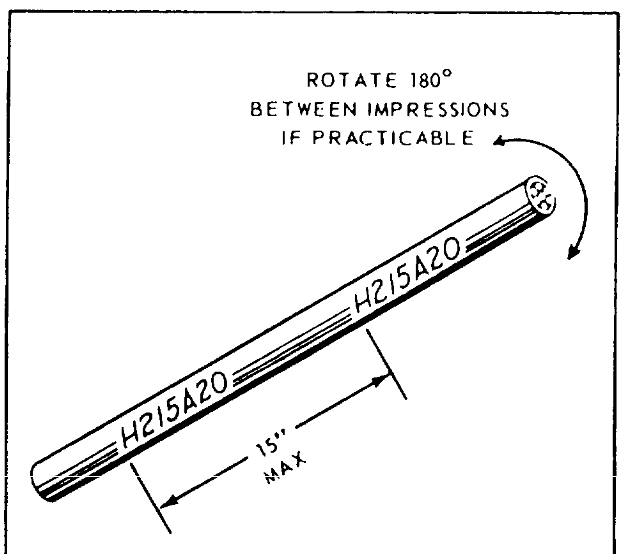

Figure 2-12.-Spacing of identification stamping on wire and cable.

point. Stamp wires which are 3 to 7 inches long in the center. You don't need to stamp wires less than 3 inches long.

Wiring and Cable Identification Codes

To make maintenance easier, each of the connecting wires in an aircraft have an identification. The identification is a combination of letters and numbers. The marking also identifies the circuit it belongs to, gauge size, and other information relating the wire to a wiring diagram. This marking is the cable identification code. The accompanying discussion explains the code used in aircraft wiring. You can find complete details in the *Military Specification: Wiring, Aerospace Vehicle, MIL-W-5088.*

NOTE: Stranded conductor wire is used for flexibility in installation and service. Wire sizes approximate American Wire Gage (AWG). However, they vary sufficiently so it is improper to refer to aircraft wire as AWG.

NOTE: For an in-depth study of wiring specifications, limitations, and repair, you should refer to NA01-1A-505.

The basic wire identification code for circuits is read from left to right, except circuit function letters *R, S, T,* or *Y.* Look at figure 2-12 as you read this section.

Unit number. Where two or more identical items of equipment are in the same aircraft, use prefix unit numbers 1, 2, 3, 4, etc., to differentiate between wires and cables. To make it easier to interchange items, identical wiring is located in left and right wings, nacelles, and major interchangeable structural assemblies, without using the unit number. Use the unit number for circuit functions *R, S, T,* and *Y,* only where complete duplicate equipment is installed. Unit numbers don't apply to duplicate components within a single complete equipment, such as duplicate indicators or control boxes.

Circuit function letter (except *R, S, T,* and Y). The circuit function letter identifies the circuit function (table 2-2). When using a wire or cable for more than one circuit function, the circuit function letter of the predominant circuit applies. When functional predominance is questionable, use the circuit function letter for the wire or cable having the lowest wire number.

Wire number. The wire number consists of one or more digits. It identifies the different wires in a circuit. A different number is used for wire

Table 2-2.-Wiring Circuit Function Code

Circuit function letter	Circuits
A	Armament
B	Photographic
C	Control surface
D	Instrument (other than instrument & flight)
E	Engine instrument
F	Flight instrument
G	Landing gear, wing folding
H	Heating, ventilating, and de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous (electrical)
P	Dc power Wiring in the dc power or power control system is identified by the circuit function letter P.
Q	Fuel and oil
R	Radio (navigation and communication)
S	Radar (pulse technique)
T	Special electronic
U	Miscellaneous (electronic)
V	Dc power cables and dc control cables for ac systems are identified by the circuit function letter V.
W	Warning and emergency
X	Ac power Wiring in the ac power system is identified by the circuit function letter X.
Y	Armament special systems
Z	Experimental circuits

not having a common terminal or connection, as shown below:

1. Wires with the same circuit function having a common terminal connection or junction have the same wire number but different segment letters.
2. Beginning with the lowest number, assign a number to each wire in numerical sequence, insofar as practical.

Wire segment letter. A wire segment is a conductor between two terminals or connections. The wire segment letter identifies different conductor segments in a particular circuit. Use a different letter for wire segments having a common terminal or connection. Wire segment letters are in alphabetical sequence. The letter *A* identifies the first segment of each circuit starting at the power source. If a circuit contains only one wire segment, this wire segment is *A*. Do not use the letters I and *O* as segment letters. Use double letters *AA, AB, AC,* etc., when there is more than 24 segments. Two permanently spliced wires do not require separate segment letters if the splice is for modification or repair.

Wire size number. The wire size number identifies the size of the wire or cable. For coaxial cables and thermocouple wires, the wire size number is not included. For thermocouple wires, a dash (-) is used instead of the wire size number.

Ground, phase, or thermocouple letter(s).

1. Ground cable letter N is a suffix to the wire identification code. It identifies any wire or cable that completes the circuit to the ground network. Such wires and cables connect to the ground network of aircraft electrical systems without causing any circuit malfunctions. For electronic systems with interconnecting **ground** leads, but only one segment actually grounded to structure, N identifies the segment actually grounded to the structure.

2. Phase letter *A, B,* or *C* is a suffix on the wire identification code. It identifies the phase or wires in the three-phase power ac distribution systems. The phase sequence is $A \rightarrow B \rightarrow C$.

3. Phase letter *V* is a suffix on the cable identification code. It identifies the ungrounded wire or cable in a single-phase system.

4. For thermocouple wire, use the following suffixes:

- CHROM—Chromel
- ALML—Alumel
- IRON—Iron
- CONS—Constantan
- COP—Copper

Suffix (when required). When using aluminum wire, add ALUMINUM OR ALUM to the identification code.

CABLE STRIPPING AND HEAT SHRINKABLE TUBING

Nearly all wire and cable electrical conductors have some type of insulation. When making electrical connections with wire, you must remove a part of this insulation, leaving the end of the wire bare. To help you remove insulation, use a wire and cable stripping tool similar to the one shown in figure 2-13.

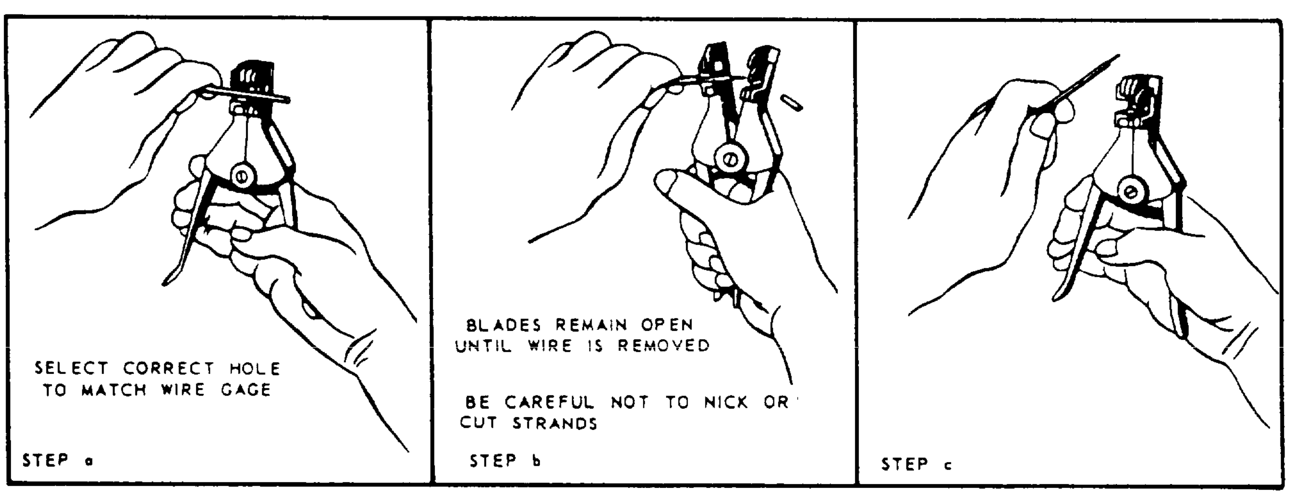

Figure 2-13.-Wire stripping method.

The operation of this basic tool is efficient and effective and extremely simple. To operate it, insert the wire end in the proper direction to the depth to be stripped. Now position the wire so it rests in the proper groove for that size wire, and squeeze.

Heat-shrinkable tubing is a plastic-like tubing (similar to insulation sleeving) that will shrink to a smaller diameter with proper heating. Place the tubing over the joint, terminal, or part needing insulation. Now apply heat with a heat gun, oven, or other appropriate heat source. When the tubing reaches a specific temperature (shrink temperature depends upon the type of tubing), it quickly shrinks around the object, forming a snug jacket. In addition to being an insulator, the shrinkable tubing helps relieve strain and adds waterproofing. Figure 2-14 gives some of the typical uses of heat-shrinkable tubing.

SOLDERING

Wires are soldered to form a continuous and permanent metallic connection, having a constant electrical value. When soldering, strive for superior workmanship. If you are sloppy, you create problems and compound difficulties in system troubleshooting techniques. Study and refer to NAVAIR 01-1A-505 when you are soldering.

The most important part of soldering is the selection of the correct iron for the job. Soldering irons are available in wattage ranges from 20 to 500 watts. Use irons with wattage ratings of 60, 100, and 200 watts for general work in aircraft electrical wiring. Use pencil irons with a rating of 20 to 60 watts for soldering small parts, The soldering iron for printed circuit soldering is a lightweight, 55-watt iron with a 600°F (316°C) Curie point tip control. This iron has a three-wire cord, which prevents leakage currents that could damage the printed circuits.

When soldering, you should select a soldering iron with a thermal capacity high enough so the heat transfer is fast and effective. (Refer to table 2-3.) An iron with excessive heat capacity will burn or melt wire insulation. One with too little heat capacity will make a cold joint in which the solder does not alloy with the work.

A soldering iron should also suit the production rate. Do not select a small pencil iron where you need a high steady heat flow.

Table 2-3.—Approximate Soldering Iron Size for Tinning

Wire Size (AN Gage)	Soldering Iron Size (Heat Capacity)
#20 - #16	65 Watts
#14 & #12	100 Watts
#10 & #8	200 Watts

REVIEW SUBSET NUMBER 4

Q1. What type of wire should you use to carry 600 to 1,000 volts with a temperature rating between 302°F to 500°F?

Q2. What type of metal used in wire forms a resistant oxide film on all its surfaces?

Q3. When stamping wire identification numbers, at what interval should you stamp the wire?

Q4. In wire identification numbers, the suffix N means the wire completes the circuit to

______________________________.

Q5. What is the most important item to consider when soldering?

AIRCRAFT ELECTRICAL HARDWARE

Learning Objective: *Recognize uses for and characteristics of aircraft electrical and mechanical hardware.*

You shouldn't always use the same mounting parts that you removed from the installation. Before reusing the parts, inspect them to make sure they aren't defective or damaged. Also check

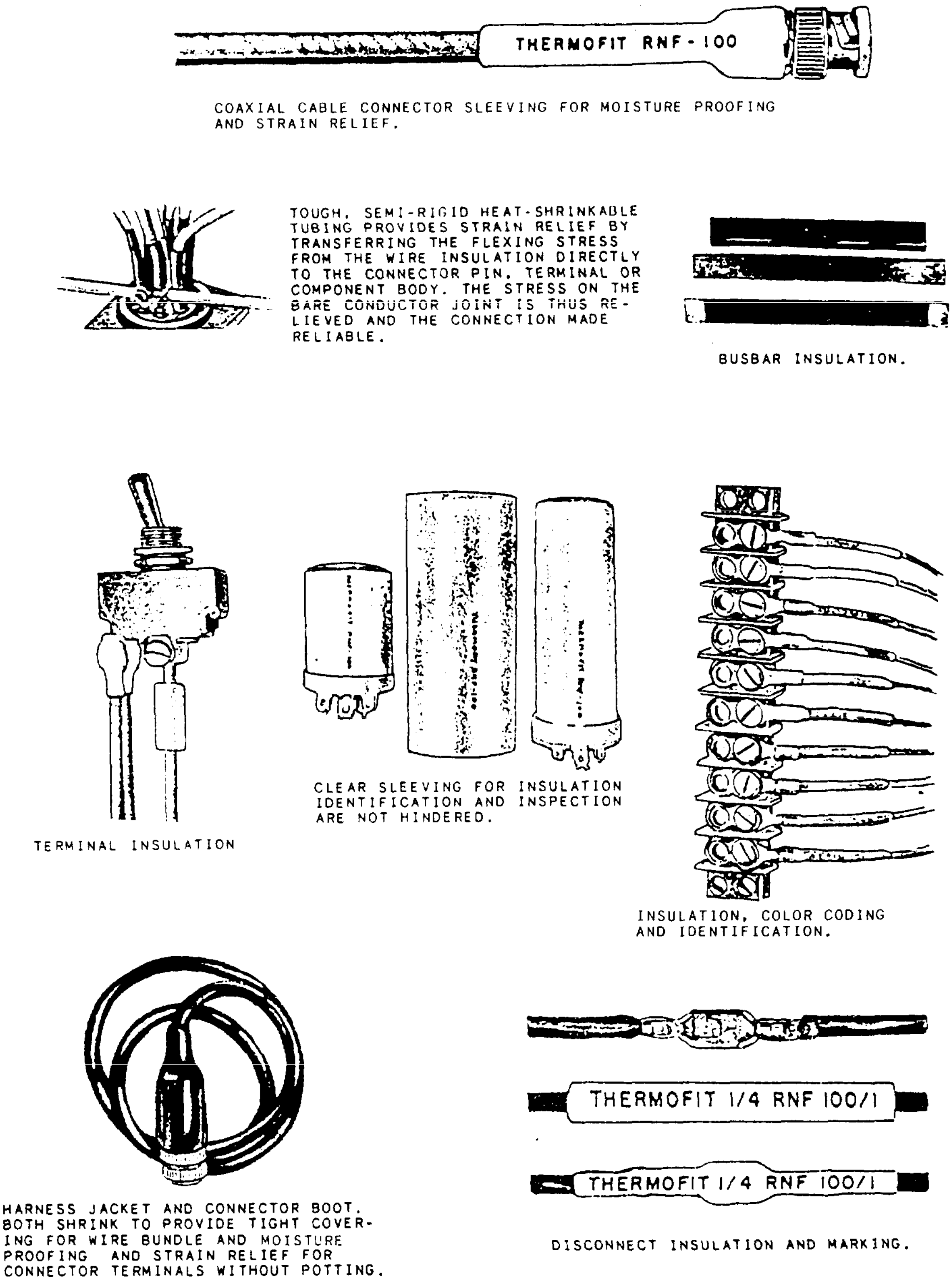

Figure 2-14.-Typical heat shrinkable tubing.

the instruct ions; some parts can't be reused. Then, and only then, may you use the removed parts.

The hardware you should use when installing electrical equipment in aircraft is specified in the applicable MIM. You should always use proper parts. If you need to substitute, make sure the substitute item is satisfactory.

General information about mounting parts and consumable components can be found in various Navy training manuals. *Aircraft Structural Hardware for Aircraft Repair,* NAVAIR 01-1A-8, and *Installation Practices Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505, are sources of detailed information.

If you can't get the mounting parts specified by the applicable illustrated parts breakdown (IPB), you may make a temporary installation using suitable substitute parts. Replace these parts with the proper items as soon as you receive them. Always check with the work center supervisor before you make any substitution. When making part substitutions, you should give special consideration to the following factors:

Corrosion. Pay attention to the chemical or metallic composition of the part. Choose a part that doesn't contribute appreciably to the danger of corrosion.

Strength. The strength of the substitute part must be the same, or greater than the one prescribed. (When determining the strength, consider the tensile, compression, and shear strength, as applicable to the specific use.)

Size. Substitute nuts, bolts, and screws should be the same size as the prescribed item. In all cases, washers must have the same inner diameter as the prescribed item. A different outer diameter or thickness is acceptable.

Length. The length of substitute screws or bolts must be enough for the particular installation. However, length can't be long enough to interfere with any moving part. Hardware shouldn't come in contact with other aircraft items, such as electrical wiring, hydraulic lines, etc.

Magnetic properties. Equipment installed in specific areas of the aircraft shouldn't cause distortion of the magnetic fields of the area. Examples of such items include the magnetic compass, magnetic anomaly detection equipment, radio direction finder, or gyros. In areas containing these types of equipment, any substitute part must have the same magnetic properties and characteristics as the one prescribed.

Style. Most items of mounting hardware are avawe in various styles. It is usually easy to find screws and bolts that are the same in all respects except the type head. Use these parts as substitutes, provided they have all required special features.

Special features. If a bolt requires torque to a given value, a suitable torque wrench for that type part must be available. If the MIM calls for lockwire, the part must have suitable provisions.

Lubrication or coating. If specific instructions call for lubrication or coating of the parts, follow those instructions for the substitute part as well as for the prescribed part.

SHOCK MOUNTS

Electrical and electronic equipment must be protected from the effects of vibration in aircraft, as vibration is a major problem. Most amplifiers, instrument panels, and other fragile parts have shock mounting protection. Shock mounts are also known as *vibration insulators.* You can trace the failure of many systems to faulty shock mounts; therefore, you should periodically check shock mounts. If you find that they are defective, replace them before equipment is damaged.

Figure 2-15, views A and B, shows two types of shock mounts used in naval aircraft. View A shows mounts that are individually replaceable. Each mount has a rod that extends into the vibration eliminating material. You can replace this type of mount by drilling out the mounting base rivets and riveting the replacement in position. The replacement must be of the same size and type as the mount that it is replacing. The weight of the unit being protected determines the type of mount you use. If you use a mount designed for a heavier unit, it won't *give* to protect the unit. [f you use a mount designed for a lighter unit, it can easily pull away from the base and damage the unit.

The shock mount unit in figure 2-15, view B, is used with a particular piece of equipment. You replace this type of mount as a unit. The vibration insulators are made of hollow rubber and locked into place when manufactured. Inspect these insulators for cracks or splits. If you find damage, replace the complete shock mount unit.

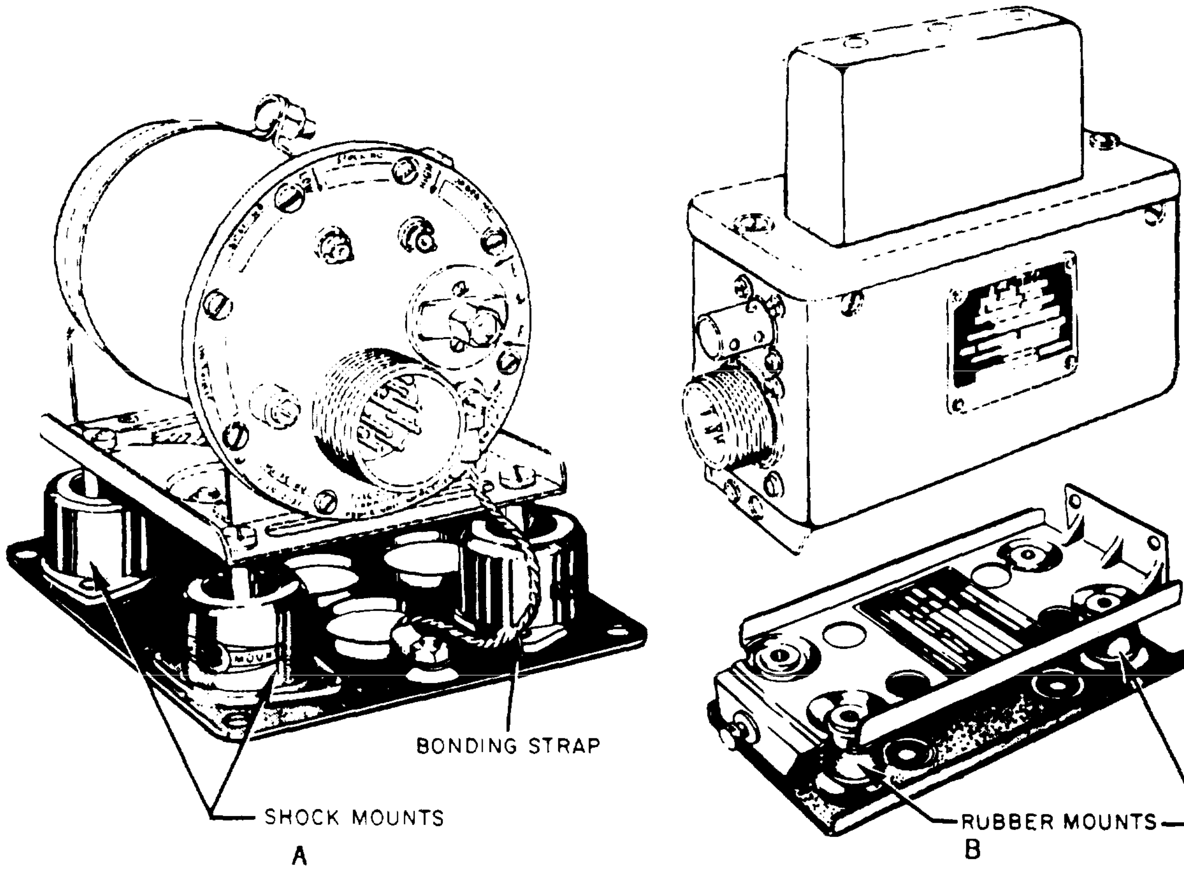

Figure 2-15.-Typical shock mounts.

Shock absorbing materials commonly used in shock mounts are usually electrical insulators. These types of shock mounts are mounted so they have an electrical bond to the aircraft structure, preventing static electricity buildup. (See fig. 2-15, view A.) You need to inspect the bonding strap when inspecting the shock mounts. Replace or repair defective or ineffective bonding straps.

ELECTRICAL CONNECTORS

In this section, the word *connector* is used in a general sense. It applies to connectors with AN numbers and those with MS numbers. AN numbers were formerly used for all supply items cataloged jointly by the Army and Navy. Many items, especially those of older design, continue to carry the AN designator; although the supply system is shifting over to military specification (MS) numbers.

Electrical connectors provide detachable coupling between major components of electrical and electronic equipment. These connectors are built to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and changes in altitude.

Connectors consist of two portions—the fixed portion, called the *receptacle,* and the movable portion, called the plug. Plug assemblies may be straight or angled (usually 90 degrees). Receptacle assemblies may be of the wall-mounted, box-mounted, or integral-mounted types. MS numbers and letters identify the type, style, and arrangement of a connector.

Connectors vary widely in design and application. A coupling nut or ring holds the two assemblies firmly together. The assembly consists of an aluminum shell containing an insulating insert, which holds the current-carrying contacts. The plug usually attaches to the cable end and is the part of the connector on which the coupling nut mounts. The receptacle is the half of the connector to which the plug connects. The receptacle is usually mounted on a part of the equipment.

In naval aircraft, connectors with crimp-type contacts are widely used. Maintenance is easier because you can remove the contact from the connector. If the connector is damaged, you can remove the contacts and replace the connector shell. If just a connector pin is damaged, you can remove and replace the pin. This is a considerable advantage over the solder-type connector, both in convenience and time savings. A discussion of the special tools you need to remove and insert crimped contacts is contained in *Installation Practices Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505.

Some common types of subminiature connectors are shown in figure 2-16. They are used on instruments, switches, transformers, amplifiers, relays, etc.

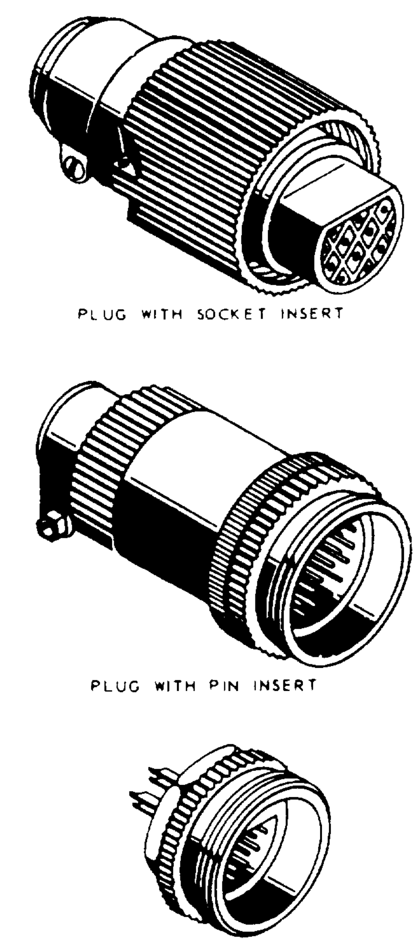

Figure 2-16.-Subminiature connectors.

FABRICATION OF CABLES

Occasionally, you will have to make a cable using connectors. The type of connector you will use is specified in the MIM for the particular aircraft. The following steps outline the procedure you should use to make a cable:

1. Disassemble the connector to allow access to the terminals. Devise a way to hold the connector so both hands are free.
2. Cut the cables to the correct length.
3. Strip the wire end with a wire stripper or knife. If you use a knife, avoid cutting or nicking the wire strands. Tin the bare wire end.
4. Run the wires through the connector assembly and coupling nuts.
5. Make sure all surfaces are clean.
6. Flow rosin-core solder into the connector terminals.
7. Hold the tip of the soldering iron against the terminal. As the solder melts, push the wire into the cavity. Hold the wire steady while the solder cools.

When you solder, be careful not to injure the connector insulation with the soldering iron. Follow a prearranged sequence (fig. 2-17). The recommended sequence is to start from the bottom connection and work left to right, moving up a row at a time. After soldering the connections, the shields, if used, are soldered to a common terminal or ferrule. Then lace the cable and reassemble and moistureproof the connector, if necessary. Fabricating instructions are contained in NAVAIR 01-1A-505.

MOISTUREPROOFING

Present Navy practice is to use potted connectors (moistureproof or environmentproof connectors). All jet- and carrier-type aircraft have potted connectors. On other aircraft, use moistureproofing sealant on electrical connectors in areas where a chance of failure exists. All

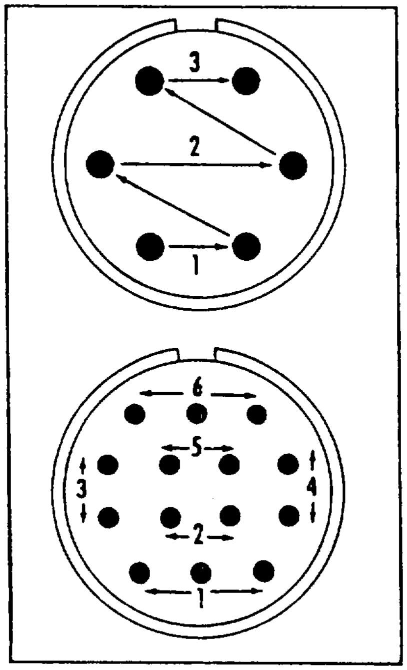

Figure 2-17.-Connector soldering sequence.

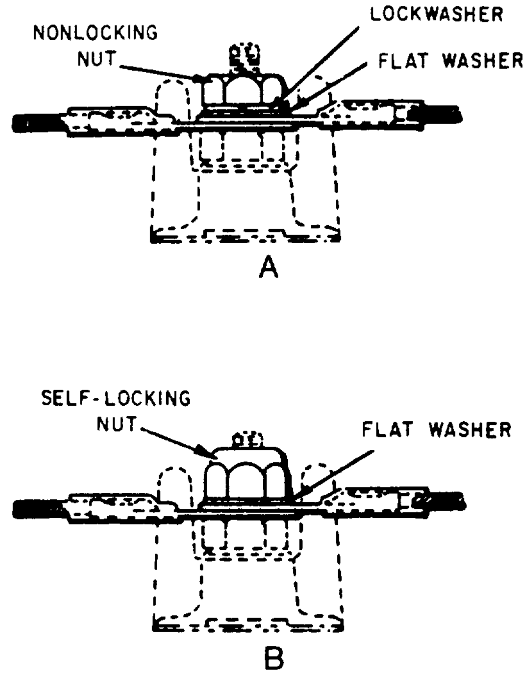

Figure 2-18.-Installation of cable terminals on terminal block.

connectors in wheel wells, wing fold areas, engine areas, engine nacelles, or cockpit decks have a high chance of failure and are sealed. In addition, moistureproof all connectors that interconnect flight/basic navigation equipment.

Vibration and lateral pressure fatigue wires at the solder cup. Moistureproofing reduces electrical connector failures by reinforcing the wires against vibration and lateral pressure. The sealing compound also protects electrical connectors from corrosion and contamination by excluding metallic particles, water moisture, and aircraft liquids. One result of the connector's better dielectric characteristics is the reduced chance of arc-over between pins.

TERMINAL BLOCKS

Terminal blocks, made from an insulating material, support and insulate a series of terminals from each other, as well as from ground. They provide a way to install terminals within junction boxes and distribution panels.

The two methods of attaching cable terminals to terminal blocks are shown in figure 2-18. View A uses a standard nonlocking nut. In this installation method, the use of a lockwasher is necessary. View B shows the preferred method. When using an anchor nut, or self-locking nut, you omit the lockwasher. The use of anchor nuts is especially desirable in areas of high vibration. In both installations, a requirement exists for the use of a flat washer, as shown in the drawing.

Each terminal board in the aircraft electrical system is identified by the letters *TB* followed by the number of the individual board. Each stud on the terminal board is identified by a number. The lowest number in the series starts at the end nearest the terminal board identification number. The identification number is on the structure to which the terminal board attaches. It mounts on any identification strip cemented to the structure under the terminal board. When replacing a terminal board, don't remove the identification marking. If the identification marking is damaged, replace it with one that is the same as the original.

JUNCTION BOXES

Junction boxes accommodate electrical terminals or other equipment. Individual junction boxes are named according to their function, location, or equipment with which they are associated. Junction boxes have a drain hole (except boxes labeled "vaportight") at the lowest point to drain water, oil, condensate, or other liquids. Figure 2-19 shows a representative junction box for housing and protecting several terminal blocks.

When you install a junction box, make sure the screw or bolt heads are inside the box. Don't install attaching hardware so the threaded part of the screw or bolt protrudes inside the junction box. The sharp thread edges of protruding hardware may damage wire insulation.

SUPPORT CLAMPS

Clamps provide support for conduit and open wiring and serve as lacing on open wiring. Clamps usually have a rubber cushion, or they are of all-plastic construction. When used with shielded conduit, the clamps are of the bonded type (fig. 2-20, view A); that is, there is a provision for electrical contact between the clamp and conduit. Use unbended clips for the support of open wiring.

A strap-type clamp (fig. 2-20, view B) or an AN 742 (fig. 2-20, view C) is used for long cable runs between panels. The preferred method for supporting cable runs of all types is using AN 742 clamps. MS 25281D plastic clamps are for use where the maximum temperature does not exceed 250°F. When using the strap-type clamp, you must make sure the clamps hold the cable firmly

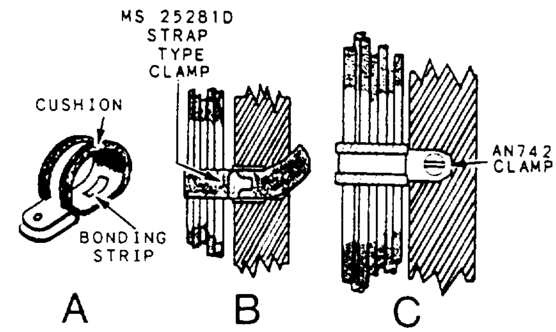

Figure 2-20.-Cable clamps.

away from lines, surface control cables, pulleys, and all movable parts of the aircraft. Use these clamps only as a temporary measure. Replace with a permanent installation as soon as possible.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 2-21. In each case, the AN 742 cable clamp holds the cable firmly. Route the cable well in the clear of the edges of the lightening hole to avoid any chance of chafing the insulation. If any wire is closer than one-fourth inch to the edge of the lightening hole, use a grommet (a rubber cushion) to protect the wires.

Protect wire bundles from the following:

- High temperature
- Battery acid fumes, spray, or spillage
- Solvents or fluids
- Abrasion in wheel wells where exposed to rocks, ice, or mud
- Damage due to personnel using the wire bundle as handholds or footsteps
- Damage due to shifting cargo

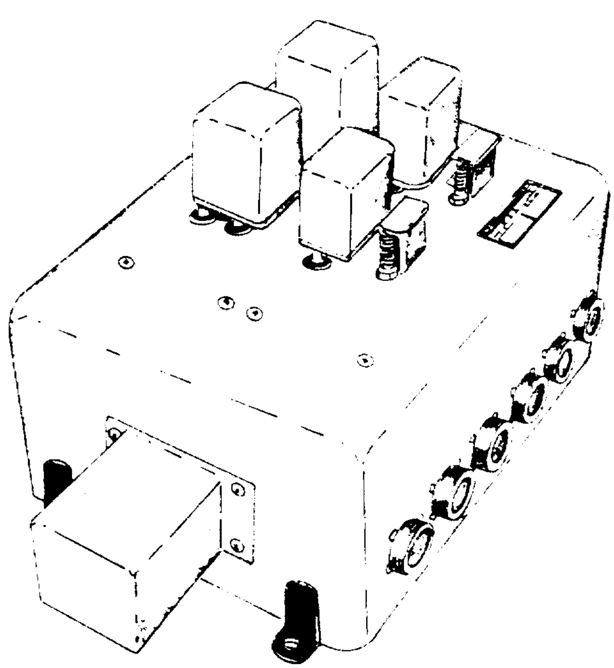

Figure 2-19.-Aircraft junction box.

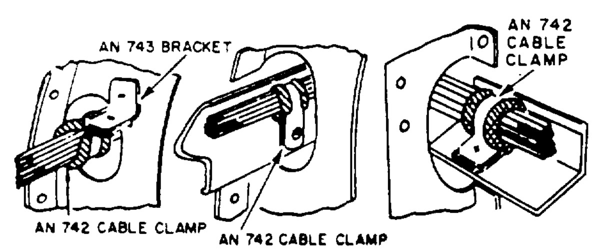

Figure 2-21.-Routing cables through lightening holes.

Never support any wire or wire bundle from a plumbing line carrying flammable fluids or oxygen. Use clamps on these lines only to ensure separation of the wire bundle from the plumbing line. Whenever possible, route wires and bundles parallel with or at right angles to the stringers or ribs of the area involved. See figure 2-22.

Don't install single wires or wire bundles with excessive slack. Slack between support points, such as cable clamps, should not normally exceed one-half inch. (This is the maximum you should be able to deflect the wire with moderate hand force.) You may exceed this slack if the wire bundle is thin and the clamps are far apart. The slack must never be so large that the wire bundle can touch any surface. Allow a sufficient amount of slack near each end for the following reasons:

- To permit ease of maintenance
- To allow replacement of terminals at least twice
- To prevent mechanical strain on the wires, cables, junctions, and supports
- To permit free movement of shock and vibration mounted equipment
- To permit shifting of installed equipment for purposes of maintenance

CONDUIT AND FITTINGS

In many aircraft, the use of conduit is limited. This is a good practice because it saves weight and ensures wide separation of cables. The separation of the electrical system makes it less vulnerable to gunfire. However, some current aircraft, especially those with limited space for wire routing, use conduit.

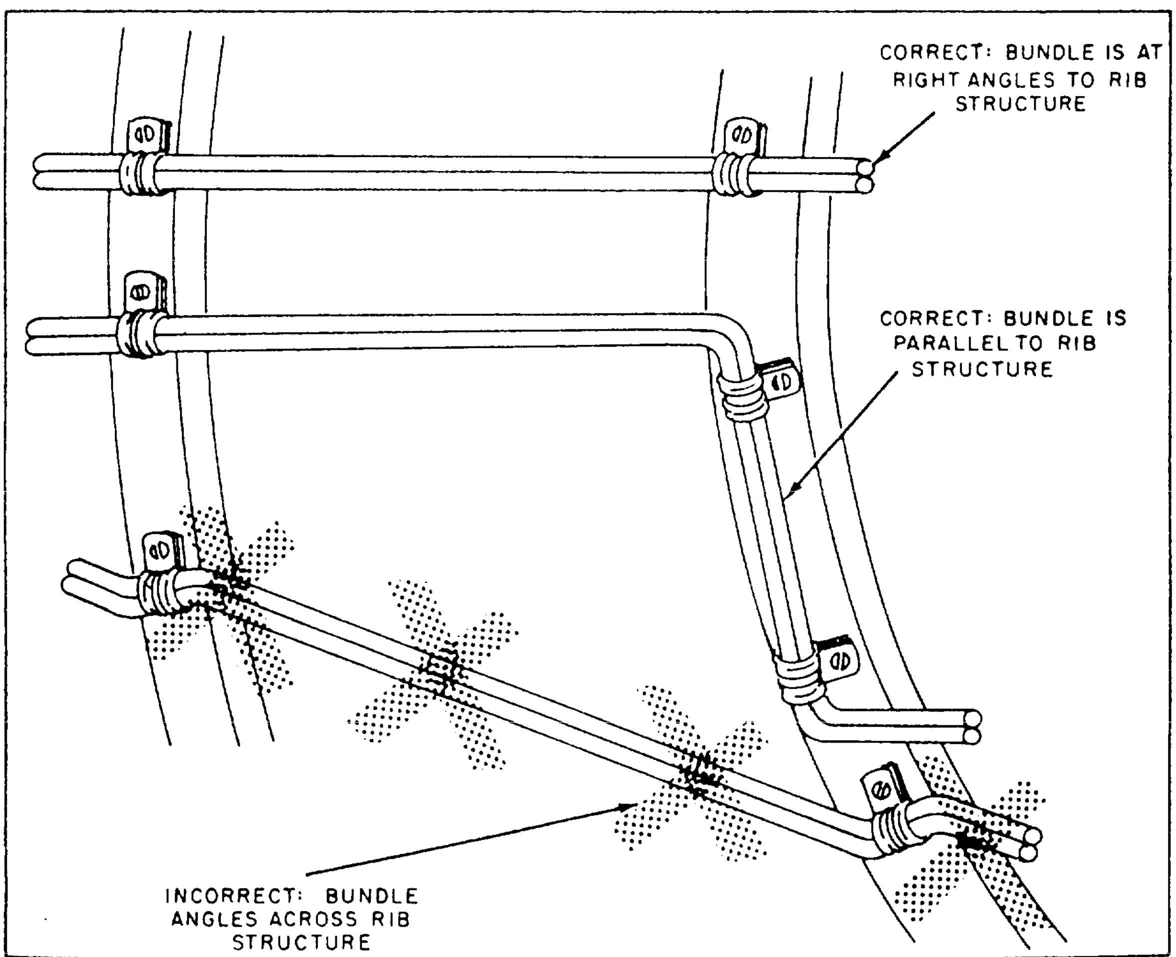

Figure 2-22.-Routing cables.

Conduit comes in two basic types—flexible and rigid. Its chief functions are to act as radio shielding and as a support and protection for wires.

Conduit fittings attach either flexible or rigid conduit to junction boxes and other equipment, and usually include ferrules and coupling nuts. Various forms of both are in use along with special designs of locknuts, box connectors, and coupling adapters.

Couplings are straight or angular in design so they fit all needs. Ferrules are bushings or flanges applied to the ends of the conduit to give greater strength and support to the coupling nuts. They are either crimped or swagged on by the use of crimping or swaging tools.

SAFETY WIRE

There are three types of safety wire:

1. Lockwire is a heavy wire used to secure parts against accidental opening. Use lockwire in all areas of high vibration such as an aircraft's compartment. Electric connectors are lockwired in high-vibration areas that are inaccessible for periodic maintenance and inspection.
2. Shear wire is a lighter wire used to secure parts subject to periodic disconnection, maintenance and inspection, or for parts you need to remove quickly.
3. Seal wire is a thin, easily breakable wire used as a seal on fire-extinguishing systems, oxygen regulators, and other emergency devices that need a quick release for use. You use seal wire to show whether these devices have been used or tampered with.

BONDING AND BONDING DEVICES

A bond is a union that exists between two metallic objects and results in electrical conductivity between them. Aircraft electrical bonding is the process of obtaining electrical conductivity between aircraft metallic parts or between the aircraft structure and installed equipments. An isolated conducting part or object is one physically separate from the aircraft structure and other conductors bonded to the structure. A bonding connector provides the electrical conductivity between metallic aircraft parts not in electrical contact. Bonding jumpers and bonding clamps are examples of bonding connectors.

Purpose

An aircraft can become highly charged with static electricity while in flight. If the aircraft doesn't have a proper bond, all metal parts won't have the same charge. A difference of potential will then exist between various metal surfaces. Neutralization of the charges flowing in paths of variable resistance produces electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is large enough, charges can collect, causing a spark, which is a fire hazard. If lightning strikes the aircraft, a good conducting path lessens severe arcs and sparks that could damage the aircraft and possibly injure its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance is necessary between the aircraft structure and the radio antenna. This means the surface area of the ground must be constant. Control surfaces, for example, may become partially insulated from the remaining structure. This is caused by a film of lubricant building up on the hinges. This would affect radio operation if bonding did not take care of the condition. Bonding also provides the necessary low-resistance return path for single-wire electrical systems. The reasons for bonding are summed up as follows:

- To reduce radio and radar interferences by equalizing static charges that accumulate
- To reduce the fire hazard by preventing static charges from accumulating between two isolated members and creating a spark
- To minimize lightning damage to the aircraft and its occupants
- To provide the proper *ground* for proper functioning of the aircraft radio
- To provide a low-resistance return path for single-wire electrical systems
- To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth

Parts Requiring Bonding

The design in current naval aircraft is to keep the number of bonding jumpers to a minimum. As a result, jumpers are very important and need replacing whenever necessary to keep them in good condition. Some of the aircraft parts that require bonding are identified below.

Control surfaces. Each control surface should have at least two bonding jumpers, This doesn't apply to trim tabs.

Engine mounts. Use at least four bonding jumpers across each engine mount support. This provides a current path between the engine mount and aircraft structure.

Engine cowling. Use at least four symmetrically placed bonding jumpers to bond the engine ring cowling to the engine across the rubber mounts at the front end of the cowling.

Equipment mounts. Place bonding jumpers across shock mounts supporting electrical and radio equipment and the instrument panel.

Methods and Materials

You should install bonding connections so they won't break or loosen. This prevents a variation in the resistance during movement. One primary objective for bonding is to provide an electrical path of low dc resistance and low RF impedance; therefore, it is important that the jumper be a good conductor of ample size. Make the bonding wire as short as possible. Bond parts directly to the basic aircraft structure rather than through other bonded parts, insofar as practical. Install bonding jumpers so they do not interfere with aircraft movable components. (See fig. 2-23.)

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action), which causes corrosion in the connection. The intensity of this electric action varies with the kinds of metals. Bonding frequently causes the direct contact of dissimilar metals. In such cases, the metals used are of the kind that produce minimum corrosion. You should make connections so that if there is corrosion, its in replaceable elements such as jumpers, washers, or separators.

Don't use self-tapping screws for bonding purposes. Jumpers shouldn't be compression-fastened through plywood or other nonmetallic material. When you are performing a bonding operation, clean the contact surfaces of insulating finishes or surface films before assembling. After installation, refinished the assembly with a suitable protective finish. You should refer to NAVAIR 01-1A-505 for detailed information about bonding procedures.

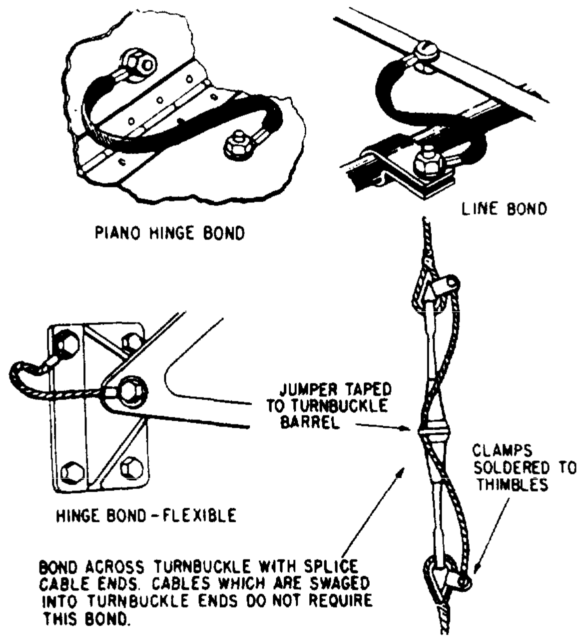

Figure 2-23.-Bonding methods.

CABLE LACING AND TYING

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. Lacing or tying keeps cables neatly secured in groups and avoids possible damage from chafing against equipment or interference with equipment operation.

You tie a group or bundle of wires by using individual pieces of cord tied around the group or bundle at regular intervals. You lace a bundle or group of wires by securing them together inside enclosures by a continuous piece of cord. You use this cord to form loops (half hitches) at regular intervals around the group or bundle.

Cotton, nylon, or fiber glass cord are used to tie or lace. The cotton cord has a wax coating to make it resist moisture and fungus.

SLEEVING

Sleeving helps protect connections from accidental shorting and moisture and to lengthen the arc-over path between contacts. Don't use insulating sleeves on connections or connectors that require moistureproofing. Don't use sleeving on connectors that have a sealing grommet that covers the soldered connection.

Sleeving, commonly called spaghetti, has many applications in naval aviation. Some of the applications are for covering soldered connections, open bus bars, and permanent splices.

For general-purpose wiring, use either clear or opaque flexible vinyl sleeving. For high-temperature applications (160°F to 400°F), you should use silicone rubber or fiber glass sleeving. Where resistance to synthetic hydraulic fluids or other solvents is necessary, use nylon sleeving, either clear or opaque.

Bus bars normally have panels or junction boxes to protect them against shorting. If the bus bars aren't enclosed, use of protective coating is desirable. You can use sleeving by slitting a piece of vinyl tubing and wrapping it around the bar after making all connections. Be careful to choose a tubing that has a large enough diameter to permit a generous overlap when tied in place (fig. 2-24, view A).

You can temporarily protect a wire with damaged insulation by using a sleeve of flexible tubing (fig, 2-24, view B) 1 1/2 times the outside diameter of the wire. The length should be at least 2 inches longer than the damaged portion of the insulation. Split the sleeve lengthwise and wrap it around the wire at the damaged section. Then, tie the sleeve with nylon braid at each end and at 1-inch intervals over the entire length. Since you must replace the damaged wire, use this procedure as an emergency measure.

To cover a permanent splice (fig. 2-24, view C), slip the sleeving on the wire before the splicing operation. After completing the splice, move the sleeving to cover the finished splice, and then tie it at each end with nylon braid.

You will use a slightly different arrangement for repairing shielded wire (fig. 2-24, view D). In this application you use two pieces of sleeving, one for the braid and one for the wire itself.

REVIEW SUBSET NUMBER 5

Q1. What publication contains information on mounting hardware for aircraft parts?

Q2. When substituting hardware, what should you consider before making the substitution?

Q3. What is the ONLY reason for clamping a wire bundle to a plumbing line?

Q4. List the three types of safety wire.

Q5. What is the purpose of bonding?

MAINTENANCE OF MOTORS AND GENERATORS

Learning Objective: *Recognize electrical motor and generator maintenance procedures.*

Since most motors and generators are not accessible during flight, the first sign of motor trouble in many instances is complete failure. Generators and motors are mechanically similar, so the preventive maintenance you perform is basically the same. You should be sure that the motor and/or generator mount is secure. Inspect the mechanical linkage for proper alignment and security. Check that the electrical connections are secure and clean. Check for signs of corrosion. Make sure of proper voltage.

You should inspect the exposed portion of the windings for evidence of overheating. If the insulation on the windings or leads is cracked and brittle, replace it. If, you smell burning insulation, or notice smoke or excessive noise, replace the motor.

When dismantling a motor, you should carefully remove the bearings and wipe them clean. Be sure to wrap the bearings in clean oil paper until needed during reassembly. Replace bearings showing pronounced stickiness or bumpy operation. During inspection of bearing assemblies, check for the presence of cracks and pitted surfaces. Also, check for any physical damage present in the bearing elements.

Most ac motors are prelubricated at the time of manufacture and have sealed bearings. The bearings require a visual inspection only. If the bearings are damaged, turn the motor in for overhaul. Before reassembling the motor, wipe the rotor and stator clean with a lint-free cloth. During all cleaning operations, use the correct cleaning solvents. As a final check, conduct an operational inspection of the motor, using the applicable MIM.

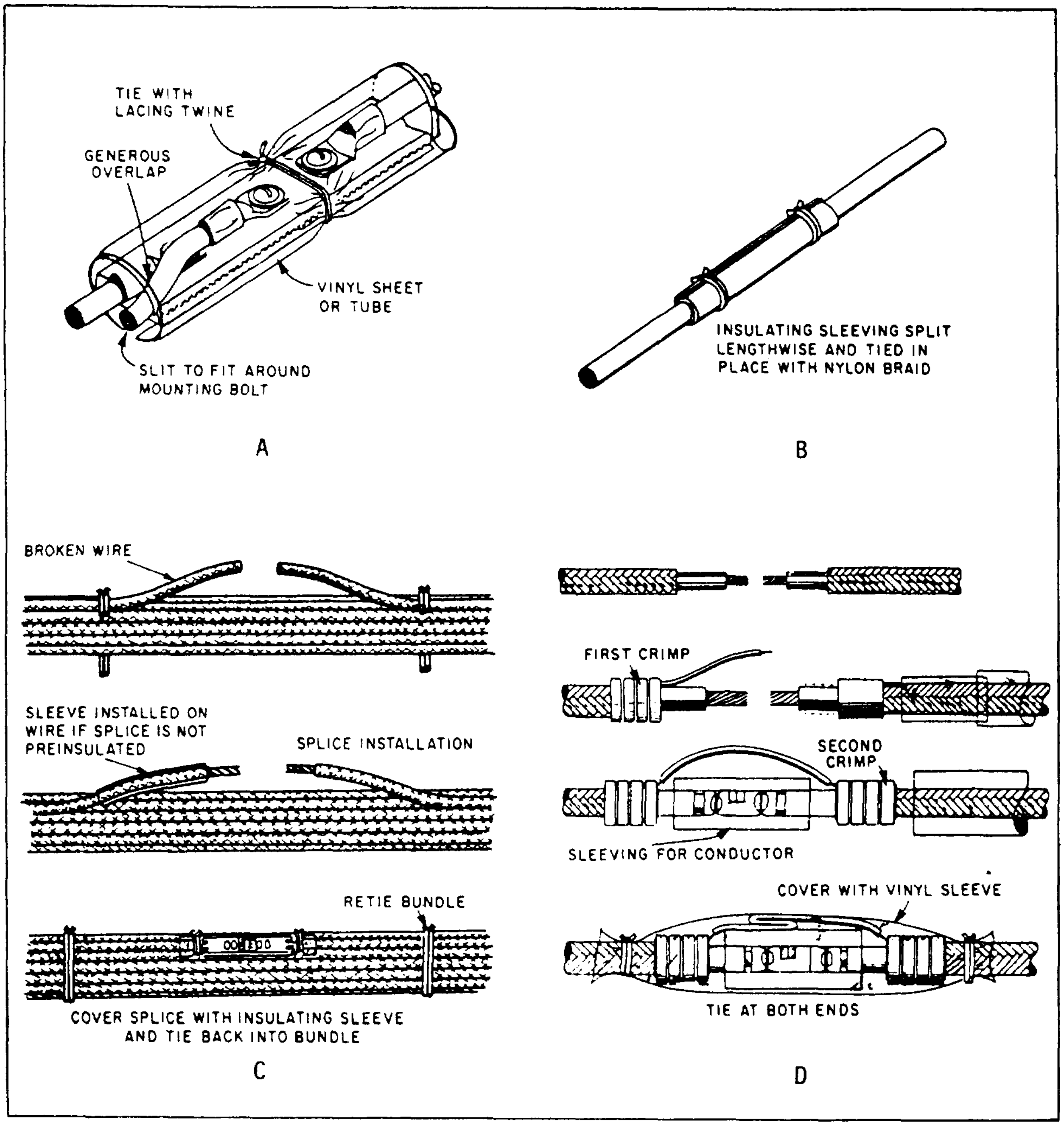

Figure 2-24.-Typical use of sleeving.

Corrosion control is a particularly important factor when dealing with rotating machinery. Corrosion inspection includes the following:

- An adequate cleaning program
- Thorough periodic lubrication
- Detailed inspection for corrosion and failure of protective systems
- Prompt treatment of corrosion and touchup of damaged paint areas

Effective protection begins with a comprehensive cleaning schedule. There is no single cleaning agent or process that will clean all parts. A cleaning agent that will clean one set of parts may not clean another. The cleaning agent may not be usable because it attacks the alloys or metal making up the part. Therefore, different cleaning agents are necessary. The selection of these agents will vary for different surfaces and equipment. You should refer to the following manuals for information on cleaning agents and their use: *Aircraft Weapons Systems Cleaning and Corrosion Control,* NAVAIR 01-1A-509, and *Avionic Cleaning and Corrosion Prevention/Control,* NAVAIR 16-1-540.

In addition to approved dry-cleaning solvents, you can use trichlorethylene and inhibited methyl chloroform to clean electrical and electronic equipment. Inhibited methyl chloroform (trichlorethane) does present hazards to personnel and insulation. For information on such hazards, refer to *NAVSHIPs' Technical Manual,* chapter 9600.

Insulation can be affected by methyl chloroform. Insulation exposed to methyl chloroform deteriorates proportionally with the time of exposure to the solvent. After a 5-minute exposure, methyl chloroform noticeably softens varnishes and reduces dielectric strength and abrasion resistance. A continuous immersion of 1 hour completely destroys the properties of most insulating materials and varnishes used in armatures, field coils, and similarly constructed electrical components. Glass melamine and laminated phenolics, however, are only slightly affected by such immersion.

Methyl chloroform itself is nonflammable, but after 90 percent evaporation, the residue contains a high percentage of the flammable inhibitor. When the solvent evaporates from containers, you must recognize the flammability of the residue.

Some of the special precautions you should observe when using methyl chloroform include the following:

- Avoid prolonged or repeated breathing of vapor or contact with the skin. Do not take internally.
- Prevent contact with open flame, as this may form highly toxic phosgene.
- Immerse electrical equipment less than 5 minutes, as prolonged immersion destroys most insulating materials.

WARNING

When using cleaning solvents, avoid burning the skin or inhaling the fumes. Use solvents in a well-ventilated room only.

- Test the solvent on a portion of the component. This ensures that it will not destroy, blister, or otherwise damage the material.
- DO NOT use on oxygen equipment—the inhibiting agent is flammable.
- DO NOT use on hot equipment—accelerated evaporation will increase the toxic hazard.

There are a variety of reasons for generator failures or apparent failures. Before removing a generator that isn't delivering its rated voltage or current, determine that the trouble is not a problem in the control, feeder, or regulating circuits. You should refer to the applicable overhaul instruction manuals as a guide in determining exact voltage and frequency tolerance during these tests.

Periodic inspection of generators includes the following:

- Check for defects in the mounting flange. If you find defects, remove and replace the generator. Inspect mounting studs, nuts, and safety wire for security.
- Check removable units such as ventilation tube, air blast cover, brush inspection band, terminal box, end shield, and conduit for tightness and general mechanical condition. Repair any minor dents. Replace any parts with cracks.
- Check the generator and cable connections for overheating. Discoloration and a burnt odor show overheating. Clean or replace the metal parts. Repair or replace damaged cables.
- If you find defects you cannot repair with the generator installed, remove it for repair or overhaul.

The maintenance and testing techniques used to maintain ac generators apply to dc generators. For detailed instructions on a specific generator, refer to the applicable manuals that are provided for the aircraft and component. Corrosion control of generators is the same as for motors /inserters.

Generators are not likely to be overloaded. A defective load (one that is highly inductive, and not the equivalent of resistance load) may result in low voltage, excessive field current, over saturation, and continued low voltage. Any condition resulting in abnormal field current may result in overheating. This condition is dangerous to the affected generator and the entire system, dc as well as ac.

PRINTED CIRCUITS

Learning Objective: *Identify characteristics of printed circuits, including modules and potted components, and recognize circuit construction features.*

The move toward replaceable units has lead to several new methods of electronic equipment construction. The printed circuit is an example of this construction. This design or type of circuit gives speed and economy to maintenance, as well as saving space and weight.

CIRCUIT CONSTRUCTION

Photoetching is one method used to manufacture printed circuits. In this method, a plastic or phenolic sheet with a thin layer of copper coating is used. The copper coating is covered with a light-sensitive enamel and a template of the circuit that appears when the sheet is exposed to light. The entire sheet is then exposed to light. The exposed area of copper reacts to the light. An etching process then removes this area. The exposure of the printed circuit is similar to a photographic exposure. The enamel on the unexposed circuit protects the copper from the etching bath that removes the exposed copper. After the etching bath, the enamel is removed from the printed circuit. This leaves the surface ready for soldering parts and connections.

Some manufacturers use machinery to mount standard parts like capacitors, resistors, and transistors—further speeding manufacture. Circuits produced by this method operate as well as conventional circuits and are easy to repair.

Look at figure 2-25. From the troubleshooters' standpoint, it shows an improved type of construction that consists of a removable modular subassembly. The modules have numerous internal and external test points to make troubleshooting easier. Most test racks have plug-in extensions that let you raise the module so all parts are accessible for test and repair. The module is not expendable, but it is easy to repair, since all parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are considered to be conventional.

PRINTED CIRCUIT MAINTENANCE

Although troubleshooting procedures for printed circuits are similar to those for conventional circuits, repair of printed circuits requires considerably more skill and patience. According to OPNAVINST 4790.2, only AIMDs being certified as having the capability may perform microminiature circuit repair. Activity certification means that the AIMD has individually certified technicians assigned and NAVAIR approved, operable repair equipment available, and does not include any specific authorization to repair.

Initial repair technician certification is granted only upon successful completion of the appropriate NAMTRAGRUDET course or equivalent contractor training course, approved and provided by NAVAIR. Each individual must be recertified periodically to assure continued quality of performance.

REVIEW SUBSET NUMBER 6

Q1. List the manuals to which you should refer for the correct cleaning agents and procedures.

Q2. For a technician to repair a printed circuit board, what certification must he/she meet?

TEST EQUIPMENT

Learning Objective: *Identify functions, capabilities, and operating characteristics of various types of aircraft test equipment.*

You can classify test equipment as either common or peculiar. In some cases, test equipment may be peculiar to a specific system, but that system may be used on several different aircraft.

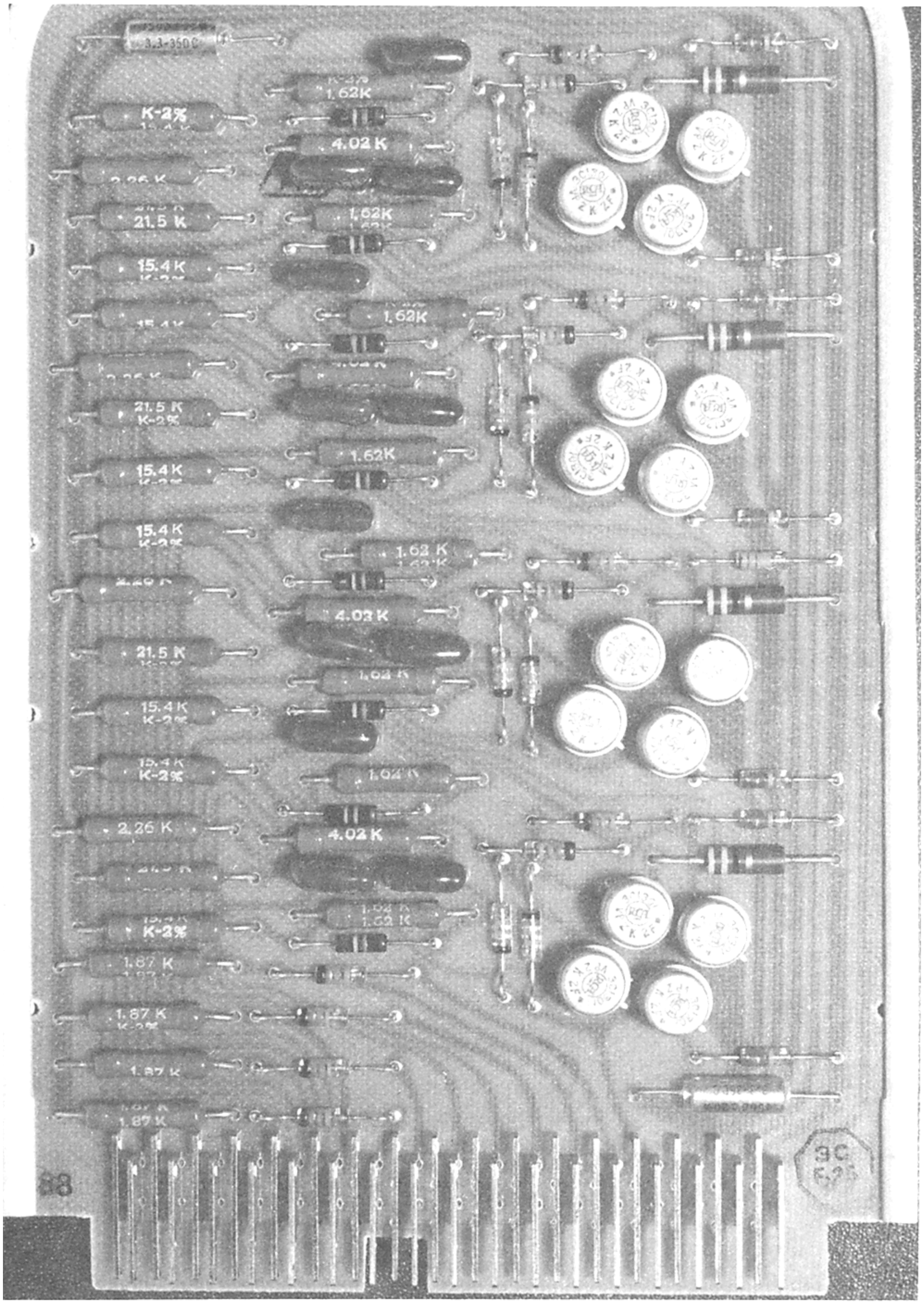

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Figure 2-25.—Printed circuit module.

Test equipment can also be classified by where it is used. You use line test equipment on the aircraft to determine a system's operational readiness and to isolate malfunctions to a particular part. Normally, this type equipment is painted yellow to distinguish it from the aircraft equipment.

Bench test equipment is used in the shop to isolate malfunctions to a particular module, subassembly, or to the exact resistor, capacitor, etc. Occasionally, you will use line test equipment with bench test equipment to perform complete checks of a part. Whenever you use test equipment, follow the instructions in the MIM or other operating instructions for the specific test equipment, aircraft, or system.

NEVER TRY TO TROUBLESHOOT EQUIPMENT FROM MEMORY!

By using test equipment instructions and the references for equipment under test, you prevent false findings. You also prevent damage to test equipment and systems and the loss of time.

MA-2 AIRCRAFT ELECTRICAL POWER TEST SET

The MA-2 aircraft electrical power test set (fig. 2-26) lets you completely test and check all aircraft ac and dc power generation system parts. The test set is of modular construction. consisting of four major assemblies:

1. Variable-speed drive
2. Control console

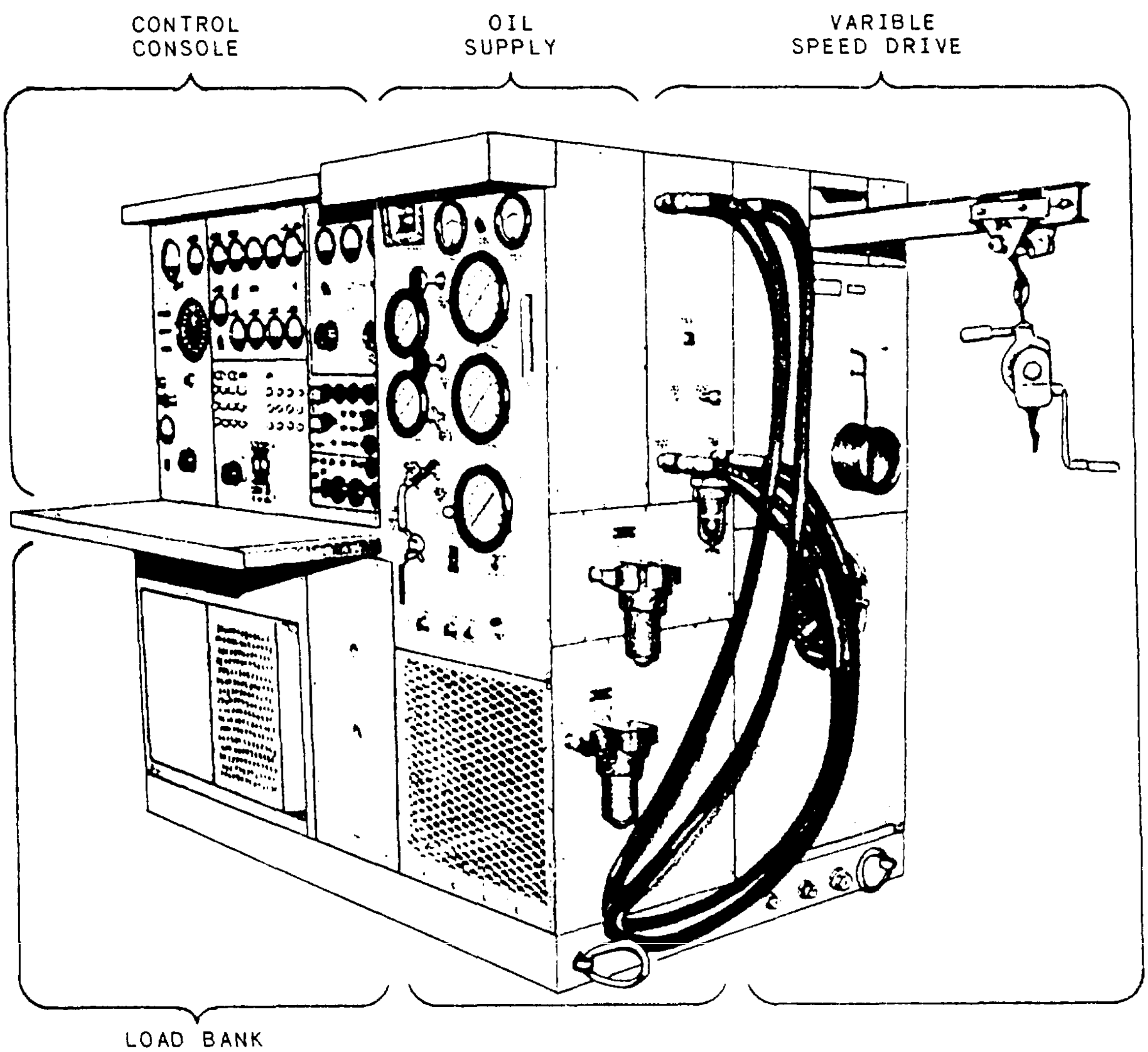

Figure 2-26.-MA-2 aircraft electrical power test set assembly.

3. Load bank
4. Oil supply system

Variable-Speed Drive Assembly

The test set variable-speed drive assembly can produce 55 horsepower loads at speeds between 2,000 and 11,000 RPM. Speed regulation is better than ± 1 percent in this speed range. Speed is controllable between 55 and 11,000 RPM. The upper frame of the variable-speed drive houses the drive motor reversing switch and main input power circuit breaker. The line radio noise filters, unit-under-test cooling air blower, and the trolley and hoist assembly are also on the upper frame. The speed control panel on the control console provides control of the gearbox output shaft speed.

Control Console

The control console may be wall mounted, floor mounted, or mounted on the test set assembly. The control console provides the means for you to program and monitor the test function remotely from the other subassemblies of the test set. A stowaway type of shelf, extending the full length of the control console, gives you working space. A card file drawer, convenient power outlets, and covered terminals are located on the left-hand end of the control console. The panels contain dead front switches and controls; and all power exceeding 125 volts ac is within enclosures for operator safety. The control console consists of a variable-speed drive panel, ac metering panel, dc metering panel, a load bank control panel, and a terminal panel.

Load Bank

The load bank provides for the loading of ac generators, inverters, dc generators, transformer-rectifiers, and frequency converters. The load bank houses the resistive elements (both ac and dc) along with the load switching relays. The temperature sensors and a self-contained, forced-air cooling system are also located within the load bank housing. The load bank is limited to selecting and applying adjustable resistive ac balanced loads from 1 to 30 kW (0 to 10 kW per phase). The dc limitation is 0- to 500-ampere dc loads.

Oil Supply System

The oil supply system is electrically driven, which provides oil cooling and pressures under test. The system contains all controls, valves, and instruments needed to maintain and monitor oil flow. It also maintains and monitors temperatures and pressures of CSD/generators under test. The test set allows the four major assemblies to operate as one unit, or they can be separated to permit operation in confined areas.

REVIEW SUBSET NUMBER 7

Q1. What are the two types of test equipment?

Q2. What test equipment is used to test generators, voltage regulators, and reverse-current relays in as many operating conditions as possible?

SEMICONDUCTOR TESTING

Since semiconductors have replaced vacuum tubes, the testing of semiconductors is vital. In this section, three basic types of equipment are discussed—the Huntron Tracker 1000, Huntron Tracker 2000, and the Automatic Transistor Analyzer Model 900 in-circuit transistor tester.

Huntron Tracker 1000

You will test components with Huntron Tracker 1000 using a two-terminal system, where two test leads attach to the leads of the component under test. The 1000 tests components in-circuit, even when there are several components in parallel. The following types of devices are tested using the Huntron Tracker 1000:

- Semiconductor diodes
- Bipolar and field effect transistors
- Bipolar and MOS integrated circuits (both analog and digital)
- Resistors, capacitors, and inductors

The 1000 is used on boards and systems with **ALL** voltage sources in a power-off condition. A 0.25 ampere signal fuse (F1) connects in series with the channel A and B test terminals. Accidentally contacting test leads to active voltage sources (e.g., line voltage, powered-up boards or systems, charged high voltage capacitors, etc.) may cause this fuse to open, making replacement necessary. When the signal fuse blows, the display shows open circuit signatures, even with the test leads shorted together.

CAUTION

The device to be tested must have all power turned off and have all high-voltage capacitors discharged before connecting the 1000 to the device.

The line fuse (F2) should only open when there is an internal failure inside the instrument. Therefore, you should always locate and correct the problem before replacing F2.

The front panel of the 1000 makes function selection easy. The 1000 uses interlocking push-button switches for range selection. A toggle switch is used for channel selection, and integral LED indicators show the active functions.

The CRT displays the signatures of the parts under test. The display has a graticule consisting of a horizontal axis that represents voltage, and a vertical axis that represents current. The horizontal axis is divided into eight divisions, which lets you estimate the voltage at which signature changes occur. This is mainly useful in determining semiconductor junction voltages under either forward or reverse bias.

Push in the power on/off switch. The 1000 should come on line with the power LED illuminated.

Before you can analyze signatures on the CRT, you must focus the 1000. To do this, turn the intensity control to a comfortable level. Now, adjust the focus control (back panel) for the narrowest possible trace. Aligning the trace is important in determining the voltages at which changes in the signature occur. With a short circuit on channel A, adjust the horizontal control until the vertical trace is even with the vertical axis. Open channel A, and adjust the vertical control until the horizontal trace is even with the horizontal axis. Once set, you should not have to adjust these controls during normal operation.

Turn the power off by pushing the power switch in. When you turn the power on again, the same intensity setting will be present.

The 1000 has three impedance ranges—low, medium, and high. To select these ranges, press the appropriate button on the front panel. Always start with the medium range; then you can adjust for other ranges. If the signature on the CRT is close to an open (horizontal trace), try the next higher range for a more descriptive signature. If the signature is close to a short (vertical trace), try the next lower range.

There are two channels (channel A and channel B) that you can select by moving the toggle switch to the desired position. When using a single channel, plug the red probe into the corresponding channel test terminal. Then plug the black probe into the common test terminal. When testing, connect the red probe to the positive terminal of the device (i.e., anode, +V, etc.). Connect the black probe to the negative terminal of the device (i.e., cathode, ground, etc.). By following this procedure, the signature will appear in the correct position on the CRT display.

The alternate mode of the 1000 provides automatic switching back and forth between channel A and channel B. This allows easy comparison between two devices or the same point on two circuit boards. You select the alternate mode by moving the toggle switch to the ALT position. The alternate mode is useful when comparing a known good device with the same device whose quality is unknown.

The signal section applies the test signal across two terminals of the device under test. The test signal causes current to flow through the device and a voltage drop across its terminals. The current flow causes a vertical deflection of the signature on the CRT display. The voltage across the device causes a horizontal deflection of the signature on the CRT display. The combined effect produces the current-voltage signature of the device on the CRT display.

An open circuit has zero current flowing through the terminals and a maximum voltage across the terminals. In the LOW range, a diagonal signature from the upper right to the

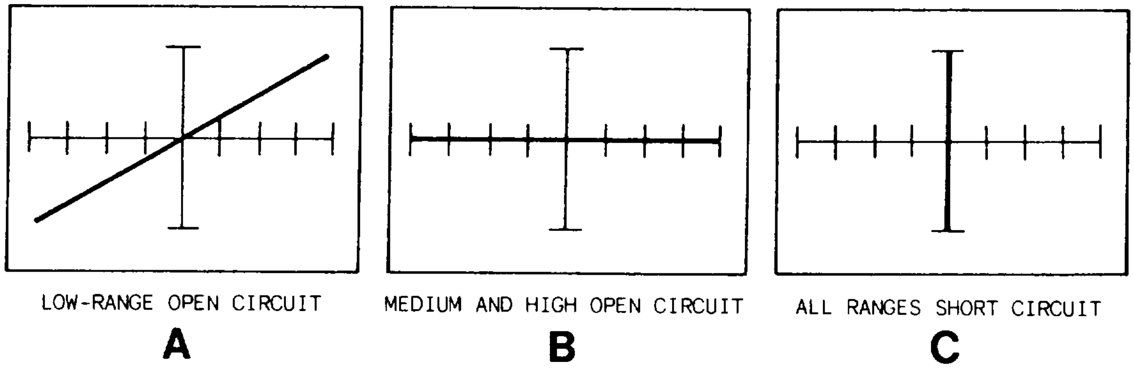

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Figure 2-27.-Circuit signatures: View A-Low-range open circuit; view B—medium and high range open circuit; and view C—all ranges short circuit.

lower left of the CRT (fig. 2-27, view A) represents an open circuit. In the HIGH and MEDIUM ranges, an open circuit shows as a horizontal trace from the left to the right (fig. 2-27, view B). When you short the terminals together, the maximum current flows through the terminals, and the voltage at the terminals is zero. A vertical trace from the top to the bottom of the CRT graticule in all ranges shows this short (fig. 2-27, view C).

The CRT deflection drivers boost the low-level outputs from the signal section to the higher voltage levels needed by the deflection plates in the CRT. The HORIZONTAL and VERTICAL controls on the front panel adjust the position of the trace on the CRT display.

You use three other CRT controls to adjust the brightness and clarity of the trace—lNTENSITY, FOCUS, and ASTIGMATISM. The front panel intensity control is the primary means of adjusting the visual characteristics of the trace. The focus control is on the back panel and is operator adjustable. The astigmatism trim pot is inside the 1000 on the main printed circuit board. The pot is factory adjusted to the correct setting.

Huntron Tracker 2000

The Huntron Tracker 2000 (fig. 2-28) is a versatile troubleshooting tool having the following features:

- Multiple test signal frequencies (50/60 Hz, 400 Hz, 2000 Hz)

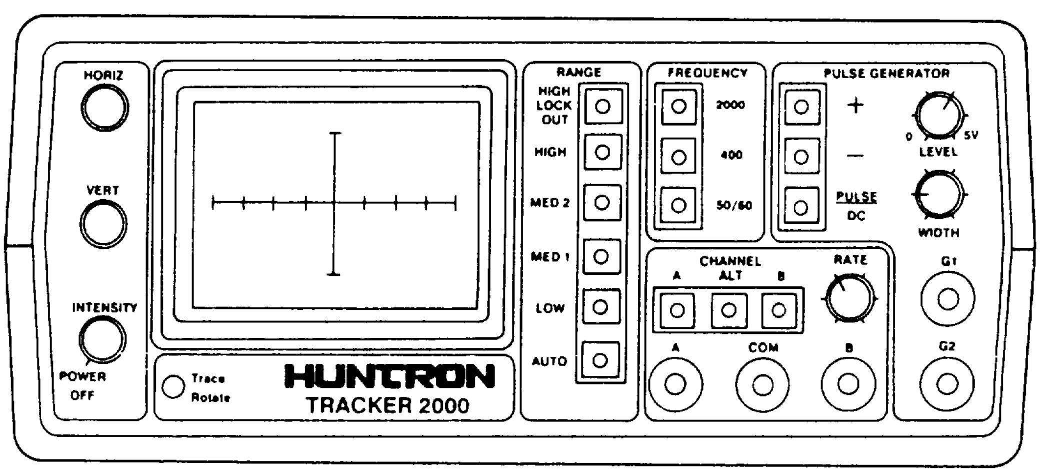

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Figure 2-28.-Huntron Tracker 2000.

- Four impedance ranges (low, medium 1, medium 2, high)
- Automatic range scanning
- Range control: High Lockout
- Adjustable rate of channel alteration and/or range scanning
- Dual polarity pulse generator for dynamic testing of three terminal devices
- LED indicators for all functions
- Dual channel capability for easy comparison
- Large CRT display with easy to operate controls

GENERAL OPERATION. —You will test components using the 2000 two terminal system. It also has a three terminal system when using the built-in pulse generator. When using this system, you place two test leads on the leads of the component under test. The 2000 tests components in-circuit, even when there are several parts in parallel.

Use the 2000 only on boards and systems with all voltage sources in a power-off condition. A 0.25 ampere signal fuse connects in series with the channel A and B test terminals. Accidental contact of the test leads to active voltage sources, such as line voltage, powered-up boards or systems, and charged high voltage capacitors, may cause this fuse to open, making replacement necessary. When the signal fuse blows, the 2000 displays short circuit signatures even with the test leads open.

CAUTION

The device under test must have all power turned off and all high-voltage capacitors discharged before connecting the 2000 to the device.

The line fuse should only open when there is an internal failure inside the instrument. Always locate the problem and correct it before replacing this fuse.

Front Panel. —The front panel of the 2000 makes function selection easy. All push buttons are the momentary action type. Integral LED indicators show which functions are active. Look at figure 2-29 and table 2-4 for details about each item on the front panel.

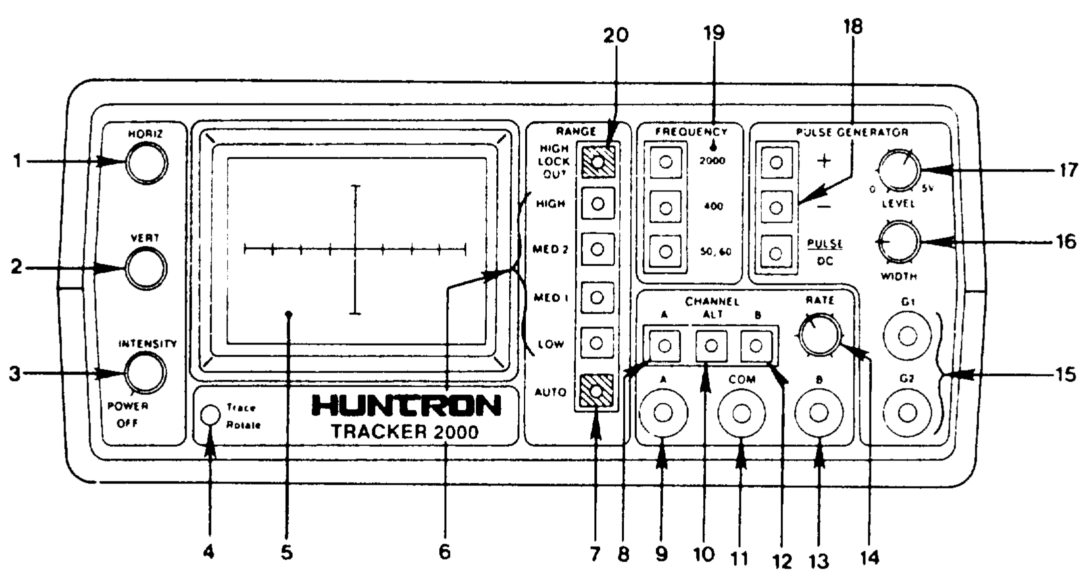

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Figure 2-29.-Front panel.

Table 2-4.-Front Panel Controls and Connectors

Item No.	Name	Function
1	HORIZ Control	Controls the horizontal position of the CRT display.
2	VERT Control	Controls the vertical position of the CRT display.
3	INTENSITY Control Power On/Off Switch	Controls the intensity of the CRT display. Power Switch: Rotate clockwise to turn on.
4	TRACE ROTATE Control	Controls the trace rotation of the CRT display.
5	CRT Display	Displays the component signatures produced by the 2000.
6	Range Selectors	Push buttons that select one of four impedance ranges: low, medium 1, medium 2, high.
7	AUTO Switch	Push button that initiates automatic scanning of the four ranges from low to high. The scanning speed is determined by the RATE control (see item #14).
8	Channel A Switch	Push button that causes channel A to be displayed.
9	Channel A Test Terminal	Fused test lead connector that is active when channel A is selected. All test lead connectors accept standard banana plugs.
10	ALT Switch	Push button that causes the 2000 to alternate between channel A and channel B at a speed determined by the RATE control (see item #14).
11	COM Test Terminal	Test lead connector that is instrument common and the common reference point for both channel A and channel B.
12	Channel B Switch	Push button that causes channel B to be displayed.
13	Channel B Test Terminal	Fused test lead connector that is active when channel B is selected.
14	RATE Control	Controls the rate of channel alternation and/or range scanning.
15	G1 & G2 Terminals	Pulse generator output test lead connectors.
16	WIDTH Control	Controls the duty cycle of the internal pulse generator.
17	LEVEL Control	Controls the amplitude of the internal pulse generator.
18	Pulse Generator Selectors	Push buttons that select various output modes of the pulse generator: Positive (+), Negative (−), PULSE/DC.
19	Frequency Selectors	Push Buttons that select one of the three test signal frequencies: 50/60 Hz, 400 Hz, 2000 Hz.
20	HIGH LOCKOUT Switch	Push button that activates a mode where it is not possible to enter the high range either by manual or automatic range selection.

Table 2-5.-Back Panel Controls and Connectors

Item No.	Name	Function
1	Accessory Output Connector	Connector which provides power and clock to the Huntron Switcher Model HSR410.
2	Power Cord Connector	IEC standard connector that mates with any CEEE-22 power cord.
3	FOCUS Control	Controls the focus on the CRT display.

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Back Panel. —Secondary controls and connectors are located on the back panel (fig. 2-30 and table 2-5).

CRT Display. —The signature of the part under test is displayed on the CRT. The display has a graticule consisting of a horizontal axis that represents voltage, and a vertical axis that represents current. The axes divide the display into four quadrants. Each quadrant displays different portions of the signatures.

- Quadrant 1 displays positive voltage (+V) and positive current (+I)
- Quadrant 2 displays negative voltage (-V) and positive current (+I)
- Quadrant 3 displays negative voltage (-V) and negative current (–I)
- Quadrant 4 displays positive voltage (+V) and negative current (–I)

The horizontal axis divides in eight divisions, which allows the operator to estimate the voltage at which changes in the signature occur. This is useful in determining semiconductor junction voltages under either forward or reverse bias.

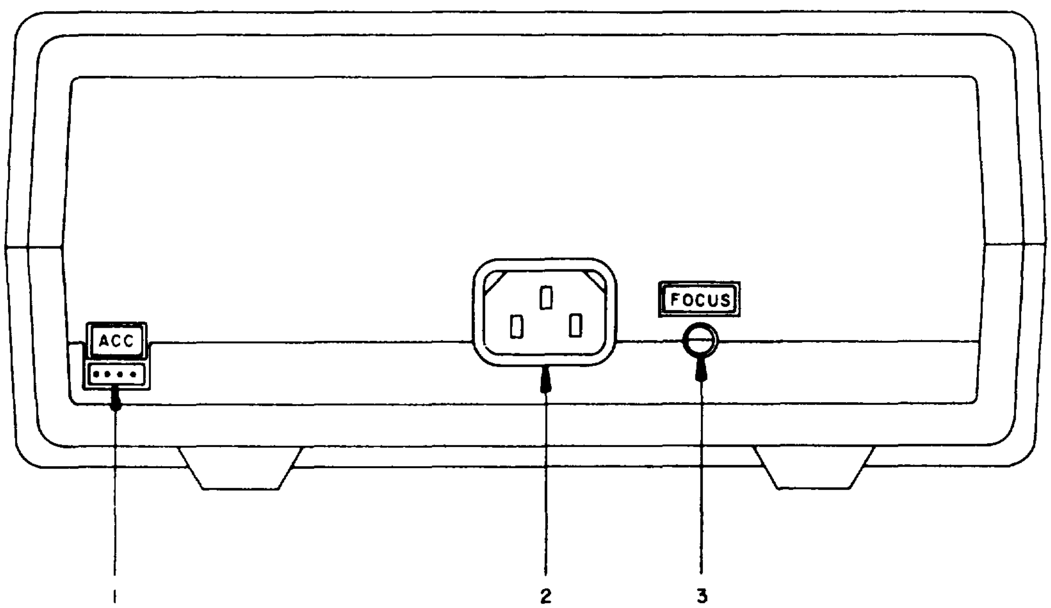


Figure 2-30.-Back panel.

OPERATION OF PANEL FEATURES. — The following section explains how to use the front and back panel features.

Turn the Power/Intensity knob clockwise. The 2000 comes on with the LEDs for power, channel A, 50/60 Hz, low range, and pulse/DC illuminated.

Focusing the 2000 display is an important part of analyzing the test signatures. First you adjust the intensity control to a comfortable level. Then, adjust the focus control (back panel) for the narrowest possible trace.

Aligning the trace is important in determining which quadrants the portions of a signature are in. With a short circuit on channel A, adjust the trace rotation control until the trace is parallel to the vertical axis. Adjust the horizontal control until the vertical trace is even with the vertical axis. Open channel A, and adjust the vertical control until the horizontal trace is even with the horizontal axis. Once set, you should not have to readjust these settings during normal operation.

Range Selection. —The 2000 has four impedance ranges—low, medium 1, medium 2, and high. You select these ranges by pressing the appropriate button on the front panel. Start with one of the medium ranges, i.e., medium 1 or medium 2. If the signature on the CRT display is close to an open (horizontal trace), select the next higher range for a more descriptive signature. If the signature is close to a short (vertical trace), select the next lower range.

The High Lockout feature, when activated, prevents the instrument from entering the high range. This feature works in either the manual or auto mode.

The auto feature scans through the four ranges—three with the HIGH LOCKOUT activated at a speed set by the RATE control. This feature allows you to see the signature of a part in different ranges while freeing your hands to hold the test leads.

Channel Selection. —There are two channels on the 2000-channel A and channel B. You select a channel by pressing the appropriate front panel button. When using a single channel, plug the red probe into the corresponding channel test terminal. Plug the black probe into the common test terminal. When testing, connect the red probe to the positive terminal of the device; i.e., anode, +V, etc. Connect the black probe to the negative terminal of the device; i.e., cathode, ground, etc. Following this procedure should assure that the signature appears in the correct quadrants of the CRT display.

The ALT mode is a useful feature of the 2000. It lets you compare a known good device with a device of unknown quality. In this test mode, you use common test leads to connect two equivalent points on the boards to the common test terminal. The ALT mode of the 2000 allows you to automatically switch back and forth between channel A and channel B, so you can easily compare two devices. You may also compare the same points on two circuit boards. Select the ALT mode by pressing the ALT button on the front panel. You may vary the alternation frequency by using the RATE control.

NOTE: The black probe plugs into the channel B test terminal.

When using the alternate and auto features simultaneously, each channel is displayed before the range changes. Figure 2-31 shows the sequence of these changes.

Frequency Selection. —The 2000 has three test signal frequencies—50/60 Hz, 400 Hz and 2000 Hz. You can select these by pressing the appropriate button on the front panel. In most cases, you should start with the 50/60 Hz test signal. Use the other two frequencies to view small amounts of capacitance or large amounts of inductance.

Pulse Generator. —The built-in pulse generator of the 2000 allows dynamic, in-circuit testing of certain devices in their active mode. In addition to using the red and black probes, you use the pulse generator. The output of the pulse generator connects to the control input of the

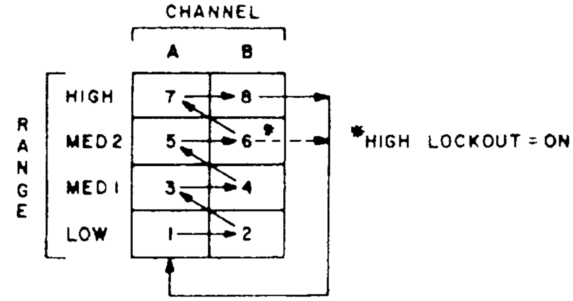


Figure 2-31.-Auto/alternate sequence.

device under test with one of the blue micro clips provided. The pulse generator has two outputs, G1 and G2, so you can test three terminal devices in the alternate mode.

A variety of output waveforms is available using the pulse generator selector buttons. First select the pulse mode or the dc mode using the PULSE/DC button.

- In the pulse mode, the LED flashes at a slow rate.
- In dc mode, the LED is continuously on.

Then select the polarity of output desired using the positive (+) and negative (–) buttons. All three buttons function in a *push-on/push-off* mode, and only interact with each other to avoid the NOT ALLOWED state.

After selecting the specific output type, set the exact output using the LEVEL and WIDTH controls. The LEVEL control varies the magnitude of output amplitude from zero to 5 volts (peak or dc). During pulse mode, the WIDTH control adjusts the duty cycle of the pulse output from a low duty cycle to 50 percent maximum (square wave). The start of a pulse is triggered by the appropriate zero crossing of the test signal. This results in the pulse frequency being equal to the selected test signal frequency. The WIDTH control setting that selects the duty cycle determines the end of a pulse. The WIDTH control has no effect when in the dc mode.

Troubleshooting Tips

You will use the Huntron Tracker 1000 and the Huntron Tracker 2000 to test various types of devices and circuits. Some troubleshooting tips are given in this section.

- Perform most tests using the medium or low range.
- Use the high range only for testing at a high impedance point, or if higher test voltages are required (i.e., to test the Zener region of a 40-volt device).
- Sometimes, component defects are more obvios in one range than another. If a suspect device appears normal for one range, try the other ranges.
- Use the low range when testing a single bipolar junction, such as a diode, a base-emitter junction, or a base-collector junction. It offers the best signature.
- Use a higher range to check for reverse bias leakage.
- When performing in-circuit testing, do a direct comparison to a known good circuit.
- The 1000 test leads are not insulated at the tips. Be sure to make good contact to the device(s) under test. **(NOTE:** This tip pertains to the 1000 only.)

When you troubleshoot, try relating the failure mode of the circuit under test to the type of defect the 1000 shows. For example, expect a catastrophic printed circuit board failure to have a dramatic signature difference from that of a normal device of the same type. A marginally operating or intermittent board may have a failed part that shows only a small pattern difference from normal.

If you cannot relate a system failure to a specific area of the printed circuit board, begin by examining the signatures at the connector pins. This method of troubleshooting shows all the inputs and outputs. It will often lead directly to the failing area of the board.

Devices made by different manufacturers, especially digital integrated circuits, are likely to produce slightly different signatures. This is normal and may not show a failed device.

Remember, leakage current doubles with every 10-degree Celsius rise in temperature. Leakage current shows up as a rounded transition (where the signatures show the change from zero current flow to current flow) or by causing curvature at other points in the signatures. Leakage current causes curvatures due to its nonlinearity.

Never begin the testing of an integrated circuit using the low range. If you initially use the low range, confusion can result from the inability of this range to display the various junctions. Always begin testing using the medium range. If the signature is a vertical line, switch to the low range. Here you can check for a short or low impedance (less than 500 ohms). Switch to the low range if the device is suspect and appears normal in the medium range. This will reveal a defective input protection diode not evident when using the medium range.

NOTE: The 2000 test leads are conductive only at the tips. Be sure to make good contact with the device(s) under test.

When testing analog devices or circuits, use the low range. Analog circuits contain many more single junctions. Defects in these junctions show more easily when using the low range. Also, the 54-ohm internal impedance in the low range makes it less likely that parts in parallel with the device under test will sufficiently load the tester to alter the signature.

When testing an op amp in-circuit, compare it directly to a known good circuit. This is because the many different feedback paths associated with op amps can cause an almost infinite number of signatures.

Often when checking a Zener diode in-circuit, it will not be possible to examine the Zener region due to circuit leakage. If you must see the Zener region under this condition, unsolder one side of the diode to eliminate the loading effects of the circuit.

HUNTRON TRACKER 1000. —Bipolar integrated circuits containing internal shorts produce a resistive signature (a straight line). This line begins in the 10 o'clock to 11 o'clock position. It ends in the 4 o'clock to 5 o'clock position on the display when using the low range. This type of signature is always characteristic of a shorted integrated circuit. It results from a resistive value of 4 to 10 ohms, typical of a shorted integrated circuit. A shorted diode, capacitor, or transistor junction always produces a vertical (12 o'clock) straight line using the low range.

HUNTRON TRACKER 2000. —Bipolar integrated circuits containing internal shorts produce a resistive signature (a straight line) beginning in the 1 o'clock to 2 o'clock position. This signature ends in the 7 o'clock to 8 o'clock position when using the low range. This type of signature is characteristic of a shorted integrated circuit. This results from a resistive value of 4 to 10 ohms. A shorted diode, capacitor, transistor junction, etc., always produces a vertical (12 o'clock) straight line when using the low range.

Automatic Transistor Analyzer Model 900

You can use this instrument to test bipolar transistors and diodes in any one of three different modes. Two modes, the VIS and SND, can be used either in-circuit or out-of-circuit.

- In the VIS mode, red and green lights flashing in or out of phase with the amber light show the condition of the device under test.
- In the SND mode, the Sonalert™ also indicates good devices by beeping out of phase with the amber light. The intent of the SND mode is to permit the operator to perform in-circuit tests on transistors or diodes without having to look at the light display.

The third mode is the METER mode. You can only use this for out-of-circuit testing. In the METER mode, you may measure Beta I_{ceo}, I_{cbo}, and material identity. Also, you can measure emitter base voltage, base current (Ib), and collector current (Ic). There are four ranges for the Beta mode—one for small signal transistors, two ranges for medium power transistors, and one for large power transistors.

In the VIS mode and the SND mode, the maximum voltage, current and signal levels applied to the device under test are within safe limits. Therefore, the device under test will receive no damage nor will any adjacent circuitry.

This instrument will test transistors and diodes in-circuit in the VIS or SND mode if the total dynamic shunt impedances across the junctions are not less than 270 ohms. Also, the total dynamic shunt for the emitter to collector must not be less than 25 ohms. If such should occur, the test set will give the indication for a SHORT.

The 8-inch meter, which reads from left to right, has two scales marked 0-10 and 0-50. The O-10 range is used in the leakage collector current and Vbe (IDENT) modes. The 0-50 range is used in the BETA modes. Notice a mark on the meter just short of half-scale with the nomenclature GERMANIUM and SILICON. This mark is the reference in the IDENT mode. As the meter markings show, those readings below the mark show the device material is germanium. The readings above the mark show the device is silicon. On the slanting horizontal panel immediately in front of the meter face are the appropriate test sockets and two push-button switches. One switch is ZERO and the other BETA. On the vertical front panel immediately below the push-button switches are knobs marked ADJ and CAL. At the top center is the POLARITY switch marked PNP and NPN. In the center of the vertical front panel is the RANGE switch, the FUNCTION switch and the Sonalert™. Near the bottom of the vertical front panel are the probe jacks. The slide switch for turning the instrument on and off is also in this location.

VIS MODE: TRANSISTOR. —To test transistors with the visual indication only, turn the FUNCTION switch to the XSTR-VIS mode. The amber light should flash at about a l-second rate. Insert the transistor under test in the proper socket.

In this mode, you perform two tests on the transistor. The amber light shows the performance of each test. When the amber light is out, this is the EB-BC test mode. When the amber light is on, this is the emitter-collector test mode. The test shows good transistors by one pair of similarly colored lights (green for NPN and red for PNP) when the amber light is off. When the amber light is on, no lights show good transistors. The left-hand lights show the condition of the emitter-base. The right-hand lights show the condition of the base-collector. The absence of one or all lights in the EB-BC test mode shows an open or opens. The occurrence of both a red and a green light on either side in the EB-BC test mode shows a short.

For more information about the Model 900 tracker, refer to *Maintenance Manual, All Levels for Automatic Transistor Analyzer Model 900, ST810-AD-0PI-010,* for patterns other than those just discussed. There are 96 possible patterns listed.

VIS MODE: DIODE. —You can not properly test diodes in the XSTER mode. To test a diode, insert the diode in the proper socket and turn the FUNCTION switch to the DIODE/VIS mode. If the diode is good, a pair of green lights will flash out of phase with the amber. If a pair of red lights flash out of phase with the amber light, the diode is either installed improperly or marked improperly. If the diode has a short, additional lights will flash out of phase with the amber. No lights will flash in phase with the amber.

You cannot properly test transistors in the DIODE mode. When testing transistors, only one transistor should be in the test socket at one time. Do not leave any diodes in the diode socket while testing transistors. When testing diodes, do not leave transistors in the transistor sockets. If you do not observe these precautions and the devices left in the socket are defective, incorrect light indications will occur. These indications may mislead the operator into believing the device under test is defective.

WARNING

Unit being tested must be disconnected from ac outlet, and all capacitors capable of storing electricity y should be discharged.

IN-CIRCUIT TESTING. —When testing diodes in-circuit, attach the emitter lead to the anode of the diode. Attach the collector lead to the cathode. When testing transistors, attach the leads to the right terminals as shown by the schematic. If the operator happens to fasten the leads to the transistor in the wrong order, an erroneous display will result. However, if the transistor is good, the instrument will give a good indication. The indication will be for the transistor of the opposite type. A good NPN improperly connected will give good PNP indications and vice versa. If the device is bad, the instrument will give a bad indication. You cannot make a qualitative analysis of the kind of failure unless you attach the proper leads to the correct terminals.

To ensure the instrument will show the correct type of transistor (PNP or NPN), you must identify the base lead. Use the following procedure to identify the base lead:

1. Disconnect the lead to the emitter terminal on the instrument. Only the light representing the emitter junction should go out.
2. Reconnect the emitter lead.
3. Disconnect the lead to the collector terminal of the instrument. Only the light representing the collector junction should go out.
4. Should both lights go out during the tests, the connections are incorrect.
5. Rearrange the leads on the transistor and perform-the tests again. You should now see the proper results.

There are six possible combinations for the connection of these leads. Four of these combinations are incorrect. These will cause the instrument to give an incorrect indication as to transistor type (PNP or NPN). The other two combinations will give proper indications, but you still may not know which leads are the emitter and collector terminals. You will know whether the transistor is good, and whether it is an NPN or PNP transistor. If you must know which leads are the emitter and collector terminals, it is possible to find out after identifying the base lead using the meter mode for Beta.

SND Mode. —In either the XSTR/SND mode or DIODE/SND mode, light patterns **showing** good devices will have an accompanying beeping sound from the Sonalert™. The beeping will be out of phase with the amber light.

METER Mode. —Before testing a transistor in any of the METER modes, you should test the transistor in one of the visual modes. This will tell you whether the transistor is an NPN or a PNP. After determining this, put the POLARITY switch in the proper position to agree with the indication in the visual mode.

Beta. —To test the Beta of the transistor, set the FUNCTION switch to the BETA position. Next, set the RANGE switch to the appropriate position according to the power capability of the transistor under test. After the RANGE switch is in the proper position, operate the push-button switch marked ZERO. Now adjust the ADJ knob for a zero reading on the meter. Next, actuate the push-button switch marked BETA and adjust the CAL knob for full-scale deflection. Release the BETA push-button switch; now the Beta of the device will show on the meter. Take care in selecting the Beta range to test the transistor. It is possible to damage small signal transistors should you try to test them in the 2 mA Ib (LG. PWR. XSTR) mode.

Leakage: I_{ceo} or I_{cbo}.- —To test a transistor for I_{ceo} or I_{cbo}, set the FUNCTION switch on the proper position. Next, set the RANGE switch to the 100 mA position. Then push the switch marked ZERO and adjust the ADJ knob for a zero reading on the meter. Now release the ZERO button. Set the RANGE switch on the lowest leakage range, which will still permit less than full-scale deflection on the meter. You may now read the leakage directly off the meter. Read the I_{ceo} first and then I_{cbo}. Use this order because the meter will read down scale when switching from I_{ceo} to I_{cbo}. Also, you can increase the meter sensitivity. However, if you read I_{cbo} first and then switch to I_{ceo},the meterill read up scale. It is now possible to peg the meter. Although the meter has protection, avoid undue abuse.

Material Identity: Transistor. —To use this instrument in the IDENTITY mode, set the FUNCTION switch to IDENT. Check the ZERO ADJUST on the meter as mentioned before. After setting the ZERO, release the ZERO pushbutton. Now note whether the needle reads above or below the mark on the meter face just short of half scale. If the meter reads below the mark, the device is a germanium transistor. If it reads above the mark, it is a silicon transistor. This information can be extremely useful when trying to substitute transistors.

Leakage: Diode. —To test the reverse leakage of diodes, install the diode in the diode socket. You now determine whether the diode is good by testing the device in the visual mode. Once you determine that the diode is good, place the POLARITY switch to NPN. Turn the FUNCTION switch to the I_{ceo} mode, and set the RANGE switch to 100 mA. Now check to see that the meter is at zero, as mentioned before. After zeroing the meter, set the RANGE switch on the lowest range possible that still permits less than full-scale deflection on the meter. Read the leakage on this range.

Material Identity: Diode. —To test the material identity of a diode with the diode properly installed in the socket. Place the POLARITY switch in the PNP position (zero the meter) and the FUNCTION switch in the IDENT position. Using the leads, short the base and collector terminals together. The meter will show either germanium or silicon, as described before in the IDENT mode for transistors.

CAUTION

Do not identity test transistor material with the base and collector leads shorted together. This may create an erroneous reading.

Model 109 Probe

The Model 109 probe, used with the Model 900 tester, is easy to use, having one-hand operation. It automatically adjusts to any spacing between one-thirty second inch to five-eighths inch. You can rotate each probe point in a full 360-degree circle. The points are individually spring loaded for proper contact. You can connect the probe to three printed circuit board terminations. The probe has the extremely low contact resistance of less than .005 ohm. The use of the probe eliminates unsoldering while making in-circuit tests of transistors, diodes, ICS, and other components. Finally, the retractable cord stretches to a full 12 feet.

DESCRIPTION. —The Model 109 three-point probe speeds servicing of printed circuit assemblies that have transistors, diodes, and most other board mounted components. You can make instant connections to three points on a printed circuit board. You will make rapid evaluation of transistors using the Model 109 probe with the Model 900 Automatic Transistor Analyzer in-circuit. You can accomplish a complete test of all stages in a piece of electronic equipment in a matter of minutes. You can also use the Model 109 to make temporary component substitutions on the printed circuit board.

OPERATION. —Connect the leads of the Model 109 probe to an appropriate piece of test equipment. Determine the connection points on the printed circuit board to connect to the test equipment. Apply the Model 109 probe points to the circuit board. Press the probe towards the board to ensure a good connection. The Model 109 probe green point is slightly shorter than the yellow and blue. This allows connection of the collector and emitter before the base to provide maximum ease of use.

The Model 109 probe is a valuable aid when making resistance and voltage measurements using a conventional VOM or VTVM. Use the yellow and blue probe points as the negative and positive meter feeds. You can make rapid evaluations of entire circuits faster than with any other method because each point pierces through conventional resist coatings and solder residues.

REVIEW SUBSET NUMBER 8

Q1. The Huntron Tracker 1000 and 2000 are for use on circuit boards and systems with all voltage sources in what condition?

Q2. What mode on the Automatic Transistor Analyzer Model 900 has the Sonalert™?

Q3. What type signal display does the Huntron Tracker 1000 and 2000 show when the signal fuse is open and the test leads shorted together?

Q4. When using the Huntron Tracker 2000, why must you make good contact with the test leads?

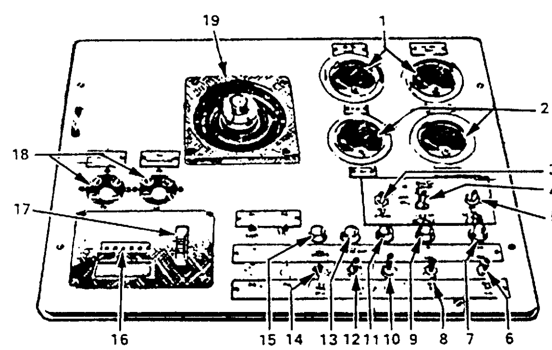
Q5. What is the minimum total shunt impedance across the junction of the diode or transistor under test using the Automatic Transistor Analyzer Model 900 to ensure a good test reading?

JET IGNITION SYSTEM TESTER

The jet ignition system tester detects and isolates faults in the jet engine ignition system. You can use the tester to make the following checks:

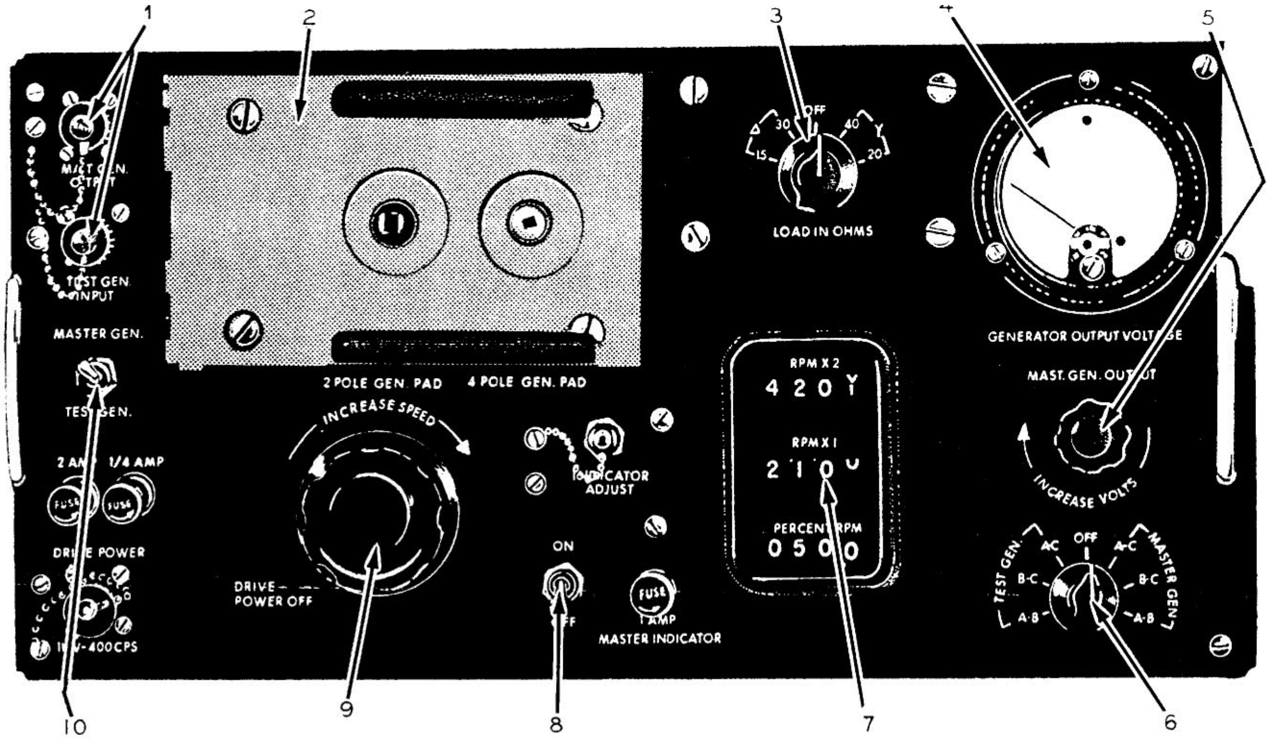
- Operational check of the ignition system. You are able to check the engine through the ignition unit to the spark plug.
- Operational check of the spark plugs.
- Check of the ignition unit output in sparks per second.
- Power input to the ignition unit.

The panel of the ignition system tester is shown in figure 2-32. If you want the procedures for using the tester, refer to the tester's operation and service instruction manual and the engine ignition system maintenance manual.



1. Ac and dc voltmeters (M3 and M4).
2. Ac and dc ammeters (M1 and M2).
3. Main ignition primary—secondary selector switch (S1).
4. Main ignition energy level switch (S2).
5. A/B ignition test on-off switch (S3).
6. High-voltage spark plug test switch (S7).
7. High-voltage spark plug test light (I5).
8. Low-voltage spark plug test switch (S6).
9. Low-voltage spark plug test light (I4).
10. Spark rate counter power on-off switch (S8).
11. Spark rate counter power indicator light (I3).
12. Spark rate counter timer power on-off switch (S9).
13. A/B ignition switch test light (I2).
14. Spark rate counter timer start switch (S10).
15. Nozzle unlock switch test light (I1).
16. Spark rate counter.
17. Spark rate counter reset knob.
18. High-voltage (P1) and low-voltage (P2) slave spark plugs.
19. Spark rate counter timer.

Figure 2-32.-Jet ignition system test panel.



1. Test GEN INPUT and MAST GEN OUTPUT
2. TWO-SPEED TEST PAD
3. LOAD IN OHMS
4. GENERATOR OUTPUT VOLTAGE meter
5. MAST GEN OUTPUT control
6. VOLTMETER SEL switch
7. RPM indicator
8. Test set ON-OFF
9. Speed control
10. Generator selector

Figure 2-33.-Tachometer Indicator-Generator Test Set TTU-27/E.

TACHOMETER INDICATOR-GENERATOR TEST SET TTU-27/E

The TTU-27/E has complete facilities for testing the percent and RPM types of tachometer indicators. You can also use it to test four-pole reciprocating engine tachometer generators and two-pole jet engine tachometer generators. You can use the tachometer indicator to make the following tests:

- Test tachometer indicators for starting voltage and calibration accuracy
- Test tachometer generators for starting voltage, calibration accuracy, speed, and output voltage under load conditions
- Test tachometer generators and indicators either on or off the aircraft

Figure 2-33 shows a TTU-27/E tester. All the operating controls, switches, and indicators required for the tester are on the panel assembly. The two-speed test pad accommodates either two-pole or four-pole tachometer generators for testing. The RPM counter indicator provides a precision readout of tachometer generator speed with scales of RPM x 2, RPM x 1, and PERCENT RPM. The tester uses 115-volt, 400-hertz ac power.

NOTE: Don't try to operate the tachometer tester until after you make the ground connection of the power lead.

The drive assembly consists of a gearbox and a master tachometer generator. The gearbox drives the two-speed test pad, which mounts the tachometer generator under test. A variable dc drive motor controls the drive speed of the gearbox. Therefore, the drive motor controls the drive speed of the master tachometer and the tachometer generator under test.

The RPM indicator assembly is part of the precision speed indicator. The assembly consists of a two-phase servomotor, which drives an in-line digital display. There are three counter ranges—0 to 10,000, 0 to 5,000, and 1 to 119.4—for the respective scales. The components of the RPM indicator are inside a solder-sealed metal container to prevent dirt from entering.

You can check indicator calibration by the master tachometer generator. Compare indicator RPM or percent RPM indication to the reading on the RPM indicator of the tachometer tester.

For additional information on the operation and service instruction of the TTU-27/E tester, refer to NAVWEPS 17-15CM-2.

JET CALIBRATION (JETCAL) ANALYZER

Of the many factors affecting jet engine life, efficiency, and safe operation, the most important are exhaust gas temperature and engine speed. If the exhaust gas temperature is just a few degrees higher than it should be, the turbine blade life is reduced as much as 50 percent. Abnormally high exhaust gas temperature resulting from excess engine speed can cause premature engine failure. If the exhaust gas temperature is too low, jet engine efficiency and thrust is reduced. Either of these two conditions makes engine operation dangerous. By using the JETCAL analyzer, you can detect or prevent these conditions.

You can more accurately check signs of fuel system trouble, tailpipe temperature, and RPM with the JETCAL analyzer than with aircraft gauges. With proper use of the JETCAL analyzer, you can detect malfunctions in these systems.

The JETCAL analyzer (fig. 2-34) is a rugged, portable instrument made of aluminum, stainless

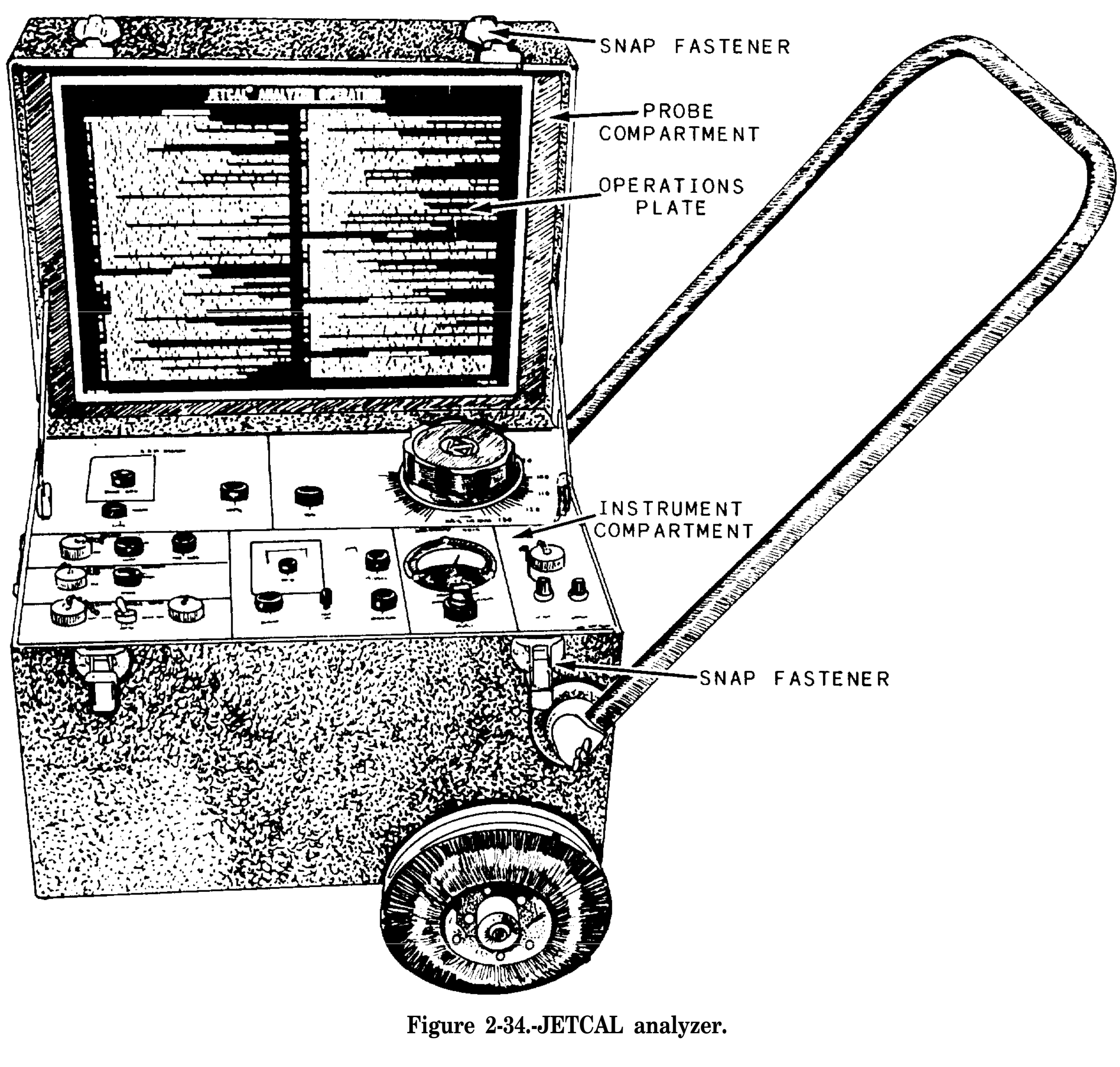


Figure 2-34.-JETCAL analyzer.

steel, and plastic. The major components of the analyzer are the thermocouples, RPM and EGT indicators, resistance and insulation check circuits, and the overheat detection test circuits.

On the EGT system functional test and the thermocouple and harness checks, the JETCAL analyzer has an accuracy of ± 4°C at the test temperature. The test temperature is usually the maximum operating temperature of the jet engine. To find the maximum engine operating temperatures, you should check the applicable MIMs.

The first test you perform is a functional test of the EGT system. In this test, you heat the engine thermocouples in the tail cone of the engine to test temperature. This heat comes from the JETCAL heater probes through the necessary cable connections. To measure the temperature of the heater probes, thermocouples are embedded in the probes. You may read the heater probe temperature on the JETCAL potentiometer. At the same time, you can read the aircraft thermocouple temperature on the aircraft EGT indicator. You can then compare the readings for accuracy.

On engines that have a balancing type of thermocouple system, you must remove the balancing thermocouple from the circuit. Then, you can check the remaining thermocouples individually or together. Check the balancing thermocouple using a single probe. Read the output of the balancing thermocouple on the JETCAL potentiometer, and compare it to the heater probe thermocouple reading.

Gas temperature is critical to engine operation; therefore, use the JETCAL for nozzle scheduling. During temperature adjustments, make all temperature readings on the JETCAL potentiometer. This is necessary because you must read engine temperature accurately to ensure the engine is operating at optimum engine conditions. When checking and adjusting the engine exhaust gas temperature, install a switch box in the EGT circuit before starting the test. You will use the switch box to switch the cockpit indicator into the circuit, or to switch the temperature indication of the engine thermocouple and harness to the JETCAL potentiometer. You can also read temperature readings from the engine thermocouple and harness on the JETCAL analyzer by making the necessary connections.

Incorporated in the analyzer is the TAKCAL unit (RPM indicator) check circuit. This circuit reads engine speed with an accuracy of ±0.1 percent. The TAKCAL unit check can also be used to troubleshoot the aircraft's tachometer system. After testing the exhaust gas temperature and engine speed systems, you may use selected portions of the JETCAL analyzer circuits to establish the proper relationship between exhaust gas temperature and engine speed.

The JETCAL analyzer requires a power supply of 95 to 135 volts, 50 to 400 hertz. It will operate in temperatures from –55°C to +70°C. You must use a 95- to 135-volt ac power supply for the TAKCAL unit check and the thermocouple check. You may perform all other operations using emergency batteries when an external power supply is not available. You actuate the batteries by a push-button switch. When the switch is released, the batteries are out of the circuit. However, you can depress the switch when using ac without damaging the batteries. To preserve the life of the emergency batteries, use an external ac power supply whenever possible.

The JETCAL analyzer has the following primary and separate functions:

- To check the entire jet aircraft exhaust gas temperature system for error without running the engine or disconnecting the wiring.
- To check individual thermocouples before placing them in the aircraft.
- To check each engine thermocouple for continuity.
- To check the thermocouples and harness for accuracy of output.
- To check the resistance of the EGT circuit, without the EGT indicator, to assure allowable limits.
- To check the insulation of the EGT circuit for shorts or grounds.
- To check the EGT indicators.
- To check engine thermocouples and harness on the engine with the engine removed from the aircraft.
- To read engine RPM to an accuracy of ±0.1-percent engine runup.
- To use the RPM check (TAKCAL) and potentiometer to establish the proper rela-

tionship between exhaust gas temperature and engine speed during tabbing. (Tabbing is the procedure to adjust fixed or variable exhaust gas tail cone areas during normal aircraft checks every 30 to 50 hours.)

- To check aircraft fire detector, overheat detector, and wing anti-icing systems by using tempcal probes.

Refer to the MIM of a particular aircraft for the proper procedure when you check and adjust the variable nozzle systems. You can get detailed instructions for adjusting the EGT with the JETCAL analyzer from the applicable MIM.

REVIEW SUBSET NUMBER 9

Q1. Which piece of test equipment would you use to test an engine ignition unit output in sparks per second?

Q2. Before using the TTU-27/E test set, what connection must you make to ensure proper operation?

Q3. What is the minimum voltage for using the TAKCAL unit of the JETCAL Analyzer?

SYNCHROPHASER TEST SET

The synchrophaser test set (fig. 2-35) tests propeller synchrophaser electronic units. The test set generates all pulses (dc and ac) required to test the synchrophaser electronic unit independent of its associated components.

The test set is completely solid state. Each switch position programs a particular test. It does this by connecting the appropriate inputs to the synchrophaser and the meter required to verify synchrophaser performance.

The test set generates a master pulse and a slave pulse. The pulse circuits closely simulate the synchrophaser pulse input under dynamic flight conditions. You program different phase and speed relationships of master and slave pulses, under test specifications, by setting the selector switches for a particular test.

Figure 2-35.-Synchrophaser test set.

The output of synchrophaser-associated components is simulated by the test set. It provides a simulated tachometer signal and the resistance of synchrophaser controls for certain tests. When programmed, these signals help measure the synchrophaser dynamic response to off-speed, off-phase, speed reset, resync, and throttle anticipation signals.

Control adjustments are minimal. Only a few of the automatically programmed tests require adjustment of either of the feedback gain potentiometers. The accuracy of control adjustment is optimized by designing test set circuits that require few adjustments. This adjustments will be to null or zero settings on center-scale zero meters.

A high degree of accuracy and repeatability is a feature of the gain measuring circuits within the tester. Conventional gain circuits require application and measurement of incremental voltages to the synchrophaser for comparison with resultant output voltages. The gain measurement circuit has a galvanometers, demodulator, dc power supply, and calibrated potentiometer in a bridge circuit. When the gain test is programmed, rotate the calibrated potentiometer to null the galvanometers. With the galvanometers nulled, the potentiometer calibration gives a direct readout of amplifier gain. This circuit avoids inaccuracies of input settings and error amplification of incremental gain comparison. It also avoids the chance of error in calculating the gain factor.

For complete instructions on this tester, you should refer to the current *Operation and Service Instruction Manual,* NA 17-15CFA-2.

PRESSURE-TEMPERATURE TEST SET TTU-205C/E

The pressure-temperature test set (fig. 2-36) provides regulated pitot and static pressure for checking performance characteristics of aircraft pneumatic instruments, air data systems, and other auxiliary equipment. You can also conduct dynamic tests, quantitative calibration tests, pneumatic-system leak tests, and total temperature probe tests using this tester.

The TTU-205C/E is a compact assembly. It consists of a control panel, components assembly, and combination carrying case with removable cover. All the controls, indicators, switches, electrical, and pneumatic connectors are on the front panel of the test set. All the components are on the underside of the control panel. This makes the subassemblies and components easily accessible when the panel is not in it's carrying case. The test set simulates airspeed and altitude information, which is displayed on the front panel. See table 2-6 for test set particulars.

The test set has the following five capabilities:

1. It performs overall system checks on the following equipment, pneumatic systems, air data systems, flight instruments, and pneumatic ancillary equipment. This equipment may be either installed in or removed from the aircraft.

2. It provides simulated total temperature for the USAF MA-1 Probe, a platinum resistance sensing element whose resistance is 50.0 ohms at 0°C.

3. It connects directly into the aircraft's pneumatic system to measure and control static pressure (Ps) and pitot pressure (PT).

4. It accepts electrical power from an external source.

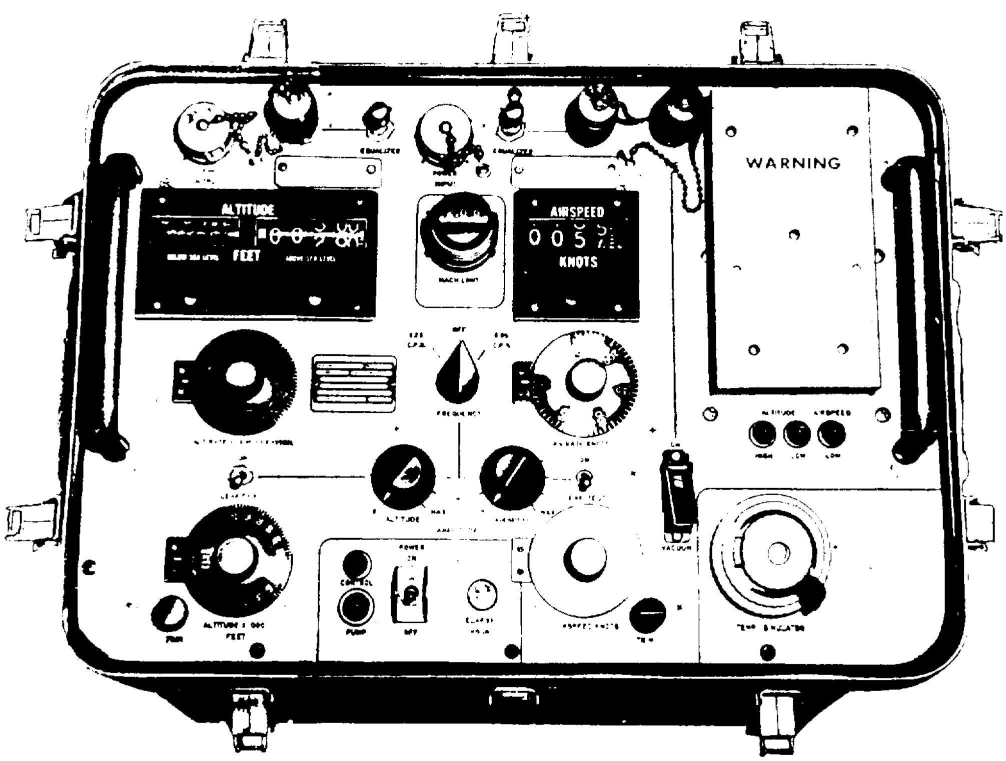


Figure 2-36.-Test Set, TTU-205C/E.

Table 2-6.-Pressure-Temperature Test Set TTU 205C/E

POWER REQUIREMENTS:	
AC Input	115 volts, 400 Hz., Single phase
Power Consumption	350 VA (approx.)
Weight	97 pounds
DIMENSIONS:	
Length	22.85 inches
Width	17.23 inches
Height	13.25 inches
Volume	3.0 Cubic feet
RANGE:	
Altitude	−1500 to +80,000 feet (approx. 31.5 to 0.82″ Hg A)
Airspeed	50 to 1000 knots (approx. 0.12 to 73.55″ Hg diff.)
Static Load Range	5 to 250 cubic inches
Pitot Load Range	5 to 100 cubic inches
SLEW RATE:	
Altitude	0 to 35,000 feet/minute
Airspeed	0 to 700 knots/minute
Static Test Fixture Vacuum	More than 4 psi below ambient
Temperature Simulation	30.0 to 129.9 ohms (approx. −99 to +430 °C)
PRESSURE MODULATION:	
Frequency	0.05, 0.25 and, 0.50 Hz
Amplitude	Variable

5. It incorporates safety features that prevent damage to the test set and the unit under test.

CAUTION

The power requirements for this tester are 115 volts, single phase, 400 Hz. For on-bench or hangar use, make sure that the correct frequency of 400 Hz is available. The tester will not work on 115-volt, 60-hertz power.

CAPACITIVE-TYPE LIQUID QUANTITY TEST SET TF-20

Many types of capacitive fuel quantity testers are in use in naval aviation. All operate on the same basic principle—that of a variable capacitor. Since it is impractical to describe all of the various testers, only the TF-20 is discussed. You can use this set to test most of the capacitive fuel quantity systems currently used on naval aircraft.

The Model TF-20 liquid quantity test set (fig. 2-37) contains circuitry that makes the tester capable of measuring tank unit probe capacitance and measuring tank unit insulation resistance. It also simulates total probe capacitance for checking aircraft fuel quantity indicators and calibrating the test set capacitance indicator dial and megohmmeter scales.

You may test the fuel-gauging system either installed in the aircraft or removed from the aircraft. The test set includes a transit case, a shock-mounted instrument case, and a set of adapter cables. The tester has circuitry for measuring capacitance and dc resistance. It also simulates the capacitance of compensated and uncompensated-type fuel tank probes. The instruments operate with 115-volt, 400-hertz power.

All operating controls are on the front panel. Three BNC-type receptacles (COMP, COAX, and UNSH) are located on the upper middle part of the panel. They provide connections to the tank unit probe under test. A pair of binding posts, (EXT RES) connect the tester to unknown high external resistances. Use these bonding posts when you can't connect the tester to the TANK UNIT receptacles with the accessory cables. Another set of three BNC-type receptacles (COAX, UNSH, and COMP) are located on the bottom right of the panel. These three receptacles let you connect the test set to the aircraft fuel-quantity-gauge indicator.

All adjustment controls for tester self-calibration are accessible on the front panel. The ZERO ADJ and HIGH ADJ controls provide adjustment for zero and the high end of the scale on the CAPACITANCE indicator. The ZERO ADJ and MIDSCALE ADJ controls adjust the MEGOHMS indicator so its pointer will position at zero and at midscale. These four adjustments have covers so the calibrating controls will not be accidently disturbed when using the test set.

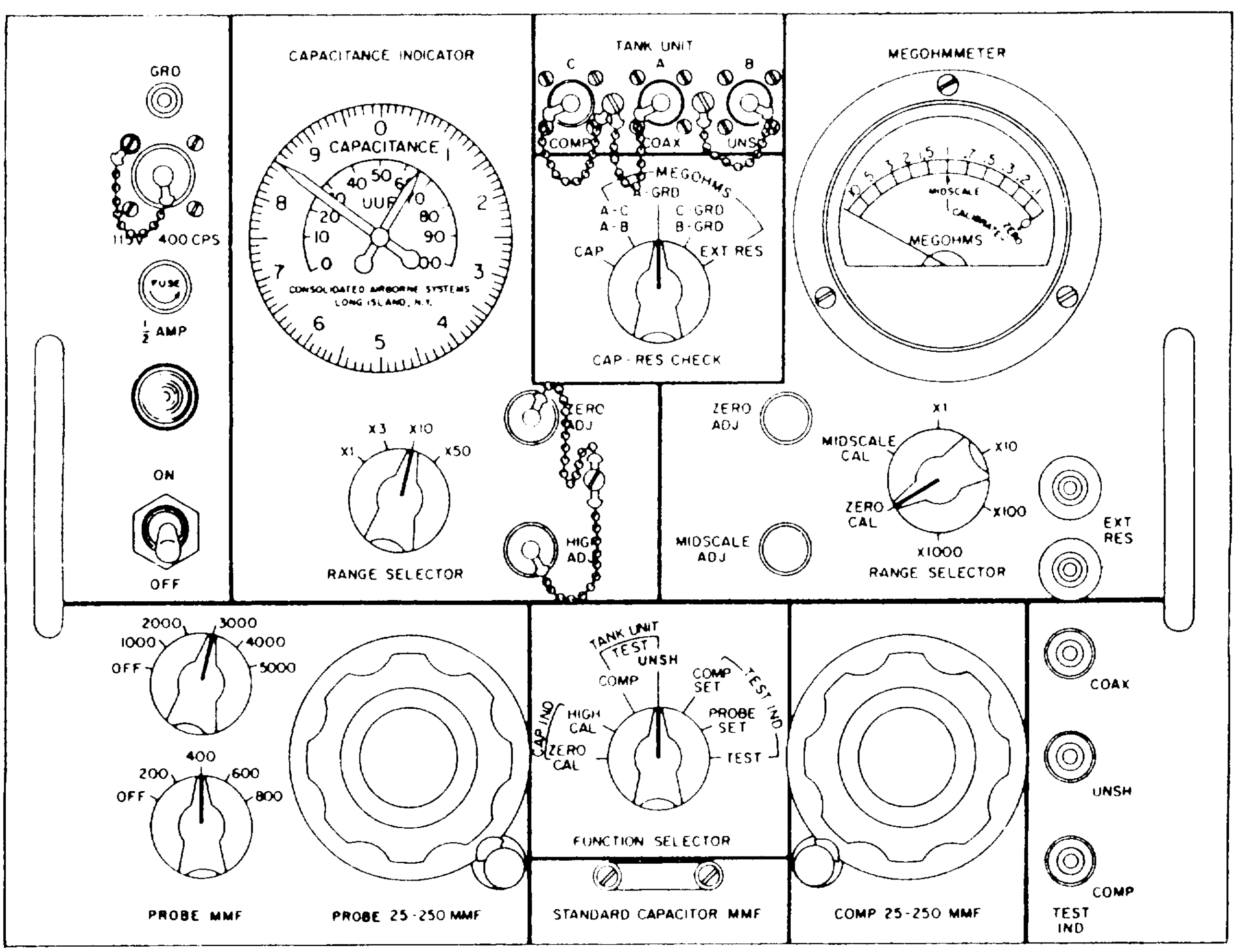


Figure 2-37.-TF-20 liquid quantity test set.

When using this test set, you should follow the instructions in the applicable MIM for the system under test.

ANGLE-OF-ATTACK TEST SET AN/PSM-17A

The angle-of-attack test set lets you test, adjust, calibrate, simulate, and monitor the angle-of-attack indicating system. The test set also provides a means for you to test the aircraft approach lights, cockpit index lights, and the stall warning system.

The test set (fig. 2-38) consists of a control panel enclosed in a case. It also includes the cables and components to interconnect and test the angle-of-attack system and associated components without their removal from the aircraft. The control panel contains a microammeter, a differential pressure gauge, a potentiometer control, a bellows assembly, indicator lamps, and electrical connectors. Also, the panel has various toggle and rotary switches to select and control circuits that are within the test set.

A radiometer system makes up the largest portion of the test set. This system consists of the nullmeter, the SIM OR NULL potentiometer control, and the NULL switch. It lets you test the angle-of-attack transmitter by placing switches in various positions and using the potentiometer dial to simulate known inputs to the indicators.

The pressure system consists of a differential pressure gauge, test pressure connector, bellows assembly, pressure control, and surge chamber (test set case). It dynamically tests the angle-of-attack transmitters. An air pressure or vacuum transmits through a hose to parts of the AOA transmitter probe by positioning the control on the bellows assembly. This slight pressure causes the probe to rotate. Thus, the pressure system of the test set simulates conditions corresponding to various aircraft angles of attack.

A series of indicator lamps (three indexer, three approach, and a stall warning) are on the test set control panel. They simulate the action of the aircraft indexer and approach lights and the stall warning vibrator. Two additional lamps show when the test set has ac and dc power.

The power requirements for the test set are 28-volt dc and 110-to 120-volt, 400 hertz, single-phase ac.

AIR-CONDITIONING TEST SET AN/PSM-21A

The PSM-21A (fig. 2-39) is for flight line checkout and troubleshooting of electrical

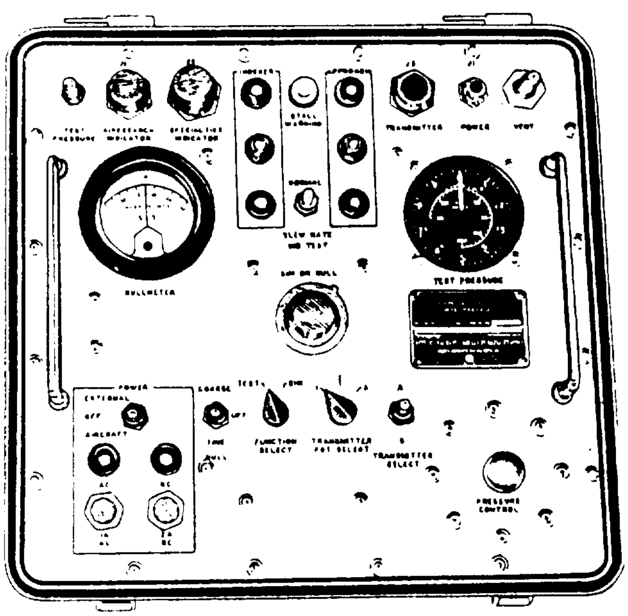


Figure 2-38.-Angle-of-Attack Test Set AN/PSM-17A.

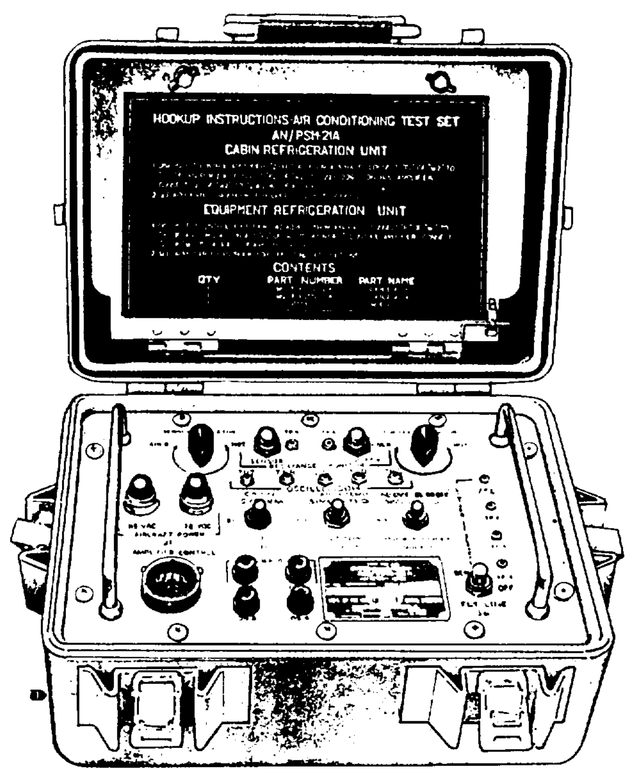


Figure 2-39.-Air-conditioning Test Set AN/PSM-21A.

components in the cabin, pressure suit, and equipment air-conditioning systems. To accomplish checkout of these systems, apply external electrical power to the aircraft.

Checkout of the system under test involves simulation of sensor and limiter inputs by the test set. You can connect external test equipment to test points on the test set to measure resistance, voltage, or waveforms to determine system operation. You can also determine system operation by visual monitoring. For example, with a known electrical input into the air-conditioning system, air-conditioning valves should move to a known position.

REVIEW SUBSET NUMBER 10

Q1. What test set is used to test pitot-static systems?

Q2. Name the two measurements you can take with the TF-20 test set.

Q3. The AN/PSM-17A test set is used to test what system?

VERSATILE AVIONICS SHOP TEST (VAST) EQUIPMENT

The VAST system now in use aboard Navy aircraft carriers can cope with the continually changing character of avionics testing. VAST will significantly reduce the space required by equivalent special and manual support equipment.

In its basic form, a VAST station is assembled from an inventory of functional building blocks. These blocks furnish all the necessary stimuli and measurement capability to check many naval avionics equipments. As new avionics come into use, test station configurations are modified by adding new building blocks to furnish new parameters or greater precision to existing capabilities.

A typical VAST station consists of a computer subsystem, a data transfer unit (DTU), and a stimulus and measurement section. The stimulus and measurement section contains functional building blocks configured to meet the intended test application. Figure 2-40 shows a typical carrier-based VAST station.

The carrier-based test station is controlled by a computer subsystem that executes test programs to assure accurate and satisfactory testing. The computer subsystem includes a general-purpose digital computer, which not only executes test routines but also provides diagnostic and computational capabilities. It also processes data and

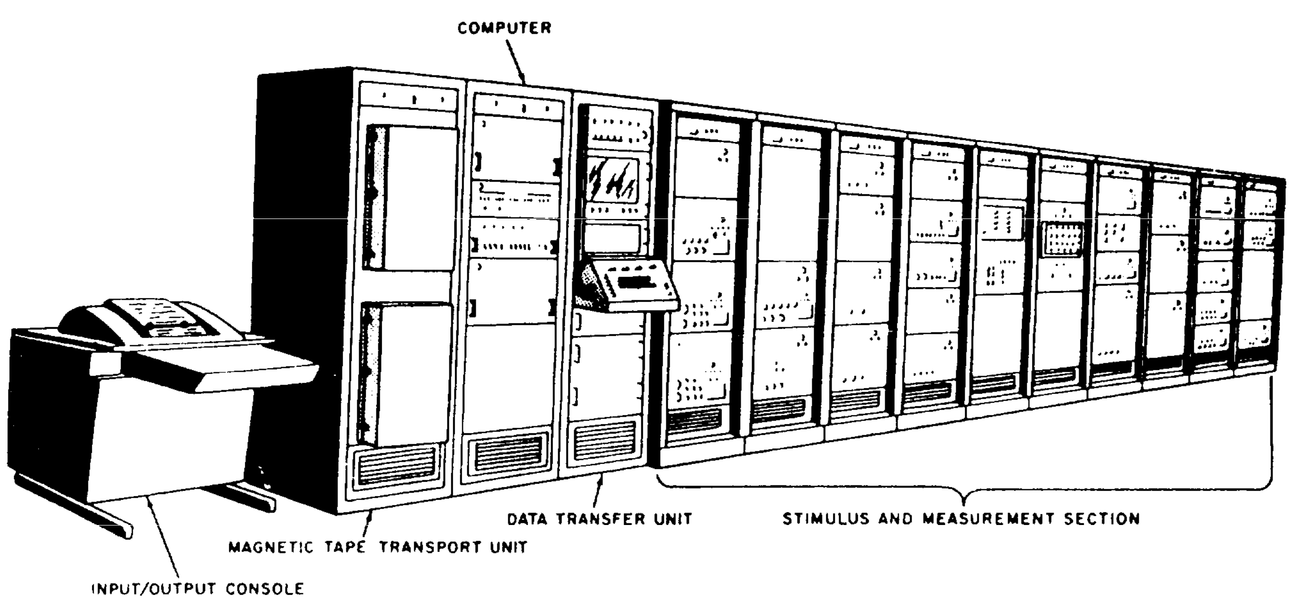


Figure 2-40.-VAST station.

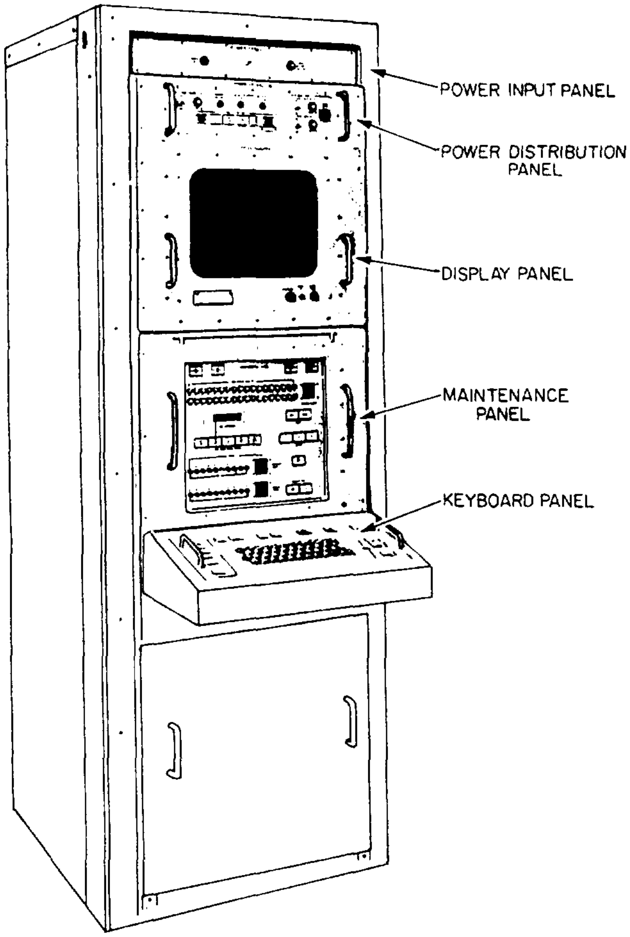


Figure 2-41.-Data transfer unit (DTU).

furnishes a permanent record of test results. Two magnetic tape transports provide rapid access to avionics test programs and immediate availability of VAST self-check programs.

The data transfer unit (DTU) (fig. 2-41) serves as the operator-machine interface. It synchronizes instructions and data flow between the computer and the functional building blocks. The DTU also contains the display and control panels.

The DTU control panel lets the operator communicate with the computer. You will also communicate with the stimulus and measurement section of VAST by a keyboard and mode select key. You can operate the test station in manual, semiautomatic, or fully automatic modes.

The DTU contains a maintenance panel that monitors station auto-check results and shows building-block faults. Transmission of instructions from the control computer is on a request/acknowledge basis. Essentially, the response rate is controlled by the stimulus and measurement systems. This lets you transmit instructions at an asynchronous rate corresponding to the maximum frequency at which a given building block or avionics unit can respond. There is no requirement for immediate program storage in the DTU.

VAST STATION

A VAST station may have as many as 14 racks of stimulus and measurement building blocks. (See fig. 2-42.) Large station configurations may contain as many as 17 core building blocks.

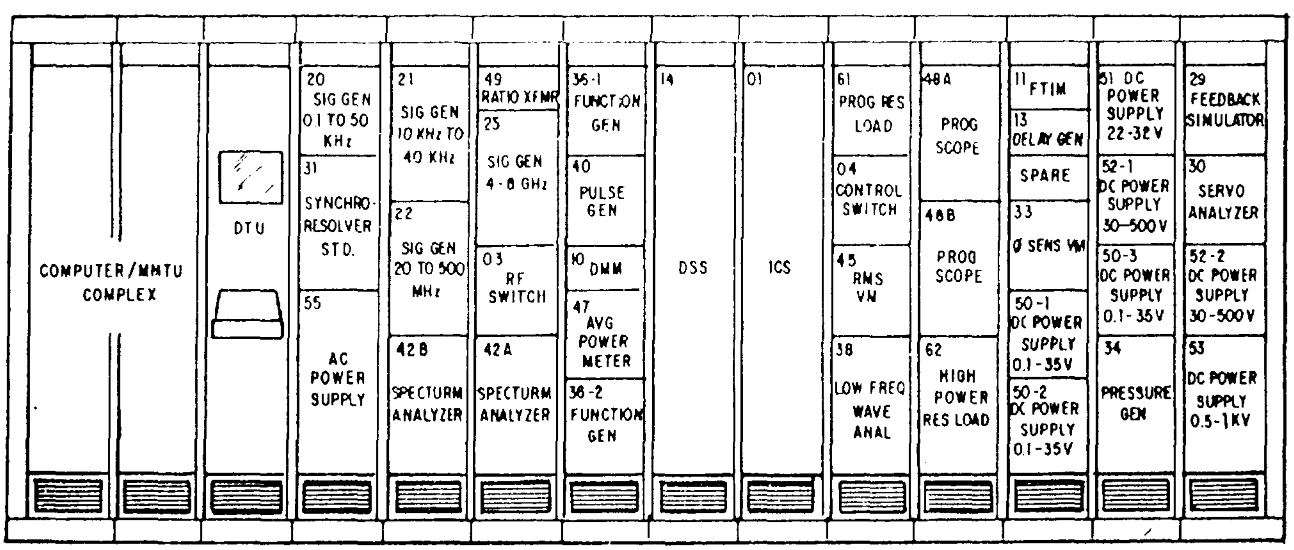


Figure 2-42.-VAST station with building blocks.

VAST was designed with ease of maintenance as a primary objective. In addition to the modularized design of VAST building blocks, there are three levels of fault detection that ensures rapid confidence tests and easy fault location. The three levels of detection are auto-check, self-check, and self-test.

You may initially uncover a fault through auto-check. The auto-check is inherent in the logic and control design of the VAST station. It includes verification of instructions and fault monitoring. Auto-check works on a continuous basis during station operation and, when a fault occurs, interrupts testing.

The second level of VAST fault detection is self-check. This is a programmed sequence that the VAST operator starts through the DTU keyboard. Self-check may be either internal or at a system level. Internal self-check measures the ability of a building block to perform against its own internal standards. System self-check requires the use of two or more building blocks in a test configuration selected to isolate faults within the test set up.

The self-check philosophy you use to verify VAST operation is based upon confirmation of key system elements first. It then uses these elements to check the remaining building blocks. Checks of basic core building blocks are by internal standards. Once satisfactory performance is assured, the system uses their capabilities to check the remaining building blocks. The system accomplishes check-out of noncore building blocks by using any combination of core measurement or stimulus building blocks.

The final level of VAST fault detection is self-test. This is a series of test programs used to locate faults within a building block. If a building block contains a malfunction as a result of the self-check routine, remove the faulty building block and connect to VAST as a unit under test. The system will then conduct self-test programs.

INTERCONNECTING DEVICE

In its simplest form, the interconnecting device consists of an adapter cable, which connects the unit under test (UUT) to the VAST interface. In some cases, passive and active circuits are introduced to change impedance levels or to amplify low signals. These circuits are introduced as part of the electrical interface in the interconnecting device. Ordinarily, this is not required if the avionics equipment has been designed with the requirements for VAST. Very often, you may obtain passive circuit functions through the use of standard plug-in modules.

The last element of the test program is the instruction booklet or microfilm strip. These instructions give the details for all the steps to follow in testing any given unit. The steps include initial procedures, such as hook up and clearing operations, and proceed to the final steps of disconnect and UUT closeout.

OPERATION OF A VAST STATION

In a typical VAST procedure, ease in operation of the actual testing becomes apparent. You may make the initial setup of the weapon replaceable assembly (WRA), including removal of dust covers, cooling provisions, and connections to the interface device, off station to minimize disruptions of station operators. Final connections between the VAST stations interface panel and the UUT take only a few moments directly at the station.

The operator begins testing by selecting the code that starts the test program. Before applying power or stimulus to the UUT, you should conduct continuity tests to ensure proper test program selection. This will also ensure no conditions exist that will damage the VAST station or the UUT once active tests start. If everything checks out OK, the testing proceeds automatically. The operator only has to respond to instructions that appear on the CRT display. The program will not stop until it encounters a fault or it reaches a program halt.

The purpose of programmed halts is to allow manual intervention during testing to make adjustments and observations. When the identification of faults and the operator's instructions are required—such as interpreting a complex waveform—the operator may refer to the test program instructions. Upon completion of the test program, the CRT display shows any closeout procedures.

A VAST station is completely autonomous and normally operated under computer control in a fully automatic mode. Of course, the operator can select any one of three semiautomatic modes or a manual mode.

The semiautomatic modes include a one-group, a one-test, and a one-step mode. These auxiliary modes permit detailed observation of various test sequences. They are also useful in performing work-around procedures in reconciling differences in equipment and program mode status, and in the verification of repairs.

In the manual mode, the test station is completely off-line with respect to the computer. Instructions come from the operator through the keyboard on a one-word-at-a-time basis. (See fig. 2-43.) Although you won't use the manual mode for avionics testing, it is useful for debugging new programs. You can also integrate new building blocks into the station, and perform self-check operations on some of the building blocks using this mode.

REVIEW SUBSET NUMBER 11

Q1. What is the second level of VAST fault detection?

Q2. For what is the manual mode of operating the VAST used?

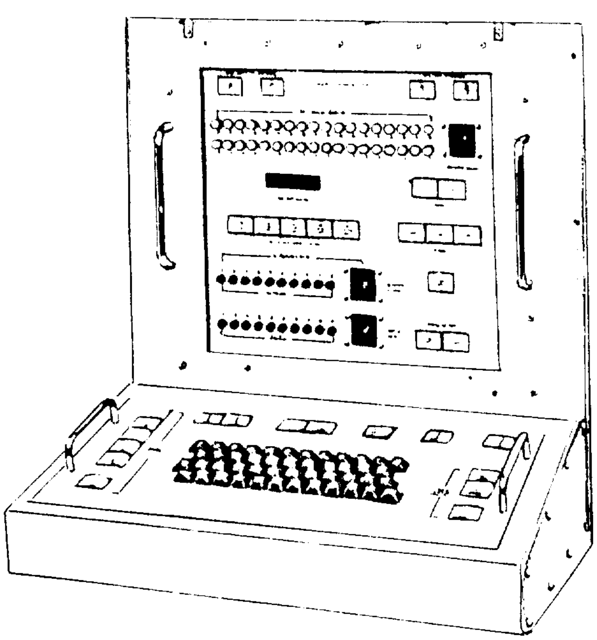


Figure 2-43.-VAST control panel.

ELECTROSTATIC DISCHARGE

Learning Objective: *Recognize the hazards to ESD-sensitive devices, to include proper handling and packaging techniques.*

The sensitivity of electronic devices and components to electrostatic discharge (ESD) has recently become clear through use, testing and failure analysis. The construction and design features of current microtechnology have resulted in devices being destroyed or damaged by ESD voltages as low as 20 volts. The trend in this technology is toward greater complexity, increased packaging density, and thinner dielectrics between active elements. This trend will result in devices even more sensitive to ESD.

Various devices and components are susceptible to damage by electrostatic voltage levels commonly generated in production, test, and operation, and by maintenance personnel. These devices and components include the following:

- All microelectronic and most semiconductor devices, except for various power diodes and transistors

- Thick and thin film resistors, chips and hybrid devices, and crystals

All subassemblies, assemblies, and equipment containing these components/devices without adequate protective circuitry are ESD sensitive.

You can protect ESDS items by implementing simple, low-cost ESD controls. Lack of implementation has resulted in high repair costs, excessive equipment downtime, and reduced equipment effectiveness.

The operational characteristics of a system may not normally show these failures. However, under internal built-in-test monitoring in a digital application, they become pronounced, For example, the system functions normally on the ground; but, when placed in an operational environment, a damaged PN junction might further degrade, causing its failure. Normal examination of these parts will not detect the damage unless you use a curve tracer to measure the signal rise and fall times, or check the parts for reverse leakage current.

STATIC ELECTRICITY

Static electricity is electrical energy at rest. Some substances readily give up electrons while others accumulate excessive electrons. When two substances are rubbed together, separated or flow relative to one another (such as a gas or liquid over a solid), one substance becomes negatively charged and the other positively charged. An electrostatic field or lines of force emanate between a charged object to an object at a different electrostatic potential (such as more or less electrons) or ground. Objects entering this field will receive a charge by induction.

The capacitance of the charged object relative to another object or ground also has an effect on the field. If the capacitance is reduced, there is an inverse linear increase in voltage, since the charge must be conserved. As the capacitance decreases, the voltage increases until a discharge occurs via an arc.

CAUSES OF STATIC ELECTRICITY

Generation of static electricity on an object by rubbing is known as the *triboelectric effect.* Table 2-7 lists substances in the triboelectric series.

The size of an electrostatic charge on two different materials is proportional to the separation of the two materials. Typical prime charge generators commonly encountered in a manufacturing facility are shown in table 2-8.

Electrostatic voltage levels generated by nonconductors can be extremely high. However, air will slowly dissipate the charge to a nearby conductor or ground. The more moisture in the air the faster a charge will dissipate. Table 2-9 shows typical measured charges generated by personnel in a manufacturing facility. Note the decrease in generated voltage with the increase in humidity levels of the surrounding air.

NOTE: The triboelectric series is arranged in an order that when any two substances in the list contact one another and are separated, the substance higher on the list assumes a positive charge.

EFFECTS OF STATIC ELECTRICITY

The effects of ESD are not recognized. Failures due to ESD are often misanalyzed as being caused by electrical overstress due to transients other than static. Many failures, often classified as *other, random, unknown, infant mortality, manufacturing defect, etc.,* are actually caused by ESD. Misclassification of the defect is often caused by not performing failure analysis to the proper depth.

Table 2-7.-Triboelectric Series

POSITIVE (+)
ACETATE
GLASS
HUMAN HAIR
NYLON
WOOL
FUR
ALUMINUM
POLYESTER
PAPER
COTTON
WOOD
STEEL
ACETATE FIBER
NICKEL, COPPER, SILVER
BRASS — STAINLESS STEEL
RUBBER
ACRYLIC
POLYSTYRENE FOAM
POLYURETHANE FOAM
SARAN
POLYETHYLENE
POLYPROPYLENE
PVC (VINYL)
KEL F
TEFLON
NEGATIVE (−)

NOTE: THE TRIBOELECTRIC SERIES IS ARRANGED IN SUCH AN ORDER THAT WHEN ANY TWO SUBSTANCES IN THE LIST CONTACT ONE ANOTHER AND ARE SEPARATED, THE SUBSTANCE HIGHER ON THE LIST ASSUMES A POSITIVE CHARGE.

COMPONENT SUSCEPTIBILITY

All solid-state devices (all microcircuits and most semiconductors), except for various power transistors and diodes, are susceptible to damage by discharging electrostatic voltages. The discharge may occur across their terminals or through subjecting these devices to electrostatic fields.

Table 2-8.-Typical Charge Generators

WORK SURFACES	• FORMICA (WAXED OR HIGHLY RESISTIVE) • FINISHED WOOD • SYNTHETIC MATS
FLOORS	• WAX FINISHED • VINYL
CLOTHES	• COMMON CLEAN ROOM SMOCKS • PERSONNEL GARMENTS (ALL TEXTILES EXCEPT VIRGIN COTTON) • NONCONDUCTIVE SHOES
CHAIRS	• FINISHED WOOD • VINYL • FIBERGLASS
PACKAGING AND HANDLING	• COMMON POLYETHYLENE — BAGS, WRAPS, ENVELOPES • COMMON BUBBLE PACK, FOAM • COMMON PLASTIC TRAYS, PLASTIC TOTE • BOXES, VIALS
ASSEMBLY, CLEANING, TEST AND REPAIR AREAS	• SPRAY CLEANERS • COMMON SOLDER SUCKERS • COMMON SOLDER IRONS • SOLVENT BRUSHING (SYNTHETIC BRISTLES) • CLEANING, DRYING • TEMPERATURE CHAMBERS

Table 2-9.-Typical Measured Electrostatic Voltages

MEANS OF STATIC GENERATION	VOLTAGE LEVELS @ RELATIVE HUMIDITY	
	LOW-10-20%	HIGH-65-90%
WALKING ACROSS CARPET	35,000	1,500
WALKING OVER VINYL FLOOR	12,000	250
WORKER AT BENCH	6,000	100
VINYL ENVELOPES FOR WORK INSTRUCTIONS	7,000	600
COMMON POLY BAG PICKED UP FROM BENCH	20,000	1,200
WORK CHAIR PADDED WITH URETHANE FOAM	18,000	1,500

LATENT FAILURE MECHANISMS

The ESD overstress can produce a dielectric breakdown of a self-healing nature when the current is unlimited. When this occurs, the device may retest good but contain a hole in the gate oxide. With use, metal will eventually migrate through the puncture, resulting in a shorting of this oxide layer.

Another structure mechanism involves highly limited current dielectric breakdown from which no apparent damage is done. However, this reduces the voltage at which subsequent breakdown occurs to as low as one-third of the original breakdown value. ESD damage can result in a lowered damage threshold at which a subsequent lower voltage ESD will cause further degradation or a functional failure.

ESD ELIMINATION

The heart of an ESD control program is the ESD-protected work area and ESD grounded work station. When you handle an ESD-sensitive (ESDS) device outside of its ESD protective packaging, provide a means to reduce generated electrostatic voltages below the levels at which the item is sensitive. The greater the margin between the level at which the generated voltages are limited and the ESDS item sensitivity level, the greater the probability of protecting that item.

PRIME GENERATORS

Look at table 2-8. It lists ESD prime generators. All common plastics and other prime generators of static electricity should be prohibited in the ESD protected work area. Carpeting should also be prohibited. If you must use carpet, it should be of a permanently anti-static type. Perform weekly static voltage monitoring where carpeting is in use.

CAUTION

Anti-static cushioning material is acceptable; however, the items cited shall be of conductive material to prevent damage or destruction of ESDS devices.

PERSONAL APPAREL AND GROUNDING

An essential part of the ESD program is grounding personnel and their apparel when handling ESDS material. Means of doing this are described in this section.

Smocks

Personnel handling ESDS items should wear long sleeve ESD protective smocks, short sleeve shirts or blouses, and ESD protective gauntlets banded to the bare wrist and extending toward the elbow. If these items are not available, use other anti-static material (such as cotton) that will cover sections of the body that could contact an ESDS item during handling.

Personnel Ground Straps

Personnel ground straps should have a minimum resistance of 250,000 ohms. Based upon limiting leakage currents to personnel to 5 milliamperes, this resistance will protect personnel from shock from voltages up to 125 volts RMS. The wrist, leg, or ankle bracelet end of the ground strap should have some metal contact with the skin. Bracelets made completely of carbon-impregnated plastic may burnish around the area in contact with the skin, resulting in too high an impedance to ground.

ESD PROTECTIVE MATERIALS

There are two basic types of ESD protective materials—conductive and anti-static. Conductive materials protect ESD devices from static discharges and electromagnetic fields. Anti-static material is a nonstatic generating material. Other than not generating static, anti-static material offers no other protection to an ESD device.

CONDUCTIVE ESD PROTECTIVE MATERIALS

Conductive ESD protective materials consist of metal, metal-coated, and metal-impregnated materials (such as carbon particle impregnated, conductive mesh or wire encased in plastic). The most common conductive materials used for ESD protection are steel, aluminum, and carbon-impregnated polyethylene and nylon. The latter two are opaque, black, flexible, heat sealable, electrically conductive plastics. These plastics are composed of carbon particles, impregnated in the plastic, which provides volume conductivity throughout the material.

ANTI-STATIC ESD PROTECTIVE MATERIALS

Anti-static materials are normally plastic type materials (such as polyethylene, polyolefin, polyurethane, nylon), which are impregnated with an anti-static substance. This anti-static migrates to the surface, and combines with the humidity in the air to form a conductive sweat layer on the surface. This layer is invisible and, although highly resistive, is amply conductive to prevent the buildup of electrostatic charges by triboelectric (or rubbing) methods in normal handling. Simply stated, the primary asset of an anti-static material is that it will not generate a charge on its surface. However, this material won't protect an enclosed ESD device if it comes into contact with a charged surface.

This material is of a pink tint, a symbol of its being anti-static. Anti-static materials are for inner-wrap packaging. However, anti-static trays, vials, carriers, boxes, etc., are not used unless components and/or assemblies are wrapped in conductive packaging.

HYBRID ESD PROTECTIVE BAGS

Lamination of different ESD protective material (that is, conductive and anti-static) is available that provides the advantage of both in a single bag.

ESDS DEVICE HANDLING

The following are general guidelines applicable to the handling of ESDS devices:

- Make sure that all containers, tools, test equipment, and fixtures used in ESD protective areas are grounded before and/or during use, either directly or by contact with a grounded surface.
- Personnel handling ESDS items must avoid physical activities in the vicinity of ESDS items that are friction-producing, for example, removing or putting on smocks, wiping feet, sliding objects over surfaces, etc.
- Personnel handling ESDS items must wear cotton smocks and/or other anti-statically treated clothing.
- Avoid the use or presence of plastics, synthetic textiles, rubber, finished wood, vinyls, and other static-generating materials (table 2-9) where ESDS items are handled out of their ESD protective packaging.
- Place the ESD protective material containing the ESD item on a grounded work bench surface to remove any charge before opening the packaging material.
- Personnel must attach personnel grounding straps to ground themselves before removing ESDS items from their protective packaging.
- Remove ESDS items from ESD protective packaging with fingers or metal grasping tool only after grounding and place on the ESD grounded work bench surface.
- Make periodic electrostatic measurements at all ESD protected areas. This assures the ESD protective properties of the work station and all equipment contained there have not degraded.
- Perform periodic continuity checks of personnel ground straps (between skin contact and ground connection), ESD grounded work station surfaces, conductive floor mats, and other connections to ground. Perform this check with a megohmmeter to make sure grounding resistivity requirements are met.

ESDS DEVICE PACKAGING

Before an ESDS item leaves an ESD protected area, package the item in one of the following ESD protective materials:

- Ensure shorting bars, clips, or non-corrective conductive materials are correctly inserted in or on all terminals or connectors.
- Package ESD items in an inner wrap, of type II material conforming to MIL-B-81705, and an outer wrap of type I material conforming to MIL-B-81705. You may use a laminated bag in instead of the above provided such meets the requirements of M-B-81705. Cushion-wrap the item with electrostatic-free material conforming to PPP-C-1842, type III, style A. Place the cushioned item into a barrier bag fabricated from MIL-C-131 and heat-seal closed, method 1A-8. Place the wrapped, cushioned, or pouched ESDS item in bags conforming to MIL-B-117, type I, class F, style 1.

Mark the packaged unit with the ESD symbol and caution (fig. 2-44).

TESTING/REPAIR

Before you work on ESDS items, make sure the following precautions/procedures are met.

- Be sure that work area, equipment, and wrist strap assembly have a proper ground.
- Attach wrist strap and place metal tools, card extractors, test fixtures, etc., on grounded bench surface.
- Place conductive container on the bench top. Remove component/assembly from packaging. Remove shorting devices, if present. Handle components by their bodies and lay them on conductive work surface or test fixtures.
- Test through the connector or tabs only.
- Do not probe assemblies with test equipment.
- After testing, replace shorting devices and protective packaging.
- Use of Simpson Model 260 or equivalent to test parts or assemblies is prohibited. You must use a high input impedance meter such as a Fluke 8000A Multimeter.
- Dielectric strength tests are not permitted.

REVIEW SUBSET NUMBER 12

Q1. ESD-sensitive devices can be damaged by electrostatic voltages as low as ________

________________________________.

Q2. When handling ESDS devices, personnel and their apparel should be connected to

________________________________.

Q3. What is the minimum resistance for personnel ground straps?

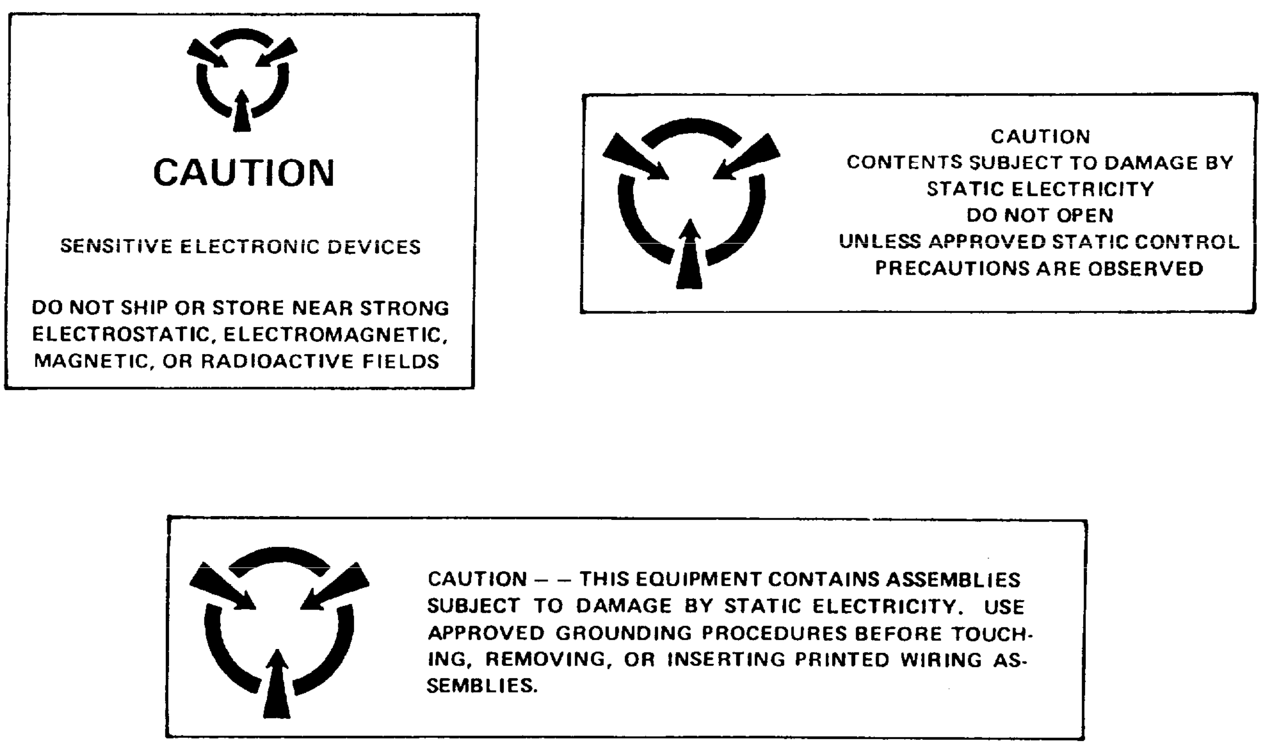


Figure 2-44.-ESDS markings.

CHAPTER 3

POWER GENERATION AND CONTROL SYSTEMS

This chapter has been deleted. For information on power generation and distribution, refer to Nonresident Training Course (NRTC) *Aviation Electricity and Electronics—Power Generation and Distribution*, NAVEDTRA 14323.

CHAPTER 4

AIRCRAFT ELECTRICAL SYSTEMS

As an Aviation Electrician (AE), you will work with many electrical systems. You must be a well-rounded aviation technician. You may work directly or indirectly with all other aviation maintenance ratings. You may work with Aviation Machinist Mates (ADs) on power plant discrepancies, or with Aviation Structural Mechanics (AMs) on electrohydraulic malfunctions.

In this chapter, you will learn about various systems that AEs regularly maintain. Maintaining naval aircraft systems is the number one priority; teamwork and maximum effort will pay dividends in flight safety and mission accomplishment.

AIRCRAFT LIGHTING SYSTEMS

Learning Objective: *Recognize operating principles and construction features of aircraft lighting, both internal and external, and identify types of lamps used in these circuits.*

The lighting system in an aircraft serves two primary purposes—it provides specialized light sources outside the aircraft and illuminates the interior. Exterior lights provide illumination at night for navigation and formation flying. Other exterior light operations include, signaling, landing, and anticollision. The interior lighting provides illumination for instruments, equipment, cockpits, and cabins. In addition, the electrical, electronic, and mechanical systems use lights to indicate normal operation or a possible malfunction. Lights also show the position of the landing gear, bomb bay doors, sonobuoy exit doors, etc.

Various types and sizes of light assemblies are used on present-day naval aircraft. The lighting requirement governs the selection of a particular light assembly. Most light assemblies consists of a housing (fixture), a lamp, and a lens.

DESCRIPTION AND TYPES OF LAMPS

Aircraft lamps are devices that provide sources of artificial light. The incandescent light is the most common type. It uses an electrical source to heat a filament until it is white hot. Normally, the source voltage is 26 to 28 volts ac or dc. However, some lighting systems use lower voltage lamps and step-down transformers to supply 3 to 6 volts to the lamps. The lower operating voltage allows the lamp filament to be larger, and it helps to reduce lamp failure due to vibrations.

When a lamp fails, the replacement must be the same as the original lamp or an approved alternate. Spare lamps in the aircraft are shock-mounted. If they weren't, they would probably fail earlier than the original lamps because cold filaments are subject to fatigue failure sooner than hot ones. You need to be sure that the glass bulb of the lamp is clear and free from grease and dirt. To help keep bulbs clean, don't touch the glass bulb with your bare hands, if possible.

The parts of a lamp are the bulb, filament, and base. Incandescent lamps vary chiefly in electrical rating, base type, bulb shape, and bulb finish.

The electrical rating of lamps is expressed as a combination of volts, watts, amperes, and candlepower. (Candlepower is the luminous intensity expressed in candles and used to specify the strength of a light source.) The lamp rating is found on either the base or the bulb of the lamp. On small lamps, an identifying number represents the electrical rating. This number is the same as the military specification (MS) dash number. You can find it on the lamp base.

The base types vary as to size, number of electrical contacts, and the method of securing in a socket. The most common types of bases are the single- or double-contact bayonet (push in and turn). These bases are used on aircraft since they lock in the socket and do not loosen because of vibration. Single contact bases are used in single-wire systems. In this system, one side of the lamp filament connects to the base and the other to the contact. Double contact bases are used if the single-wire system is not practicable. In this system, the filament connects to contacts and does not make an electrical connection to the base unless the lamp has dual filaments. Dual filaments use a common contact to the base. The single- and double-contact lamps are not interchangeable.

Some bases are of the screw type. They aren't used often because they loosen easily. Other lamps have an indexing-type base that has offset index pins. (See figure 4-1.) The index-type base is used to make sure that the lamp sits in the socket and the light shines in the proper direction.

Some lamps do not have a base; they solder directly onto a circuit board or permanently mount in control box panels. These lamps go through careful testing and selection so they last the life of the aircraft. Figure 4-2 shows one such lamp, the grain of wheat lamp.

The bulb shape is shown by a combination of letters and numerals. The letter shows the bulb shape, and the number shows the approximate maximum diameter of the bulb, in eighths of an inch. The codes and the shapes they indicate for the more common glass bulbs are as follows:

G	Globular
GG	Grimes globular
S	Straight
T	Tubular
PAR	Parabolic aluminum reflector
R	Reflector

By looking at the letter designations, you know that a bulb designated as T-6 is a tubular bulb with a 6/8-inch diameter. A variety of sizes and shapes of bulbs are listed in the *Defense Logistics Agency (DLA) Identification List.* This list is available through your local supply support center. Figure 4-3 shows some common bulb shapes.

Most aviation lamps are either clear glass or frosted on the inside. For a particular application, however, a bulb may be partially frosted; for

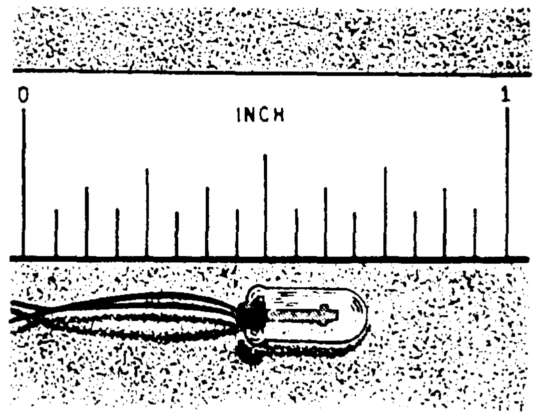


Figure 4-2.-Grain of wheat lamp.

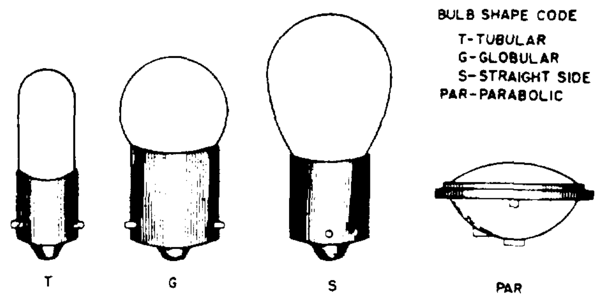


Figure 4-3.-Common bulb shapes.

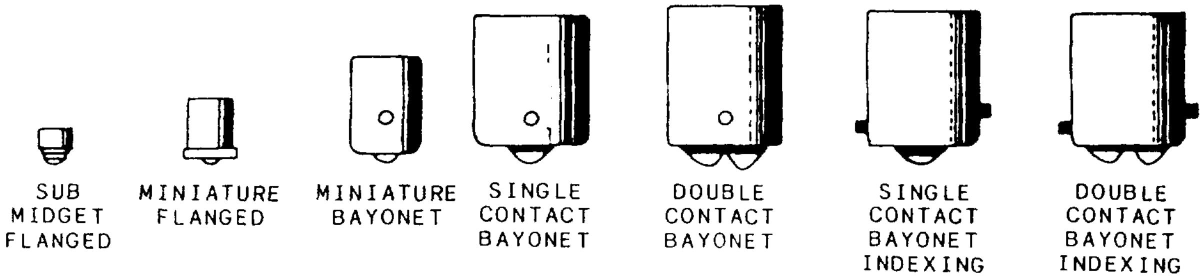


Figure 4-1.-Lamp bases.

example, to cut down emission of light in a particular direction. Another bulb may be partially silvered to prevent emission in a specified direction and/or to concentrate the light in other directions. Some applications call for colored bulbs; for example, in instrument illumination and safety lights. The letters just before the military specification (MS) dash number shows bulb finish-R for red, SB for silvered bowl. If no letter is present, the lamp is clear glass or frosted. You can also provide colored lighting by using clear lamps with a colored lens cover.

There are many special-purpose lamps in use on naval aircraft. Three of the most common types are listed below:

1. The parabolic, sealed-beam landing and taxi light. Signal lights also are used in sealed-beam lamps.
2. The midget-flange type of light is for use in instrument panels and control boxes.
3. Fuselage and signal lights use lamps having two filaments in parallel to provide fast signaling (smaller filaments heat and cool faster).

EXTERIOR LIGHTING

Many types of lights are used to meet the exterior lighting requirements of naval aircraft. The principal types of exterior lights are the navigation or position lights, anticollision lights, landing lights, and formation lights.

Figure 4-4 shows the components used in the exterior lighting system of a carrier-type aircraft. This figure shows the lights common to naval aircraft, but does not show every type of light in use on different aircraft. The lighting

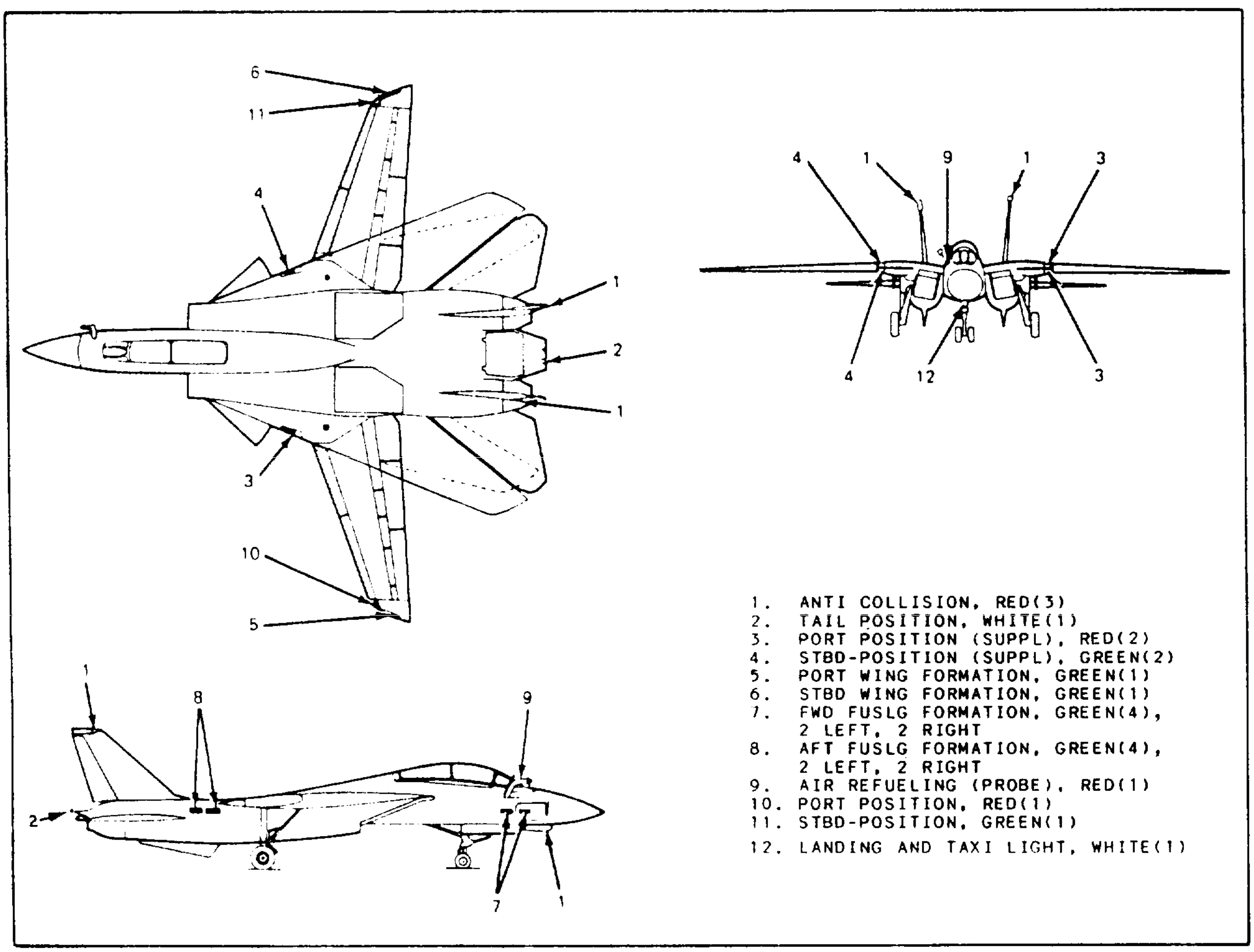


Figure 4-4.-Exterior lighting.

requirements vary from one aircraft to another, depending upon the aircraft type.

Navigation Lights (Position Lights)

Navigation lights on the aircraft attract visual attention to its position and heading at night. A standard minimum set of navigation lights, meeting Federal Aviation Administration (FAA) requirements for light distribution and intensity, is on all military heavier-than-air aircraft.

The standard **minimum** set of navigation lights for night operations consists of the following:

1. One red light on the tip of the left wing
2. One green light on the tip of the right wing
3. One white light on the tail, so it is visible over a wide angle from the rear

NOTE: The position for these navigation lights is on a stationary surface to the extreme left, right, and aft on helicopters (fig. 4-5).

In some aircraft configurations, navigation lights burn steadily; in other configurations they burn steadily or flash about 80 flashes per minute.

Fuselage Lights

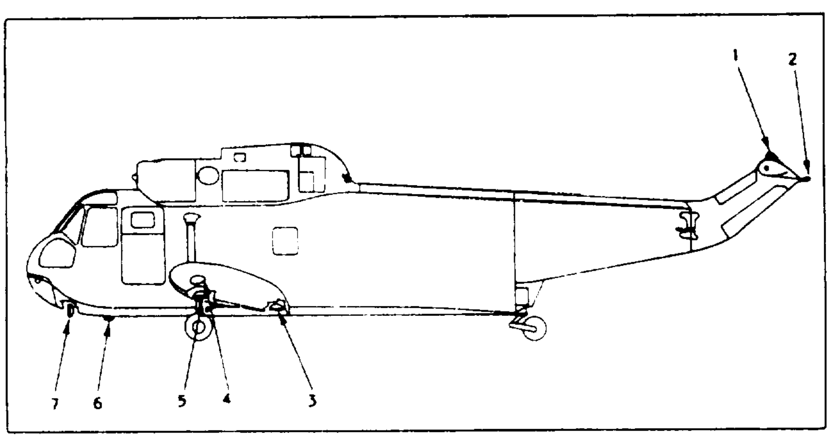
Fuselage signal lights are part of the aircraft navigation lighting system. They provide a method of visual signaling. When installed, two or more fuselage lights are necessary, one on the top and one on the bottom of the aircraft. If it is not practicable to install the light on the bottom of the aircraft, such as a seaplane or a radome obstruction, you install two lights. Position one on each side as near the bottom of the aircraft as possible. Fuselage lights may burn steadily or flash at a constant rate. On some aircraft, manual keying of lights for signaling is available.

Anticollision Lights

Anticollision beacon lights are an FAA requirement for all aircraft. Their primary purpose is flight safety, during daylight hours as well as night.

One type of anticollision light consists of two 40-watt reflector-type lights and a red lens assembly. An ac or dc motor rotates the bulb assembly, causing it to flash 80 to 90 flashes per minute. Slip rings provide electrical power to the bulbs.

On another type of anticollision light, the bulb is stationary. The flashing is caused by motor-driven reflectors in the light assembly.



1. Rotating anticollision light (tail—red)
2. Position lights (tail—white)
3. Hover lights (2)
4. Position light (right side—green, left side—red)
5. Main landing gear down—locked lights
6. Rotating anticollision light (bottom—red)
7. Controllable spotlight

Figure 4-5.-Typical helicopter lighting.

Most aircraft are now using strobe lights to provide anticollision warning to other aircraft. This system has a 3,000 to 3,500 candlepower white light for day and 150 to 200 candlepower red light for night. Both flash at 60 flashes per minute.

Aircraft equipped with in-flight fueling tanker capabilities can turn off the lower anticollision light during delivery of fuel to another aircraft. Tanker aircraft use a bluish-green lens over their anticollision lights to identify this capability to other aircraft in need of fuel.

Landing Lights

Modern naval aircraft have high candlepower landing lights to illuminate the landing strip. Multiengined aircraft usually have a landing light mounted on each wing. Single-engine aircraft use only one landing light, which normally mounts on the port wing.

Landing lights are usually retractable (fig. 4-6). Sealed-beam lights with a rating of 28 volts, 600 watts are used. They use split-field series dc

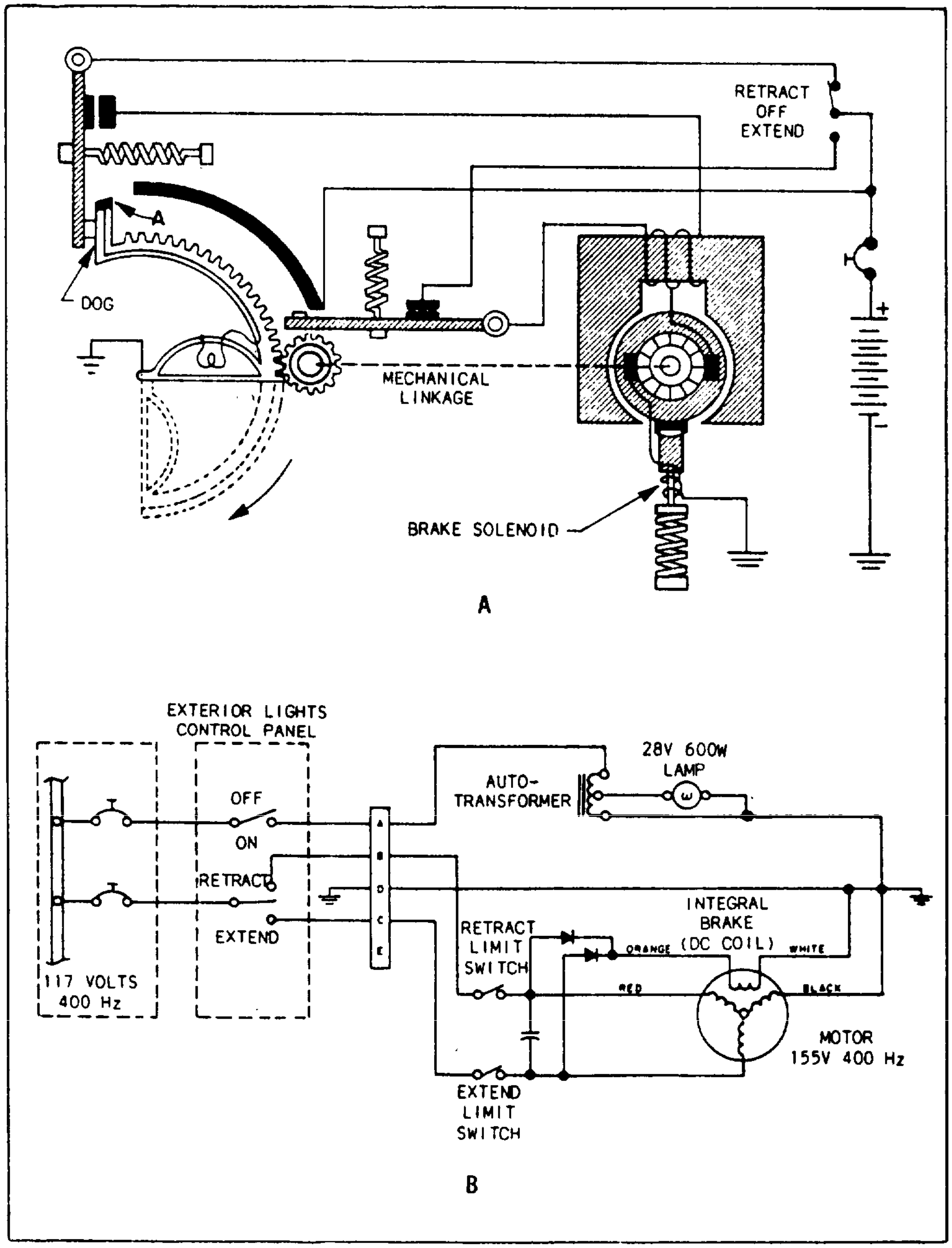


Figure 4-6.-Retractable landing lights.

motors or ac induction motors to provide drive operation. The 28-volt ac is provided by an autotransformer located within each light assembly. In the retracted position, movable lights are flush with the undersurface of the wing. In some aircraft, you can install a landing light in the nosewheel fairing door. Other aircraft have a fixed landing light, mounted in the leading edge of the wing.

As you read this section, refer to figure 4-6. You are going to learn about the operating principles of a typical retractable landing light.

The landing light switch on the pilot's lighting panel controls the landing light motor. When the switch is in either the EXTEND or RETRACT position, power goes simultaneously to the magnetic brake (releasing the brake) and the drive motor. Limit switches open the motor circuit when the light has reached its limit of travel in either direction (extended or retracted position). This light can be put in any position between its travel limits by turning the switch off. When the power to the motor is off, the gear train holds the light in that position.

The lamp illuminates by a sliding contact after the light assembly travels downward about 10 degrees. Illumination continues until the lamp again reaches the 10-degree position when traveling in the upward direction. The lamp will remain lighted in any extended position past the 10-degree position, regardless of power application to the control motor. The pilot can adjust the angle of the light beam to fit the operation. A switch lets you turn the lamp off while the light is in any position, as shown in figure 4-6, view B.

The landing light assembly design lets you adjust the maximum extended position for each particular aircraft installation. The light opens to an extended position of 73 degrees, ±3 degrees, from the retracted position. The light assembly is capable of being extended to positions ranging from 50 degrees to 85 degrees from the retracted position.

When you ground-test landing lights, don't let them overheat or be damaged by extending them against ground support equipment. You should NEVER look directly at an illuminated landing light because it can cause permanent eye damage.

Approach Lights

The carrier aircraft approach light systems give the pilot and landing safety officer (LSO) positive indication of safe or unsafe landing configurations. All shipboard naval aircraft have approach lights mounted so they are clearly visible to the LSO. Installations of the approach lights vary with aircraft. Older aircraft have them in the port wing leading edge. Modern aircraft, such as the F-14 (fig. 4-7) and F/A-18, have the approach lights on the nose landing gear door. Most jet aircraft have a three-lamp approach light assembly connected to the angle-of-attack indicator. The approach light control is by cam-actuated switches in the angle-of-attack indicator. The lights operate with landing gear completely down, with aircraft off the gear, and arresting gear extended.

The three lights in the approach light assembly are red, amber, and green. When the red light is on, it shows that the angle of attack of the aircraft is low. When the green light is on, it shows that the angle of attack of the aircraft is high. When the amber light is on, the angle of attack is prefect for the landing approach.

The approach lights work in conjunction with the cockpit angle-of-attack indexer lights (fig. 4-7), which give the pilot angle-of-attack information. These lights mount in the cockpit on either side of the windshield. They are clearly visible to the pilot, but don't obstruct vision.

The indexer lights operate by cam-operated switches in the angle-of-attack indicator. At very low angles of attack, a red-colored inverted V illuminates. This warns the pilot to increase the aircraft angle of attack. At slightly low angles of attack, both the inverted V and circular symbol (doughnut) illuminate. At desired angles of attack, the amber-colored doughnut illuminates. At slightly high angles of attack, both the V and doughnut illuminate. At very high angles of attack, a green-colored V symbol illuminates, warning the pilot to decrease the aircraft angle of attack. The indexer information corresponds to the approach lights assembly information displayed to the LSO.

Approach lights show the LSO three things—(1) aircraft angle of attack, (2) landing gear is down and locked, and (3) arresting gear extension. A limit switch in the arresting gear circuit operates when an unsafe condition exists, causing the lights to flash.

An arresting gear (tailhook) override switch allows bypass of the tailhook circuit for carrier landing practice at airfields. The override switch is of the momentary ON type. When in the ON position, the arresting gear switch bypass relay energizes. The approach lights operate only in conjunction with landing gear, since the arresting gear is up. When the circuit de-energizes, it automatically reverts to its normal condition

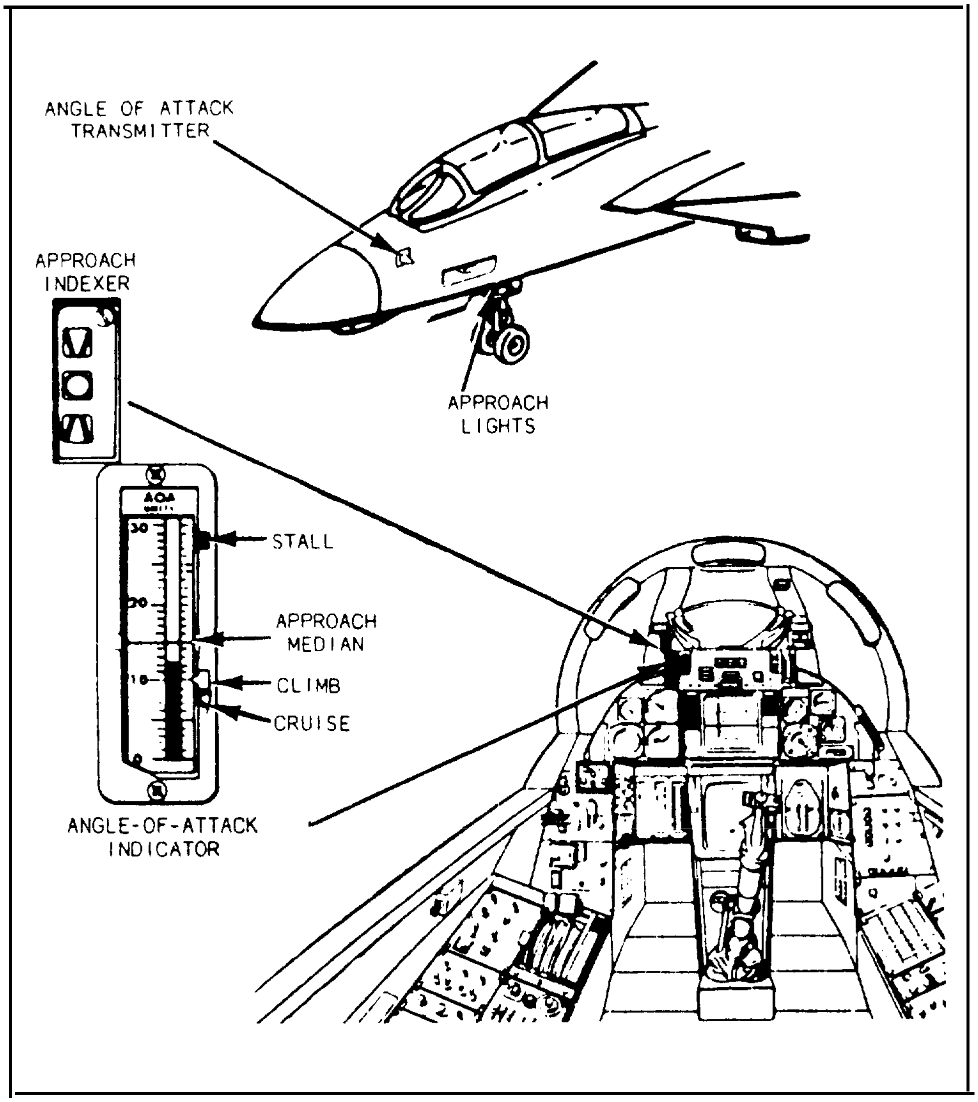


Figure 4-7.-Angle-of-attack components.

(arresting gear switch not bypassed). In most aircraft, the circuit returns to normal by lowering the arresting gear, turning off the battery or generator switch, or removing external power.

Formation Lights

Naval aircraft have formation lights for night formation flying. In a typical formation light installation, wingtip formation lights mount within the upper and lower surfaces of the aft section of each wingtip. Translucent diffusing windows mount flush with the wingtip surface above and below each light. The right-hand (starboard) light covers are green and the left-hand (port) light covers are red. The lamp assembly is accessible through the lower wingtip cover plate.

Fuselage formation lights installations (fig. 4-4) are in box assemblies on each side of the fuselage. Each has a plastic window for light emission and access to the lamp is by removing the box cover. These lights connect in parallel with the wingtip formation lights; therefore, they illuminate simultaneously.

NOTE: Manufacturers sometimes identify lights having the same purpose as formation lights by another name such as join-up lights or strip lights.

Taxi Lights

Taxi lights help the pilot maneuver the aircraft before and after flight. On aircraft having a nosewheel, the taxi light assembly mounts on the movable strut so the light turns with the wheel. Light installation provides maximum visibility for the pilot and co-pilot. (See figure 4-4 for a typical taxi light installation.)

In-Flight Refueling Probe Light

Most modern carrier aircraft have limited range due to their small fuel capacity. To increase range and flight time, day and night in-flight refueling is necessary. Most naval shipboard aircraft have provisions for in-flight refueling. For night refueling, in-flight refueling (IFR) probe lights mount on the fuselage forward of the probe. The light lens is usually red in color and illuminates the refueling probe and drogue from the refueling aircraft at night. Figure 4-4 shows a typical IFR probe light installation.

Hover Lights and Spotlights

In helicopter installations, hover lights illuminate the area directly beneath the aircraft (fig. 4-5, callout 3). These lights serve several different purposes, including landing and search and rescue. A spotlight can be mounted in the nose of a helicopter (fig. 4-5, callout 7), and it can extend or retract. An ON/OFF/RETRACT switch on the pilot's control stick and a spring-loaded, four-way thumb switch marked EXTEND/RETRACT/LEFT/RIGHT control the spotlight. It can rotate through 360 degrees of azimuth.

INTERIOR LIGHTING

Various types of lights and lighting systems are used for interior illumination of naval aircraft. Almost all lights and lighting systems fall under one of the following types:

- Instrument lighting
- Cockpit lighting
- Cabin and passageway lighting
- Indicator lights

An important consideration in interior lighting of aircraft is the prevention of undue eyestrain. Your eyes adjust slowly to changing light intensities, which can cause fatigue or eyestrain. Aircraft lighting designs produce as little discomfort as possible. As an AE, you maintain the lights. You should follow the specifications when replacing fixtures and lamps. You should observe the following general considerations when working with the interior lighting of aircraft:

- Use lenses to diffuse light that lies within the pilot's field of vision.
- Eliminate all bright spots of light, direct sources of light, and reflections.
- Use sparingly any surface that reflects light, such as chromium or nickel.
- Use quick-change lighting fixtures so that lamps may be changed rapidly.

Instrument Lights

The first use of artificial light in aircraft was for the instrument illumination. Operating modern aircraft depends on instruments; therefore, instrument lighting is important. There are different methods of instrument lighting, and which one is best makes a decision difficult. No matter what system of lighting is in the aircraft, the light must not be visible outside the aircraft.

Indirect (mask) lighting is desirable because it doesn't produce objectionable reflections. The lamps mount in the instrument panel. The panel has a reflector cover (mask), which has openings in it for observing the instruments. The light reflects until it becomes diffused and floods the entire panel. Even though this system produces satisfactory lighting, it is not in common use today because of space and weight requirements.

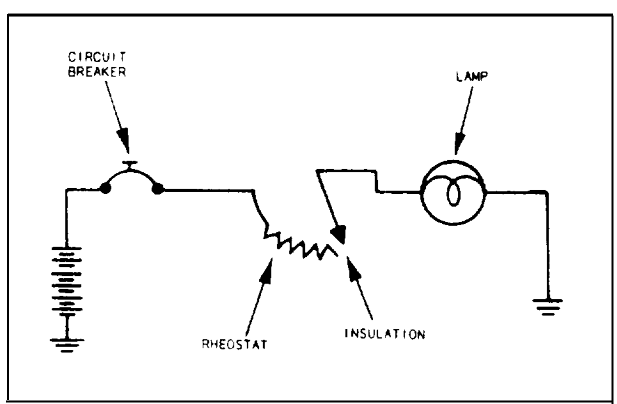
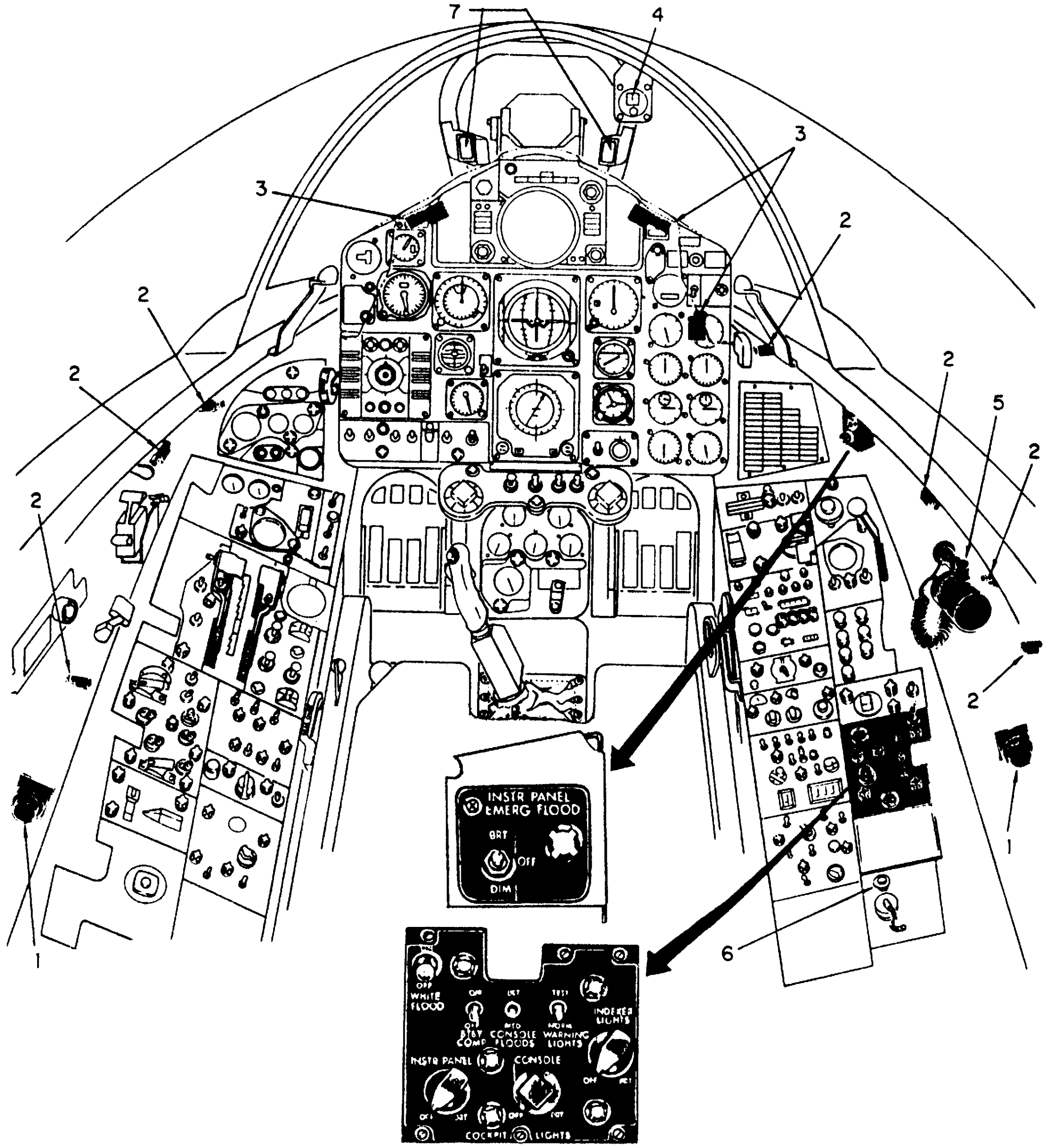


Figure 4-8.-Rheostat switch.



1. **White floodlights**
2. **Red floodlights**
3. **Instrument emergency floodlights**
4. **Standby compass light**
5. **Utility spotlight and floodlight**
6. **Spare lamp container**
7. **Angle-of-attack indexer lights**

Figure 4-9.-Interior lighting.

Another method of instrument lighting (commonly called *post lighting)* uses installation of specially adapted shields in front of the instruments. Small lamps in red-filtered sockets mount in the front surface of the cover shields, which cast light down and onto the instruments. These shields mount around the instrument for vision and are flanged to direct the lights properly for dial illumination.

Rheostats control the intensity of light in most aircraft (fig. 4-8). The rheostat is a variable resistor used to limit current through the circuit. When the pivoting arm reaches the high-resistance end of the rheostat, it slips off the contact surface and breaks the circuit. This arrangement is a rheostat switch.

A typical aircraft instrument lighting system is shown in figure 4-9. You should refer to this figure as you read this section. The lighting equipment consists of edge-lighted control panels, individual lights for instruments, and red floodlights for overall lighting. The edge-lighted panels provide diffused lighting for the control and indicator panels.

Some instruments have a light source as an integral part of the instrument, and all instrument designs will soon have integral lighting. Since individual lights for instruments are compatible with the integrally lighted instruments, the two types of light sources may be intermixed.

Edge-lighted control and indicator panels (fig. 4-9) have a nongloss, black background with white lettering for maximum ease of reading. Small lamp assemblies are mounted so light is diffused through the plastic panels. These lamps have red filters to cut out glare. Bulb replacement is relatively simple, Just unscrew the top cap from the assembly, pull the bulb from the cap, replace the bulb, and reassemble the unit.

Most instrument lights consist of panel lights and instrument integral lights. The essential bus powers the instrument lights through circuit breakers or autotransformers through fuses.

The CONSOLE panel lights control is a variable intensity control for the console panel edge lights. As the control rotates clockwise, the intensity of the console edge lights increases. Also, as the control rotates to the OFF position, a switch within the control actuates, removing power from the console flood switch dim contact. Therefore, the console red floodlights operate in dim only when the console panel lights control is in a position other than OFF.

The CONSOLE FLOODS switch is a three-position switch (BRT/DIM/MED) for selecting the intensity of console floodlights. Selection of the BRT or MED position energizes the lights regardless of the position of the console panel lights control. The WHITE FLOOD switch has two positions—OFF and ON. Placing the switch to ON energizes the white floodlights. The NORMAL WARNING LIGHTS switch has two positions—NORMAL and TEST—and it is spring loaded to the NORMAL position. Placing the switch in the momentary contact TEST position illuminates all of the warning lights in the pilot's cockpit.

The INSTR PANEL EMERG FLOOD switch (fig. 4-9) has three positions–OFF, DIM, and BRT. The switch turns on the red floodlights above the main instrument panel in an emergency when normal instrument lighting malfunctions.

In some aircraft, tiny grain-of-wheat lamps have permanent mounts in the control-box panels. Having been aged and carefully selected for output and reliability, the lamps should last for the lifetime of the aircraft.

Cavities and shallow trenches in the panel back accommodate the panel connector, lamps, and route lamp leads to the panel connector. The connector, lamps, and leads are then potted into the back of the panel with a clear plastic potting material. Normally, the lamps are in parallel, and failure of one lamp will not appreciably degrade the panel lighting. The main advantages of embedded lamps are long life, ruggedness, resistance to aircraft vibrations, and better illumination.

Cockpit Lights

The term *cockpit lighting* is rather broad. Its meaning varies, depending on the type aircraft being described. In fighter-type aircraft, it may be interior lighting that consists of individually lighted instruments and switches, lighted control panels, and necessary floodlights. It includes the interior lighting just mentioned as well as many other special lighting assemblies.

A much used lighting device is the small incandescent spotlight known as a utility light assembly. These assemblies, installed at crew stations, are in a position where they provide illumination of equipment that the crew member uses. The light from the lamp assembly can focus in either a small spot or in a wide beam. It also has a red filter for night use. Figure 4-10 shows one type of light in which an ON-OFF switch and an intensity control rheostat control light operation.

Cockpit extension light assemblies provide crew members with an extension light for reading maps or illuminating small areas. These assemblies consist of a connecting cord, switch, and lamp housing assembly. By adjusting the assembly, you can change the size of the light beam.

Indicator Lights

Cockpit personnel get aircraft operating status from various indicator (warning, caution, and advisory) lights in the cockpit. These lights have many purposes, such as showing the position of the landing gear, arresting hook, wings, and bomb bay doors. They can also show low oil pressure, equipment overtemperature, generator failure, and other data.

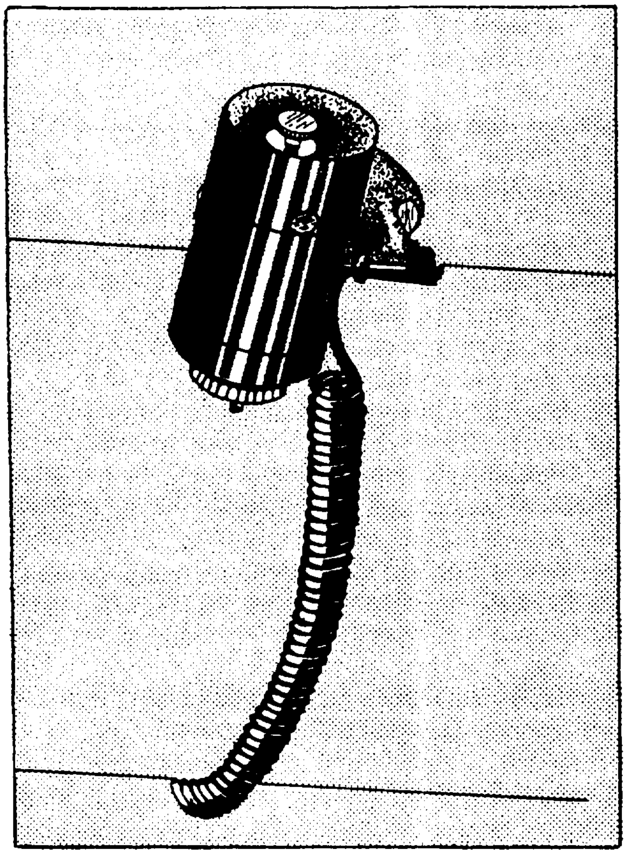


Figure 4-10.-Cockpit utility light.

The construction of indicator lights varies, depending upon the particular job they perform. They mount in the aircraft where they are easily noticeable when glowing. It is important that bulb replacement be quick and easy since some lights relay vital information concerning safety of flight. Whenever practical, assembly design allows bulb replacement in flight without the use of tools. Most warning light designs have a push-to-test feature or a test switch that lets you determine if the bulb is good. The test switch energizes various test relays, which, in turn, either provide power or a ground circuit for energizing the lights. This allows you to check the bulb without operating the equipment.

Legend-type lights (fig. 4-11) show specific functions on the lens surface. They are prominent on late model aircraft.

- The **warning lights** are red. They warn the crew of an emergency or unsafe operating condition, which requires immediate corrective action.
- The **caution lights** are yellow. They alert the crew to a minor malfunction or impending dangerous condition requiring attention, but not necessarily immediate corrective action.
- The **advisory lights** are green. They show the crew a safe or normal configuration, or a performance condition.

Indicator lights must be bright enough to see during daylight operation but not bright enough to cause eyestrain at night. You obtain brilliance control by connecting resistors in the lighting circuit, and by placing dimmer caps on the lights. Other ways of control are special adaption of edge lighting, and special types of lenses that dim by twisting the lens.

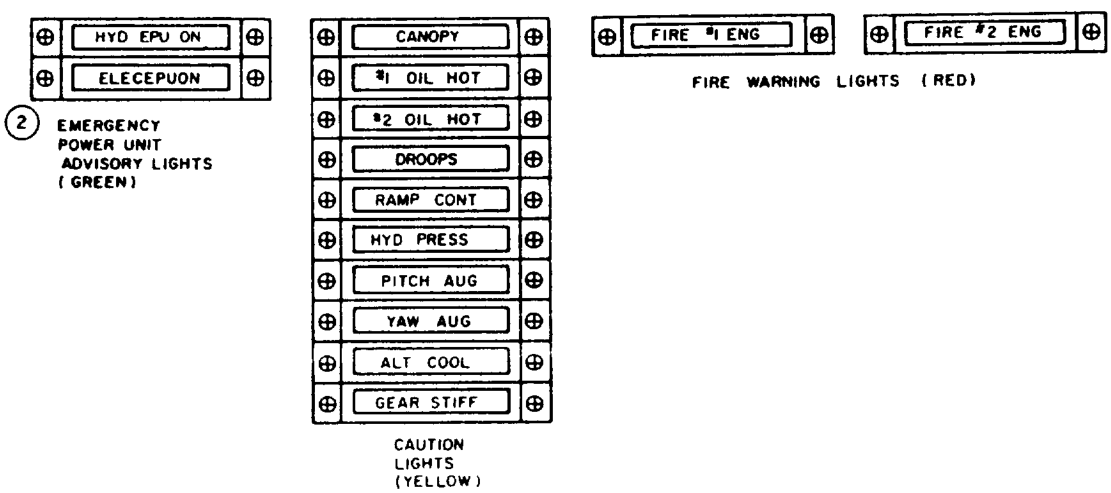


Figure 4-11.-Legend-type lights.

An example of the use of indicator lights is the system used to show high oil temperature. A thermoswitch in the oil return line closes when the temperature reaches above normal. This usually provides a path to ground illuminating the OIL HOT light. The light goes out only when the oil cools to normal temperature.

Another application of the use of an indicator light is the landing gear unlocked warning light. In some aircraft, a red light glows in the translucent landing gear control lever when the gear is not in either the up or down position.

REVIEW SUBSET NUMBER 1

Q1. List the two primary purposes of aircraft lighting.

Q2. Why should spare light bulbs be shock mounted?

Q3. What are the two most common types of bulb bases?

Q4. What type of light is used to attract visual attention to the aircraft's position and heading at night?

Q5. On which wing tip will the green navigation light be found?

Q6. A bluish-green anticollision light identifies what type of aircraft?

Q7. When the angle of attack is perfect for the landing approach, what color AOA light illuminates?

AIRCRAFT ELECTROHYDRAULIC AND PNEUMATIC SYSTEMS

Learning Objective: *Recognize operating principles and characteristics of aircraft electrohydraulic and pneumatic systems.*

The word *hydraulics is* from the Greek word for water. Hydraulics originally meant the study of physical behavior of water at rest and in motion. Today the meaning includes the physical behavior of all liquids, including hydraulic fluid.

Hydraulics is the science of liquid pressure and flow. In its application to aircraft, hydraulics is the action of liquids, forced under pressure through tubing and orifices, to operate various mechanisms.

The primary concern in working with hydraulics is to control the flow of fluid. You do this by using solenoids that simply turn on, shut off a flow of fluid, or change flow direction. In some cases, electrical devices may schedule a precise amount of fluid flow. In any case, you must understand the characteristics of liquids.

You should recall from chapter 1 that a liquid has no definite shape and conforms to the shape of its container. Also, a liquid can be only slightly compressed. Another fact you should recall is the ability of a liquid to transmit pressure.

The physics of fluids and basic hydraulic principles are contained in *Fluid Power,* NAVEDTRA 14105. Study the first two chapters of this publication with this chapter if you need to review basic hydraulic principles.

Although some aircraft manufacturers make greater use of hydraulics than others, the hydraulic system of the average modern aircraft performs many functions. Among the units commonly operated by hydraulics are the landing gear, wing flaps, speed brakes, wing folding mechanisms, flight control surfaces, canopy, bomb bay doors, wheel brakes, and arresting gear.

BASIC HYDRAULIC SYSTEM

All hydraulic systems are essentially the same, regardless of their function. Hydraulics are on the

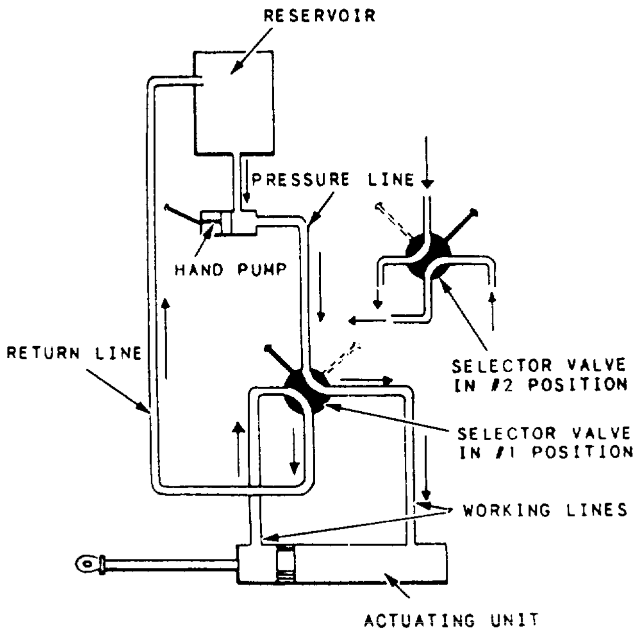


Figure 4-12.-Basic hydraulic system, hand-operated pump.

farm, in industry, aboard ship, and many other places as well as in aircraft. Regardless of its application, each hydraulic system has a minimum of four components—reservoir, pump, selector valve, and actuating unit—plus lines through which the fluid flows. Figure 4-12 shows a basic hydraulic system, with the four essential components and their relationship within the system.

The reservoir provides storage for a supply of fluid for operation of the system. It replenishes the fluid of the system when needed, provides room for thermal expansion, and normally provides a means for bleeding air from the system.

The pump creates a flow of fluid. The pump in this system is hand operated; however, aircraft systems have engine-driven or electric-motor-driven pumps. There are two types used in naval aircraft—the piston type and the gear type. One aircraft may incorporate both types due to the requirements of the various hydraulic systems.

The selector valve directs the flow of fluid. These valves actuate either manually or by solenoid; they may operate directly, or they may operate indirectly with the use of mechanical linkage.

The actuating unit converts fluid pressure into useful work. The actuating unit may be an actuating cylinder or a hydraulic motor. An actuating cylinder converts fluid pressure into useful work by linear/reciprocating-mechanical motion. A hydraulic motor converts fluid pressure into useful work by rotary-mechanical motion.

Look at figure 4-12, You can trace the flow of hydraulic fluid from the reservoir through the pump to the selector valve. With the selector valve in the #1 position, fluid flow created by the pump is through the valve to the right-hand end of the actuating cylinder. Fluid pressure then forces the piston to the left. As the piston moves left, fluid on that side of the piston flows out, up through the selector valve, and back to the reservoir. With the selector valve in the #2 position, fluid from the pump flows to the left side of the actuating cylinder, reversing the process. You can stop piston movement at any time by moving the selector valve to neutral. In this position, all four ports close, and pressure is equal in both working lines.

You can see how hydraulic systems work by looking at this basic system. You can make additions to it to provide additional sources of power, operate additional cylinders, make operation more automatic, or increase reliability. These additions are all made on the framework of the basic hydraulic system diagram shown in figure 4-12.

ELECTROHYDRAULIC SYSTEMS

Basically, there are two types of electrically controlled, hydraulically operated components. Selector valves that start, stop, or change the direction of a fluid flow (similar to a switch in an electrical circuit), and control valves that schedule fluid flow (much like a potentiometer controls current flow). Each of these components is manufactured in varying degrees of complexity, depending on its use. Each manufacturer uses its own identification for its components, such as transfer valve, engagement valve, servo valve, etc.

Aircraft hydraulic systems normally operate at a pressure of 3,000 PSI; therefore, each component must be capable of operating at this pressure. You should observe all applicable safety precautions when working with high-pressure hydraulic or pneumatic systems.

Hydraulic Surface Control Booster System

The hydraulic surface control booster system contains (figs. 4-13 and 4-14) both selector and control components. The automatic flight control system (AFCS) engagement valve is a selector valve. It either applies pressure to or removes pressure from the AFCS portion of the booster. The hydraulic transfer valve controls the direction and amount of fluid to the booster.

AFCS ENGAGEMENT VALVE. —The AFCS engagement valve (fig. 4-13) is in the disengage or relaxed position. No voltage is at the coil, and 3,000 PSI hydraulic pressure pushes the solenoid piston to the left. This action allow the hydraulic fluid to flow to the right side of the spring-loaded piston. With the same pressure on both sides, the spring-loaded piston moves to the left, preventing any further flow in the system.

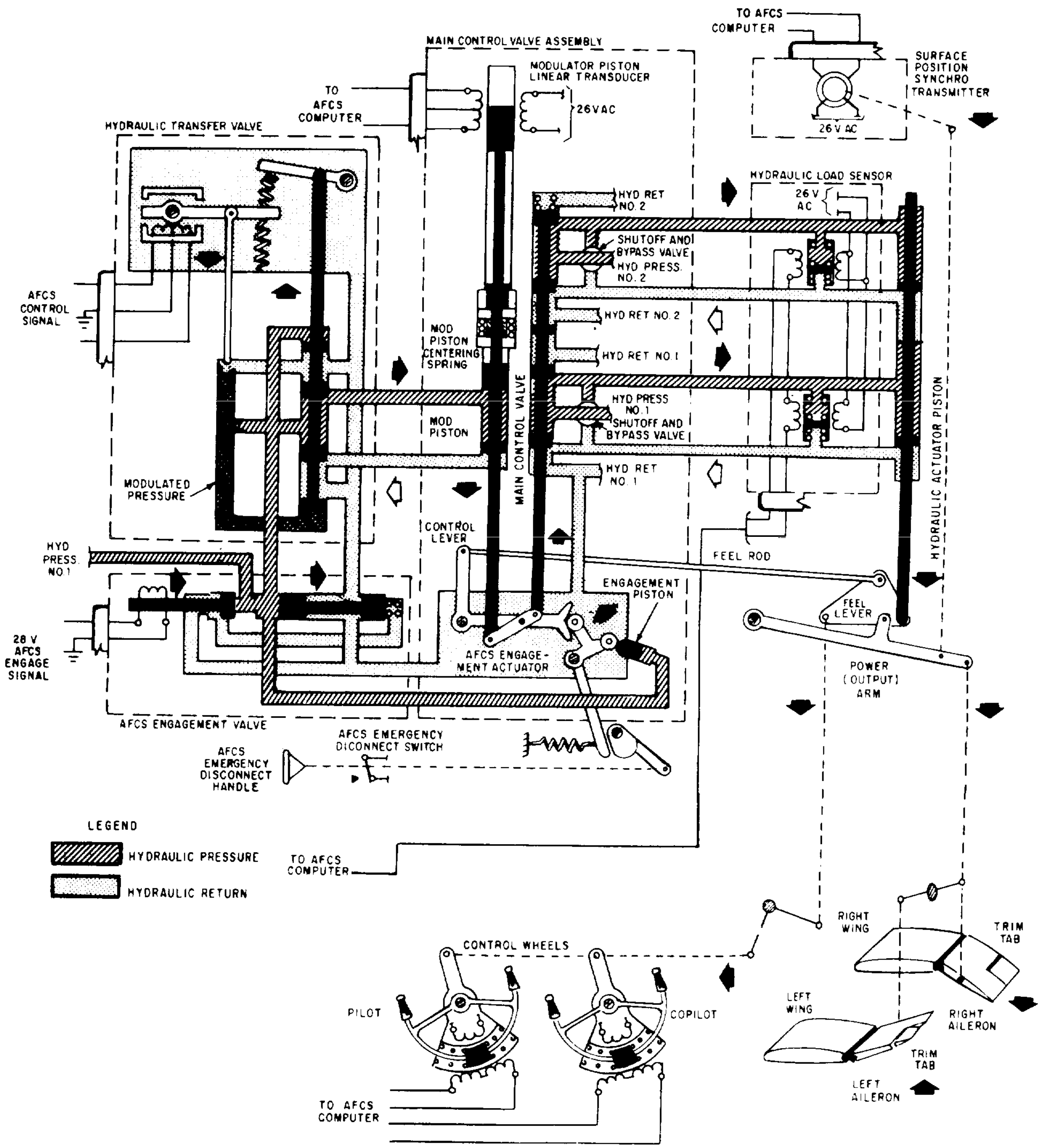


Figure 4-13.-Hydraurlic surface control booster with no mechanical input and AFCS disengaged.

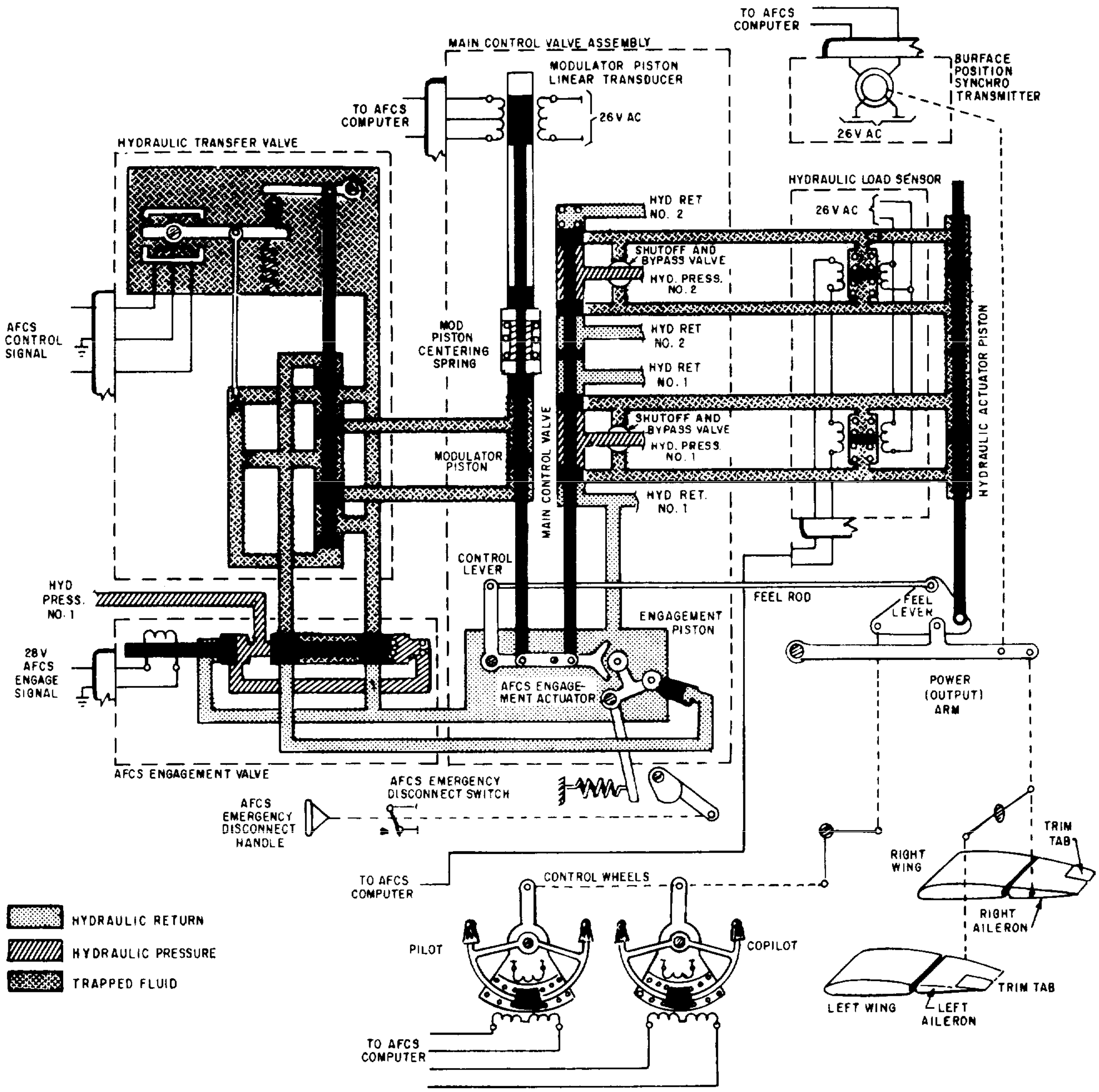


Figure 4-14.-Hydraulic surface control booster with no mechanical input and AFCS engaged.

When AFCS engages (fig. 4-14), a 28-volt dc signal goes to the solenoid coil to drive its piston to the right. This action relieves hydraulic pressure from the right side of the spring-loaded piston. This allows pressure on the left side to move the piston to the right, compressing the spring. Hydraulic pressure then flows to the other AFCS components of the boost system.

HYDRAULIC TRANSFER VALVE. —With AFCS engagement, a dc control signal goes from the AFCS computer to the transfer valve. In the static state (zero signal), dc flow through the transfer valve coil is equal, and the plunger mechanism remains in the centered position (with help from the centering springs).

Hydraulic pressure from the engagement valve flows to the top land on the hydraulic transfer valve piston. Fluid also flows through a small orifice to the bottom land of the same piston. Pressure to the bottom of the piston is regulated by controlling the amount of fluid leaving the modulated pressure chamber. If chamber pressure is 1,500 PSI and one drop of fluid leaves the chamber for every drop that enters, the pressure remains constant. To increase pressure, an unbalanced dc voltage on the coil causes the plunger to block the return orifice for an instant so more fluid enters the chamber than leaves. Conversely, an unbalanced dc signal from the AFCS computer that causes the plunger to rise for an instant lowers chamber pressure.

With zero input signal from the AFCS computer, the transfer valve piston is in the centered position (fig. 4-13). The pressure acting on the smaller surface area of the piston's upper land and the modulated pressure acting on the larger area of the piston's lower surface are in balance, keeping the piston centered.

With an electrical signal input, as shown in figure 4-14, a higher pressure in the modulated chamber causes the piston to raise. This action allows fluid to flow to another component of the boost system. The larger the electrical signal input, the more pressure difference on the piston; therefore, more fluid flow.

BOOSTER SYSTEM OPERATION. —The booster operates in two separate modes—manual and AFCS. In the manual mode, control surface deflection desired by the pilot starts by a lateral movement of the control wheel (fig. 4-13). This small movement of the control wheel transmits through the feel lever and feel rod to the control lever. The control lever is free to move about its pivot, and a centering spring holds the modulating piston in place. Movement of the control lever displaces the main control valve, porting fluid from two hydraulic systems to the hydraulic actuator piston. (The main control valve and hydraulic actuator work identically, whether in manual or AFCS modes.)

When the hydraulic actuator piston moves, both the feel lever and the power arm position the control surface and the control wheel to the position the pilot selects. As the pilot applies more pressure to the control wheel, the control surface moves faster. The direction of the pressure determines the direction of control surface movement.

If there is no pressure at the control wheel, the main control valve centers (fig. 4-13). Trapped fluid holds the hydraulic actuator piston in position.

The manual operation of the dual shutoff and bypass valves is from the flight station. If there is a loss of hydraulic pressure or a malfunction in the boost system, the flight crew pulls the handle. Operation of the valves shuts off hydraulic pressure to the hydraulic actuating piston and opens both working lines to each other. This prevents hydraulic lock in the actuator piston and allows control surface movement without the aid of the boost system.

Trapped hydraulic pressure in the modulator piston aids the mod piston centering spring in holding the piston centered. This allows positive control of the main control valve by the control lever.

Upon AFCS engagement, the engagement valve ports hydraulic fluid to the hydraulic transfer valve and to the engagement piston. Movement of the engagement piston locks the control lever in its centered position and prevents mechanical inputs from the control wheels. This piston can, however, be overpowered by about 15 pounds of force on the control wheel, if necessary, in an emergency.

Electrical inputs from the AFCS computer change to hydraulic fluid pressures in the hydraulic transfer valve, and the pressure controls the modulator piston. The modulator piston changes the hydraulic pressure into linear mechanical motion, which repositions the main control valve. Movement of the main control valve ports hydraulic fluid to the actuator piston to position the control surface and control wheel as previously described.

Electrical devices on the booster provide information inputs to the AFCS. The modulator piston linear transducer tells the AFCS the rate of control surface movement, and the surface position synchro transmitter provides position information. Read chapter 8 for more information about automatic flight control system operation.

Landing Gear System

Most naval aircraft have hydraulically actuated, electrically controlled, retractable landing gear. Normally, locking the landing gear in the retracted or extended position is automatic. Figure 4-15 is an electrical schematic of the

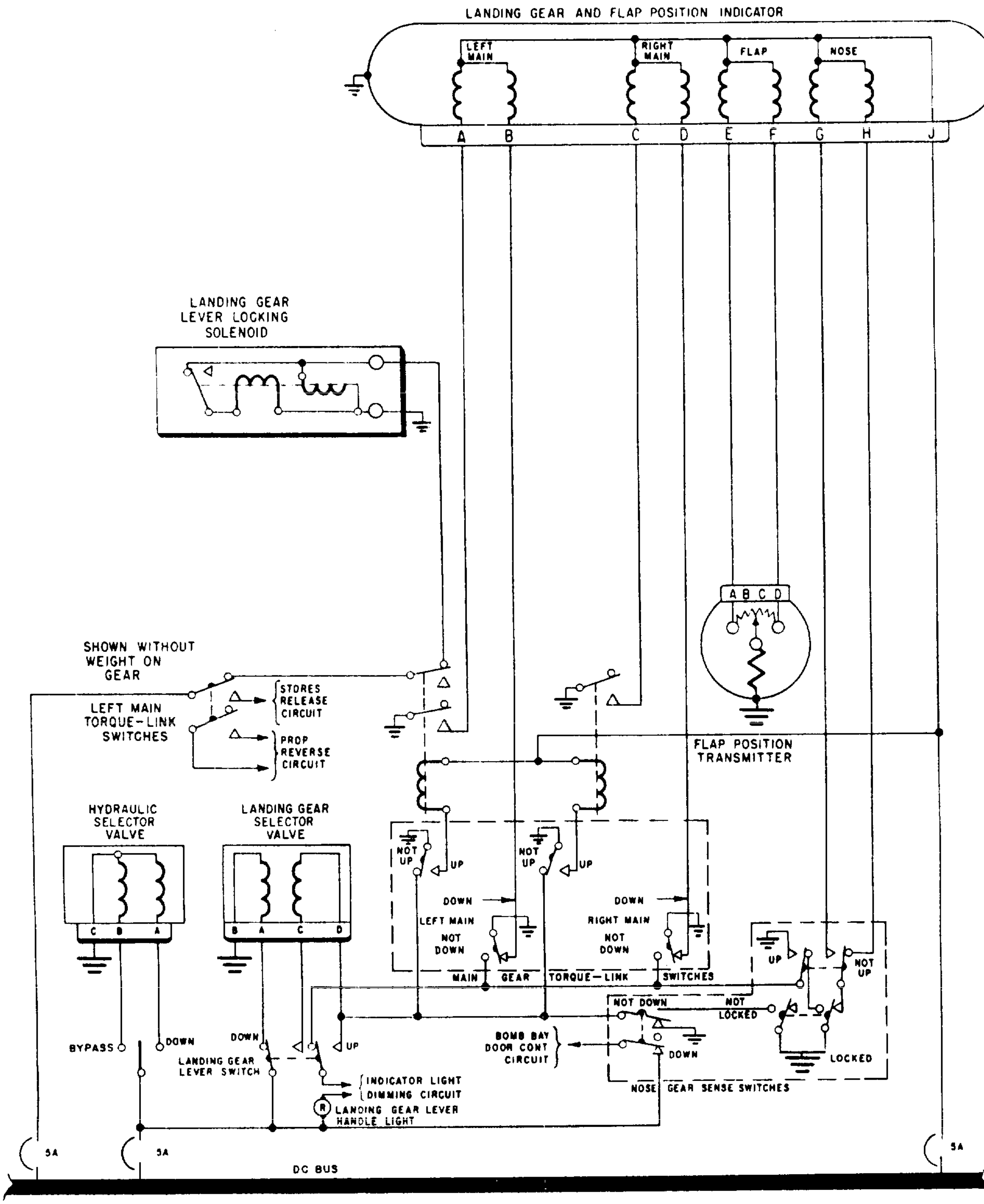


Figure 4-15.-Landing gear control circuit.

landing gear control circuit of a patrol type aircraft.

CIRCUIT OPERATION. —The landing gear circuit includes an electrical, solenoid-operated selector valve to control hydraulic actuation of the landing gear. Current goes to the landing gear selector valve through two single-pole, double-throw (SPDT) switches. These switches operate by a cam on the landing gear control lever, permitting current to flow to either the up or down coil of the valve. Coil selection depends on control lever position. The landing gear control circuit also includes electrical control for emergency extension of the nose gear with emergency hydraulic system power. A center-off switch (SPDT type) provides control of a double solenoid-actuated hydraulic selector valve. The center-off position of the switch is the normal position during operation of the landing gear with the main hydraulic system. The down position selects emergency hydraulic system power for nose gear extension. The bypass position is for use only during retraction of the nose gear with main hydraulic power after extension by emergency hydraulic power. The bypass also allows for release of emergency system hydraulic pressure any time you desire.

ADDITIONAL CIRCUITS. —In some aircraft, the landing gear control circuit also controls the supply of power to the propeller-reversing circuit (through left and right main torque-link switches) and to the stores release circuit (through left main torque-link switch). The left main gear torque-link switch supplies power to energize the landing gear lever locking solenoid. The weight of the aircraft must be off the landing gear shock strut before you move the landing gear control lever from the wheels down position. The solenoid will be de-energized by the up sense switch of the left main gear after the gear retracts. This switch energizes a relay, whose normally closed contacts are in series with the solenoid circuit. The left and right main gear torque-link switches (parallel connected) are in series with the power to the throttle lever-locking solenoid to prevent the throttles from being placed in reverse propeller range. When one of the torque-link switches actuates (by aircraft weight compressing one or both main landing gear strut oleos), the throttle levers come into the reverse pitch range. The left main landing gear torque-link switches (series connected) also open the stores release circuit. This prevents accidental release of wing station external stores when the weight of the aircraft has compressed the shock strut oleo.

A solenoid mechanically prevents movement of the landing gear control lever from the wheels down position when the aircraft weight is on the gear. When the weight of the aircraft is on the landing gear, this solenoid de-energizes, allowing the solenoid armature pin to protrude outboard. This solenoid armature pin position mechanically prevents movement of the landing gear control lever from the wheels down position. Depressing the solenoid armature pin allows control lever movement for emergency or test procedures.

Arresting Gear System

The arresting gear system stops the aircraft during carrier landings and emergency field arrestments. The primary component of the system is the arresting hook on the underside of the aft fuselage. The hook is pivoted at the forward end allowing up, down, and sideways motion. The hook engages a runway or cross deck pendant when in the down position. A lever in the cockpit controls raising and lowering of the hook (fig. 4-16). The lever electrically energizes a hydraulically actuated vertical damper cylinder for hook retraction and trips an uplatch mechanism through mechanical linkage for lowering the hook. Two horizontal dampers and one vertical damper dampen hook motion from deck impact forces. Two centering spring assemblies maintain the hook in the center position.

EXTENSION. —You extend the arresting hook by moving the control handle in the cockpit from the up to the down position. This removes tension from the cable and allows the uplatch mechanism to deflect to the opposite extreme of travel (aft). The arresting hook is then free to extend by action of the vertical damper cylinder and its own weight. At the same time, a switch in the control handle actuates, de-energizing both the arresting hook relay and the selector valve solenoid. This action permits fluid from the vertical damper cylinder to return. The surge damper prevents return line high-pressure surges, caused by hook extension, from damaging other subsystems by reducing the surge.

RETRACTION. —Moving the cockpit lever from the down to the up position puts tension back onto the cable. This action moves the uplatch mechanism forward to receive the arresting hook and latch it in the retracted position. As the lever is brought up, a switch in the lever mechanism actuates, sending current through the de-energized arresting hook relay to energize the selector valve solenoid. Hydraulic pressure then goes to the vertical damper cylinder to raise the hook. When the hook reaches the retracted position, it actuates the up limit switch, which completes the circuit, energizing the arresting hook relay. This, in turn, breaks the circuit to the selector valve solenoid and stops the flow of hydraulic fluid to the vertical damper. The arresting hook relay has a 1.1 second time delay to assure the hook is up and locked before removal of hydraulic pressure.

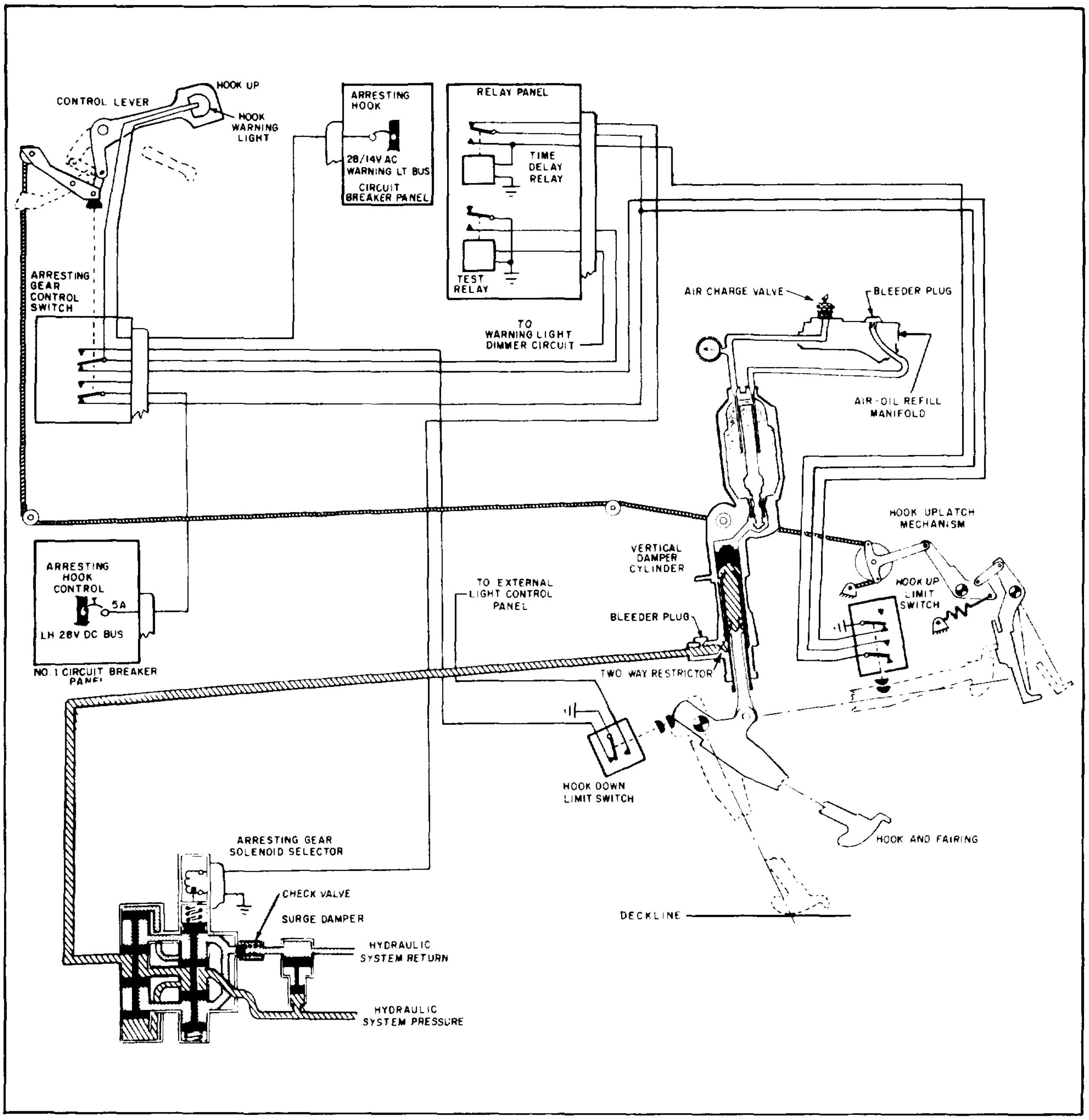


Figure 4-16.-Arresting gear control and indicating system.

Nosewheel Steering System

As you read this section, refer to figure 4-17. The nosewheel steering system is an electrically controlled, hydraulically operated system. It provides a nonlinear relationship between the rudder pedals and the angular position of the nosewheel. The system provides the pilot with adequate directional control of the aircraft during ground operation. It consists of a hydraulic steer-damp unit, solenoid-operated shutoff valve, command potentiometer, steering feedback potentiometer, steering amplifier, and an electrical control system. Control of the electrical power to the system is through either of the ground safety switches on the left or right main landing gear. The landing gear handle switch, a push-button switch on the pilot's stick grip, and the rudder pedals also control electrical power.

When the steering system electrical circuits energize, the steering system aligns for steering operation. At this point, the solenoid-operated hydraulic shutoff valve opens to supply fluid to the steering actuator. Simultaneously, all related circuitry for controlling the steering servo valve activates. The electrical section of the steering system is essentially a bridge circuit. One side of the bridge circuit runs through the command potentiometer; the opposite side runs through the feedback potentiometer. Output of each potentiometer goes to the steering system amplifier. Amplifier output currents flow to the hydromechanical servo valve coils, and the net signal actuates the servo valve, causing nosewheel steering action.

During operation, the nosewheel steering system attempts to maintain symmetry of the electrical bridge circuit. The circuit is symmetrical when both potentiometers supply equal voltages to the amplifier and the servo valve is at a null position. The bridge circuit becomes unbalanced when initiating a turn request by repositioning of the command potentiometer wiper. Current differential in the servo valve windings reflects an unbalanced bridge circuit. Movement of the servo valve ports hydraulic pressure to the appropriate side of the actuator piston to cause the nosewheel to turn.

STEER-DAMPER UNIT. —The steer-damper unit is an electrically controlled, hydraulically operated package on the nose gear strut assembly. The unit provides both nosewheel steering and the required shimmy damping effect. The package consists of a check valve, servo valve, bypass valve, two unidirectional restrictors, the steering actuator, and fluid compensator.

The check valve prevents reverse flow from the unit to the shutoff valve. The servo valve controls the actuator position by controlling fluid flow to and from the actuator in response to signal variations from the amplifier. The bypass valve closes off the interconnecting passages between both ends of the actuator whenever hydraulic pressure is available to the unit. This permits the actuator to act as a steering unit instead of a damping unit. The unidirectional restrictors provide a restricted reverse flow to dampen nosewheel shimmy. The steering actuator is a balanced piston-type hydraulic actuator, which provides the force to turn the nosewheel. Also, with the restrictors, the steering actuator provides the shimmy damper action. The fluid compensator is in the return passage in the unit and traps a quantity of fluid at 40 to 100 PSI. The compensator supplies fluid to the actuator through the bypass valve and the restrictor when the unit is being used as a shimmy damper, and extra fluid is necessary to prevent cavitation of the actuator. Since the compensator traps fluid in the actuator, it includes thermal relief provisions to prevent excessive pressure buildup within the steer-damper unit.

SHUTOFF VALVE. —The steering shutoff valve is a three-way, two-position, normally closed, solenoid-operated valve. The valve controls hydraulic system pressure to the steer-damper unit. When the valve de-energizes, fluid flow is cut off from the steer-damper unit. When the valve energizes (during normal steering or arrested landings), pressure flows to the check valve, bypass valve, and servo valve in the steer-damper unit.

COMMAND POTENTIOMETER. —The steering system has a rotary-type, pedal-position (command) potentiometer. This potentiometer mechanically links to, and is driven by, the rudder pedals. It provides a nonlinear steering response. The potentiometer sends a signal to the nose gear steering amplifier showing the degree and direction of turn commanded by the pilot. Moving the potentiometer, with the steering system operating, unbalances a bridge circuit causing the steering amplifier to signal the servo valve to turn the nosewheel.

FEEDBACK POTENTIOMETER. —The steering feedback potentiometer assembly consists

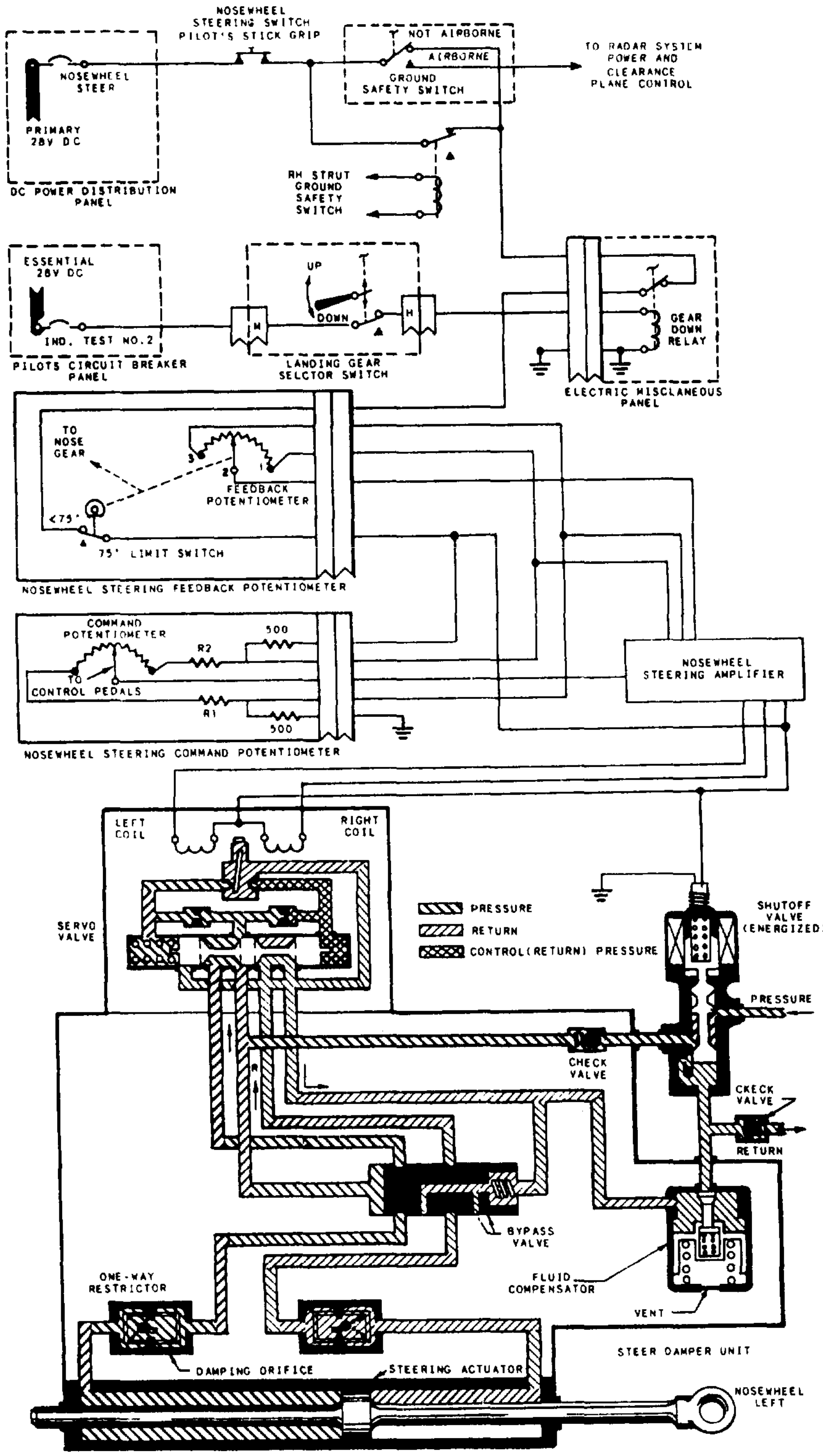


Figure 4-17.-Nosewheel steering system.

of a potentiometer that attaches to and is driven by the drive arm on the nose gear spindle. As the nose gear moves in response to the pilot's command, the feedback potentiometer feeds back a signal to the steering amplifier. When the feedback potentiometer signal matches the command potentiometer signal, the amplifier output causes the servo valve to neutralize and stop movement of the nosewheel. The feedback potentiometer assembly contains a swivel disconnect switch, which opens when the nosewheel turns 750 to 800 either side of straight ahead. This action electrically de-energizes the circuit to prevent reverse steering or damage to the aircraft.

AMPLIFIER. —The steering amplifier is a small transistorized differential amplifier. The amplifier detects the differential positions of the command potentiometer and the steering feedback potentiometer. Any difference in signals received results in a signal going to the servo valve to port hydraulic pressure to the steering actuator. This causes the nosewheel to turn and the steering feedback potentiometer to move. When the feedback potentiometer signal matches the command potentiometer signal, the nosewheel stops turning. In addition, the amplifier contains a circuit that provides a centering signal, which holds the nosewheel in the straight-ahead position during arrested landings.

OPERATION. —When the nosewheel steering switch button is depressed, power goes to the electrical control system and the solenoid-operated shutoff valve. As the valve opens, hydraulic pressure flows to the servo valve on the steer-damper unit. Signals go to the amplifier from the command potentiometer and from the feedback potentiometer on the steering linkage. If these signals are equal, the amplifier signals the servo valve to stay in the neutral position. When the nosewheel (and consequently the feedback potentiometer) does not correspond to rudder pedal position (and command potentiometer), the signals going to the amplifier are different. This causes the amplifier to send a signal to the servo valve.

The signal sent to the servo valve causes the valve to port pressure to the steering actuator in the steer-damper unit. The hydraulic pressure causes the actuator to move the nosewheel (and the feedback potentiometer) to a position corresponding to rudder pedal position (command potentiometer). When the nosewheel reaches a position corresponding to the pedal position, the signals to the amplifier are equal. The amplifier now signals the servo valve to a neutral position. When the servo valve goes to a neutral position (with the steering system energized and hydraulic pressure available), it blocks off both pressure and return passages to the steering actuator. Thus, the actuator is hydraulically locked in position. The steering actuator will remain locked in position until the servo valve receives a signal to turn the wheel or hydraulic and/or electrical power is removed from the system. When the steering system is not in use, the steer-damper unit performs the functions of a shimmy damper. The system accomplishes shimmy damping by trapping hydraulic fluid on both sides of the steering actuator piston and forcing this fluid from one side of the actuator to the other side through the restrictor.

Catapulting System

The catapulting system (fig. 4-18) provides catapult handling and attachment capabilities for carrier operations. The system consists of a catapult launch bar, a launch bar actuating cylinder and gimbal, swivel joints, a cockpit-controlled selector valve, leaf centering spring, leaf retracting springs, and a catapult tension bar socket. The launch bar is swivel mounted on the nose gear outer cylinder and can extend and retract during taxi operations. The launch bar automatically retracts after catapulting. A launch bar warning light comes on during any of the following conditions:

- The launch bar control switch is in EXTEND.
- The selector valve is in bar extend position (solenoid A energized).
- The launch bar is not up and locked with weight off the landing gear.
- The launch bar control switch is in RETRACT and the launch bar actuator is not up and locked.

Accessories for the catapulting system include a tension bar and a catapult holdback bar. The catapult tension bar socket mounts on the nose gear axle beam and provides for attachment of the tension bar for tensioning the aircraft before catapulting.

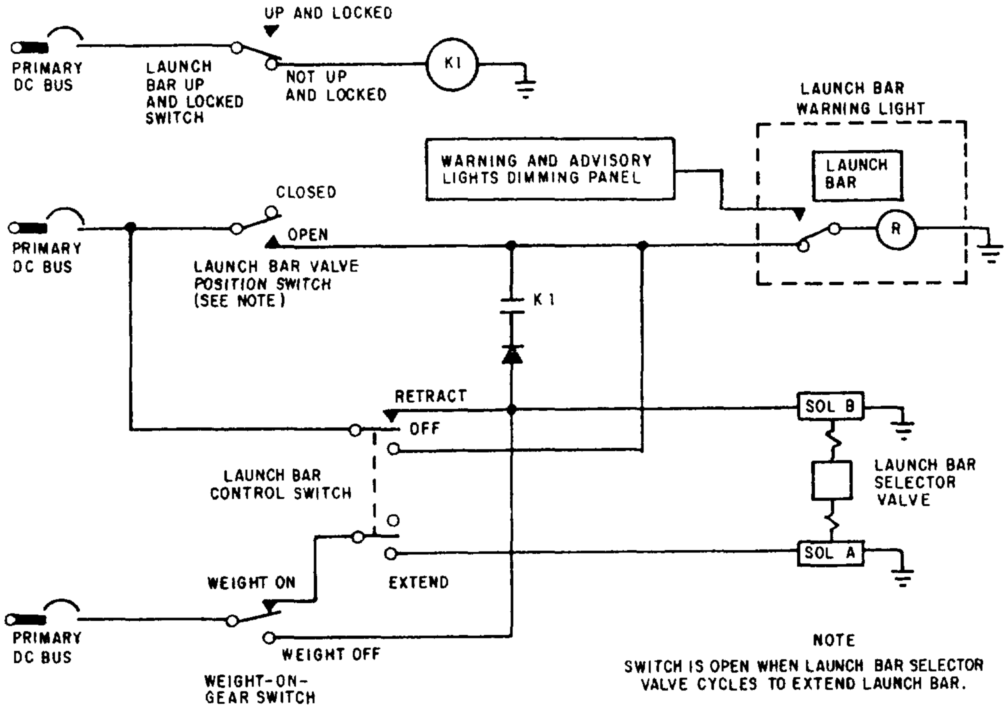


Figure 4-18.-Catapulting system control and indicating system.

Placing the launch bar control switch in EXTEND completes a power circuit through the weight-on-gear switch, applying 28-volt dc to the launch bar selector valve extend solenoid (solenoid A). The launch bar valve position switch also completes a circuit through its closed contacts to apply 28-volt dc to the launch bar warning light. The warning light comes on and remains on as long as the switch is in EXTEND. When the selector valve actuates, hydraulic pressure extends the launch bar actuator. A plunger on the end of the valve mechanically actuates the launch bar valve position switch. Switch actuation completes a parallel circuit to the warning light. When the control switch is in the OFF position, with weight on the landing gear, the warning light should go off. If the control switch is in RETRACT, the warning light should come on until the launch bar is up and locked. If the light remains on, the selector valve did not cycle from the bar extend position, and pressure is still on the launch bar actuator extend side.

The hydraulic pressure to the launch bar actuator unlocks locking fingers inside the actuator and extends the actuator to lower the launch bar. As the locking fingers unlock, they close the contacts of the launch bar up-lock switch inside the actuator. After catapulting, the weight-on-gear switch moves to the weight-off position. This applies 28-volt dc to the launch bar selector valve retract solenoid (solenoid B) and to the launch bar warning light through the energized contacts of relay K1. K1 remains on until the launch bar is up and locked. Power to the launch bar selector valve retract solenoid provides automatic hydraulic retraction and locking of the launch bar after catapulting. The launch bar actuating cylinder, locking in the fully retracted position, de-energizes K1, turning off the launch bar warning light. The approach light circuit goes through de-energized relay K1, giving an additional indication that the launch bar is up and locked.

The launch bar control switch goes to RETRACT and is held thereto retract the launch bar hydraulically. This completes a power circuit to apply 28-volt dc to the launch bar selector valve retract solenoid (solenoid B). The energized selector valve directs hydraulic pressure to retract the launch bar. The control switch returns to OFF when released, de-energizing the selector valve.

Speed Brake System

Speed brakes are moveable control surfaces used for reducing the speed of aircraft. Some manufacturers refer to them as *dive brakes,* others call them *dive flaps.* On some aircraft, they are on the sides or bottom of the fuselage; on others they attach to the wings. Regardless of their location, speed brakes serve the same purpose on all aircraft—they keep the speed from building up too high in dives. They can also slow down the speed of aircraft preparing to land. Speed brakes have electrical control and hydraulic operation. Figure 4-19 shows a typical speed brake system, and you should refer to it while reading this section.

EXTENSION. —Extension of the speed brakes is done by placing the speed brake control switch (located on the throttle lever grip) to the OUT position. The OUT position is a momentary-contact position, the switch being spring loaded to return to STOP when released. Holding the control switch in the OUT position energizes both selector valve solenoids (solenoids A and B). This action connects hydraulic pressure to the actuator extend side and connects the return to the actuator retract side. Any desired brake position may be attained and will be held by a **hydraulic lock** within the selector valve. The speed brake out warning light illuminates when either the left or right speed brake is not fully retracted. The warning light circuit completion is through either the left or right speed brake retract position switch.

NOTE: Figure 4-19 shows the speed brake control switch being held in the OUT position. This allows hydraulic pressure to port to the extend side of the speed brake actuators, forcing the speed brakes to the extend position.

RETRACTION. —In normal operation, the speed brakes retract by moving the speed

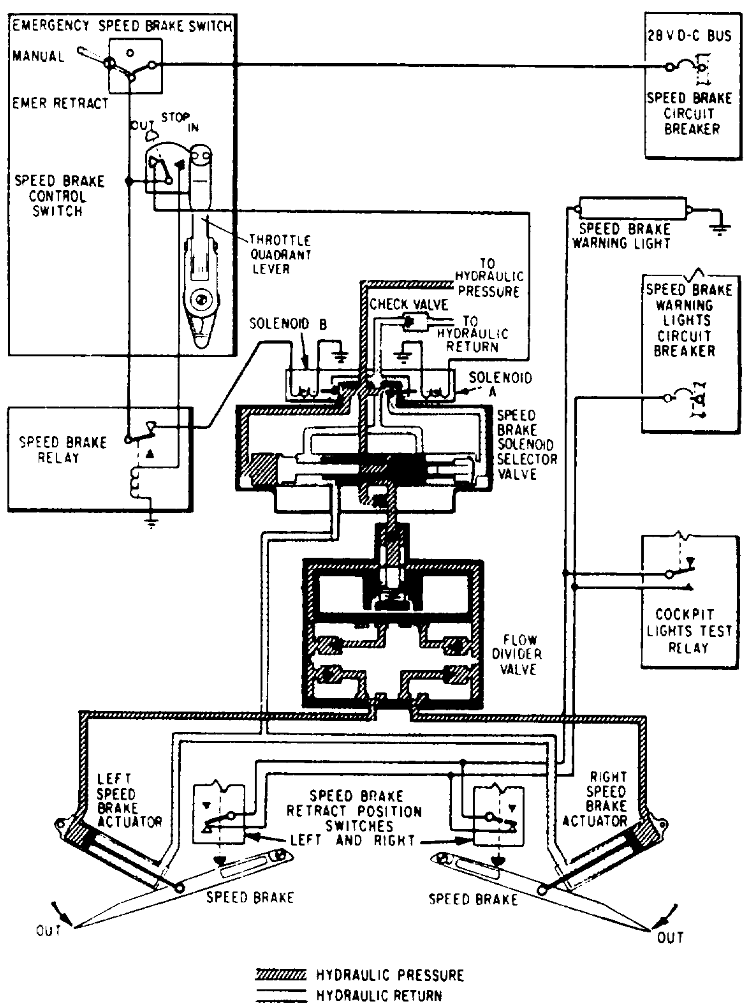


Figure 4-19.-Speed brake system.

brake control switch to the IN position. This de-energizes solenoid A by removing the power to the solenoid and energizes the speed brake relay. The action of the speed brake relay removes the power from solenoid B.

With both selector valve solenoids de-energized, the selector valve permits pressure flow to the retract side of the speed brake. It also allows return flow from the extend side to the hydraulic ret urn. The speed brake warning light goes out when both speed brakes are in the fully retracted position.

EMERGENCY RETRACTION. —To accomplish emergency speed brake retraction, place the emergency speed brake switch in the EMER-RETRACT position. This switch de-energizes solenoids A and B of the selector valve (normal solenoid positions for retracting the speed brakes), which connects both the extend and retract sides of the speed brake actuators to the system return. With the removal of hydraulic pressure, the speed brakes are shut by the airstream. This action is necessary only if the speed brake relay does not energize when the speed brake control switch is in the IN position. If an electrical failure (such as a popped circuit breaker) occurs with the speed brakes extended, retraction is the same as actuation of the emergency retract switch.

Canopy System

As you already know, solenoid valves have many applications in naval aircraft. The canopy hydraulic system shown in figure 4-20 is an electrohydraulic system using a solenoid selector valve. The canopy selector valve is a four-way, two-position spool valve, which actuates either electrically or manually.

The canopy system consists of a sliding canopy mounted over the cockpit area and the components required for normal operation and emergency jettison of the canopy. The entire system is hydraulically operated except for the

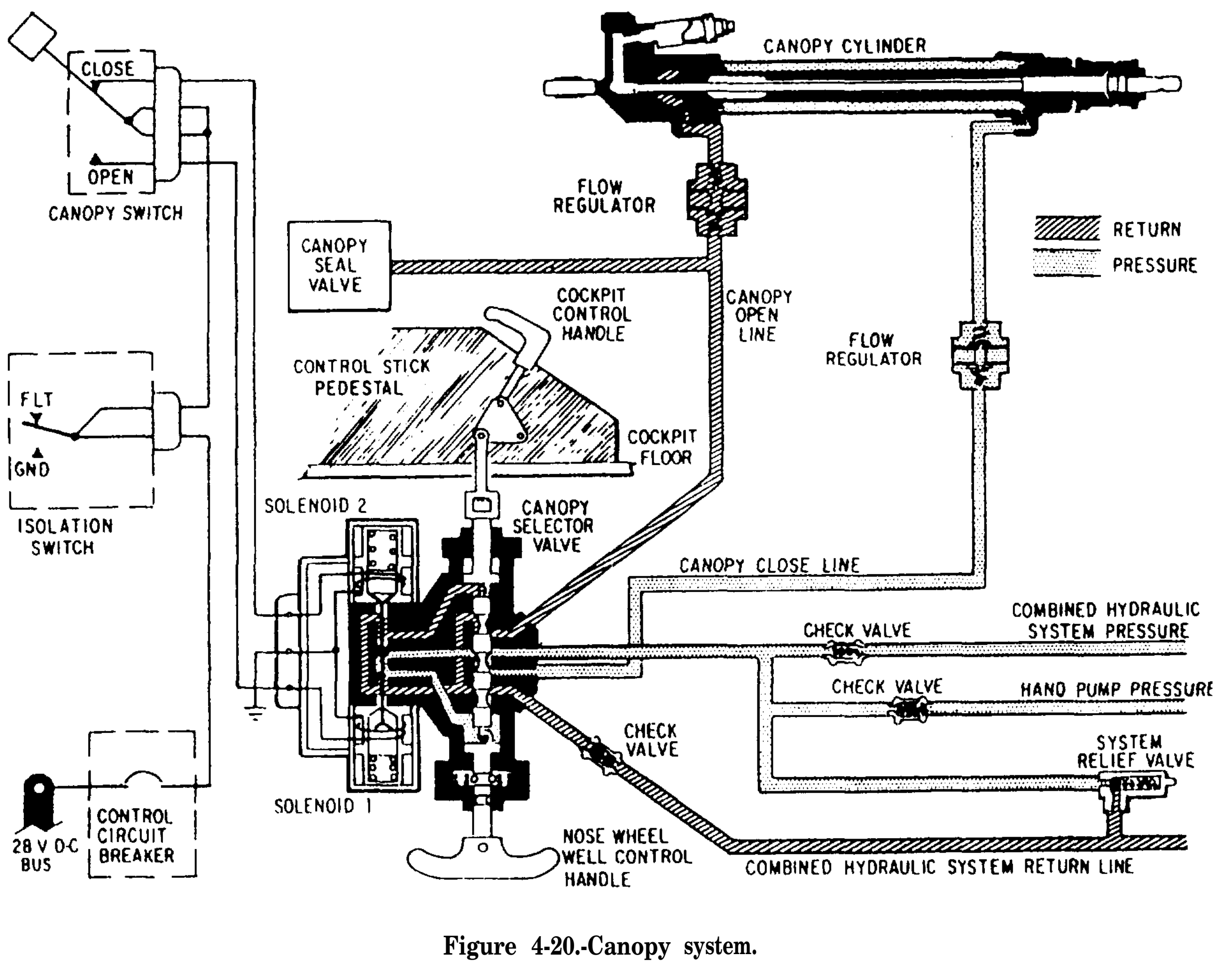


Figure 4-20.-Canopy system.

electrical canopy jettison device. Hydraulic power for operation of the canopy is from either the combined hydraulic system or the hand pump system.

When a canopy switch is in the CLOSE position, it completes a circuit from the 28-volt dc bus to a terminal on the isolation switch. Current flows from the terminal, through the closed contacts of the canopy switch, to solenoid 2 of the canopy selector valve. The selector valve then energizes to the close position. Now, hydraulic pressure from either the combined hydraulic system or the hand pump system flows through the selector valve into the canopy close line. Pressure through a flow regulator to the rod end of the canopy actuating cylinder causes the piston and rod to retract closing the canopy.

When the canopy switch is in the OPEN position, power flows from the 28-volt dc bus through the control circuit breaker, the isolation switch terminal, the opposite contacts of the canopy switch, to solenoid 1 of the canopy selector valve. The selector valve energizes to the open position, reversing the sequence of pressure and return flow. Hydraulic pressure flows through the canopy open line to the canopy seal valve and hydraulically trips the seal valve. Thus, the air pressure in the canopy seal is dumped, allowing the seal to deflate. Pressure in the canopy open line continues its flow through a flow regulator to the backhead end of the cylinder. This action extends the cylinder, opening the canopy. Hydraulic fluid in the opposite end of the cylinder returns through the canopy close line to the selector valve, across the valve, and into the combined hydraulic system. Fluid then returns to the main reservoir of the system.

For canopy jettison (fig. 4-21), the emergency canopy jettison switch, or either of the two emergency outside jettison switches initiates a firing circuit. Closing any of the three switches completes the circuit to the electrically fired canopy jettison cartridge on the canopy cylinder backhead end. The cartridge discharges through the canopy cylinder, causing the canopy to jettison.

PNEUMATIC POWER SYSTEM

The pneumatic power system supplies compressed air for various normal and emergency

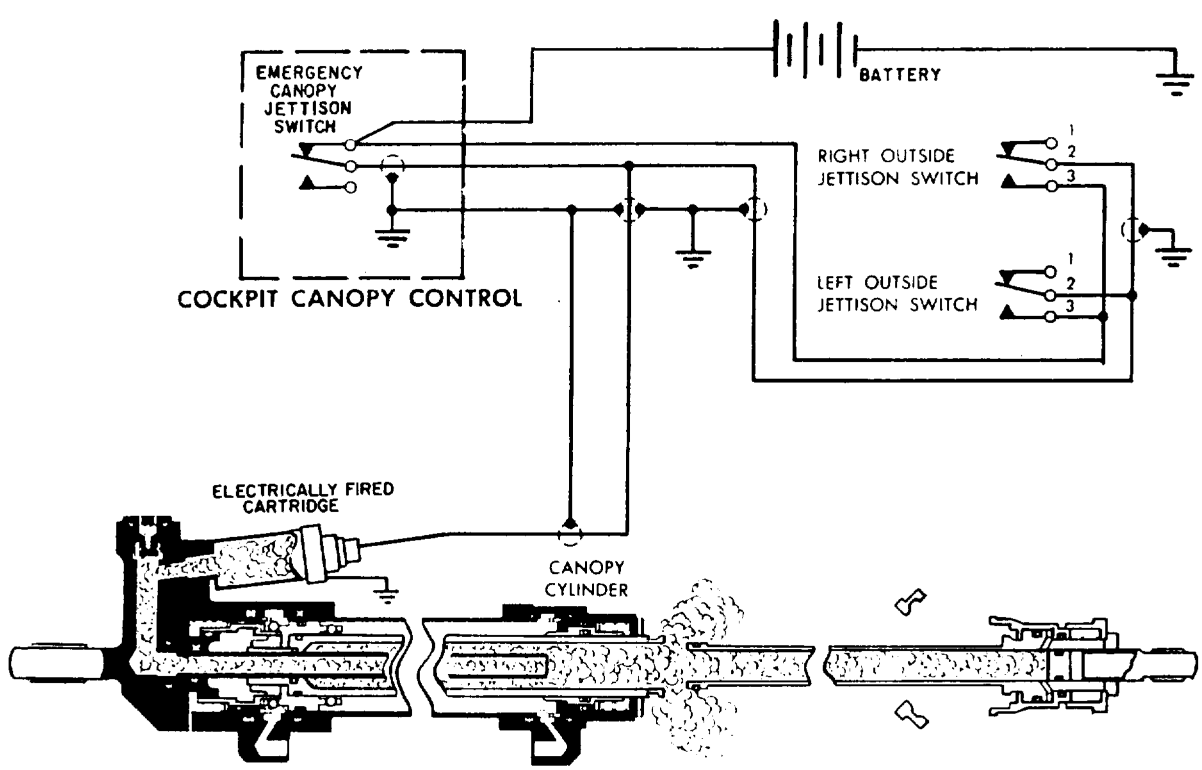


Figure 4-21.-Canopy jettison.

pneumatically operated systems. The compressed air is held in storage cylinders in the actuating systems until required by actuation of the system. These cylinders and power system manifold receive an initial charge of compressed air or nitrogen from an external source. In flight, the air compressor replaces the pressure and volume lost through leakage, thermal contraction, and system operation.

The air compressor receives supercharged air from the engine bleed air system. This ensures an adequate air supply to the compressor at all altitudes. The air compressor is driven by an electric or a hydraulic motor. The system under discussion in this chapter is hydraulically driven. (See figure 4-22.)

The aircraft hydraulic system provides power to operate the hydraulic-motor-driven air compressor. The air compressor hydraulic actuating system consists of a solenoid-operated selector valve, flow regulator, hydraulic motor, and motor bypass line check valve. When energized, the

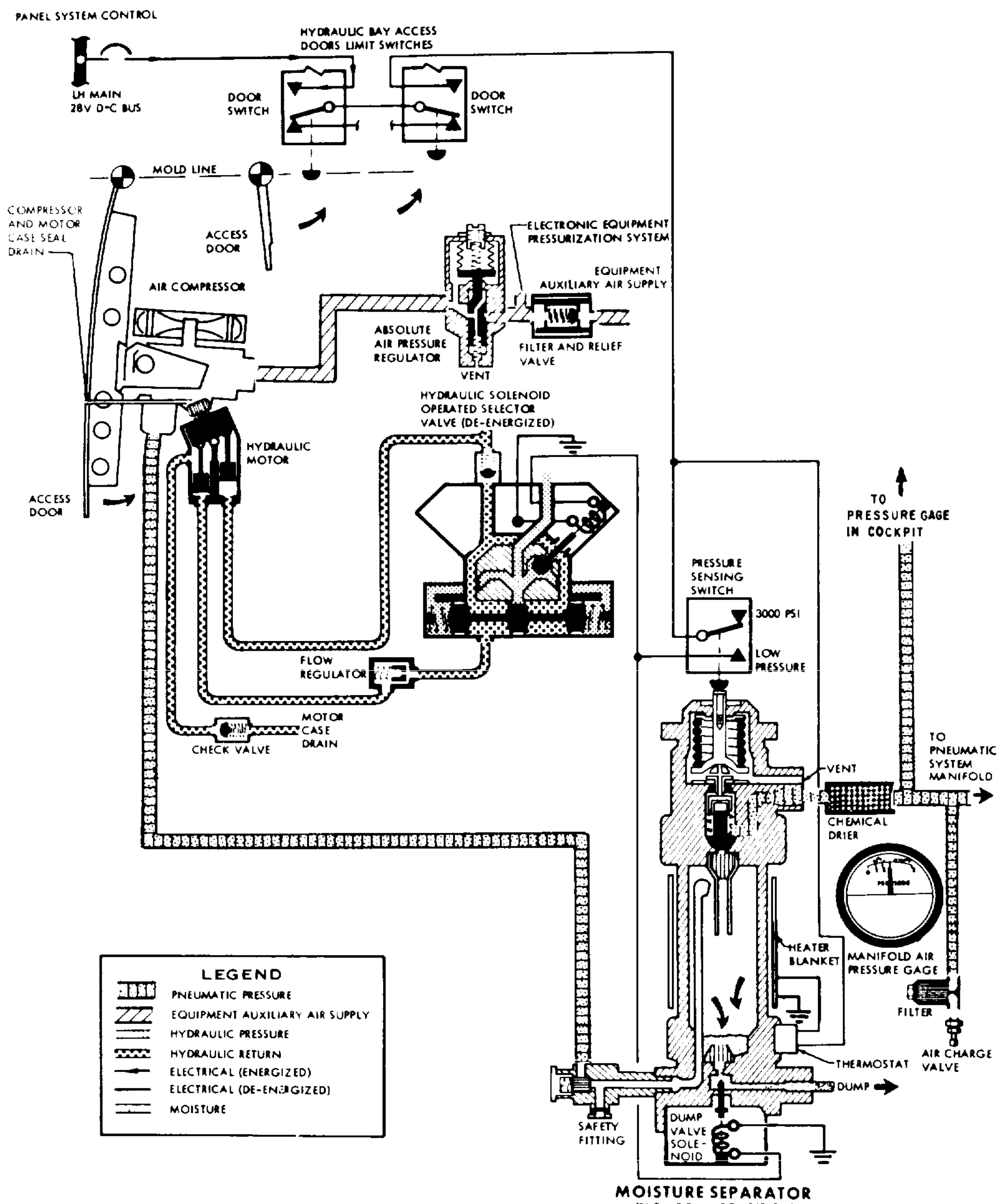


Figure 4-22.-Pneumatic system.

selector valve allows the system to pressurize and run the hydraulic motor. When de-energized, the valve blocks off hydraulic pressure, stopping the motor. The flow regulator compensates for the varying hydraulic system flow and pressures by metering the fluid flow to the hydraulic motor. Thus, excessive speed variation and/or over-spending of the compressor is prevented. A check valve in the motor bypass line prevents system return line pressure from entering the motor and stalling it.

The air compressor is the pneumatic system's pressurizing air source. The compressor activation or deactivation is by the manifold pressure sensing switch, an integral part of the moisture separator assembly.

The moisture separator assembly is the pneumatic system's pressure sensor-regulator and relief valve. The manifold pressure switch governs air compressor operation. When manifold pressure drops below 2,750 PSI, the pressure sensing switch closes, energizing the separator's moisture dump valve and hydraulic selector valve, activating the air compressor. When manifold pressure reaches 3,150 PSI, the pressure sensing switch opens, de-energizing the hydraulic selector valve, deactivating the air compressor and dump valve. The deactivated dump valve vents overboard any moisture in the separator. The separator includes a thermostat and heating element. The thermostatically controlled wraparound blanket heating element prevents moisture from freezing within the reservoir in low-temperature atmospheric conditions.

The safety fitting, at the moisture separator inlet port, protects the separator from internal explosions due to hot carbon particles or flames that the air compressor may emit.

A chemical drier further reduces the moisture content of the air emerging from the moisture separator.

An air charge valve provides the entire pneumatic system with a single external ground servicing point. An air pressure gauge, near the air charge valve, is for servicing the pneumatic system. This gauge shows manifold pressure.

The ground air charge line air filter prevents entry of particle impurities into the system from the ground servicing power source.

REVIEW SUBSET NUMBER 2

Q1. The science of liquid pressure and flow is known as ____________________.

Q2. As an AE your primary concern with hydraulics will be to ________________.

Q3. In a hydraulic system, what unit creates fluid flow?

Q4. What does the hydraulic actuating unit convert fluid pressure into?

Q5. Why does the arresting gear hook relay have a 1.1 second delay?

Q6. What system provides the pilot with adequate directional control during ground operations?

Q7. During emergency retraction, what is used to close the speed brake?

Q8. The pneumatic system compressor comes on when system pressure drops below what value?

AIRCRAFT ENVIRONMENTAL SYSTEMS

Learning Objective: *Recognize terms, definitions, components, and aircraft environmental systems operating principles and features including controls for temperature, pressure, and icing.*

The proper operation of today's aircraft requires maintaining a proper environment not only for personnel but also for equipment on board. Similarities exist in the electronic equipment controlling these systems and the components within these systems.

The environmental systems on most aircraft include cockpit/cabin air conditioning and pressurization, equipment cooling, windshield anti-icing and defogging, and equipment pressurization systems. Some aircraft accomplish equipment cooling by teeing off with ducting from the cockpit/cabin system; other aircraft use a separate system. These systems are not the exclusive responsibility of the AE, but rather are the responsibility of other ratings with the AE assisting.

TERMS AND DEFINITIONS

The system that maintains cabin air temperatures to meet the requirements for pilot efficiency is the air-conditioning system. You must become familiar with some terms and definitions to understand the operating principles of air-conditioning systems.

The following terms are self explanatory: *engine heat, solar heat, electrical heat,* and *body heat of personnel*. These sources of heat make cabin air conditioning necessary, and another source is ram air temperature. Ram air temperature is the frictional temperature increase created by ram compression on the skin surface of an aircraft. This factor becomes serious only at extreme airspeeds. For example, for an aircraft flying at 45,000 feet, at 1,200 MPH, the ram air temperature would be about 2,000°F on some parts of the aircraft. This extreme temperature, plus the heat from other sources, would cause cabin temperature to rise to about 190°F. The maximum temperature that a crew member can endure and still maintain top physical and mental efficiency is about 80°F. Prolonged exposure to a temperature greater than 80°F will seriously impair his/her mental and physical abilities. Furthermore, under low-speed operating conditions at low temperature, cabin heating may be necessary.

NOTE: Some of the terms were discussed in chapter 1, "Elementary Physics." Although they are briefly defined in this chapter, a review of chapter 1 will be helpful.

Definitions for some of the terms relative to temperature control are as follows:

Absolute temperature. Temperature measured along a scale that has zero value at that point where there is no molecular motion (–273.1°C or –459.6°F).

Adiabatic. A word meaning no transfer of heat. The adiabatic process is one in which no heat transfers between the working substance and any outside source.

Ambient temperature. The temperature in the area immediately surrounding the object under discussion.

Ram air temperature rise. The increase in temperature created by the ram compression on the surface of an object traveling at high speed through the atmosphere. The rate of increase is proportional to the square of the speed of the object.

Temperature scales.

1. Celsius (C)—A scale on which 0° represents the freezing point of water, and 100° is the boiling point of water at sea level.

2. Fahrenheit (F)—A scale on which 32° represents the freezing point of water, and 212° is the boiling point of water at sea level.

CABIN SYSTEM

The primary function of the cabin air-conditioning and pressurization system is to maintain cockpit temperature and pressure within parameters for crew safety and comfort. To do this, the system forces a mixture of dehumidified refrigerated air and hot engine bleed air through cockpit diffusers. The temperature of the mixture is automatically maintained through a continuously selective range by a temperature control system, consisting of temperature sensors with associated flow control valves and an electronic controller. A pressure regulator and safety valve control cabin pressure. The manual dump control is available if the safety valve malfunctions. A block diagram for the airflow of

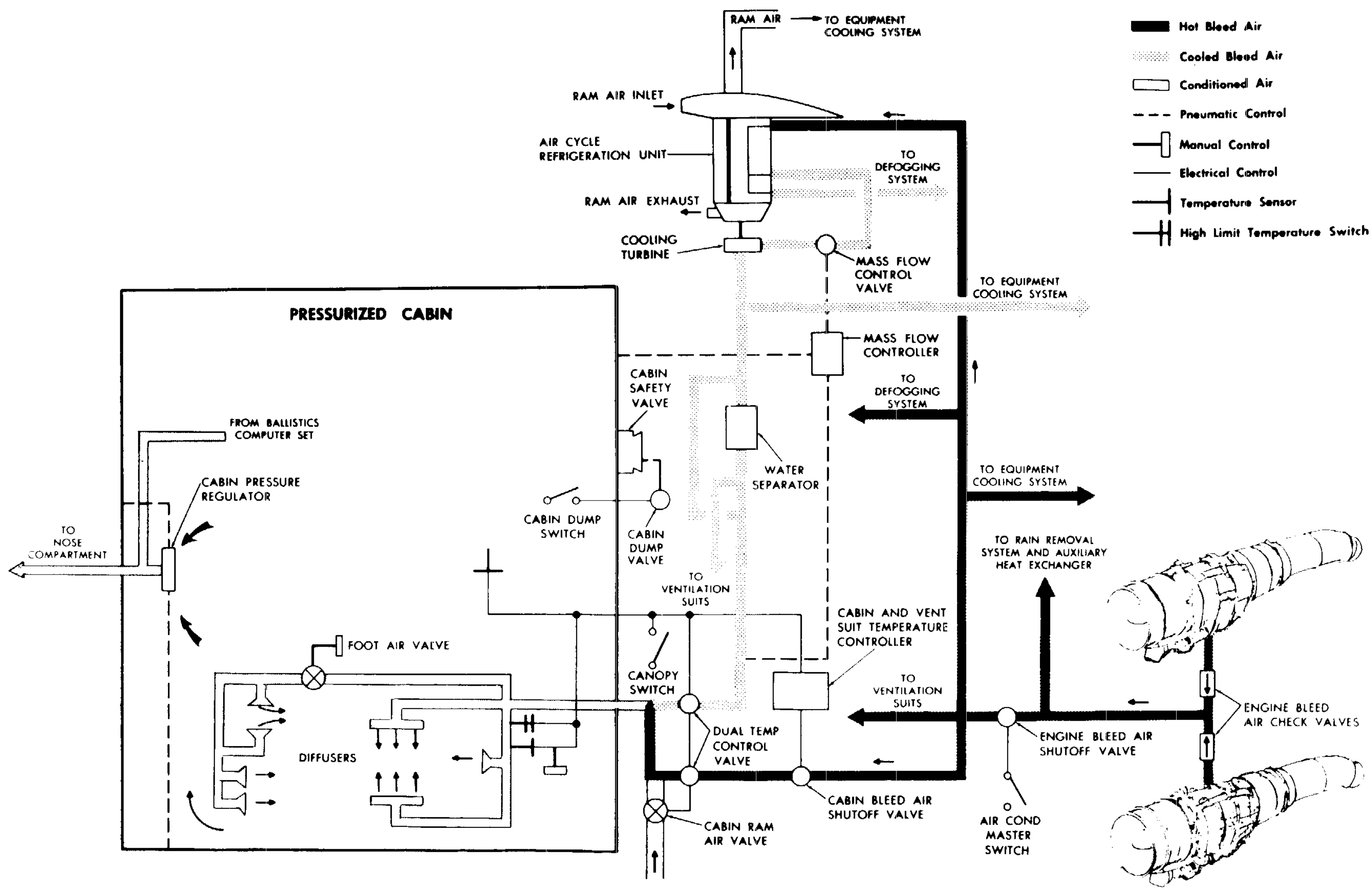


Figure 4-23.—Cabin air-conditioning and pressurization diagram.

a cabin air-conditioning and pressurization system is shown in figure 4-23.

System Controls

The air-conditioning control panel is shown in figure 4-24. Three switches and one control knob on the panel control the air-conditioning operation.

The air-conditioning master switch is a two-position (NORM and OFF) toggle switch, guarded to the NORM position. When the switch is in NORM, the main bleed air shutoff valves opens if the engine is providing air at 8 PSI or more. Also the air-conditioning caution light will go to off. Hot engine bleed air is now available for operation of the various environmental systems. Placing the switch in the OFF position closes the shutoff valve, thus shutting off hot engine bleed air to the environmental system. A spring-loaded guard over the air-conditioning master switch prevents the switch from being placed in the OFF position by mistake.

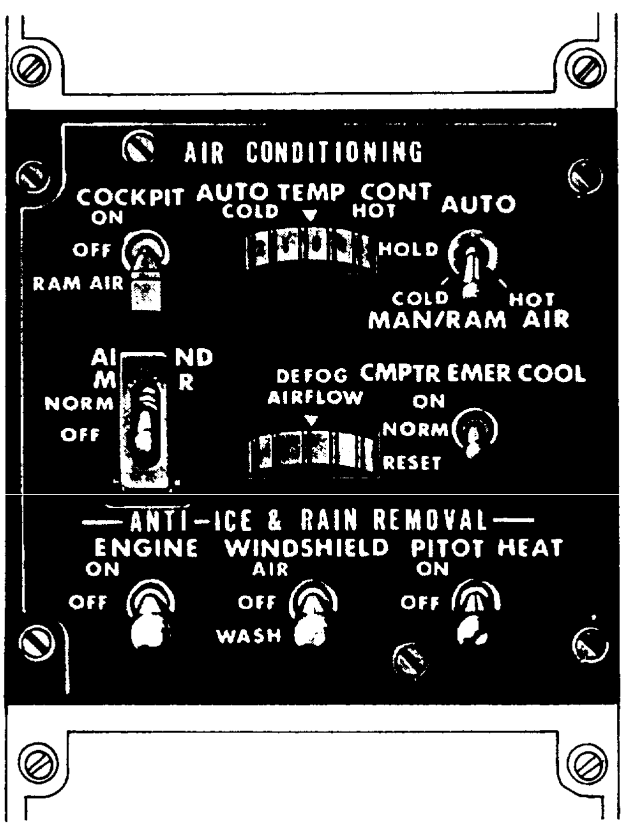


Figure 4-24.-Temperature control panel.

The cockpit switch is a three-position toggle switch marked ON, OFF, and RAM AIR. When the engine is running and the air-conditioning master switch at NORM, placing the cockpit switch to ON engages the air-conditioning and pressurization system. Placing the switch to ON energizes the dual temperature control valve and opens the cabin bleed air shutoff valve. Depending on the setting on the automatic temperature control thumbwheel, conditioned air flows into the cockpit. When the cockpit switch goes to the OFF position, the cabin bleed air shutoff valve closes and drives the dual temperature control valve to the full hot position. This prevents any airflow to the cockpit. The RAM AIR position closes the cabin bleed air shutoff valve and drives the dual temperature control valve to the full hot position. You now control the ram air flow manually using the MAN/RAM AIR switch.

The MAN/RAM AIR switch is a four-position toggle switch marked AUTO, HOLD, COLD, and HOT. The AUTO position enables the dual temperature control valve to accept inputs from the automatic temperature control thumbwheel. Place the switch to HOLD when the dual temperature control valve is removed from automatic control. The switch is spring loaded to HOLD when not in AUTO. Momentarily holding the switch in COLD or HOT alters the positions of the hot and cold sides of the dual temperature control valve to change the cockpit air temperature. Upon releasing the switch, it springs back to HOLD, and the dual temperature control valve remains fixed. The COLD and HOT positions should be toggled intermittently to avoid overshooting the desired temperature. With the selection of RAM AIR on the air-conditioning cockpit switch, you manually control airflow by using the RAM AIR switch. The RAM AIR switch opens and closes the ram air valve.

The automatic temperature control thumbwheel enables the crew to adjust the cockpit air temperature. With the air-conditioning controls appropriately positioned, you can move the thumbwheel to any setting between 0 and 14. Rotating the thumbwheel automatically regulates the openings of the hot and cold sides of the dual temperature control valve, thus varying the cockpit air temperature. You can select a temperature within a range of 60°F to 80°F.

System Operation

As you read this section, refer to figure 4-25. Placing the cockpit switch to ON causes contact 3 to remove power from the cabin bleed air shutoff valve. This valve opens, allowing hot air to flow to the dual temperature control valve. Simultaneously, a second portion of the cockpit switch, ganged to the first, connects the center tap of the MAN/RAM AIR switch through energized contact of the air-conditioning control relay, the COLD side of the cabin duct thermal switch, and contact 4 of the COCKPIT SWITCH to the control phase of the dual temperature control valve. Contact 1 of the cockpit switch powers the coil of the air-conditioning control relay when the cockpit switch is in the ON or OFF position. Cockpit switch contact 2 (in the ON or OFF position) supplies 120 volts to the close winding of the cabin ram air valve. A phase shifting capacitor powers the open winding of the same valve, which drives the two-phase induction motor to the full close position.

In the air-conditioning mode (cockpit switch ON), hot engine bleed air flows through the cabin shutoff valve to the dual temperature control valve, where it mixes with refrigerated, dehumidified air. The cabin temperature control system automatically maintains the cabin at a selected temperature by continuously modulating the dual temperature control valve. The modulating signals are cabin temperature errors that the cabin temperature sensor translates into error voltages. The cabin and ventilation suit temperature controller modulates and amplifies these signals. Then, they go to the control winding of the dual temperature control valve. The hot side of the valve starts to close and the cold side opens until the selected cabin temperature is achieved. To prevent temperature hunting by the cabin temperature sensor, the cabin duct dual temperature sensor anticipates changes in cabin temperature by sensing changes in the duct inlet temperature.

The dual temperature sensor transmits error signals to the cabin and ventilation suit temperature controller when cabin air supply temperature changes. The size of the transmitted signals depends on the rate of temperature changes. When the cabin duct inlet temperature exceeds 121.1°C (250°F), the overtemperature sensor portion of this sensor transmits a fixed signal. The signal goes through the temperature controller to the dual temperature control valve control winding. The valve drives to the full cold position until duct temperature returns to normal, then automatic control resumes.

The cabin duct thermal switch provides an additional override to the cabin temperature sensor. This temperature-sensitive switch closes when the duct inlet temperature exceeds 121.1°C or the dual temperature sensor malfunctions. During either of these conditions, 120-volt ac from the ENVIRONMENT/SEATS CB goes through the HOT side of the cabin duct thermal switch and contact 4 of the cockpit switch to the control winding of the dual temperature control valve. The valve drives to the full cold position. When cabin duct inlet temperature falls to 121.1°C, the switch goes to the cold position and automatic temperature control again resumes.

In the automatic mode, positioning the AUTO TEMP CONT thumbwheel selects cockpit temperature. This fixes the output voltage of the bridge circuit in the cabin and ventilation suit controller. The controller amplifies the signal and transmits through contact 4 of the air-conditioning relay to the AUTO position of the MAN/RAM AIR switch. The signal travels back through contact 3 of the air-conditioning relay to the COLD side of the cabin duct thermal switch. The signal then goes through the cockpit switch to the control winding of the dual temperature control valve.

To gain manual control of the cabin air-conditioning system, momentarily position the MAN/RAM AIR switch at COLD or HOT. In the COLD position, power from the ENVIRONMENT/SEATS CB goes through contact 1 of the air-conditioning control relay, the MAN/RAM AIR switch, through contact 3 of the air-conditioning control relay, the COLD contacts of the cabin duct thermal switch, and contact 4 of the cockpit switch to the control winding of the dual temperature control valve. This voltage lags the fixed-phase voltage by 900 and drives the two-phase induction motor. This allows more refrigerated air and less hot air to enter the cabin. The valve will continue to move until the switch is released. After the switch is released, it returns to HOLD and the valve remains fixed.

When the MAN/RAM AIR switch is toggled to the HOT position, power from the ENVIRONMENT/SEATS CB goes through the reversing transformer, contact 2 of the air-conditioning control relay, the MAN/RAM AIR switch, contact 3 on the air-conditioning control relay, the COLD contacts on the cabin duct thermal switch, and contact 4 of the cockpit switch to the control winding of the dual temperature control

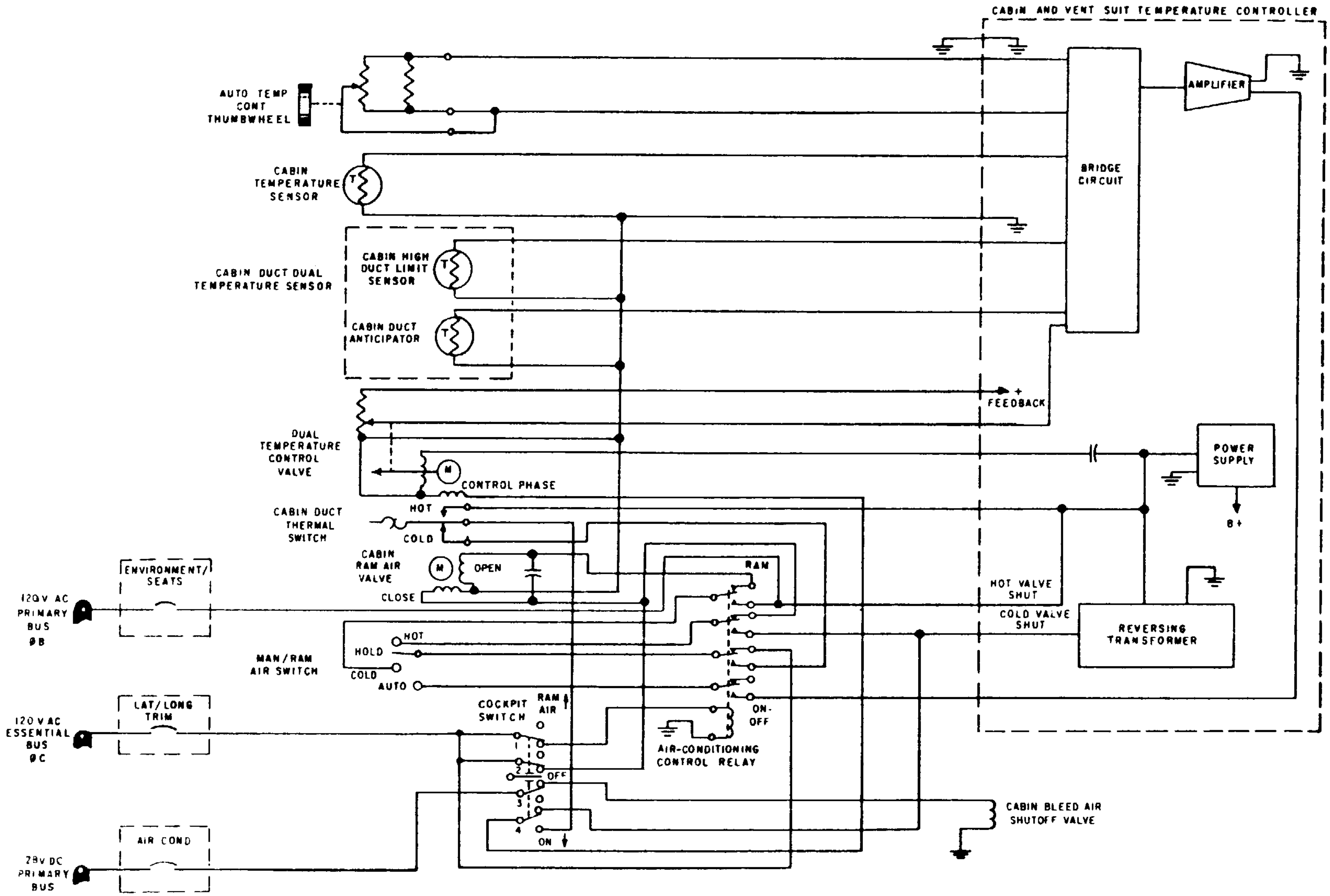


Figure 4-25.—Cabin air-conditioning and pressurization schematic diagram.

valve. Because the voltage goes through the reversing transformer, it shifts 180°, and the control winding voltage leads the fixed-phase voltage by 90°. This causes the valve to drive in a direction to decrease cold air and increase hot air to the cockpit. Upon releasing the switch, the valve remains fixed.

Under any of the previously described conditions—in either the automatic or manual mode—failure of electrical power to the cabin and ventilation suit temperature controller, or to the dual temperature control valve, causes the valve to remain in the position it was maintaining at the time of electrical failure.

The cabin may be ram air ventilated by placing the cockpit switch at RAM AIR. With the canopy closed, this action de-energizes the air-conditioning control relay, closes the cabin bleed air shutoff valve, and drives the dual temperature control valve to the full hot position. This effectively blocks the flow of both hot and cold bleed air to the cabin. Either crew member may control the degree of ram air ventilation by depressing the MAN/RAM AIR switch to either HOT OR COLD. The HOT position drives the cabin ram air valve toward the closed position, restricting the ram air flow. The COLD position drives the cabin ram air valve toward the open position, increasing the ram air flow. You can select any position of the cabin ram air valve from full open to full closed.

Cabin pressurization automatically starts at 8,000 feet. The cabin pressure remains at 8,000 feet until reaching a pressure differential of 5 PSI. The cabin pressure now maintains a pressure differential of 5 PSI.

The cabin pressure regulator maintains the pressure schedule. This valve allows the air passed into the cabin air-conditioning system to exhaust into the nose compartment. From sea level to 8,000 feet, the exhaust flow is unrestricted. Above 8,000 feet, the valve closes down, restricting the exhaust flow until reaching a cabin pressure equivalent to 8,000 feet altitude. The cabin remains at this pressure as the aircraft climbs until reaching a cabin-to-ambient pressure differential of 5 PSI. Beyond this altitude, the valve regulates the exhaust flow to maintain this constant pressure differential throughout the remaining altitude range.

A cabin pressure safety valve provides a maximum limit to cabin pressure in the event of a regulator malfunction. This valve limits the cabin-to-ambient pressure differential to 5.5 PSI. The CABIN DUMP switch permits either crew member to dump cabin pressure through the cabin safety valve. Placing the CABIN DUMP switch to ON completes a circuit to the cabin dump valve, which opens the cabin safety valve.

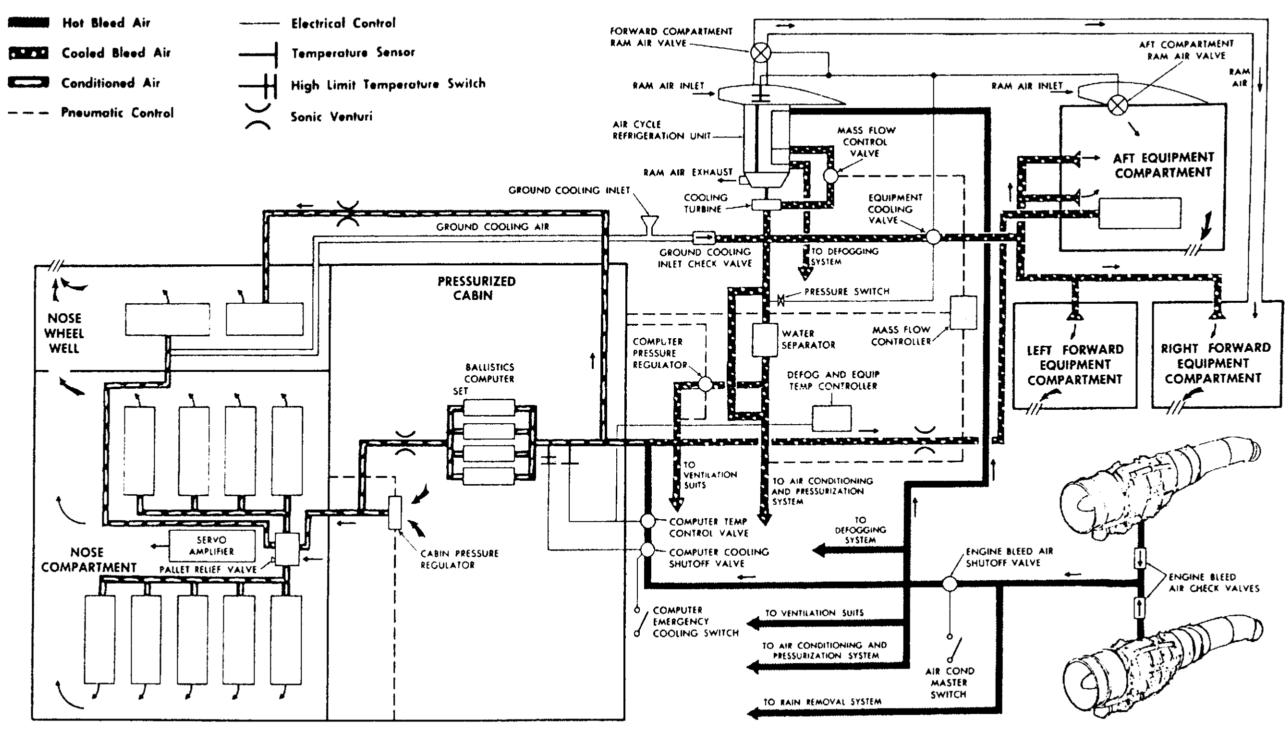


Figure 4-26.—Equipment cooling flow diagram.

EQUIPMENT COOLING SYSTEM

Ram air is the primary means of ventilation for the forward and aft equipment compartments. The ram air thermal switch, equipment cooling valve, forward compartment ram air valve, and the aft compartment ram air valve control ventilation of these compartments.

The equipment cooling system flow diagram is shown in figure 4-26. When the aircraft is in flight, the equipment cooling valve closes and the forward and aft compartment ram air valves open. Under these conditions, the right forward and aft equipment compartments are ram air ventilated. When temperature in the right wing ram air duct reaches 46.1°C (115°F), the equipment cooling valve opens, and the forward and aft compartment ram air valves close. This permits moist, cooled bleed air into the right forward and aft equipment compartments, ensuring adequate cooling when ambient air temperatures are excessive.

With an engine running, the equipment cooling system (fig. 4-27) automatically engages

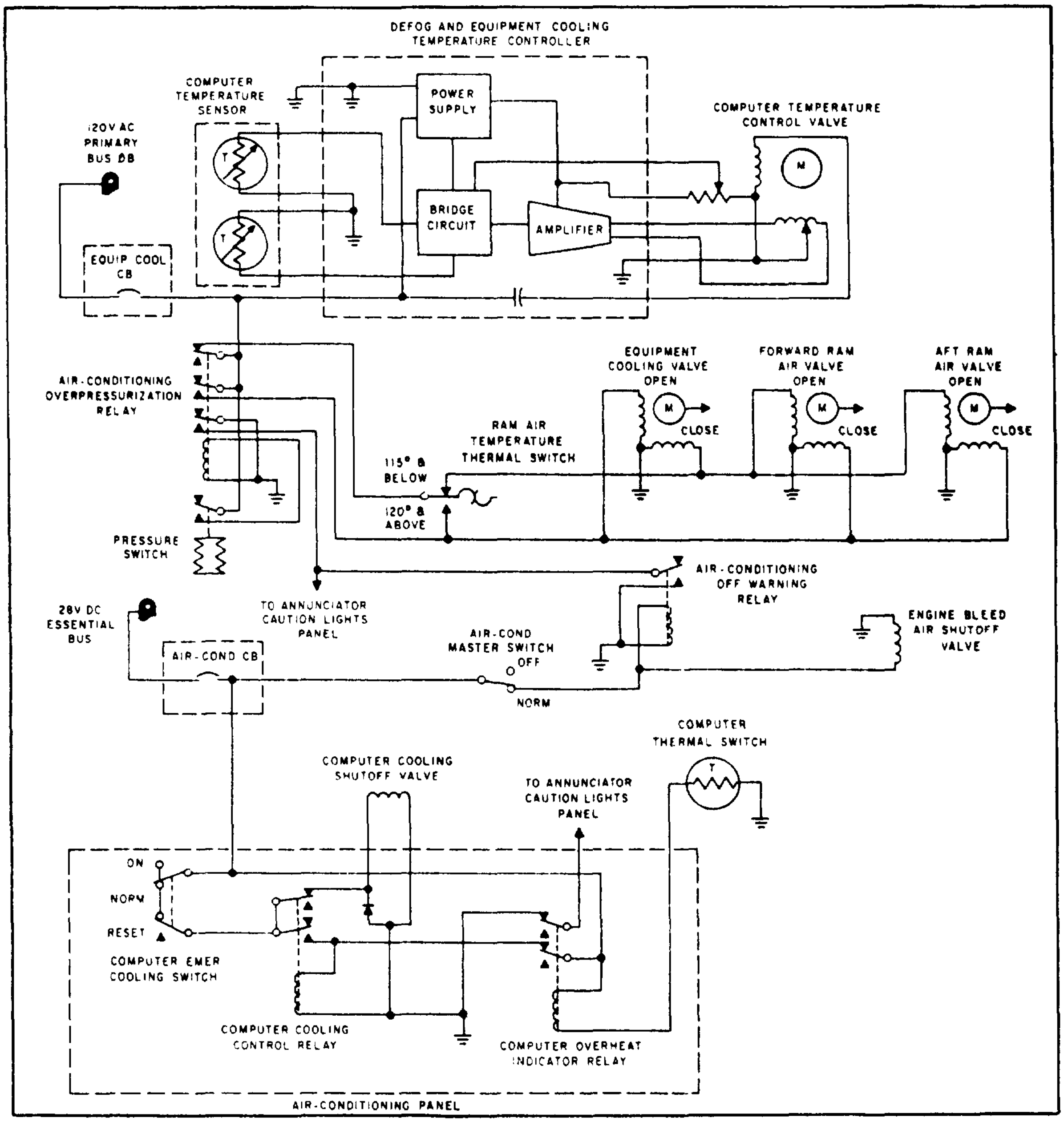


Figure 4-27.-Equipment cooling schematic diagram.

when the AIR COND MASTER switch is at NORM. Under these conditions, the circuit from the 28-volt dc essential bus to the solenoid of the engine bleed air shutoff valve is complete. Bleed air now flows to the air cycle refrigeration unit. The discharge from the cooling turbine supplies the cooled bleed air used by the equipment cooling system.

When the aircraft is airborne and the ram air temperature is below 46.1°C (115°F), voltage from the 120-volt ac primary bus runs through the overpressurization relay, and the unoperated ram air thermal switch to the equipment cooling valve, the forward compartment ram air valve, and the aft compartment ram air valve. The equipment cooling valve runs to the fully closed position, and the forward compartment and aft compartment ram air valves run to the open position. Ram air flows to the right forward and aft equipment compartments and the cooled, bleed airflow is shutoff.

When the ram air temperature exceeds 46. 1°C, the ram air temperature thermal switch operates. Voltage from the 120-volt ac primary bus goes through the overpressurization relay, and the operated ram air thermal switch to the equipment cooling valve, the forward compartment ram air valve, and the aft compartment ram air valve. The equipment cooling valve runs to the open position, and the forward compartment and aft compartment ram air valves run to closed position. Undried, cooled bleed air flows to the forward and aft equipment compartments. The ram air to these compartments is shutoff.

When an overpressurization condition occurs, the pressure switch operates. This closes the overpressurization relay. Voltage from the 120-volt ac primary bus runs through the overpressurization relay to the equipment cooling valve, the forward compartment ram air valve, and the aft compartment ram air valve. The equipment cooling valve goes to the open position and the forward and aft compartment ram air valves run to the closed position. Under these conditions, the overpressure dumps into the forward and aft equipment compartments.

The computer pressure regulator maintains a pressure of 2 to 3 PSI in the equipment cooling line. The pressure-regulated, partially-dried cooled bleed air from the regulator automatically mixes with controlled quantities of hot bleed air. The servo-controlled computer temperature control valve controls the mixture process. This valve modulates in response to temperature signals from the computer temperature sensor in the computer inlet duct to maintain a computer duct temperature of 4.4° ± 2.8°C (40° ± 5°F). The temperature controlled air flows through the ballistics computer set. Sonic venturis in the ballistics computer outlet duct and the transmitter modulator inlet duct limit the flow of cooling air.

A computer cooling shutoff valve upstream of the computer temperature control valve provides a safety override for the computer temperature control valve. If the computer duct temperature exceeds 65.6°C (150°F), the computer thermal switch opens. This de-energizes the computer overheat indicator relay and completes the circuit to the COMPUTER OVERHEAT caution light. Voltage from the 28-volt essential dc bus runs to the computer overheat indicator relay. This energizes the computer cooling control relay, thereby closing the computer cooling shutoff valve. If the computer duct temperature drops below 65.6°C, the contacts of the computer thermal switch close, energizing the computer overheat indicator relay. This action interrupts the circuit to the COMPUTER OVERHEAT caution light. The computer cooling control relay remains energized through the computer emergency cooling switch and its own contacts. Placing the CMPTR EMER COOL switch momentarily to RESET de-energizes the computer cooling control relay, completing the circuit to open the computer cooling shutoff valve. If the COMPUTER OVERHEAT caution light should cycle on and off indicating a constant overheat condition, place the CMPTR EMER COOL switch to ON, permanently closing the computer cooling shutoff valve. This allows uncontrolled, cooled bleed air to duct to the ballistics computer.

Air exhausted from the ballistics computer set and from the cockpit circulates through the less critical electronic equipment compartments. This air supplies direct cooling requirements for communication, navigation, and identification (CNI) equipment in the aft equipment compartment.

CABIN AND VENT SUIT TEMPERATURE CONTROL SYSTEM

The cabin and vent suit temperature controller is a transistorized electronic device. It operates on 120 volts, 400 hertz. Maximum power consumption is 28 watts.

Electrically, the controller consists of two channels—the cabin temperature channel and the ventilated suit channel. Both channels operate in basically the same manner. Bridge circuits compare temperature selector and temperature sensor resistances, which represent selected and actual temperature conditions and generate a resultant dc error voltage. The dc error voltage is then modulated and amplified. The resulting ac signal is the controller output, and it has phase and voltage characteristics proportional to the magnitude of the dc error signal. It goes to the two-phase servomotor of the appropriate control valve, where it modulates the valve to maintain the selected temperature.

The cabin temperature channel (fig. 4-28) of the temperature controller uses three bridge circuits to maintain cabin temperature. Selection of the desired temperature with the cabin temperature selector varies resistance of one leg of the cabin temperature bridge. The varying cabin temperature changes the resistance of the cabin sensor in the second leg of the bridge circuit. Thus, a selected temperature must have a change of cabin temperature to provide bridge balance between the cabin sensor and selector. Whenever bridge imbalance exists, the resulting dc voltage is ac modulated by the modulator circuit, amplified by the cabin amplifier, and fed to the control valve servomotor to either increase or decrease cabin temperature.

The function of the cabin duct limit bridge is to limit the temperature of the cabin inlet air. A diode-biasing network permits the cabin duct limit bridge to override the cabin temperature bridge upon reaching the duct temperature limit. The resulting dc voltage goes to the modulator circuit, the cabin amplifier, and to the control valve servomotor to decrease cabin temperature.

The cabin duct anticipator bridge functions with sudden changes of air temperature in the cabin air inlet duct. To do this, the error voltage is capacitor coupled to the modulator. When the cabin temperature is being held at the selected temperature with constant cabin inlet air temperatures, the anticipator bridge is in balance. Should duct temperature suddenly change, with all other conditions remaining the same, the anticipator bridge is unbalanced. This unbalance causes an

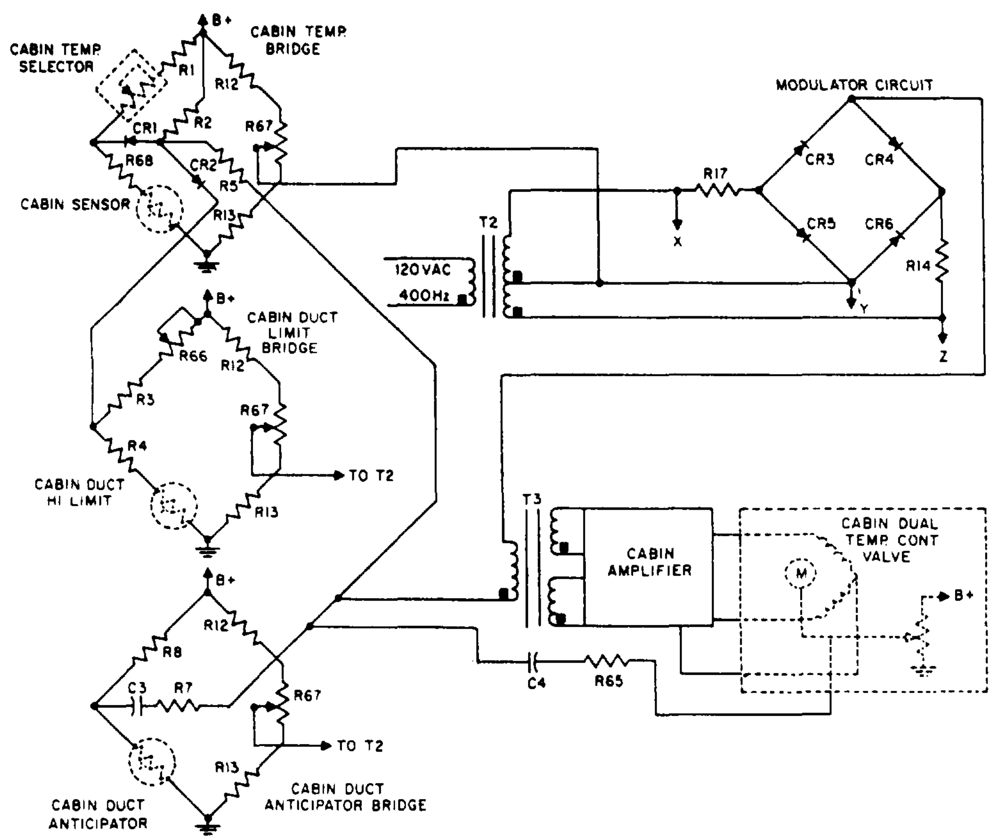


Figure 4-28.-Cabin temperature channel.

error voltage to go to the modulator circuit. The resulting amplified signal regulates the cabin control valve to return the duct air to its original temperature. Error voltages caused by cabin temperature bridge or cabin duct limit bridge imbalance override the cabin duct anticipator bridge, provided the duct air temperature error is gradual or small.

One additional error voltage is capacitor coupled to the modulator circuit. The voltage change is proportional to the rate of change of the feedback potentiometer of the cabin dual temperature control valve. This voltage change is applicable only when the valve is being regulated (the feedback potentiometer is rotating). Therefore, the error feedback voltage seen at the control input is proportional to the feedback potentiometer rate of change. Once regulation of the valve starts, the potentiometer rate-of-change voltage reduces initial starting voltage to the control valve actuator motor, slowing valve actuator rotation.

The vent suit channel (fig. 4-29) of the temperature controller uses one bridge circuit to maintain suit temperature. Operation of this bridge is similar to that of the cabin temperature bridge. The suit temperature selector resistance in one leg balances against the suit duct temperature sensor resistance in the opposite leg. Imbalance between these legs of the suit temperature bridge results in a dc error voltage. This voltage is ac modulated by the modulator circuit, amplified, and goes to the suit temperature control valve, altering suit air temperatures.

Rate-of-change voltage from the feedback potentiometer in the ventilated suit temperature control valve is capacitance-coupled to the modulator circuit. As in the cabin temperature channel, this voltage is present only when the valve is operating. It reduces the initial starting voltage to the valve once actuator rotation has started, thus slowing actuator rotation.

ANTI-ICING AND DEICING EQUIPMENTS

The anti-ice and defrost system on some aircraft having the air-conditioning and pressurization system described in this chapter use the air cycle systems as an air source. The anti-ice and defrost equipment consists of the windshield anti-ice system (fig. 4-30.) and the windshield defrost system. Each receives its hot air supply from the same manifold. The anti-icing switch is on the pilot's temperature control panel.

In a typical system, a windshield overheat thermostat and a shutoff valve in the windshield defrosting duct operate together to prevent windshield overheating. The thermostat opens the valve automatically when the temperature

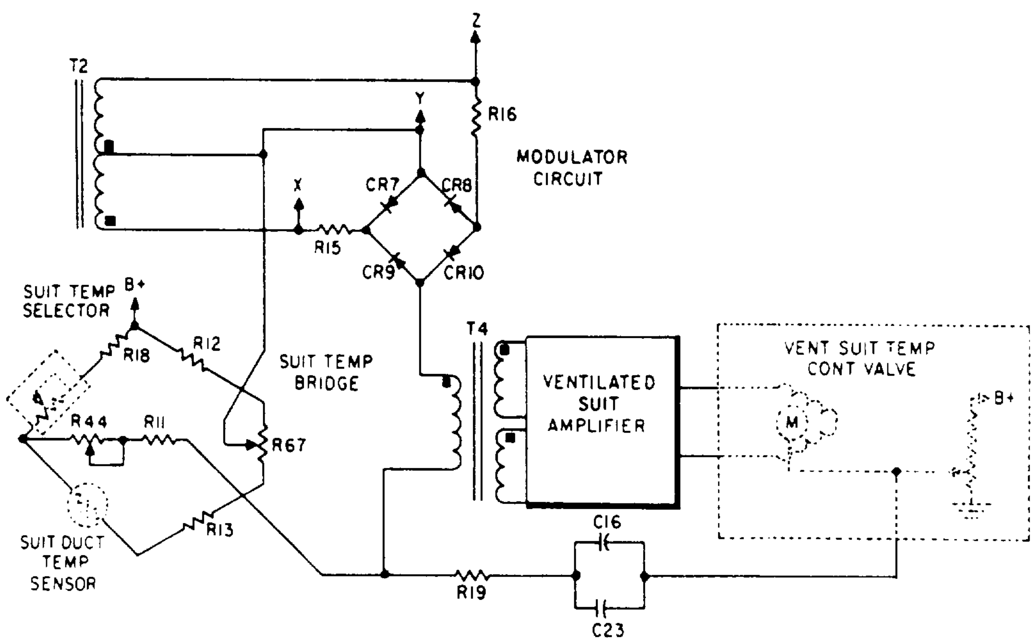


Figure 4-29.-Vent suit channel.

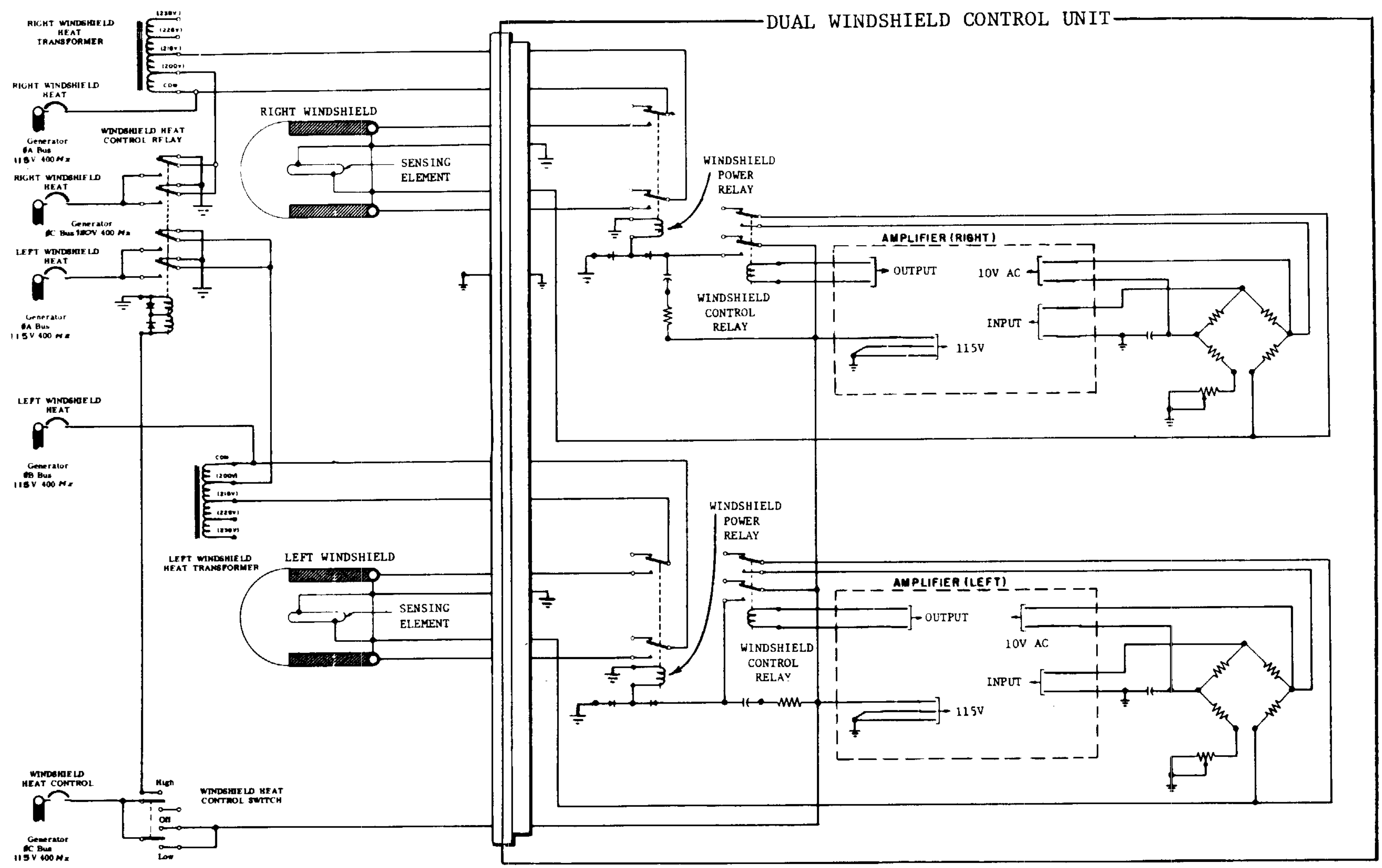


Figure 4-30.—Windshield anti-icing system.

becomes too high. This action diverts the hot defrosting air to the air-conditioning outlet at the floor of the cockpit until the temperature drops. Windshield overheating occurs only if the cabin air temperature high limit pickup fails.

Windshield Anti-Icing and Defogging System

An electrical anti-icing and defogging system is now in the windshield panels of current naval aircraft. The panels are constructed of two pieces of semitempered plate glass laminated with a vinyl plastic core. The core acts as a safety device to prevent shattering in a collision with birds when it is in the heated condition. The resistance heating element for anti-icing and defogging consists of a transparent, electrically conductive film, evenly distributed over the inner surface of the outer pane of glass. The system includes the following additional components:

- A windshield wire terminal box, located between the windshield panels
- A temperature-sensing element embedded in each panel
- Two windshield autotransformers and a heat control relay
- A dual windshield control unit
- A windshield heat control toggle switch located in the cockpit

The system receives power from the ac buses through the windshield heat control circuit breakers. When the windshield heat control switch is in HIGH, 115 volts, 400 hertz goes to the left and right amplifiers in the dual windshield control unit. The windshield heat control relay then energizes, applying two phases of ac power at 200 volts, 400 hertz to the windshield heat autotransformers. These transformers provide 218-volt ac power to the windshield heating current bus bars through the dual windshield control unit relays. The sensing element in each windshield has a POSITIVE temperature coefficient of resistance and forms one leg of a bridge circuit. (Some systems use a thermistor, which has a negative temperature coefficient, as a sensing element to control windshield temperature.)

When windshield temperature is above calibrated value, the sensing element has a higher resistance value than needed to balance the bridge. This decreases the flow of current through the amplifiers, and the relays of the control unit are de-energized. As the temperature of the windshield drops, the resistance value of the sensing element also drops. Now, the current through the amplifiers again reaches sufficient magnitude to operate the relays in the control unit, thus energizing the windshield heaters.

When the windshield heat control switch is in LOW, autotransformers provide 115 volts, 400 hertz ac to the left and right amplifiers in the dual windshield control unit. In this condition, the transformers provide 121-volt ac power to windshield heating current bus bars through dual windshield power relays. The sensing elements in the windshield operate in the same manner as described for high heat operation. The calibrated units maintain windshield temperature between 40°C and 49°C (105°F to 120°F).

Wing and Tail Anti-Icing

Some aircraft have a thermal anti-icing system that prevents formation of ice on the leading edge of the wing panels and tail surfaces. This system uses hot air to heat the leading edges. The hot air comes from a combustion heater in the wings and tail section, or from the compressor section of a jet engine. An electrically operated pump supplies fuel for the anti-icer heaters. Heater demand determines the amount of fuel the pump delivers. In some aircraft, thermostats automatically determine heater demands. Various types and combinations of solenoid-operated valves control fuel flow and airflow in the system.

Wing and Tail Deicing

Some aircraft may have air-inflated, rubber deicer boots on the leading edges of wing and tail surfaces. Air pressure or vacuum is alternately applied to these boots and cracks off any ice that has formed. Once the ice has cracked, the force of the airstream peels it back and carries it away. Pressure for inflating the air cells in the deicer boots is normally from engine-driven pumps. Air pressure or vacuum is alternately applied either by the use of motor-driven rotary distribution valves or by the combination of an electronic timer and solenoid distributor valves.

Empennage Deicing

The P-3 empennage deicing system combines both anti-icing and deicing for the vertical and horizontal stabilizers. The system uses electrical power to prevent or remove the accumulation of ice. Electrical heating elements are in the leading edges and surfaces of the empennage. The system has ac power and dc control. Parting strips in the leading edge of each stabilizer accomplish anti-icing requirements. The parting strips remain on once the system actuates. Twenty cyclic heat areas accomplish deicing requirements. During normal operation, each of the cyclic areas heat for 8 seconds and are off for 168 seconds. Overheat sensors and a thermal-sensitive relay protect the system. Any time the system detects an overheat, power is shut off automatically to prevent damage to the metal structure.

Pitot Tube Anti-Icing

To prevent the formation of ice over the opening in the pitot tube, a built-in electric heating element (fig. 4-31) is in use. A switch on the pilot's console controls power to the heaters. System power is from either the ac or the dc bus. Exercise caution when ground checking the pitot tube since the heater can not operate for long periods unless the aircraft is in flight. Also, the danger exists for ground personnel to be accidentally burned.

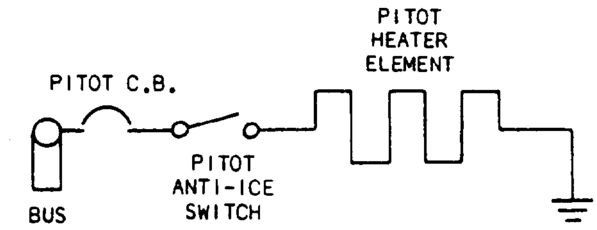


Figure 4-31.-Pitot tube anti-icing circuit.

REVIEW SUBSET NUMBER 3

Q1. The frictional temperature increase created by ram compression on the skin surface of the aircraft is known as ____________.

Q2. What is the primary purpose of an air-conditioning and pressurization system?

Q3. Where is the resistance heating element installed in electrically heated windshields?

Q4. What do aircraft equipped with wing deice systems use to prevent ice buildup on the leading edge?

Q5. What does the P-3 empennage anti/deicing systems use to prevent ice buildup?

CHAPTER 5

AIRCRAFT POWER PLANT ELECTRICAL SYSTEMS

A naval aircraft requires a mechanism to propel it through the air. Aviation Machinist's Mates (ADs) maintain the power plant and its associated controls. There are, however, several electrical systems (such as starting, ignition, fire warning, fire extinguishing, anti-icing, fuel, and indicating systems) that support the power plant. AEs maintain these systems.

STARTING EQUIPMENT

Learning Objective: *Identify the types of starting equipment used to start aircraft engines.*

Jet engine starters provide high starting torque to initially overcome the engine rotor weight and high speed to increase rotor RPM until the engine is self-sustaining. The following paragraphs describe the various starting systems used on turbojet, turboprop, and turbofan engines.

CONSTANT SPEED DRIVE/STARTER

The starting system on the A-6 *Intruder* aircraft is the constant speed drive/starter (CSD/S). It has three separate modes of operation:

1. Start mode.
2. Constant speed drive mode. This mode maintains main generator frequency control regardless of engine RPM or generator loads.
3. Air turbine motor generator mode. This mode is used for auxiliary and emergency operation of a main generator when the main engine is shut down.

Air for starting or emergency/auxiliary operation of the generator is received from the other engine or from an external source.

The CSD/S unit (fig. 5-1) consists of two sections and connects to the engine input drive shaft through a generator. The turbine motor section contains an axial flow turbine wheel and variable area nozzle that directs air and controls turbine wheel speed. The planetary differential transmission section is a variable gear assembly with infinite gear ratios.

In the **start mode** of operation, an external air source drives the turbine wheel. The gear reduction in the transmission section converts the high speed of the turbine to high torque. The hollow core of the generator shaft delivers torque to the engine input drive shaft.

After the engine gains a self-sustaining speed, the ring brake releases and the system changes to the **constant speed drive mode.** In this mode, electromechanical, pneumatic, and pneumatic-hydraulic components act to vary the gear ratio of the planetary differential transmission. These components maintain an output of 8,000 RPM from the engine input drive shaft.

If it becomes necessary to shut down an engine, airflow routes from the remaining operating engine to the CSD/S. This places the system in the **air turbine motor-generator drive mode** of operation. In this mode, power to drive the generator comes entirely from the turbine drive wheel. A planetary differential transmission section disconnects the generator and turbine from the engine.

AIR TURBINE STARTER

The air turbine starter is a lightweight unit designed to start turbojet, turboprop, and turbofan engines when supplied with compressed air. The unit consists primarily of a scroll assembly, rotating assembly, reduction gear system, overrunning clutch assembly, and output shaft. An overspeed switch mechanism limits maximum rotational speed. Compressed air, supplied to the scroll inlet, goes to the turbine wheel through the nozzle in the scroll assembly. The reduction gear system transforms the high speed and low torque of the turbine wheel to low

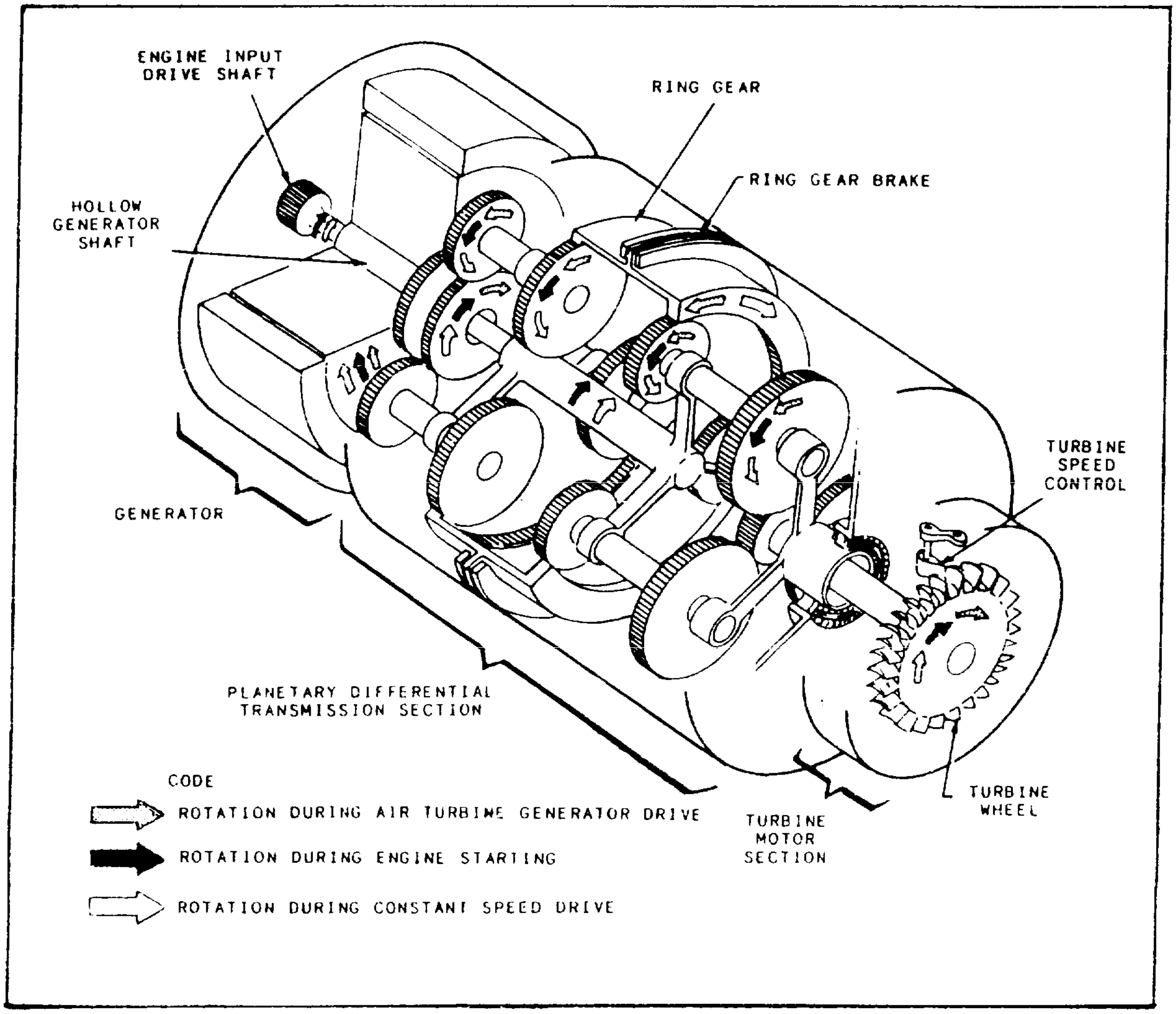


Figure 5-1.-Constant speed drive/starter.

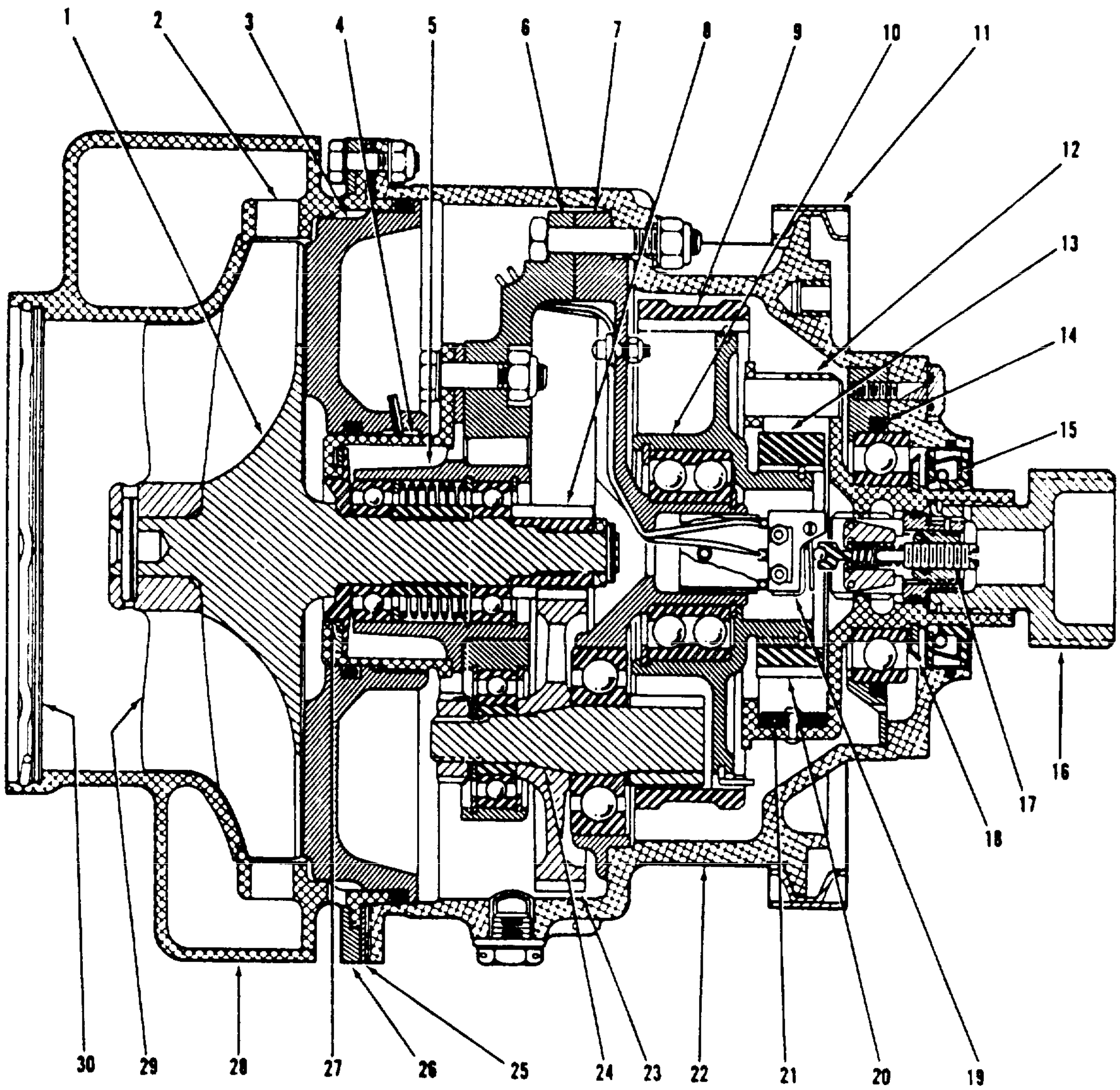
speed and high torque at the output shaft. When at the desired starter rotational speed, the flyweights in the governor assembly throw out and open the limit switch. This section sends a signal that shuts off the supply air. At a higher, predetermined rotational speed, the overrunning clutch assembly releases the output shaft from the rotating assembly.

A source of compressed air flows to the shutoff valve inlet duct to drive the starter. The starter is a turbine air motor equipped with a radial inward-flow turbine wheel assembly, reduction gearing, splined output shaft, and a quick-detaching coupling assembly. The complete assembly mounts within one scroll assembly and gear housing (fig. 5-2). As you read this section, you should refer to figures 5-2 and 5-3.

The air turbine starter converts energy from compressed air to shaft power. This power goes to a splined output shaft at speed and torque values for starting aircraft engines.

Initial control of the air shutoff valve (fig. 5-3) is by a normally open, momentarily closed, start switch and a relay box. After pressing the start switch, the sequence of operation of the valve and starter is automatic. A normally closed, momentarily open, stop switch provides a means of manually stopping the starter when motoring an engine without fuel or in emergencies.

When the external start switch momentarily closes, a double-pole, single-throw, holding relay in the relay box actuates. This action completes electrical circuits to the air shutoff valve and the starter. When the external start switch opens, the



1. Turbine wheel assembly
2. Scroll nozzle
3. Air barrier seal
4. Oil seal
5. Bearing carrier
6. Turbine end gear carrier
7. Output end gear carrier
8. Pinion gear
9. Internal ring gear
10. External hub gear
11. Quick-attach/detach coupling assembly
12. Drive shaft
13. Drive jaw
14. Bearing retainer assembly
15. Shaft seal
16. Output shaft
17. Overspeed control assembly
18. Oil baffle
19. Switch assembly
20. Drive pad
21. Pawl spring assembly
22. Gear housing assembly
23. Reduction gear
24. Reduction shaft
25. Heat barrier
26. Scroll flange
27. Wheel slinger
28. Scroll assembly
29. Wheel exducer
30. Screen assembly

Figure 5-2.-Air turbine starter.

holding relay receives a positive potential through the normally closed external stop switch. The relay also receives a negative potential through the closed overspeed control provided within the starter. The relay continues to hold until the external stop switch removes the positive potential or until the closed overspeed control removes the negative potential.

When high-pressure air is at the normally closed regulating valve inlet and the start switch energizes the holding relay, the regulating valve opens. Thus, admitting compressed air to the starter. The

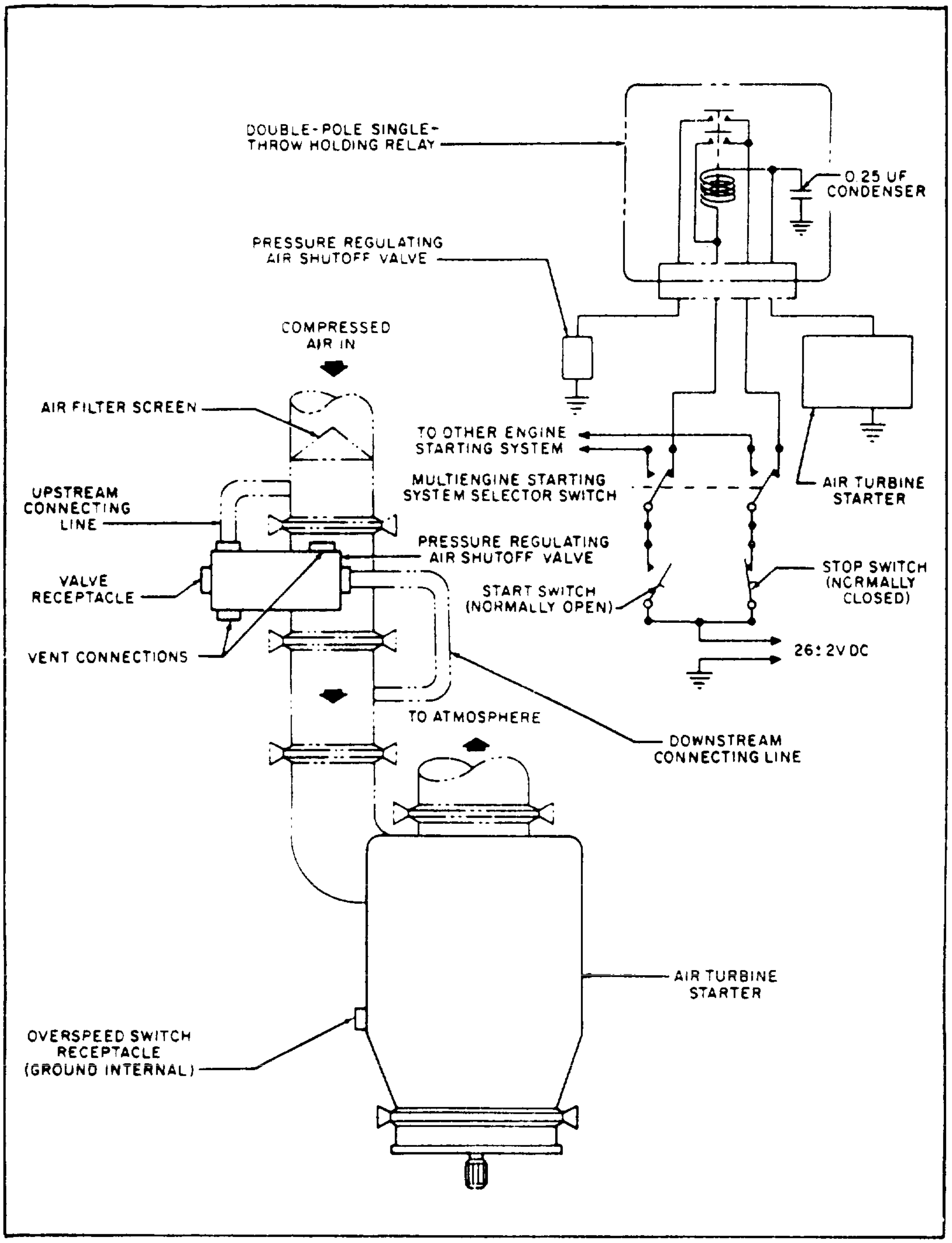


Figure 5-3.-Air turbine starting system diagram.

control mechanism regulates the compressed air to specified conditions. The mechanism senses upstream and downstream conditions, and it positions the valve butterfly to supply the desired flow.

The compressed air enters the inlet port of the starter and expands as it flows radially inward through the nozzle vanes. The airflows against the blades of the turbine wheel to rotate the turbine wheel. The reduction gear system (fig. 5-2), which transmits power to the drive shaft, converts the high-speed, low-torque output of the turbine wheel to low-speed, high-torque output.

As compressed air enters the starter inlet port through the pressure regulating valve, the turbine wheel rotates, transmitting torque to the drive jaw through reduction gearing. This torque transmits to the drive shaft through the splined drive shaft. When aircraft engine speed exceeds the starter drive shaft speed, the speed of the starter output shaft (directly connected to the engine drive) also exceeds the drive jaw speed. When this condition occurs, the pawls begin to ratchet. When the output shaft (driven by the aircraft engine) attains enough speed, centrifugal force releases the pawls completely from the drive jaw. This action releases the starter from the aircraft engine. When the starter reaches cutoff speed, the internal overspeed control actuates, breaking the electrical circuit to the holding relay. Then, the pressure regulating valve butterfly closes and prevents compressed air from entering the starter.

NOTE: If engine shaft speed fails to exceed starter driving mechanism speed before the starter reaches cutoff speed, the cutout switch actuates, shutting down the starter.

A starting operation begins by momentarily closing the start switch to energize the pressure regulating valve circuit. Sequence of the regulating valve and start operation becomes automatic. The start continues until engine light-off occurs, and the engine overspeeds the starter driving mechanism or until output shaft speed reaches the calibrated cutoff point. In either condition, disengagement of the starter from the engine or interruption of the supply air to the starter is automatic. Starter operation also stops when the stop switch momentarily opens, which closes the pressure regulating valve and interrupts the supply air to the starter.

NOTE: During operation of the starter, you should stand clear of the plane of rotation of the high-speed rotating turbine wheel. Only qualified ADs should install and service the unit and its pressure regulating valve.

REVIEW SUBSET NUMBER 1

Q1. List the three modes of operation of the A-6 aircraft constant speed drive/starter unit.

Q2. In the air turbine starter, what unit limits rotational speed?

Q3. The air turbine starter converts energy from what type of air to shaft power?

Q4. The external stop switch de-energizes the air turbine start control holding relay by

______________________________________ .

IGNITION SYSTEMS

Learning Objective: *Recognize operating parameters and characteristics of aircraft engine ignition systems.*

Three things are necessary to cause a fire—a combustible material (such as aircraft fuel), oxygen, and heat. A fire will not start without all three, and removing any one of the three puts the fire out. All internal combustion engines use fire to produce mechanical energy, and the piston-type engine uses the higher degree of fire—an explosion.

The gas turbine (jet) engine also produces its energy through the use of fire. However, its operation is considerably different from the piston engine. Rather than a series of independent explosions, a jet engine produces a continuous burning fire. Ignition is necessary only during the start cycle to ignite the fire.

Electronic ignition systems provide internal combustion for turboprop, turbofan, and turbojet engines. Unlike reciprocating engine systems, timing is not a factor in turbine-power ignition systems. All that is needed is a series of sparks with enough intensity to cause combustion.

The exciter develops voltage of sufficient amplitude to produce a spark. The exciter unit contains a capacitor or capacitors to develop the voltage and current necessary to supply a spark plug (called an igniter). The resultant spark is of high heat intensity, capable not only of igniting abnormal fuel mixtures but also of burning away any foreign deposits on the plug electrodes. The exciter is a dual unit and produces sparks at each of two igniter plugs.

The igniter plugs are, in general, similar to the spark plugs on reciprocating engines. The main differences were changes necessary to operate at higher energies, voltages, and temperatures of jet engines. In general, the igniter plug is larger, more open in construction, and the gap is much wider than spark plugs of familiar design. Figure 5-4 shows a typical jet igniter plug.

Control of jet ignition systems is through relays or switches that operate automatically during the engine start cycle. Fuel or oil pressure switches or centrifugal speed switches energize a relay to begin ignition. Ignition stops by actuation of a centrifugal switch at a speed between 45 percent and 65 percent of rated engine speed.

CAPACITOR-DISCHARGE IGNITION SYSTEM

This ignition system has three major components—one ignition exciter and two lead assemblies. The exciter unit's hermetical seal permanently protects internal components from moisture, foreign matter, inadvertent maladjustments, pressure changes, and adverse operating conditions. This type of construction eliminates the possibility of flashover at high altitude due to pressure change and gives positive radio noise shielding. The complete system design, including leads and connectors, gives adequate shielding against leakage of high-frequency voltage that interferes with radio reception of the aircraft. It supplies energy to two surface-type spark igniters.

Figure 5-5 is a functional schematic of the system. You should refer to this figure when studying the theory of operation of a capacitor-discharge system.

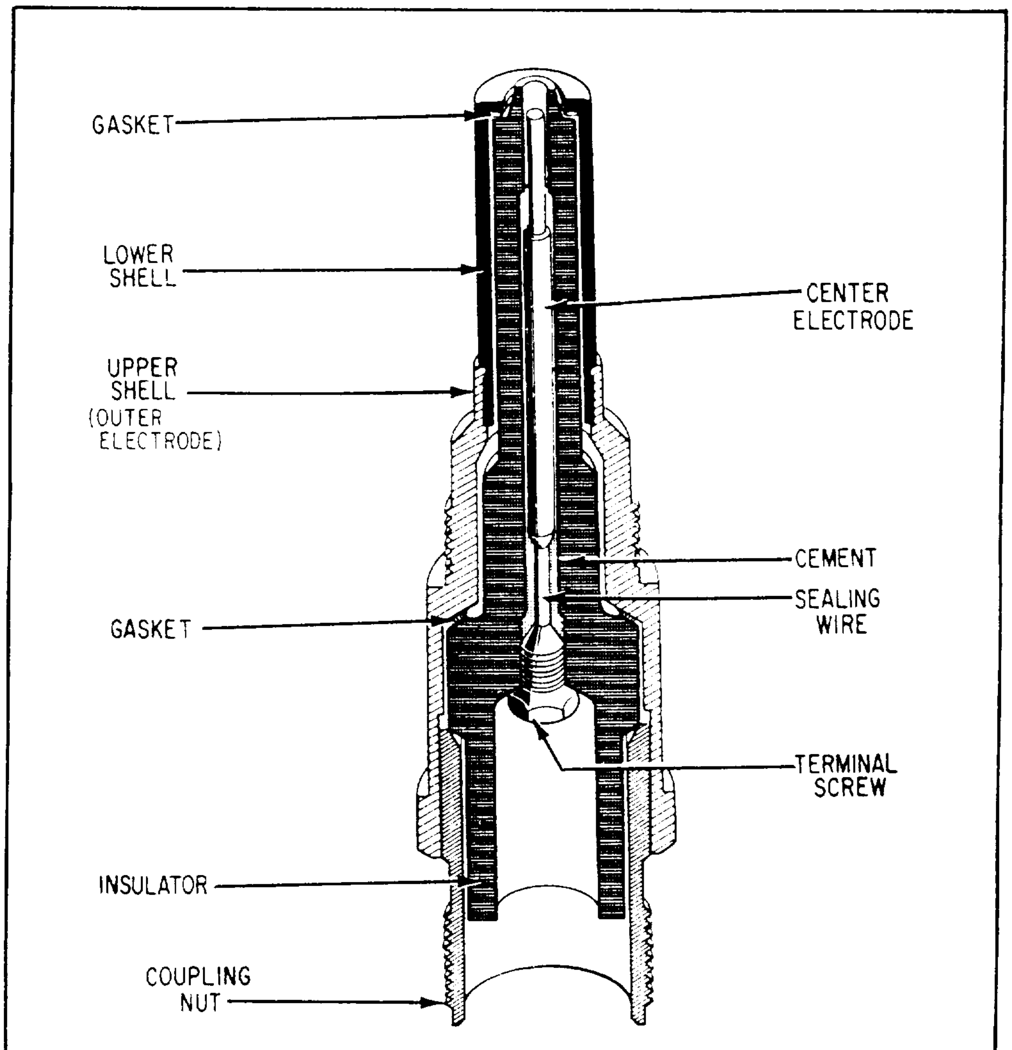


Figure 5-4.-Cross-sectional view of a jet igniter plug.

The ignition system gets its input power from the low-voltage dc power supply of the aircraft electrical system. Its function is to produce high energy, capacitance-type sparks at the spark igniters in the engine.

Input power from the low-voltage supply connects through a noise filter to a dc motor. The motor drives a multilobe cam that operates two breakers, and a single-lobe cam that operates two contractors. One breaker and one contactor associate with each side of the system. The two sides are identical. The following description applies to either side.

When the multilobe cam closes the breaker (fig. 5-5), input current flows through the autotransformer's primary winding, establishing a magnetic field. Then the breaker opens, the flow of current stops, and the field collapse induces about 1,000 volts in the secondary. This voltage causes a pulse of current to flow into the storage capacitor through a rectifier that limits the flow to a single direction. You can see that each time the breaker opens, the capacitor receives a charge of electricity, and the action of the rectifier prevents any loss of this charge. After 34 such pulses accumulate a charge on the capacitor, the contactor closes by mechanical action of the single-lobe cam. Then, the capacitor discharges its stored energy through a triggering transformer, and the energy dissipates at the igniter. The triggering transformer increases the output voltage of the ignition unit and ensures reliability of the system.

The igniter spark rate varies in proportion to the voltage of the dc power supply, which affects the speed of the motor. However, as the same shaft operates both cams, the storage capacitor always accumulates its energy from the same number of pulses before discharge.

CAUTION

Due to the high voltage and amperage of this system, you should use extreme caution around the equipment.

ELECTRONIC IGNITION SYSTEM

The development of more powerful jet engines demands a reliable, maintenance-free ignition system. This chapter doesn't cover all ignition systems; rather, the system described represents most modern systems. An electronic ignition system has an advantage over the capacitor-discharge system; it has no moving parts and breaker points or contractors that can become pitted or burned.

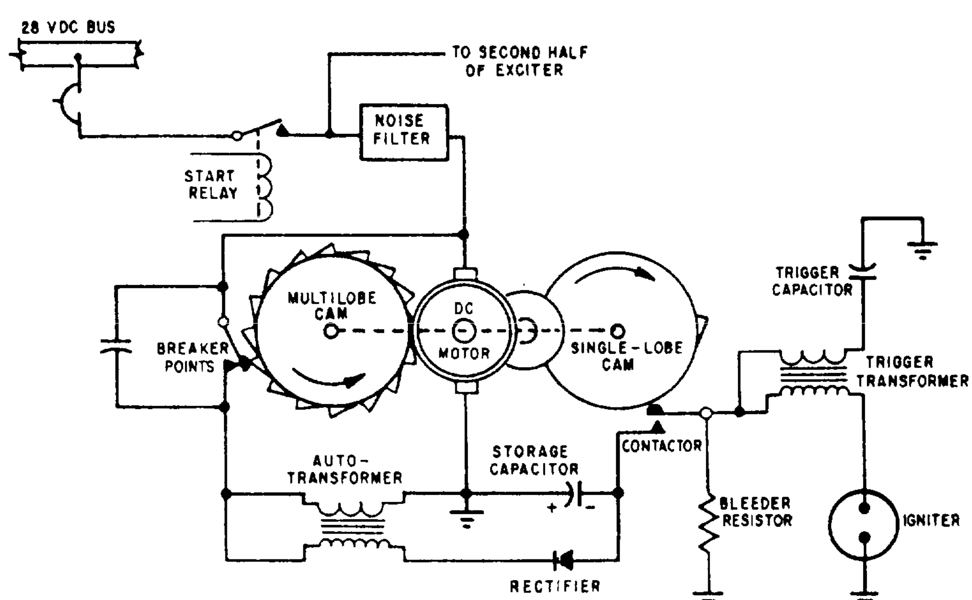


Figure 5-5.-Functional schematic of capacitor-discharge system.

The engine ignition system (fig. 5-6) provides the necessary electrical energy and control to begin engine combustion during aircraft armament firing and starting, and for automatic reignition in case of engine flameout.

Engine Ignition Exciter

The engine ignition exciter is a dual-circuit, dual-output unit that supplies a high-voltage. high-energy electrical current for ignition. The exciter consists of a radio frequency interference filter and two power, rectifier, storage, and output elements. The exciter mounts on the forward part of the compressor section of the engine.

Engine Control Amplifier

The engine control amplifier is the electronic control center of the engine. It controls the function of the ignition system as well as other engine operational functions. The amplifier mounts on the compressor section aft of the engine front frame.

Engine Ignition Leads and Igniter Plugs

The ignition leads are high-tension cables, which transmit electrical current from the exciter to the igniter plugs. The igniter plugs mount in the combustion chamber housing.

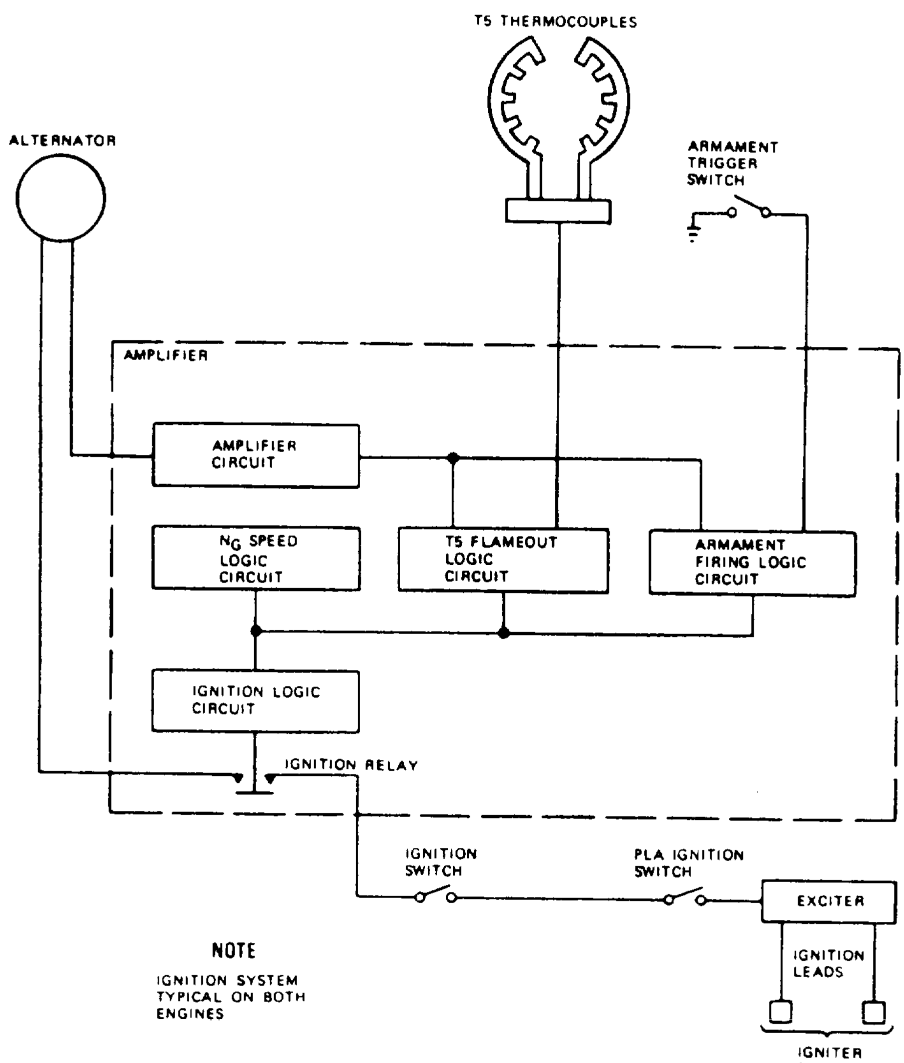


Figure 5-6.-Jet engine electronic ignition system.

Engine Alternator Stator

The engine alternator stator is an engine-driven single-phase, ac electrical-output unit mounted on the engine accessory gearbox. It supplies electrical power to the engine, independent of the aircraft electrical system. It contains three sets of windings. Two windings supply electrical power to the ignition exciter, and the third supplies electrical power to the control amplifier.

Ignition Operation

As you read this section, refer to figure 5-6. With the ignition switch ON, the engine cranking for starting, and throttle advanced to 10-degree power lever angle (PLA) position, current flows from the alternator stator to power the control amplifier. At the same time, the PLA ignition switch in the fuel control closes. The gas generator (N_g) speed logic circuit closes the ignition relay to provide ignition when N_g is within the 10 to 48 percent N_g range. With the relay closed, it completes a circuit from the alternator stator ignition windings, through the ignition exciter, to the igniter plugs. Current flows from the alternator, through the control amplifier, to the ignition exciter. At the ignition exciter, current is intensified and discharged as a high-voltage output, and conducts through the igniter cables to the igniters. Current crossing the gaps in the igniters produces a continuous high-intensity spark to ignite the fuel mixture in the combustion chamber. When engine speed reaches 8,500 RPM, N_g and interturbine temperature (ITT) reaches operating range, a signal from the T5 temperature detectors flows through the T5 circuit to the control amplifier ignition logic circuit. The control amplifier ignition relay opens and ignition ends. Combustion then continues as a self-sustaining process.

Ignition automatically reactivates when either a flameout occurs or when aircraft armament fires. When T5 temperature drops more than 800°F (427°C) from T5 selected by PLA, the T5 detectors signal control amplifier T5 flameout logic to close the amplifier ignition relay. This activates ignition system operation. Ignition continues until engine operating temperature is again normal and the 800°F temperature error signal cancels, causing the control amplifier to end ignition operation.

An armament-firing protection circuit prevents flameout from armament gas ingested by the engine during armament firing. When firing aircraft armament, a signal from the armament trigger switch activates the armament-firing logic circuit in the control amplifier. The amplifier logic circuit causes ignition operation to activate. Ignition operation ends after a 1-second time delay in the amplifier logic circuit following release of the armament firing trigger.

REVIEW SUBSET NUMBER 2

Q1. Why is timing not a factor in jet engine ignition systems?

Q2. What unit in an ignition system develops enough voltage to produce a spark?

Q3. At what engine RPM does ignition normally stop?

Q4. In the capacitor-discharge ignition system, what total number of pulses must occur before the capacitor discharges?

Q5. Engine ignite automatically reactivates when either of what two conditions occurs?

ENGINE TEMPERATURE CONTROL SYSTEMS

Learning Objective: *Recognize operating conditions and characteristics of aircraft engine temperature control systems.*

On most reciprocating engines, the engine cowl flaps control cylinder head temperature (CHT). In turbine-powered engines, turbine temperature is controlled differently. Engine temperature is a measure of power, and temperature is a product of fuel consumption. In most turbine-powered aircraft, then, the pilot selects desired power through a mechanical linkage to the fuel control. As the power increases, so does the temperature, In turbojet aircraft, this also causes an increase in engine speed. The only electrical circuits required are those to show temperature and speed.

The engine temperature control system on turboprop engines lets the operator control turbine inlet temperature and torque through the use of power and condition levers. These levers connect to each engine coordinator through pushrods, sectors, cables, and pulleys. When the engine is operating in the flight range, engine speed is constant. Engine power is controlled by increasing or decreasing fuel flow, which results in a corresponding change in turbine inlet temperature. The main components of the engine temperature control system are—

- Power levers,
- Condition levers,
- Engine coordinators,
- Temperature datum controls,
- Turbine inlet thermocouples, and
- Temperature datum switches.

Figure 5-7 shows the block diagram of an engine temperature control system. You should refer to it while you study this section.

POWER LEVERS

The power levers (one for each engine) can move separately or together to control engine power. The range of power lever settings is from REVERSE (reverse thrust) to MAX POWER (takeoff). Power lever switches within the cockpit pedestal supply electrical power to other systems. A detent at the FLT IDLE position prevents inadvertent movement of the power levers below FLT IDLE while airborne. To move the power levers to the taxi range, you must raise the levers from the detent. During a catapult-assisted takeoff, a retractable catapult grip helps the pilot maintain the power levers at MAX POWER.

CONDITION LEVERS

The condition levers are located next to the power levers on the cockpit pedestal. They have four positions—FEATH, GRD STOP, RUN, and AIRSTART. Switches at each condition lever position complete electrical circuits for other systems. The pilot must raise the detent release handle of each condition lever to move the levers to different positions. A detent holds the lever at FEATH, GRD STOP, or RUN. When the condition lever is in the AIRSTART position, the propeller unfeathers and the engine starting cycle begins. The lever is held in the AIR START position until the engine speed reaches 100 percent RPM. Then, you release the lever, which springs back to RUN and remains there for normal operation. When set to RUN, the condition lever positions the mechanical linkage to open the fuel shutoff valve. A mechanical stop in the pedestal prevents both condition levers from being set to FEATH at the same time. When set to FEATH, the condition lever electrically and mechanically closes the corresponding fuel shutoff valve and feathers the propeller. At GRD STOP, the condition lever electrically closes the fuel shutoff valve to shut down the engine.

ENGINE COORDINATORS

The coordinators are mechanical devices that coordinate the power and condition levers, propeller, fuel control, and electronic fuel trimming circuit. One engine coordinator mounts on each fuel control. The main components of a coordinator are a variable potentiometer, a discriminating device, and a cam-operated switch. A scale calibrated from 0 to 90 degrees attaches to the outside case, and a pointer secures to the main coordinator shaft. Pushrods, connected from the coordinator to a cable sector, transmit power and condition lever movement to the coordinator. Power lever movement through the coordinator changes resistance of the variable potentiometer and changes the temperature datum control temperature reference signal. The cam-operated switch changes the temperature datum control from temperature limiting to temperature controlling with power lever above 66-degree coordinator and engine speed above 94 percent RPM. Power lever movement transmits to the coordinator, propeller, and fuel control through a series of rods and levers. With the condition lever in FEATH, the discriminating device mechanically positions propeller linkage toward feather and closes the fuel shutoff valve, regardless of the power lever setting.

The temperature datum control consists of electronic units that automatically compensate for

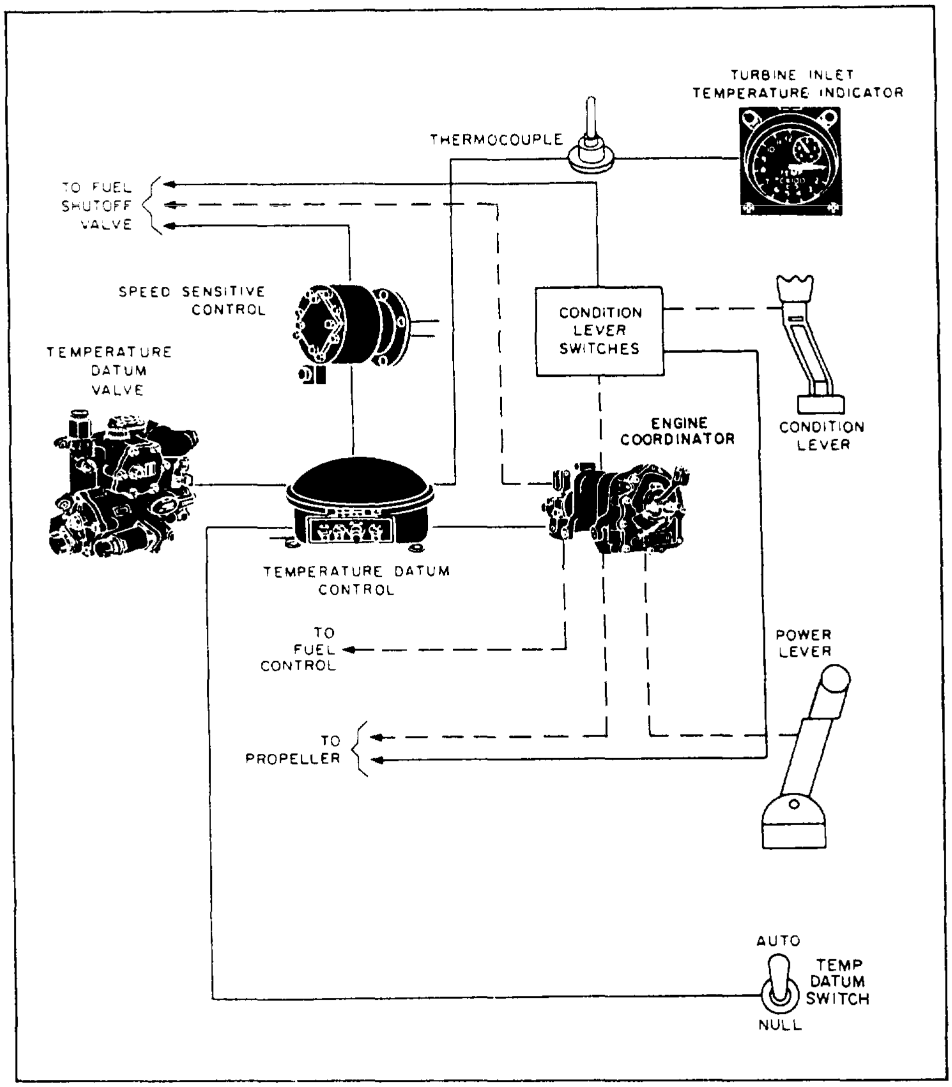


Figure 5-7.-Engine temperature control (turboprop) system block diagram.

changes in fuel density, manufacturing tolerances in fuel controls, and variations in engine fuel requirements between engines. With the power lever above 66-degree coordinator (temperature controlling range) and the TEMP DATUM switch in AUTO, the temperature datum control compares the actual turbine inlet temperature signal and desired temperature reference signal. If there is a difference greater than 1.9°C (4.5°F), the control electrically signals the temperature datum valve to reduce or increase fuel flow to the engine. This action brings the turbine inlet temperature to the desired value. A damping voltage goes back to the control from a generator within the temperature valve motor, preventing overcorrection and stabilizing the system. When engine speed is above 94 percent RPM and the power lever is below 66-degree coordinator (temperature limiting range), the normal limiting temperature automatically becomes 978°C (1,792°F). However, when engine speed is below 94 percent RPM, regardless of power lever position, the limiting temperature is 830°C (1,524°F). This prevents high turbine inlet temperature during starting and acceleration when the compressor bleed valves are open.

Dual-unit thermocouples are mounted radially in the turbine inlet case of each engine. The junction portion of the thermocouples protrudes through the case to sense the gas temperature before the gas enters the turbine section. Four leads, two of Chromel and two of Alumel, connect to each thermocouple to form two independent parallel circuits. One circuit connects to the cockpit turbine inlet temperature indicator. The second circuit supplies the temperature datum control with temperature signals for the electronic fuel trimming circuit. As the gases heat the thermocouples, they generate an electromotive force that goes to the cockpit indicator and the temperature datum control. Because the thermocouple connections are in parallel, the signal they send is the average temperature of the thermocouples. If one parallel circuit fails, the other circuit continues to operate normally.

TEMPERATURE DATUM SWITCHES

The left and right engine temperature datum (TEMP DATUM) switches are on the engine control panel in the cockpit. Each switch has AUTO and NULL positions. When the switch is in AUTO, the engine RPM is above 94 percent, and the engine coordinator is above 66 degrees, the temperature datum control compares the turbine inlet temperature to a reference temperature. If the temperatures differ, the temperature datum control electrically signals the temperature datum valve to bypass more or less fuel from the engine to bring turbine inlet temperature to the selected value.

If the electronic fuel trimming circuit malfunctions, position the TEMP DATUM switch to NULL. The circuit de-energizes and the fuel control, through movement of the power lever, controls turbine inlet temperature. Overtemperature protection is not available.

REVIEW SUBSET NUMBER 3

Q1. List the four positions of the E-2 aircraft condition lever.

Q2. When is the temperature datum control in the temperature controlling range?

Q3. At what RPM is the engine limiting temperature 830°C?

Q4. Thermocouple leads are made of ______ ______________________________.

Q5. List the main components of an engine coordinator.

ENGINE START CONTROL SYSTEM

Learning Objective: *Recognize operating parameters and characteristics of aircraft engine starting systems.*

In this section, you will learn about engine starting, engine ignition, and engine fuel temperature starting systems. By combining these systems, you will understand how they interrelate. The engine start control system covered in this section is the one found in the P-3C aircraft.

MAJOR COMPONENTS

Major components of the engine start control system include the air turbine starter, the speed-sensitive control, the ignition exciter, the engine fuel pump and filter, the fuel control, the fuel nozzles, the fuel control relay, the starting fuel enrichment valve, the temperature datum valve, the drain valves, and the compressor bleed air valves. You should refer to figure 5-8 and to table 5-1 as you read about these components.

Air Turbine Starter

You have learned that the air turbine starter is pneumatically driven and mechanically connected to the engine through a gearbox. The air turbine starter operates on compressed air from an external gas turbine compressor (GTC), internal auxiliary power unit (APU), or bleed air from an operating engine. The compressed air goes through a manifold, an engine isolation bleed air valve, and a starter control valve into the starter's turbine. The engine start switch, located in the cockpit, controls the opening of the starter control valve, which allows compressed air to enter the air turbine starter. The speed sensitive control, through a holding solenoid, holds the engine start switch on until engine speed reaches 65 percent RPM.

Speed-Sensitive Control

The speed-sensitive control, located on the engine, contains internal switches that activate at three predetermined intervals. These intervals are relative to the engine's normal speed—16 percent, 65 percent, and 94 percent of engine RPM. Activation of these switches controls many operations in the engine start cycle.

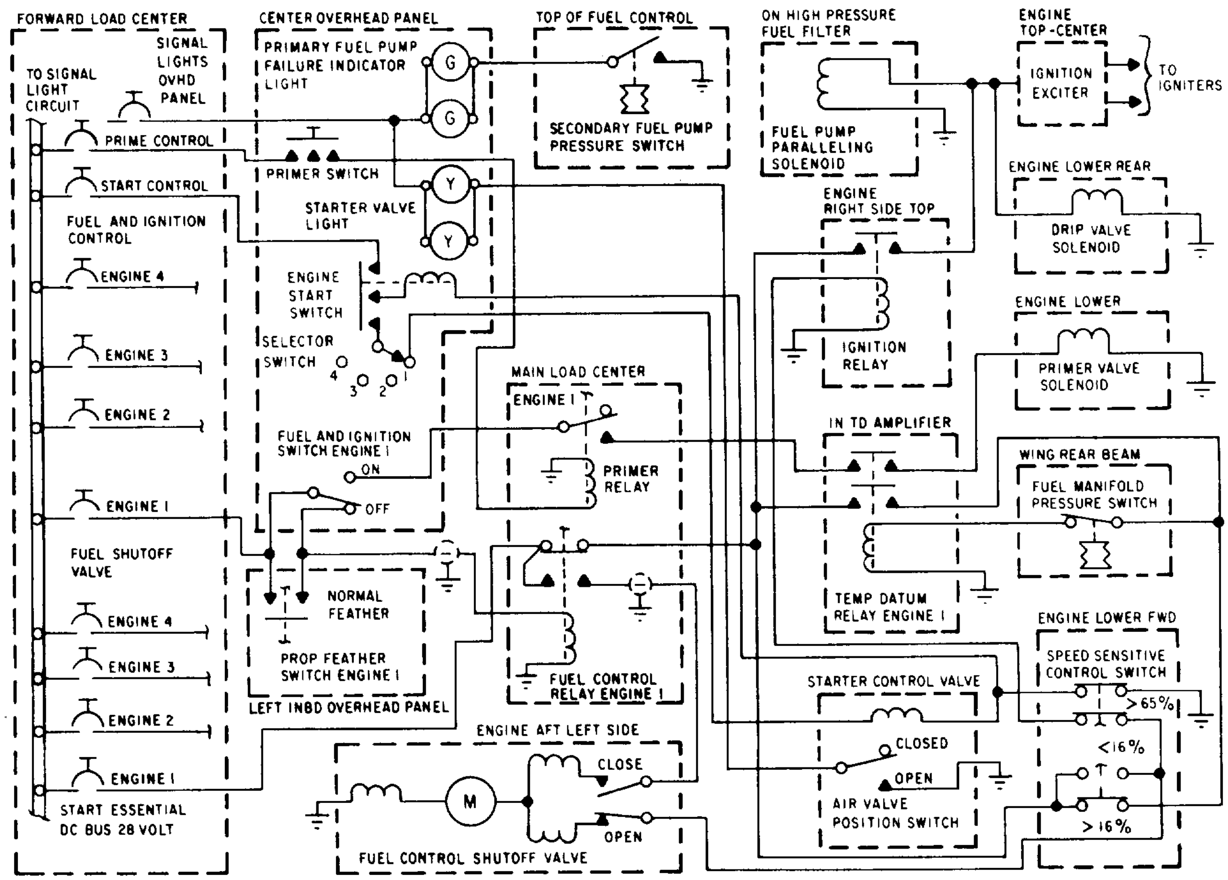


Figure 5-8.-Engine start control system.

Ignition Exciter

The ignition exciter (discussed earlier) is a dual electronic ignition unit that uses 28-volt dc from the ignition relay. The exciter then steps up the voltage to a proper level for firing the igniter plugs. The exciter unit contains two identical circuits, each one independently capable of firing its own igniter plug. The speed-sensitive control energizes the ignition relay so the exciter is in operation between 16 and 65 percent of engine RPM.

Engine Fuel Pump and Filter

The fuel pump and high-pressure filter assembly mount on the rear of the accessories case. This assembly consists of a centrifugal boost pump, two gear-type pressure elements, and a high-pressure filter.

Fuel entering the pump assembly passes through the centrifugal boost pump, which raises the pressure to a minimum value. Fuel passes through the low-pressure filters before going to the secondary element. There is a differential pressure switch connected across the inlet and outlet of the filters. If the pressure differential exceeds 7.5 PSI, the switch closes and completes a circuit to a filter light at the flight deck. Fuel then flows to the primary element and through the high-pressure filter assembly before entering the fuel control. Both the low- and high-pressure filters have bypass valves that open if the filters become clogged.

The capacity of the pump's primary element is 10 percent greater than that of the secondary element. If the primary element were to fail, the secondary element would provide enough flow to operate the engine.

During engine starting, the elements operate in parallel to provide enough fuel flow at low RPM; above 65 percent, they operate in series. Parallel operation occurs during starting when engine speed is between 16 percent and 65 percent

Table 5-1.—Engine Starting Sequence

		16%		65%	94%
ENGINE RPM	*0%* *10%*	*20%*	*30%* *40%* *50%* *60%*	*70%* *80%* *90%*	*100%*
STARTER	CRANKING ENGINE			NOT CRANKING ENGINE	
STARTER CONTROL VALVE	ENERGIZED			DE-ENERGIZED	
FUEL CONTROL SHUTOFF VALVE	DE-ENERGIZED	ENER-GIZED	DE-ENERGIZED		
FUEL FLOW TO FUEL NOZZLES	NO	YES			
IGNITION RELAY	DE-ENERGIZED	ENERGIZED		DE-ENERGIZED	
IGNITION EXCITER	DE-ENERGIZED	ENERGIZED		DE-ENERGIZED	
MANIFOLD DRAIN VALVE SOLENOID	DE-ENERGIZED	ENERGIZED		DE-ENERGIZED	
MANIFOLD DRAIN VALVE	OPEN	CLOSED BY SOLENOID AND HELD CLOSED BY FUEL PRESSURE			
PARALLELING VALVE SOLENOID	DE-ENERGIZED	ENERGIZED		DE-ENERGIZED	
PARALLELING VALVE	OPEN	CLOSED		OPEN	
FUEL PUMP OPERATION	SERIES	PARALLEL		SERIES	
PARALLELING LIGHT	OFF	ON, WHEN SECONDARY PRESSURE EXCEEDS 150 PSIG		OFF	
ENRICHMENT VALVE SOLENOID	DE-ENERGIZED	ENER-GIZED	DE-ENERGIZED		
ENRICHMENT VALVE	CLOSED	OPEN	OPENED BY SOLDENOID AND CLOSED WHEN FUEL PRESSURE EXCEEDS 50 PSIG		
T.D. VALVE TAKE SOLENOID		ENERGIZED			DE-ENER-GIZED
%TAKE POSSIBLE		50%			20%
TEMP. LIMIT†		START LIMIT 830°C			1083°C
5TH & 10TH STAGE BLEED AIR VALVES		OPEN			CLOSED

RPM, If both elements are operating properly, the paralleling light will be on between 16 percent and 65 percent RPM only. If the secondary element fails, the light never comes on; if the primary element fails, the light is on above 65 percent RPM.

Fuel Control

The fuel control is on the accessories drive housing and mechanically links to the coordinator. The fuel control provides a starting fuel flow schedule that, in conjunction with the temperature datum valve, prevents overtemperature and compressor surge.

The fuel control schedule is 20 percent richer than the nominal engine requirements to accommodate the temperature datum valve. The valve bypasses 20 percent of the control output when in the null position. This excess flow gives the temperature datum valve the capacity to add as well as subtract fuel. The valve is then able to maintain the temperature scheduled by the coordinator and the temperature datum control.

The fuel control includes a cutoff valve for stopping fuel flow to the engine. It actuates either manually or electrically. During engine starts, the cutoff valve remains closed until the engine reaches 16 percent RPM. The speed-sensitive control then opens the cutoff valve, permitting fuel to flow to the engine.

Fuel Nozzles

The fuel output from the temperature datum valve flows through the fuel manifold to the six fuel nozzles. Fuel flows through both the primary and secondary nozzle orifices during normal operation. At low fuel flow rates, fuel flows through the primary orifice only.

Fuel Control Relay

The fuel control relay is a fail-safe-type relay that energizes when the FUEL and IGNITION switch is off, or when the propeller is feathered. With this arrangement, the engine can still operate with an electrical power failure during flight. The pilot shuts the engine down by placing the FUEL and IGNITION switch in the OFF position, or by feathering the propeller. Power then goes to the fuel control shutoff valve, which closes and stops all fuel to the engine.

Starting Fuel Enrichment Valve

The primer switch (with two positions, ON and spring-loaded OFF) operates the fuel enrichment valve, providing increased fuel flow during engine starting. The primer switch must be in the ON position and held there before the engine reaches 16 percent RPM. Further, it must remain on until the fuel control shutoff valve opens at 16 percent RPM or enrichment will not occur. The enrichment (primer) valve closes when fuel pressure in the fuel manifold reaches 50 PSI. Fuel enrichment is needed only in very cold climates.

Temperature Datum Valve

The temperature datum valve is located between the fuel control and the fuel nozzles. It is a motor-operated bypass valve that responds to signals from the temperature datum control. If the power lever positions are between 0 degrees and 66 degrees, the valve remains in null and the engine operates on the fuel flow scheduled by the fuel control. The valve remains in null unless the temperature datum control signals it to limit turbine inlet temperature. The valve then reduces the fuel flow (up to 50 percent during starting, 20 percent above 94 percent RPM) by returning the excess to the fuel pump. When turbine inlet temperature is at the desired level, the temperature datum control signals the valve to return to the null position.

In power lever positions between 66 degrees and 90 degrees, the temperature datum valve acts to control turbine inlet temperature to a preselected schedule corresponding to power lever position. This is the temperature controlling range. In this range the temperature datum control may signal the valve to allow more (higher temperature desired) or allow less (lower temperature desired) fuel to flow.

Drain Valves

A spring-loaded, solenoid-operated manifold drain valve is located at the bottom of the fuel manifold. It drains the fuel manifold when fuel pressure drops below 8 to 10 PSI. This action minimizes the amount of fuel dropping into the combustion liners while the engine unit is being stopped.

Compressor Bleed Air Valves

The fifth and tenth bleed air valves release air from the compressor to reduce the compressor load during engine starts. During starting, the bleed valves are open up to 94 percent RPM. At 94 percent RPM, the speed-sensitive valve ports compressor-discharge air to close the bleed valves.

ENGINE START CYCLE OPERATION

The following sequence of events is typical of a normal engine start cycle. While reading this section, you should assume that external compressed air and electrical power are being applied to the aircraft. Also, assume that all other system switches are in the proper position for an engine start. Refer to figure 5-8 and table 5-1 throughout this discussion.

The operator places the ENGINE START SELECTOR switch to the engine number 1 position. Position FUEL and IGNITION switch, engine 1 to the ON position, de-energizing the fuel control relay. This allows power to pass through the contacts of the fuel control relay, the 16 percent speed-sensitive control switch, and the fuel manifold pressure switch to energize the temperature datum relay.

When the operator depresses the ENGINE START switch, the current flows through the engine start switch, engine start selector switch, starter control valve, and speed-sensitive control 65 percent switch to ground. Current also flows through the engine start switch holding coil to ground through the same 65 percent switch in the speed-sensitive control.

With power applied to the starter control valve, the valve opens. This allows compressed air to flow to the air turbine starter. It also closes the contacts of the air valve position switch. The yellow starter valve lights illuminate to show the operator the starter control valve is open. The air turbine starter now causes engine rotation.

If fuel enrichment is needed, depress the PRIMER switch and hold in the ON position until the engine reaches 16 percent. Power then goes through the primer relay contacts and the temperature datum relay contacts, energizing the primer valve solenoid.

When the engine reaches 16 percent RPM, the speed-sensitive control mechanically actuates the 16 percent switch from 16 percent to 65 percent. Power then goes through the 16 percent switch contacts, energizing the ignition relay. Power then flows through the ignition relay contacts, energizing the fuel pump paralleling solenoid, the drip valve solenoid, and the ignition exciter. Power also goes to the fuel control shutoff valve, allowing fuel to enter the engine fuel manifold. Extra fuel for fuel enrichment (if used) flows to the temperature datum valve. The temperature datum relay remains energized by a holding circuit consisting of the lower temperature datum relay contacts and the fuel manifold pressure switch.

As engine speed increases, the fuel pressure increases. When fuel manifold pressure reaches 50 PSIG, the fuel manifold pressure switch opens, de-energizing the temperature datum relay, stopping fuel enrichment. When the secondary fuel-pump pressure exceeds 150 PSIG, a paralleling light illuminates showing parallel operation of the fuel pumps to the operator.

At 65 percent RPM, the speed-sensitive control 65 percent switches open to de-energize the ignition relay. The ignition relay removes power from the ignition exciter, the fuel pump paralleling solenoid, and the drip valve solenoid. The fuel pumps now operate in series, and fuel pressure now holds the drip valves closed. The starter control valve and the engine start switch lose their common ground, and current flow ceases through those circuits. The starter control valve closes, stopping airflow to the air turbine starter, and the engine start switch opens. The air valve position switch opens, causing the starter control valve light to go out. This completes the engine start cycle.

When engine speed increases above 94 percent, contacts in the speed-sensitive control (circuit not shown) de-energize the temperature datum valve take solenoid. This reduces the fuel take capability from 50 percent to 20 percent. The fifth and tenth stage bleed air valves also close now. When the power lever advances above 66 degrees of coordinator travel, the temperature datum system switches from temperature limiting range to temperature controlling.

REVIEW SUBSET NUMBER 4

Q1. During a P-3 engine start, at what percent RPM does the start control switch re-energize?

Q2. What are the three switches in the speed-sensitive control?

Q3. How much greater is the capacity of the primary pump than the secondary pump?

Q4. Why is the fuel control schedule 20 percent richer than nominal engine requirements?

Q5. What unit minimizes the amount of fuel dropping into the combustion liners during engine shutdown?

POWER PLANT ANTI-ICING AND DEICING SYSTEMS

Learning Objective: *Recognize operating principles and characteristics of aircraft power plant anti-icing and deicing systems.*

Naval aircraft deicing lets you fly in any type of weather. When there is enough moisture in the air and you encounter freezing temperatures, you must protect the power plant against ice buildup. There are two electrical systems that do this—the anti-icing and deicing systems. Anti-icing systems prevent ice from forming and deicing systems remove ice that has already accumulated.

Many types of anti-icing systems are used today. All systems use heated air from the engine to perform the anti-icing function. The use of heated air causes engine power loss; so use anti-icing only when necessary. In some aircraft, a reversible electric motor opens and closes an air valve to supply the needed air. In other aircraft, an electrical solenoid positions a pneumatic valve to allow regulated heated air into the engine anti-ice system.

Where the mission of the aircraft dictates that it fly routinely in adverse weather conditions, a fail-safe anti-ice system is used. Fail safe means the solenoid-actuated air valve electrically actuates closed. If the switch is turned on, or if electrical power fails, the valve is spring loaded to the open position. Some systems anti-ice the complete inlet duct; while in other systems, only the guide vanes are anti-iced.

GUIDE VANE ANTI-ICING SYSTEM

There are a variety of engine anti-icing systems in use today. The system covered in this TRAMAN is representative of several systems designed for Navy aircraft. Look at figure 5-9. Here, you see that the electrical portion of the circuit serves only to turn the system on or off.

The guide vanes of a turbine-powered engine direct the flow of inlet air into the compressor section. At this point, the air is coldest and most subject to icing. The biggest problem caused by ice forming here is blockage of inlet air, causing air starvation and thus engine failure. Also, there is a possibility that chunks of ice can be inducted into the engine. Therefore, turn on the anti-icing system at the first indication of any icing condition or before entering an icing condition. Normally, icing doesn't occur in supersonic flight because friction of the aircraft passing through the air creates enough heat to prevent ice formation.

The anti-icing valve is a solenoid-operated bleed valve. With no electrical input to the solenoid, the bleed valve closes, and there is no anti-icing airflow through the valve. When the engine is operating with the valve solenoid de-energized, the main poppet will remain in the closed position. When the solenoid energizes, the solenoid valve unseats and permits air pressure within the main poppet to escape through the overboard vent.

With pressure decreasing in the poppet valve body, inlet pressure on the main poppet valve face overcomes spring tension and raises the valve from its seat. This permits high-pressure air to discharge through the outlet of the valve to the anti-icing manifold on the engine. The regulating piston and spring valve assembly control discharge air from the anti-icing valve to a preset pressure.

PROPELLER DEICING SYSTEMS

One method of preventing excessive accumulation of ice on the propeller blades of turboprop or reciprocating engines is using electric heaters. Figure 5-10 is a simplified schematic diagram of a system for a two-engine aircraft.

The propeller deicing system consists of a three-position, two-speed selector switch (propeller deicer switch) and an indicator light, a two-speed timer, and two propeller deicer relays (one for each propeller). Also, included (for each propeller) are the brush pad bracket assembly, slip-ring assembly, the aft portion of the propeller assembly, and a neoprene rubber heating element and connector for each blade. Abrasion strips protect the blade heaters. The deicing system operates at either a slow cycle of 40-75 seconds on, 120-225 seconds off; or a fast cycle of 17-22

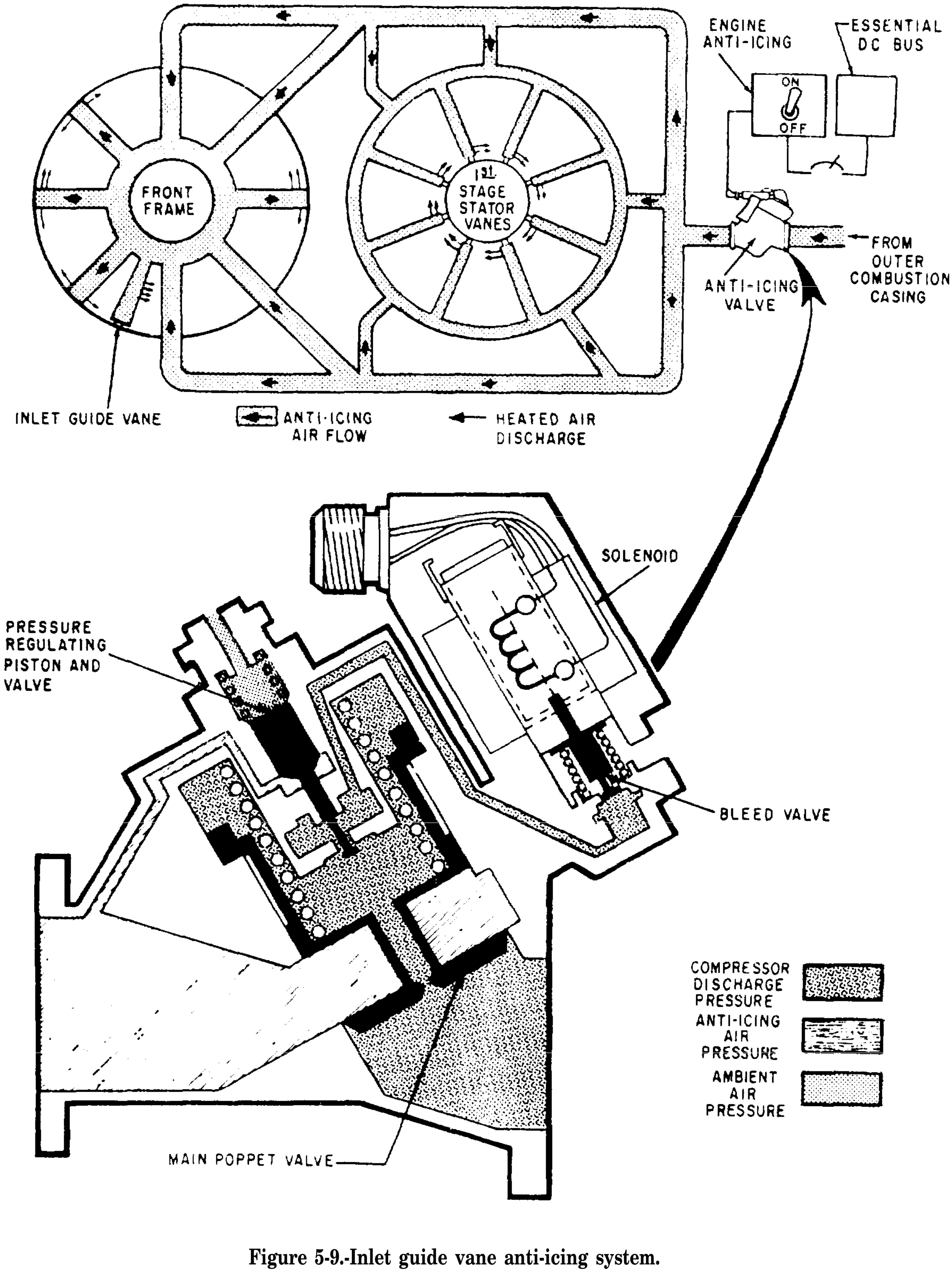


Figure 5-9.-Inlet guide vane anti-icing system.

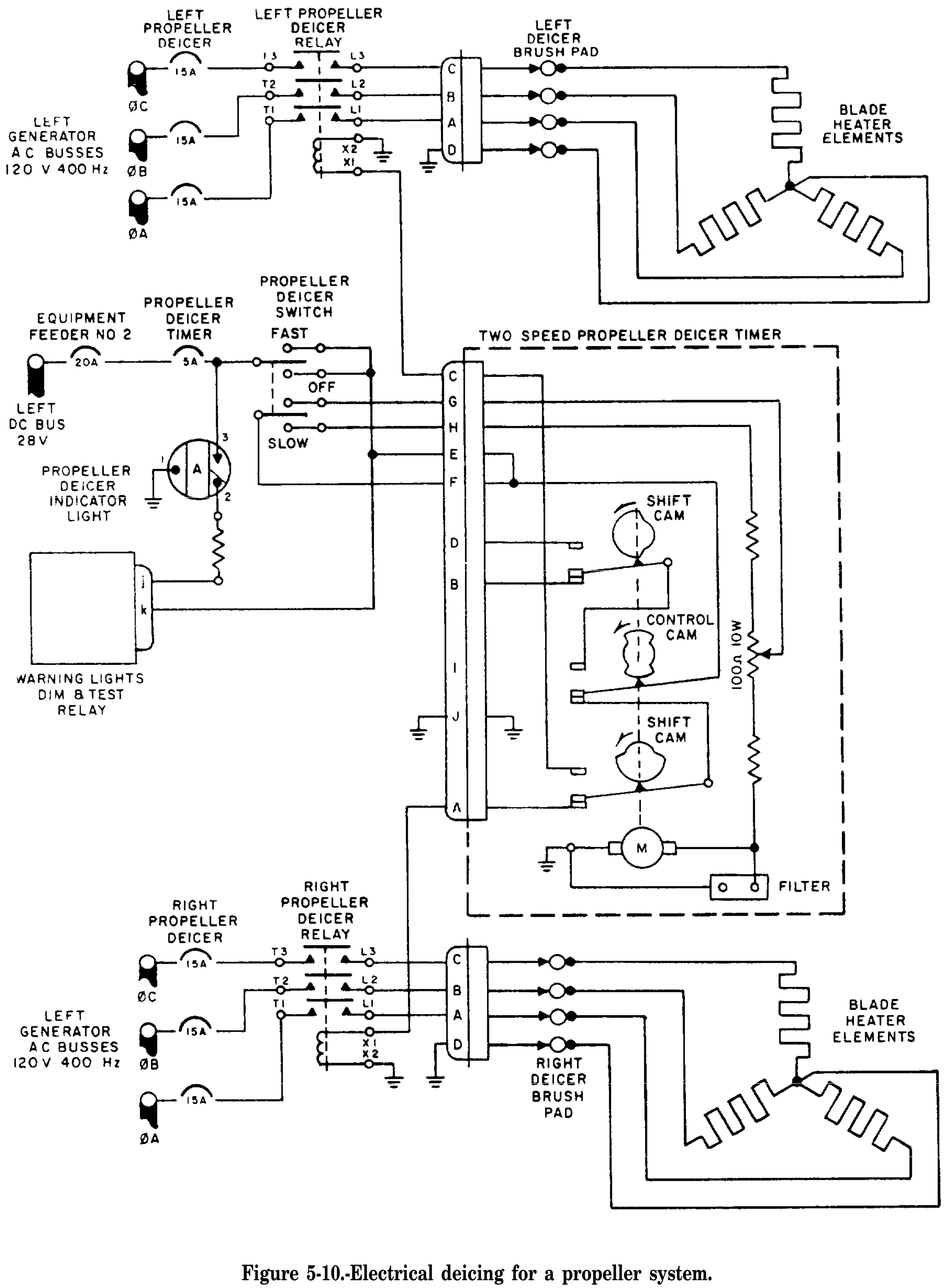


Figure 5-10.-Electrical deicing for a propeller system.

seconds on, 51-66 seconds off. The icing conditions during flight determine the switch position.

Setting the selector switch to SLOW or FAST permits dc power from the essential bus to energize the deicer timer motor and turn on the indicator light. Resistances in the timer determine the speed of the timer motor. The motor, through reduction gears, causes the camshaft to rotate. This rotation positions the cam switches alternately between the right and left contacts. Current flows through these contacts to cycle their respective propeller deicer relays. With the relays being energized alternately, current from the three-phase generator ac buses, through propeller deicer circuit breakers, flows to the propeller brush pad bracket assemblies. Carbon brushes contact the copper slip rings, transmitting ac power through the slip rings to the blade heating elements. Placing the selector switch in the OFF position stops the propeller deicing operation, and the indicator light goes out.

The propeller deice timer is a two-speed, automatically controlled timer. It regulates, in cycles, the time duration and sequence of electrical impulses to the propeller blade heating elements. The unit is located in a moistureproof, airtight case, which isolates the unit from temperature extremes and vibration. The deice timer consists of a fractional horsepower, constant-speed dc motor, including reduction gear, camshaft with three cams, three cam switches, two fixed resistors, and variable resistor. The unit also includes a filter to minimize radio interference.

With the propeller deice switch set to FAST, direct current flows from the left dc bus, through the propeller deicer circuit breaker and switch, to the timer. This current follows two paths in the timer. One path, from pins E and F that connect in the timer, directs the current flow to the control cam switch. The other path, from pin G, directs the flow through the variable resistor and one fixed resistor to the timer motor, the filter, and to ground. The adjustment of the variable resistor determines the speed of the motor. The motor, through the 3,000 to 1 reduction gear, rotates the camshaft and cams. Two single-lobed shift cams and a single two-lobed control cam are on the camshaft. Positioning on the camshaft is so the two single-lobed shift cams are on either side of the two-lobed control cam. As the control cam rotates, it alternately makes and breaks its right and left cam switch contacts. This permits the flow of current to the shift cam switches. As the current flows to the other cam switch, rotation of the single-lobed cam makes and breaks the shift cam switch contacts. This action cycles first the right and then the left propeller deicer relays.

With the propeller deicer switch set to SLOW, the operation is the same as the fast cycle with the one exception. Direct current enters the timer through a different pin (pin H) in the plug and flows through the two fixed resistors and the variable resistor to the motor. (Dc power to the control cam switch is through the same pins as for the fast cycle.) Because of the increase in resistance, the motor operates at a slower speed. Thus, with motor speed reduction, rotation of the camshaft, through the reduction gear, is slower, and the timer now functions at the slower cycle.

Several aircraft have an anti-icing and deicing system that prevents the formation of ice (anti-icing) on the forward portion of the propeller spinner. The system removes any ice formation (deicing) from the blades and cuffs, aft portion of the spinner, and spinner islands. This system operates similarly to the system described previously, except that the anti-icing elements are on continuously and the deicing elements cycle. Figure 5-11 shows the location of the heating elements. The system usually contains a safety feature for testing the propellers on the ground. This feature provides a low voltage to the heating elements, which prevents damage to the prop from overheating.

REVIEW SUBSET NUMBER 5

Q1. In supersonic flight, icing doesn't occur for what reason?

Q2. What are the two types of anti-icing/deicing systems used on aircraft?

Q3. At what point in the engine is the air the coldest and most likely to ice?

Q4. What is the difference between propeller deicing and anti-icing?

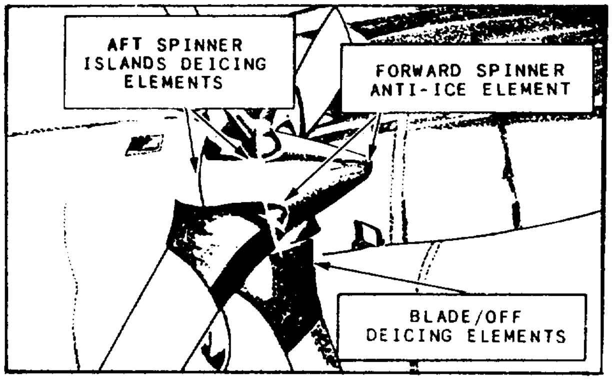


Figure 5-11.-Propeller heating elements.

FIRE WARNING AND EXTINGUISHING SYSTEMS

Learning Objective: *Recognize operating conditions and characteristics of aircraft engine fire warning and extinguishing systems.*

Some turbine engines operate at temperatures of more than 1,000°C. Fuel and oil lines run with in a few inches of these extreme temperatures. For this reason, you must closely monitor the engine, and immediately take corrective action when an abnormal condition occurs. Performance of precision work is necessary when maintaining fire warning systems to ensure their reliability. An undetected fire may cost the lives of the aircrew and possibly millions of dollars in aircraft and equipment.

In multiengined aircraft, a fire warning usually dictates that the engine be shut down and the fire extinguished. The least that can happen if there is an erroneous fire warning is the aircraft will abort its assigned mission.

WARNING SYSTEM

The engine fire detector system is an electrical system for detecting the presence of fire or dangerously high temperatures in the engine(s) areas. The system for each engine consists of a control unit, test relay, signal lamp, test switch, and several sensing elements. The detect or uses a continuous strip of temperature-sensing elements to cover the paths of airflow in the engine compartment. The same engine fire warning systems are in multiengined aircraft, one for each engine.

Look at figure 5-12. It shows the electrical schematic for a fire warning system that is

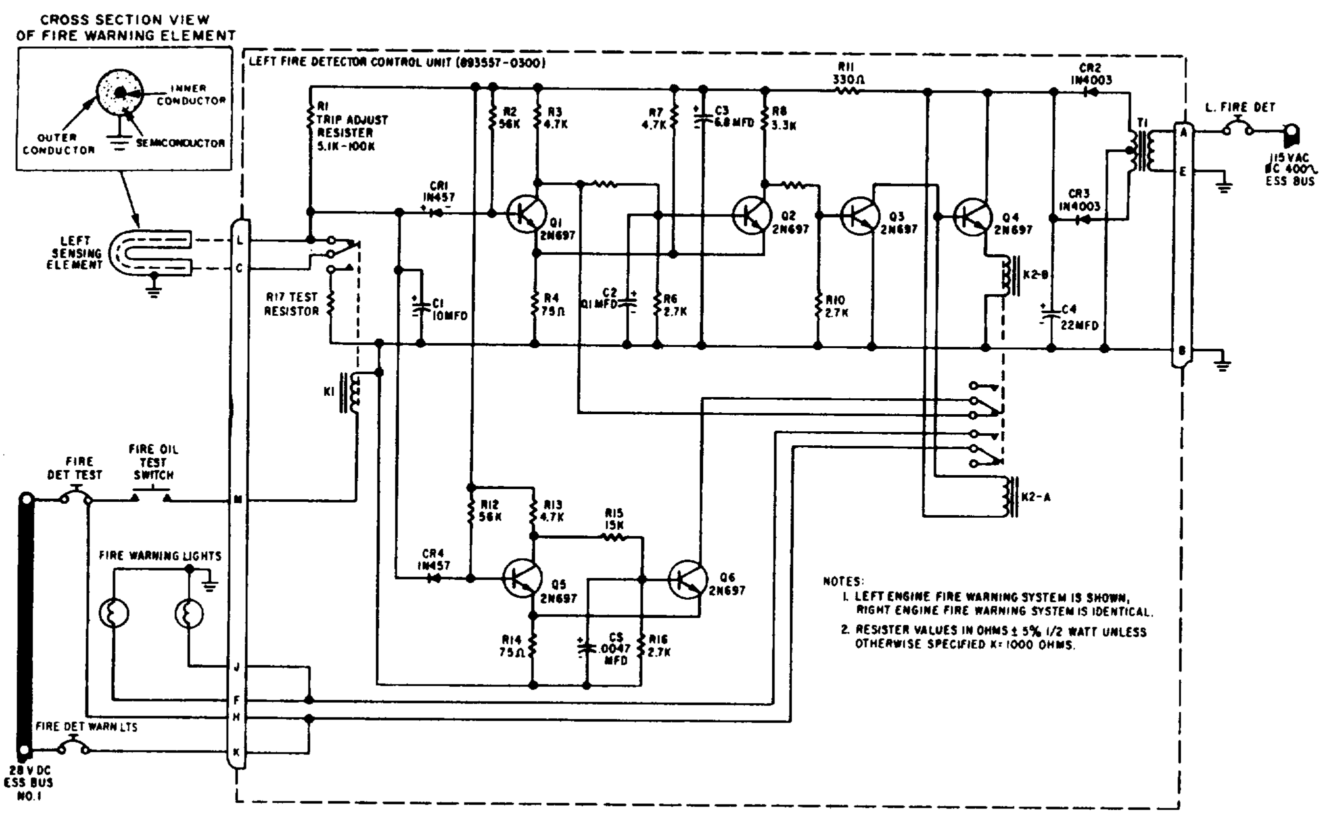


Figure 5-12.-Typical engine fire warning circuit schematic.

representative of systems found in modern Navy aircraft. The system is of the continuous-element, resetting type. The sensing element consists of two conductors separated by a semiconductor. The outer conductor is at ground potential, and the center conductor connects to an amplifier input in the fire detector control unit. The semiconductor portion of the element has an inverse temperature coefficient; as the temperature increases, the resistance of the sensing element decreases.

The fire detector control unit continuously monitors the electrical resistance of the fire detector system's sensing element. The control unit activates a fire warning light (in some units an audible warning is also given) when one of the following conditions exist:

1. The sensing element resistance decreases to the predetermined level (established by the fire alarm setting) due to an increase in temperature.
2. The sensing element resistance decreases at a predetermined rate due to the rate of temperature increase in the sensing element.

NOTE: In the past, flights have aborted and crewmen actually ejected because of a fire warning light illumination caused by a short circuit in the system. Modern aircraft fire warning systems have a short discriminator circuit that differentiates between an overtemp (fire) and a short circuit. If there is a short in this system, the fire warning light will NOT illuminate.

The rest of this section contains a description of a dual jet engine aircraft fire warning system. Both systems operate identically and are similar in operation to fire warning systems found on other Navy aircraft. The left side is discussed in this section.

Look at figure 5-12. Electrical power from the L FIRE DET circuit breaker supplies the left fire detector and sensing element circuit through pin A of the detector control unit. The left fire-sensing element loop connects to pins L and C of the detector control unit. This completes the sensing circuit through normally closed contacts of the de-energized relay K1. At normal temperatures, the sensing element resistance is high, reverse-biasing diode CR1. This allows current through resistor R2 to turn transistor Q1 on. With Q1 on, the base current at Q2 is shut off, turning Q2 off. With Q2 off, the current flows into the base of Q3. This turns Q3 on and Q4 off. Transistors Q3 and Q4 are relay-driving. With Q3 on, relay coil K2-A energizes, opening K2 contacts, de-energizing the warning circuit and turning out the L FIRE warning indicator lights. Normal temperature conditions energize relay coil K2-A.

When the temperature rises, the sensing element resistance decreases, shunting the current from resistor R2 through diode CR1, turning transistor Q1 off. This switches transistor Q2 on, transistor Q3 off, and transistor Q4 on. With transistor Q4 on, relay coil K2-B energizes, and relay coil K2-A de-energizes. This transfers (switches) contacts of relay K2, energizing the warning circuit. Then, 28 volts of dc powers the warning circuit through pin K of the detector, turning on the L FIRE warning indicator lights. If the temperature drops, the warning circuit de-energizes, causing the fire warning indicator lights to go out.

Transistors Q5 and Q6 make up the short discriminator circuit. Its principle of operation works on the rate of change of sensor resistance. In a fire, the resistance rate of change is slow. In an electrical short condition, the resistance rate drops abruptly. There are two timing circuits—one is made up of resistors R5 and R6 and capacitor C2, and the other of resistors R15 and R16 and capacitor C5. These circuits are preset. This allows a slow change of sensor resistance to let transistor Q1 switch transistor Q2 before transistor Q5 switches transistor Q6. A fast change of sensor resistance allows transistor Q5 to switch transistor Q6 before transistor Q1 can switch transistor Q2. If transistor Q6 switches first, transistor Q2 is unable to switch. This action holds

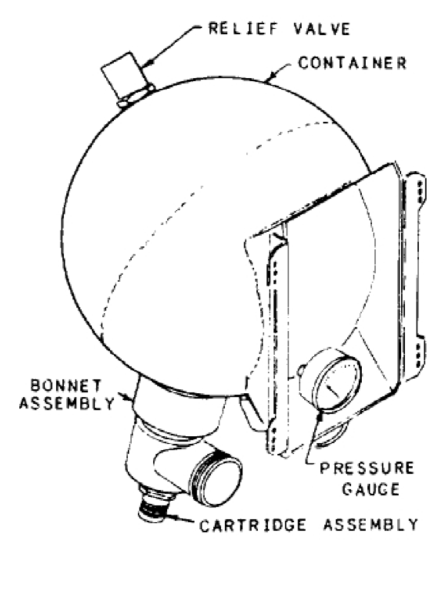


Figure 5-13.-Container and dual valve assembly.

the rest of the circuits in the de-energized (no alarm) condition. If transistor Q2 switches first, the contacts of relay K2-B remove transistor Q6 from the discriminator circuit.

EXTINGUISHING SYSTEM

The fire-extinguishing system on many aircraft provides control for fires within the engines and nacelles. The extinguishing system is an electrically controlled, high rate discharge (HRD) system. Normally, you, the AE, will troubleshoot the HRD system electrical circuits only.

The extinguishing agent container is a welded steel sphere, 9 inches in diameter and cadmium plated for corrosion prevention (fig. 5-13). Each container has a charge of bromotrifluoromethane and is pressurized with nitrogen. Bromotrifluoromethane (CF_3Br in liquid form) is nontoxic and classed as a nonpoison; however, it readily vaporizes, is odorless, and can be harmful. You should handle it carefully. Don't let it come in contact with your skin; frostbite or low-temperature burns may result.

As it leaves the system, vaporization changes the liquid to a gas, displacing the oxygen within the compartment. The lack of oxygen in the compartment won't support combustion or life. Don't enter an area where bromotrifluoromethane has been discharged until it is safe to do so.

Each container has two valve assemblies for discharging the agent. Each valve assembly contains an explosive, electrically controlled cartridge. When a fire-extinguishing discharge switch actuates, it completes a circuit (fig. 5-14). The cartridge electrically fires, allowing the slug to rupture the frangible disk in the neck of the container. When the frangible disk is ruptured, nitrogen pressure expels the extinguishing agent.

CAUTION

The cartridge mentioned in the above paragraph is an explosive device. Use extreme caution when working on or near this device.

Refer to "Cartridge Activated Devices (CADS) Manual," NA 11-100-1. You need to have an ordnance certification before working on this system.

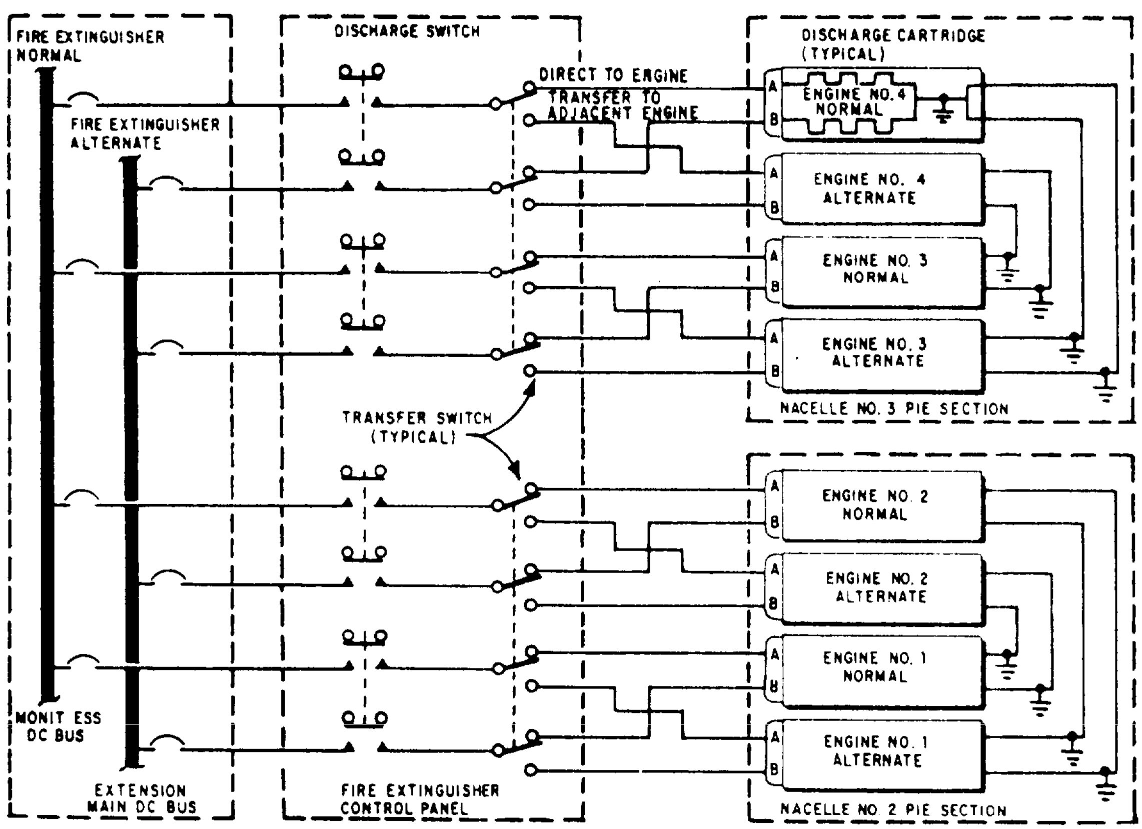


Figure 5-14.-Engine fire-extinguishing circuit schematic.

REVIEW SUBSET NUMBER 6

Q1. The circuit that differentiates between an overtemp (fire} and a short circuit in afire warning system is known as a ________

____________________________________.

Q2. The fire warning element has an inverse temperature coefficient. What does this statement mean?

Q3. In the fire warning circuit (fig. 5-12), what happens when Q6 switches before Q1?

Q4. What chemical is used in the engine extinguishing system HRD bottles?

FUEL TRANSFER SYSTEMS

Learning Objective: *Recognize operating parameters and characteristics of aircraft fuel transfer systems.*

The F/A-18 aircraft fuel transfer system is described in this section of the TRAMAN. The F/A-18 carries fuel internally in four interconnecting fuselage (bladder) tanks and two internal wing (wet) tanks. External fuel is carried in three 315- or 330-gallon tanks. All tanks may be refueled on the ground through a single-point refueling receptacle. Airborne, they can be refueled through the in-flight refueling probe. The internal wing tanks—tank 1 and tank 4—are transfer tanks. The tanks are arranged so internal fuel gravity transfers (at a reduced rate) even if the transfer jet ejectors fail. Regulated engine bleed air pressure is used to transfer fuel from the external tanks and also provides a positive pressure on all internal fuel tanks. Float-type fuel level control valves control fuel level during refueling of all tanks. Fuel level control shutoff valves in tanks 1, 2, 3, and 4 control fuel levels during external fuel transfer. During internal wing transfer, fuel level control shutoff valves control fuel levels in tanks 1 and 4.

Fuel level sensors control the fuel level in tanks 2 and 3 (engine feed tanks) during fuel transfer from tanks 1 and 4. All internal and external fuel (except engine feed tanks) can dump overboard through flame arrester protected outlets in each vertical fin. All internal fuel tanks vent through outlets in the vertical fins. The external tanks vent overboard through pressure relief valves in the individual external tanks. A fuel quantity indicating system provides fuel quantity indications in pounds.

FEED TANKS

The internal transfer system design keeps fuel in the feed tanks (tanks 2 and 3) at all engine power settings. Fuel being transferred from tanks 1 and 4 flows to the feed tanks, where the fuel level is maintained by fuel level sensors.

WING TANKS

Wing tanks transfer fuel to tanks 1 and 4. They are an integral part of the wing structure. Wing tanks are sealed by filling channels with sealant injected through fittings on the outside of the wings.

TRANSFER MOTIVE FLOW

The internal fuel transfer system is powered by motive flow pressure, generated by two airframe-mounted accessory drive-mounted (AMAD) motive flow/boost pumps contained in a closed loop circuit.

Flow pressure passing through the left and right engine motive flow check valves combines to create transfer motive flow pressure. Transfer motive flow pressure operates the wing transfer ejectors and tanks 1 and 4 transfer jet ejectors. Transfer motive flow pressure also closes the refuel/defuel shutoff valve and defuel valve.

WING TRANSFER

Wing transfer starts when the fuel level drops below the high level pilot valves in tanks 1 and/or 4. This opens the fuel level control shutoff valve, allowing the wing transfer jet ejectors to transfer fuel through the refuel/transfer manifold. As the fuel level in the wings drops below the transfer motive flow pilot valves, the wing transfer motive flow shutoff valves close, stopping transfer from the wings. Refuel/transfer check valves in tanks

1 and 4 keep fuel from entering the refuel line and the feed tanks.

As fuel from the hot fuel recirculation system increases wing fuel, the wing motive flow pilot valve and motive flow shutoff valve open, allowing wing transfer. A flapper check valve at each wing ejector inlet prevents transfer from one wing to the other.

Transfer motive flow pressure to each wing ejector is controlled by the normally open wing damage shutoff valve in tank 4. If wing damage occurs, the pilot sets the INTR WING switch to INHIBIT on the cockpit EXT LT control panel. This closes the wing damage shutoff valve, preventing loss of fuel through a wing transfer motive flow line and stopping wing transfer.

If normal wing transfer does not occur, all wing fuel can be gravity transferred to tank 4 with 5 degrees of roll. A check valve in each gravity transfer line prevents reverse flow.

FUSELAGE TRANSFER

Fuselage transfer (transfer from tanks 1 and 4 to tanks 2 and 3) starts when the fuel level sensors open the transfer shutoff valves in tanks 2 and 3.

Fuel flow (transfer) from tanks 1 and 4 transfer jet ejectors enters a fuselage transfer manifold that supplies fuel to a transfer shutoff valve in feed tanks 2 and 3 and to the dump valve. Transfer from the tank 1 or 4 ejector alone is enough to keep both the feed tanks full at maximum engine demand.

When a transfer tank is empty, the transfer pilot valve and transfer shutoff valve close, preventing transfer motive flow pressure from entering the transfer line. Fuel transfer between fuselage transfer tanks is prevented by check valves in the inlets of each transfer jet ejector.

Fuel levels in the feed tanks are maintained by a fuel level sensor and transfer shutoff valve within each feed tank.

If transfer from tanks 1 and 4 to the feed tanks fails, fuel gravity transfers through an always open interconnecting line in the bottom of tank 4 and through an orifice in the interconnect valve in tank 1. If motive flow pressure to either engine fuel boost jet ejector or engine fuel turbine boost pump is interrupted, tanks 2 and 3 fuel gravity feed through the ejector to the engine.

If the left engine shuts down and/or left motive flow boost pressure is lost, the tank 1 and tank 2 pressure-operated interconnect valves open. This allows fuel to gravity feed from tanks 1 and 2 to tank 3. Reverse flow from tank 3 is prevented by a flapper check valve on tank 3 interconnect valve.

If the right engine is shut down and/or right motive flow boost pressure is lost, the tank 3 pressure-operated interconnect valve opens. Tank 4 interconnect line is always open. Fuel gravity feeds from tanks 3 and 4 to tank 2. Reverse flow is prevented by the flapper check valve on tank 2 interconnect valve and tank 3 flapper check valve.

On some series aircraft, motive flow pressure to the tank 1 fuel low-level shutoff and pressure-operated interconnect valve controls gravity feed to tank 2. The fuel low-level shutoff valve energizes closed when fuel in tank 2 is below 700 to 900 pounds. The closed fuel low-level shutoff valve stops motive flow fuel to the pressure-operated interconnect valve, allowing the flapper to swing open. Once the flapper is open, fuel in tank 1 can gravity feed to tank 2. The positions of the tank 2 and tank 3 pressure-operated interconnect valves are tested using the fuel check panel.

CENTER OF GRAVITY (CG) CONTROL SYSTEM

The fuel quantity gauging intermediate device continuously compares the ratio of fuel between tanks 1 and 4. When tank 1 transfers fuel at a faster rate than tank 4, the transfer control valve in tank 1 is energized closed, stopping transfer from tank 1. Tank 1 will not resume transfer until tank 4 transfers (depletes) fuel to within the parameters defined by the intermediate devices. If fuel distribution in tanks 1 and 4 has caused the aircraft CG to be further aft than desired, a CG caution will display on the left digital display indicator.

Once tank 1 depletes below 150 pounds of fuel, the intermediate device will stop monitoring tanks 1 and 4 fuel ratios. Tank 1 will then transfer fuel until the transfer pilot valve closes the shutoff valve.

REVIEW SUBSET NUMBER 7

Q1. In the F-18 fuel transfer system, what fuel tanks feed the engines?

Q2. When does fuel transfer from the wing start?

Q3. When does the fuel transfer center of gravity control system energize?

OIL TEMPERATURE CONTROL SYSTEM

Learning Objective: *Recognize operating principles and characteristics of aircraft engine oil temperature control systems.*

The cooling capacity of the oil cooler system (fig. 5-15) in an aircraft depends on the airflow that passes through the cooler. Airflow is controlled by an oil cooler door actuator, which varies the oil cooler air exit duct.

The door actuator is a split-field, reversible dc motor. It includes a magnetic brake for stopping it quickly when it reaches the limits of travel. The control switch has four positions—OPEN, CLOSE, AUTOMATIC, and OFF. In the OPEN or CLOSE position, electrical power goes to the actuator, which opens or closes the oil cooler door. When the switch is in AUTOMATIC, a thermostat controls the actuator.

The thermostatic control unit is in the oil return line. The unit contains two floating contact arms and a central contact arm that actuates by a bimetallic coil immersed in the oil return line.

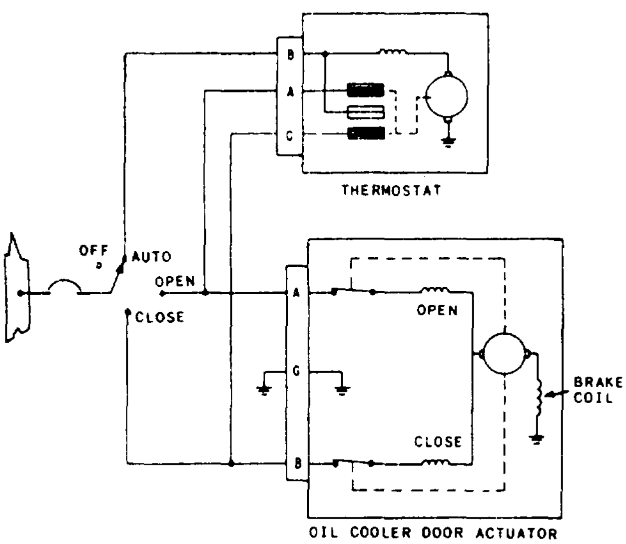


Figure 5-15.-Oil temperature control circuit.

One of the floating contacts is in the door open circuit and the other is in the door closed circuit. The two arms rest on a cam, which a small motor constantly rotates. Thus, the floating contacts are constantly vibrating toward the central contact.

When oil temperature rises above normal, the thermostatic element causes the central contact to move toward the door open contact. As the contact vibrates, it intermittently closes the door open circuit. As the actuator intermittently energizes, the door slowly opens. When the oil temperature returns to normal, the central contact moves back to a neutral position.

When oil temperature falls below normal, the central contact moves in the opposite direction, closing the door. To prevent excessive hunting of the system, a tolerance is maintained by an adjustment of the cam on the floating contact.

When the oil temperature rises high above the normal value, the central contact lifts the floating contact clear of the cam, completing a continuous circuit. The door then moves to the full open position where a limit switch in the actuator breaks the circuit.

Figure 5-16 shows another type of engine oil temperature regulator. This regulator has a mercury-filled thermostat, and relays automatically control the position of the engine oil cooler doors. When the engine temperature is low requiring more heat, the two relays energize, allowing the oil cooler door to close. As the temperature increases, the thermostat completes a path to ground, bypassing the relay coils and de-energizing them. Power then goes through the contact of one of the relays, opening the actuator coil and causing the oil cooler door to open and reduce engine temperature.

VARIABLE EXHAUST NOZZLE CONTROL SYSTEM

Learning Objective: *Recognize operating conditions and features of aircraft engine variable exhaust nozzle control systems.*

As you read this section, refer to the simplified schematic diagram of a typical variable exhaust

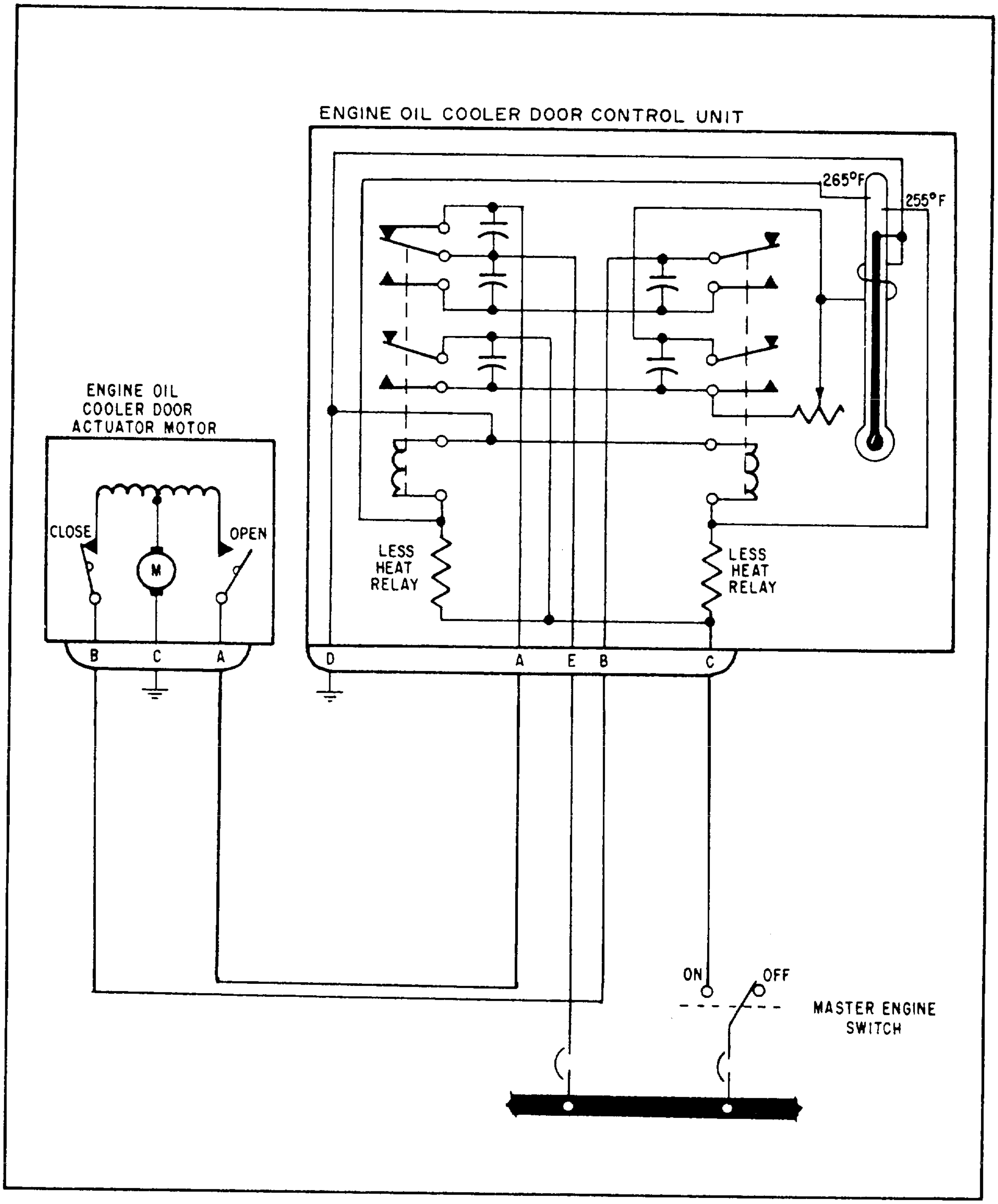


Figure 5-16.-Automatic oil temperature control circuit.

nozzle (VEN) control system (fig. 5-17). This is the control system for the F-18 aircraft, and it is a converging-diverging nozzle system. When operating, this system varies the exhaust escape area size to obtain desired thrust, while maintaining safe operating conditions throughout the engine. The VEN control system consists of electrical, hydraulic, and mechanical components that position the VEN while maintaining exhaust gas temperature (EGT).

MAJOR COMPONENTS

The VEN control system has nine major components. As you read about these components, locate each component in figure 5-17 as you read about it in the text.

VEN power unit. The VEN power unit provides hydraulic power to actuators for positioning the VEN area.

Main fuel control (MFC). The MFC provides a regulated flow of fuel to the fuel nozzles.

Electrical control assembly (ECA). The ECA computes, schedules, and controls engine operation.

Fan speed transmitters. The transmitters are eddy-current sensors mounted in line with the second stage fan blades. A permanent magnet, rotating at the RPM of the fan blades, induces a voltage into a coil indicative of the fan speed.

Afterburner control (ABC). The ABC schedules fuel to the afterburner pilot and main spray bars.

Afterburner (AB) flame sensor. This sensor provides an electrical signal to the ECA. This signal must coincide with the AB no-light/light condition to start the afterburner.

Thermocouple harness. This device senses the exhaust gas temperature (EGT).

VEN position transmitter. The transmitter provides feedback to the ECA to ensure the VEN is in the correct position. It also gives feedback to the engine monitor indicator (EMI) to indicate percent of nozzle position.

VEN actuators. These actuators hydraulically operate to position the VEN.

OPERATING PRINCIPLES

The VEN schedule is in response to movement of the throttle. Throttle setting repositions the power lever angle (PLA) cam in the MFC, providing a linear variable differential transformer (LVDT) signal to the ECA. The ECA biases the VEN area schedule according to inputs from the following sources:

- Fan inlet temperature transmitter
- Air data computer (ADC) ambient pressure
- Fan/low-pressure turbine speed
- Compressor/high-pressure turbine speed
- Main fuel control metering valve
- LVDT
- Afterburner control metering valve
- Afterburner flame sensor
- Afterburner permission signal
- Thermocouples
- VEN area position transmitter
- AB permission switch

The VEN area closes when the engine shuts down and the throttle is in the off position. As the throttle is moved to the idle position, the VEN area rapidly moves to an almost full open position. This aids engine starting and lowers engine thrust, allowing higher idle speeds and reducing engine acceleration time. As the throttle advances past the idle position, the VEN area schedule closes the VEN area, increasing thrust. As the VEN area decreases, EGT increases.

The ECA adjusts the VEN area for varying atmospheric conditions. When the ECA receives an ambient pressure signal from the air data computer, it means the aircraft is at a pressure altitude of 9,000 feet or greater. The ECA now increases low-pressure turbine discharge temperature and fan/low-pressure turbine speed limits, providing more thrust.

Below 4,000 feet pressure altitude, the schedules trim back to reduce fuel consumption

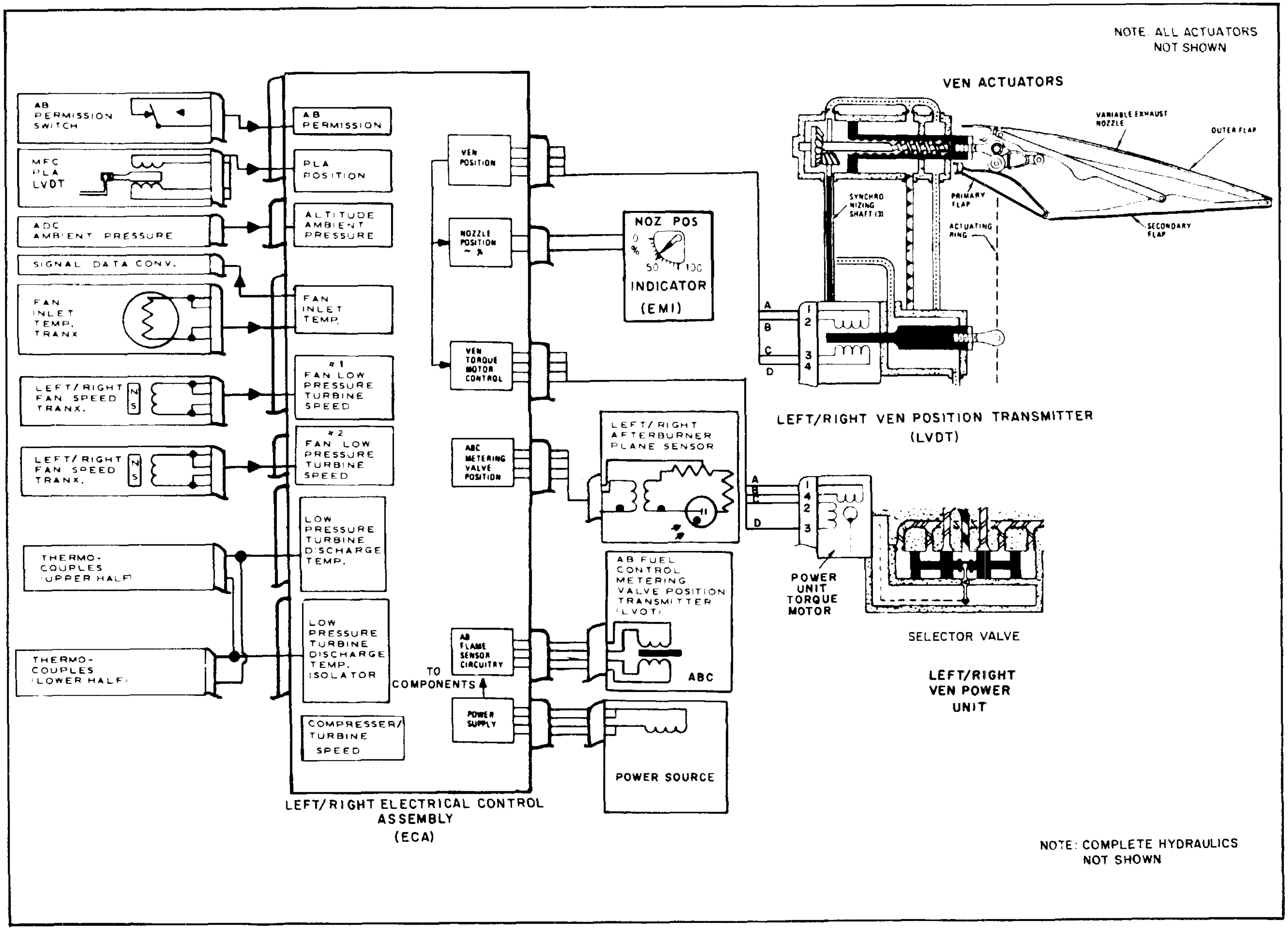


Figure 5-17.—Variable exhaust nozzle system schematic (simplified).

and to increase hot section life. This trim signal varies in size between 4,000 and 9,000 feet. To ensure correct positioning of the VEN area, the VEN position transmitter LVDT provides feedback to the ECA. Any error between the actual VEN area position and its required position goes to the bias signal to readjust the VEN area to its correct position.

As the throttle advances into military (MIL) power (100 percent) and afterburner (AB) ranges, the VEN area maintains the low-pressure turbine discharge temperature within established limits. Throttle position establishes this limit. This limit is adjustable for ambient pressure for fan inlet temperature and for actual low-pressure turbine discharge temperature values from the thermocouple harness.

As the throttle enters AB range, the VEN area reopens slightly above the normal throttle setting, and low-pressure turbine discharge temperature resets to a lower value. These conditions are held until the flame sensor signals the ECA of an AB light-off. The ECA then releases its hold on the VEN area and re-establishes actual low-pressure turbine discharge temperature values. The VEN area will adjust to maintain actual low-pressure turbine discharge temperature limits.

The VEN power unit supplies hydraulic power for positioning the VEN. The power unit activates on an electrical signal from the ECA to the power unit torque motor. The torque motor drives a servo, which supplies high oil pressure to the synchronized actuators to open or close the VEN.

REVIEW SUBSET NUMBER 8

Q1. *When the engine is shut down and the throttle is in the off position, the variable exhaust nozzle is in what position?*

Q2. *What unit in the variable exhaust nozzle adjusts the VEN for atmospheric conditions?*

PROPELLER SYNCHROPHASING SYSTEM

Learning Objective: *Recognize operating principles and features of propeller synchrophasing systems.*

The propeller synchrophaser system discussed here is common to the P-3 and C-130 aircraft and similar to the E-2 aircraft. In this section, you will learn about the electrical operation of controlling and synchrophasing the hydromatic propellers of multiengined aircraft.

PROPELLER GOVERNOR

A propeller governor is a control device that controls engine speed by varying the pitch of the propeller. Increasing the propeller pitch adds load on the engine and increases propeller thrust. This load reduces engine speed. Conversely, decreasing the propeller pitch reduces engine load, which increases engine speed. Therefore, engine speed is a function of propeller pitch. Furthermore, if the propeller governor setting remains unchanged, any variation of power produced by the engine translates into a corresponding variation of propeller thrust. The system does this by varying the propeller pitch while engine speed remains constant. The best engine efficiency is when engine speed is constant; therefore, because it controls engine speed, the propeller governor achieves engine efficiency.

The pitch of hydromatic propeller blades changes by porting hydraulic fluid onto the propeller piston in the propeller dome. The action on the piston transmits through a geared cam mechanism that rotates the propeller blades to the pitch desired.

The governor is the constant speed control device used with the hydromatic propeller. The output oil of the pump goes to either the inboard or the outboard side of the propeller piston.

There are two separate ranges of propeller operation—the flight range and the ground operating range. The flight range includes the takeoff roll after the power levers advance forward for takeoff. For the ground operating range, power levers return aft of the flight-idle detent. In the ground operating range (taxi range), power lever position determines propeller blade angle. A hydromechanical system, with linkage to the power lever, meters oil pressure to either the increase or decrease side of the propeller dome. As the power lever moves forward toward FLIGHT IDLE, a simultaneous increase in blade angle and fuel flow occurs, providing increased power, As the power lever moves aft from FLIGHT IDLE, blade angle decreases and fuel flow decreases, reducing power. Fuel flow begins to increase when the blade angle decreases to the point that the propeller is delivering negative thrust. Reverse power continues to increase until the power levers reach the full aft position. During operation in the ground operating range, there is no electronic governing.

In the flight range of operation, the power lever is forward of the flight-idle detent. In this range, a flyweight governor, driven by propeller rotation, mechanically controls propeller speed. In normal operation, the pitch-change oil goes through the feather valve to either the increase or decrease pitch portion of the propeller.

SYNCHROPHASING

The synchrophaser has different functions, depending upon the mode of governing selected by the flight crew. The synchrophaser does not function in the mechanical governing mode, but the mechanical governor controls the blade pitch and so propeller RPM. In a normal governing mode, the synchrophaser helps the mechanical governor by limiting engine transient speed changes, or to changes in flight conditions affecting propeller speed.

In a synchrophasing governing mode, the synchrophaser helps the mechanical governor by maintaining all propellers at the same RPM. It does this by maintaining a preset phase relationship between the master propeller number 1 blade and the number 1 blades of the slave propellers. This serves to reduce noise and vibration in the aircraft. In the synchrophasing governing mode, the synchrophaser also provides the limiting of transient speed changes as it does in normal governing mode.

The synchrophaser consists of four main components—a pulse generator, a phase and trim control, a speed-bias servo assembly, and the synchrophaser.

Pulse generator. The pulse generator provides the information needed by the synchrophaser system to produce speed and phase control of the aircraft propellers.

Each propeller has a pulse generator that consists of a permanent magnet on the propeller spinner and a stationary coil installation in the governor control. Each time the permanent magnet passes by the coil it generates a pulse. In other words, each revolution of the propeller generates one pulse.

Phase and trim control. The phase and trim control functions as a means of setting phase relationships between mast er and slave propellers. It also trims the master engine.

The phase and trim control consists of seven potentiometers that receive a fixed dc voltage from the synchrophaser. The wiper of the master trim potentiometer supplies a voltage through the master select switch to the synchrophaser to trim master engine speed. The other six wipers connect to relay contacts that separate the wipers into two groups of three per group. One group corresponds to engines 1, 3, and 4 when engine 2 is master. The other group corresponds to engines 1,2, and 4 when engine 3 is master. These wipers supply bias voltages to the phase correction circuits of the synchrophaser to set propeller phase angles of other than 0 degree.

Speed-bias servo assembly. The speed-bias servo assembly functions as a means of translating synchrophaser electrical signals into a mechanical bias on the mechanical governor speeder spring.

The synchrophaser supplies the servomotor with a reference voltage that is 90 degrees out of phase with the aircraft 400-Hz source. The synchrophaser also supplies a control voltage that is either in phase or 180 degrees out of phase with the aircraft 400-Hz source. Therefore, the in-phase control voltage lags the reference voltage by 90 degrees. This lag results in counterclockwise motor rotation when viewed from the output gear of the electric brake. The 180-degree out-of-phase control voltage leads the reference voltage and causes clockwise rotation. The amplitude of the control voltage determines motor speed and torque output.

The motor drives a reduction gear train, which, in turn, drives a potentiometer wiper and the electric brake. The potentiometer receives a fixed dc supply from the synchrophaser across its resistive element. When the motor rotates, the wiper transmits a corresponding feedback voltage to signal winding number 2 of the magnetic modulator. The electric brake has clutch-controlled input and output shafts. The output shaft drives a lever, which biases the speeder spring in the propeller governor. Energizing the clutch decouples the two shafts, locking the output shaft and leaving the input shaft free to turn.

The synchrophaser. The synchrophaser has four channels, which correspond to the aircraft's four engines. Figure 5-18 is a schematic of the synchrophaser. For explanation purposes, only two channels (one slave channel and one master channel) are shown. Each channel has a push-pull power amplifier feeding the control winding of its corresponding servomotor in the speed-bias servo assembly. Magnetic modulators using dc control current furnish a phase and amplitude controlled ac signal to the push-pull amplifier input. The synchrophaser changes all signal inputs to dc voltages proportional to the error before they are applied to the modulator. The modulators are the signal summing devices for the two operational modes of the synchrophaser.

The magnetic modulators function on a core saturation basis. Each modulator consists of a dc bias winding, a 400-Hz excitation winding, and two control windings (signal winding number 1 and signal winding number 2). With no signals applied elsewhere, the 400-Hz excitation vohage appears as a 400-Hz output of negligible amplitude due to the bias winding current. Any current in either or both signal windings will change the output.

The size of the signal windings current controls the amplitude of the output; the current direction controls the phase of the output. Thus, current from pin 10 to 9 in winding number 2 and current from pin 8 to 7 in winding number 1 of any modulator produces a voltage 180 degrees out of phase from the excitation voltage. Current in the opposite direction in the signal windings produces an in-phase voltage. Simultaneous currents flowing in opposite directions in the two signal windings produce a signal that is the algebraic sum of the two signals. Then, the modulator produces a 400-Hz signal, which is either in phase or 180 degrees out of phase with the excitation voltage. This signal is amplified and fed to the servomotor control winding. The 400-Hz voltage in the reference winding of the servomotor goes through a series capacitor, giving the voltage a 90-degree phase shift from the aircraft power source. Appropriate signals to the modulators cause clockwise or counterclockwise rotation of the motor because of phase difference in the speed bias motor windings. The use of the two signal windings in the modulators, along with appropriate relay switching, permits the two modes of synchrophaser operation.

OPERATIONAL MODES

The normal governing mode provides improved engine response to transient RPM changes. In this mode, the synchrophaser receives signals from the power lever anticipation potentiometers and the engine tachometer generators. Signals from these result in a temporary resetting of the mechanical propeller governor. This resetting adjusts for power lever changes and engine speed changes, thus limiting engine overspeeds or under speeds.

The synchrophasing governing mode synchronizes engine speeds, regulates propeller phase angles, and maintains the limiting features of the normal governing mode. In the synchrophasing governing mode, one engine (2 or 3) is the master. The master engine operates in normal governing mode, while the other three engines (slaves) follow changes in speed or phase of the master within preset limits.

Normal Governing Mode

In normal governing mode, the propeller governor switch is in the NORMAL position and the power lever switch closes, providing reference voltages to the servomotors. The synchrophase master switch is OFF and the PROP RESYNCH switch is in NORMAL. All relays are de-energized, resulting in the speed and phase error circuits being grounded. Each phase- and speed-error signal side of every magnetic modulator signal winding number 2 (pin 10) ends on a dummy load (fig. 5-18) within the synchrophaser. The other side (pin 9) connects to the feedback circuit in the speed-bias servo assembly. The controlling signals go to signal winding number 1 (pin 8) of each modulator. All channels function identically while in the normal governing mode.

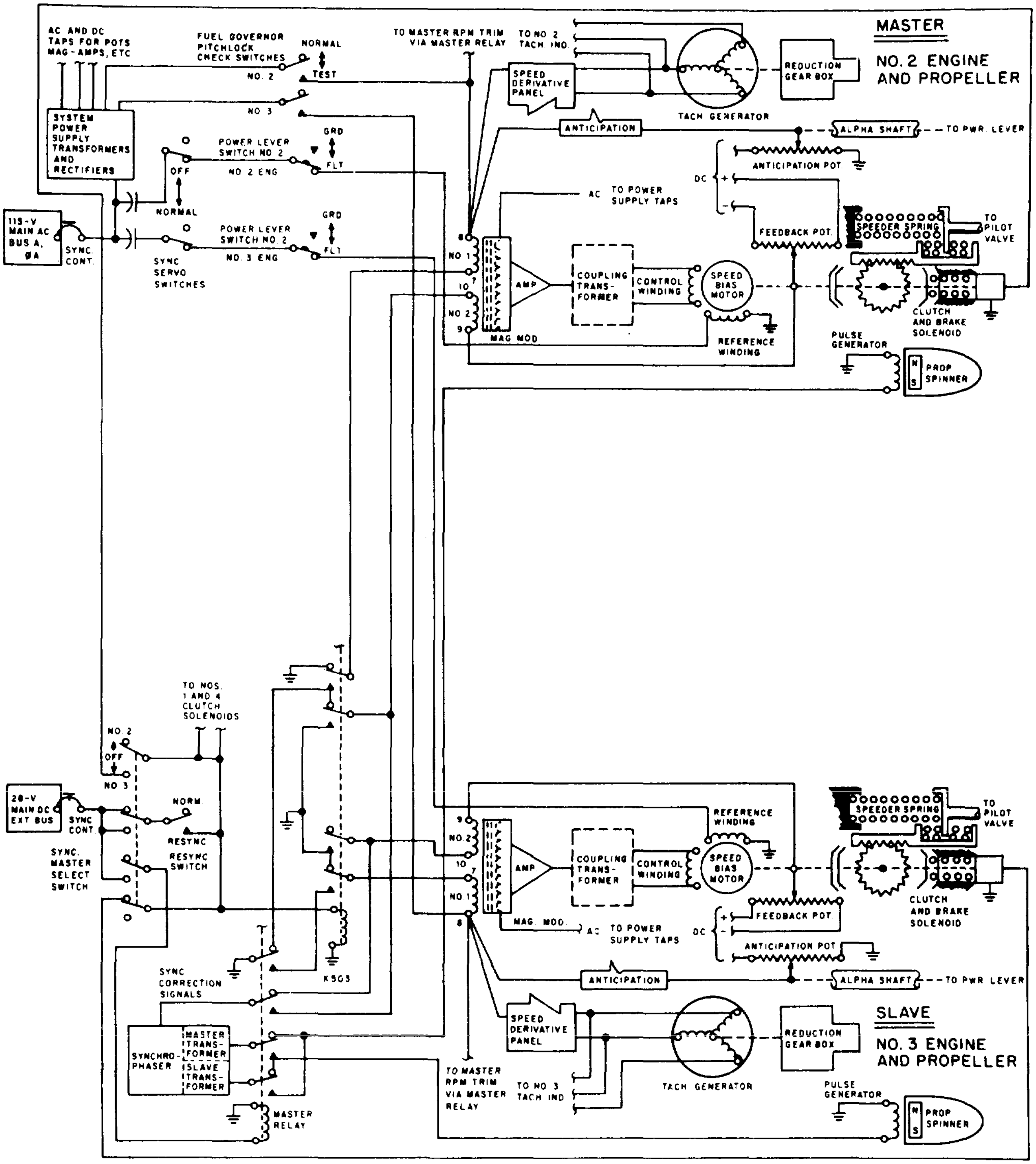


Figure 5-18.-Synchrophaser control schematic diagram.

THROTTLE LEVER ANTICIPATION. — Any power lever movement (fig. 5-19) causes a change in dc voltage at the anticipation potentiometer wiper, which serves as a voltage divider for the RC circuit. The charging voltage for the capacitor is directly proportional to the position of the power lever. The change in charge on the capacitor is directly proportional to the rate at which the power lever moves. If the power lever movement is to decrease engine power, the capacitor charges up to a more positive voltage value. This results in a current from pin 7 to pin 8 in signal winding number 1 of the magnetic modulator. A lagging voltage surge appears in the servomotor control winding, causing counterclockwise rotation. This rotation resets the mechanical governor towards decrease pitch to compensate for the reduced power setting. As the servomotor rotates, the feedback potentiometer begins canceling the error signal by causing a

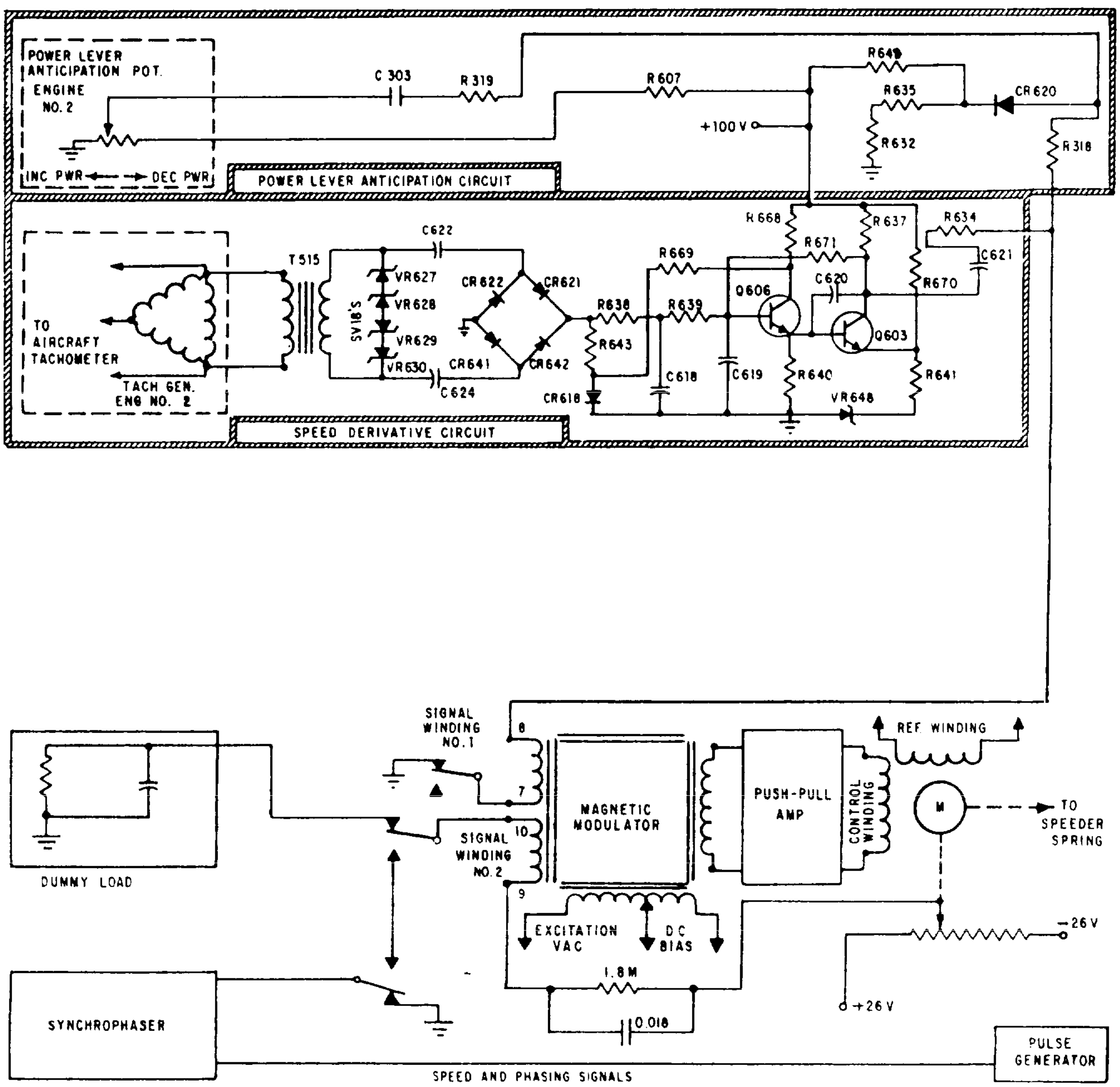


Figure 5-19.-Power lever anticipation and speed derivative circuits in normal governing mode.

current in signal winding number 2. The magnetic field of this current is in opposition to the magnetic field of the signal current in winding number 1. This stops the servomotor. As the anticipator capacitor continues to charge to its new peak value, the current in signal winding number 1 decays to zero. The feedback potentiometer is still applying voltage to signal winding number 2. This results in a leading voltage to the servomotor control winding that returns the motor to its original position. This position corresponds to a zero-volt feedback potentiometer position. In retarding the throttle lever very rapidly, the peak voltage will overcome the reverse bias on diode CR620. This will limit the signal value to prevent overcompensation toward a flat blade pitch. For an increase in engine power, the capacitor discharges. This causes a current in the opposite direction in signal winding number 1, which results in a temporary resetting toward increased pitch. The amount of reset in either case depends on the rate at which the lever moves. Mechanical stops in the speed-bias servo assembly limit speed resets to plus 10 and minus 10 percent regardless of the applied signal. Furthermore, stops in the propeller control valve housing linkage reduce the limits to plus 6 and minus 4 percent.

LIMITING ENGINE TRANSIENT SPEED CHANGES. —The speed-derivative circuit in the synchrophaser (fig. 5-19) senses changes in engine RPM and produces output signals, which dampen the engine RPM changes. The speed-derivative circuit does this by translating the frequency changes received from one phase of the tachometer generator into signal voltages. The magnitudes of the signal voltages vary at the rate the tachometer generator frequency changes. The signal voltage goes to signal winding number 1 of the magnetic modulator, where it is summed and sent to the push-pull amplifier. After amplification, the signal goes to the servomotor control winding. The servomotor adjusts the speeder spring tension, which begins a change in propeller pitch, thus dampening the change in engine RPM.

The action of the speed-derivative circuit is further described as follows: The voltage produced on the collector of transistor Q603 is proportional to the output frequency of the tachometer generator. When engine RPM is constant, the voltage on the collector is constant and capacitor C621 charges through resistor R634 and signal winding number 1 of the magnetic modulator. Current in signal winding number 1 decays to zero as the charge on capacitor C621 reaches the potential on the collector of transistor Q603. When engine RPM changes, a change in the collector voltage of transistor Q603 proportional to the change in tachometer generator frequency occurs. This causes capacitor C621 to change its charge at the rate in which the tachometer generator frequency is changing. This produces a current in signal winding number 1. The current size varies at the rate at which the engine is varying offspeed. Its direction is such that the amplified signal in the servo-bias assembly control winding drives the servomotor in a direction to dampen the drift in engine RPM. Speed-error signals in signal winding number 1 from the speed-derivative circuit cancel in the same manner as anticipation signals from the anticipation circuit cancel.

The speed-derivative and power lever anticipation circuits are much more sensitive to engine RPM changes than the mechanical governor flyweight speeder spring. The governing action of the flyweight and speeder spring improves the mechanical governor's response to changes in power lever settings and engine RPM.

Synchrophaser Mode

In adding synchrophasing to normal governing mode, the master switch selects either engine 2 or 3 as the master engine (fig. 5-18). With master engine selection, relays energize, removing dummy loads from signal winding number 2 of all magnetic modulators, except the master channel modulator. Also, the outputs of the speed-error and phase-error circuits of each synchrophaser channel (except the master) are taken from ground and connected to signal winding number 2 of their respective modulators. While the slave engines are in synchrophasing mode, the master engine remains in normal governing mode. Essentially, pulses from the master engine form into sawtooth waves and are compared to pulses from each of the slave engines in the slave channel sampling circuits. If slave pulses are not in phase with the master pulse (sawtooth), error detection occurs in the respective synchrophaser channel. The errors then go to signal winding number 2 of the channel magnetic modulator. Here, they are summed with any error signals that exist in signal winding number 1. The result of the error signals is amplified and fed to the control winding of the respective speed-bias servomotor. This alters the tension of the slave governor speeder spring, correcting for engine speed differences and

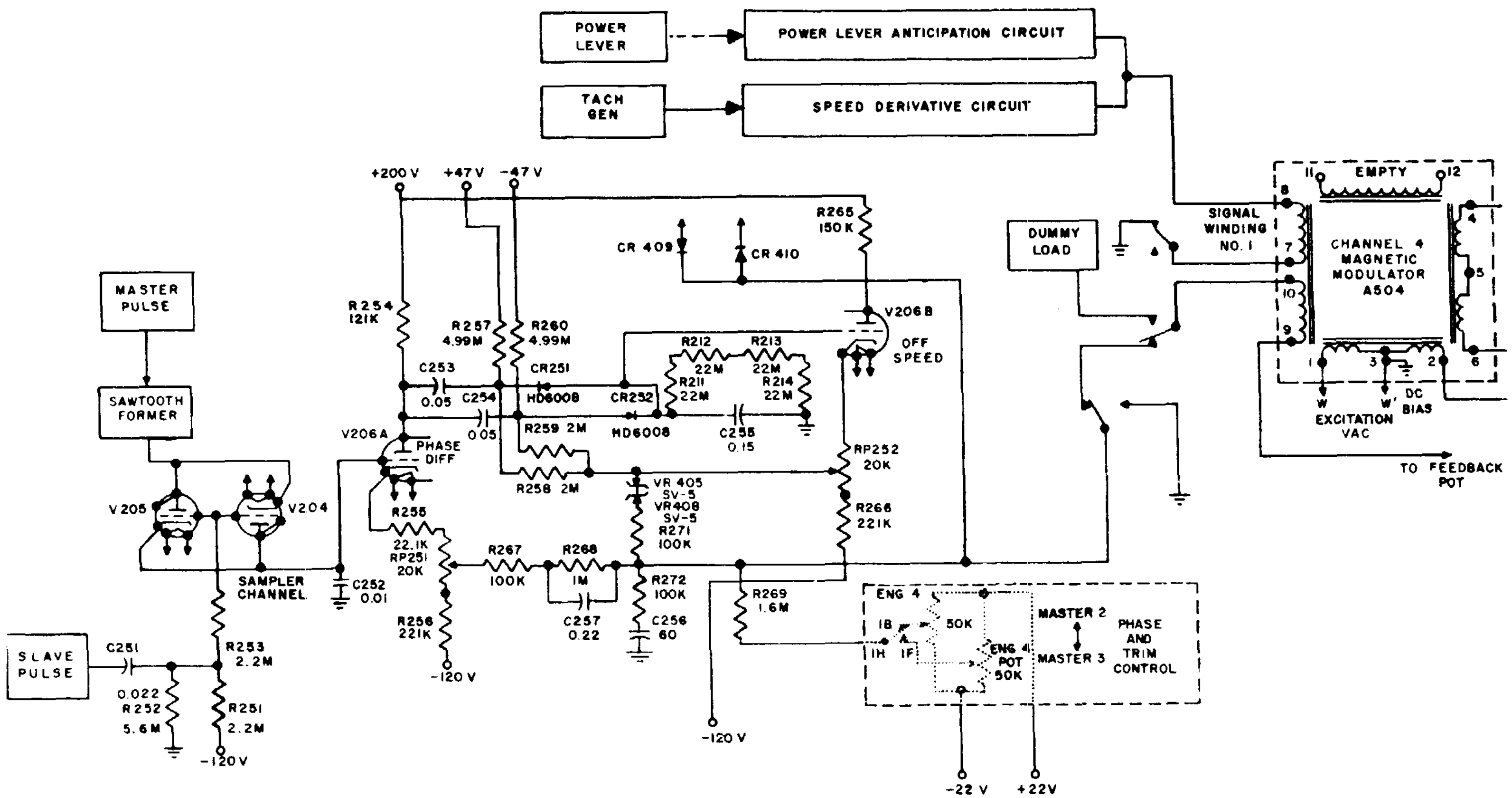


Figure 5-20.—Synchrophaser schematic diagram, synchrophaser mode (slave channel).

propeller blade angle errors. (Figure 5-20 shows one channel of the synchrophasing circuit.)

The following paragraphs describe phase and speed error sensing.

SAWTOOTH FORMER.—The pulse from the master pulse generator is transformer-coupled to the sawtooth former. The slave pulse generators are transformer-coupled to the channel sampler circuits. Figure 5-21, views A and B, shows the master pulse and the resultant sawtooth formed in the sawtooth former.

SAMPLING CIRCUITS.—Pulses from the three slave engines couple to the grids of the sampling circuit tubes, while the sawtooth voltage goes to the plate of one tube and the cathode of the other tube in all sampling circuits. The positive-going portion of the slave pulse places the tubes in a conductive state. (Sampling is the same in all channels.) Refer to figure 5-20. If the sawtooth is at zero potential when the slave pulse occurs, neither tube conducts, so the phase difference and speed error circuits receive no signal. With the sawtooth in the positive region, tube V205 conducts. The corresponding voltage changes go to the grid of phase difference tube V206A.

You can see the nature of the sampling action by referring to figure 5-21. The time interval between master pulses is the time interval for 360 degrees of propeller rotation (fig. 5-21, view A). The time interval of the sawtooth, which the master pulse generates, is 360 degrees. The half-time interval, or 180-degree position, is the sawtooth zero potential point (fig. 5-21, view C). When the slave pulse occurs at the zero point, the propellers are on phase with a 180-degree phase difference between them. All references to slave pulses are with respect to the 360-degree interval. The point of occurrence of the slave pulse determines the signal size in the sampler circuit (fig. 5-21, view D). This signal represents the phase difference between propellers.

NOTE: Since the propellers are four-bladed, the relative blade position between the master and slave propellers is exactly the same when the slave

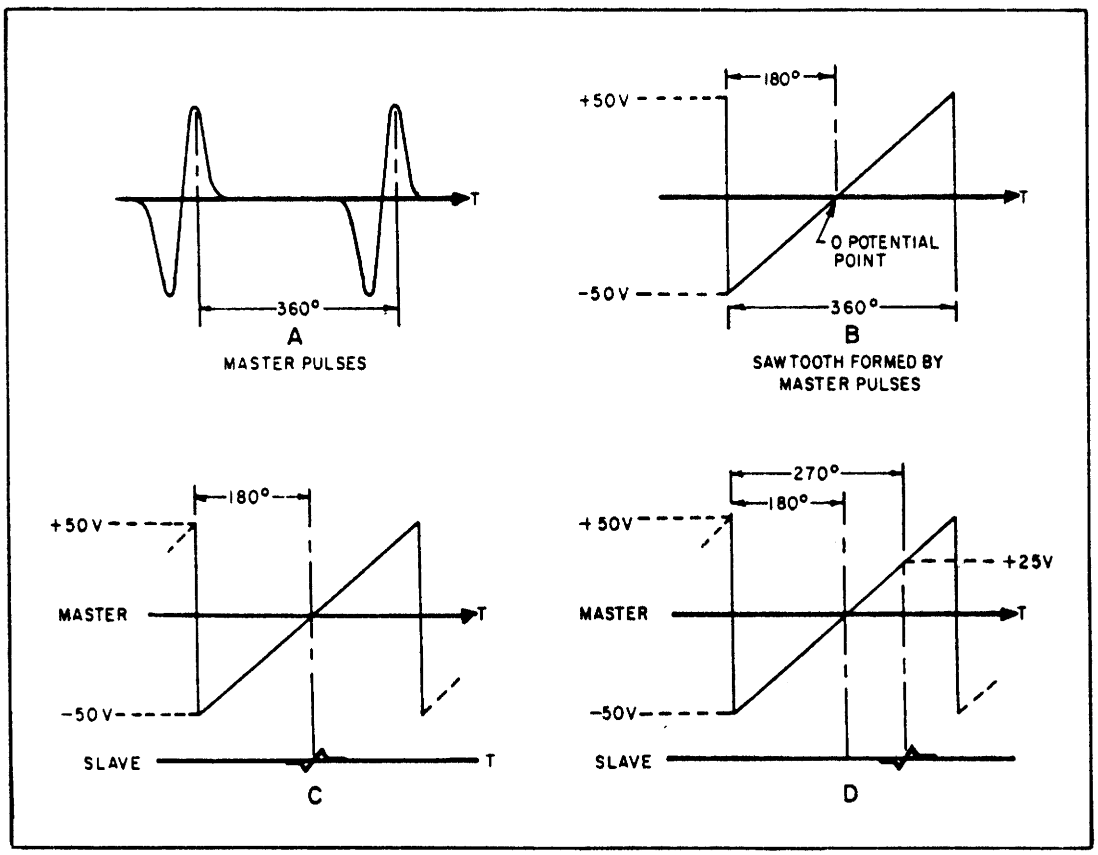


Figure 5-21.—Master and slave pulse comparisons.

propellers differ from the master by one-half revolution. Therefore, consider a 180-degree phase difference as an on-phase condition in pulse comparisons.

PHASE DIFFERENCE CIRCUITS. —Look at figure 5-20. The phase difference circuits receive the voltages the sampling circuits generate at the grids of the respective tubes. With a 180-degree phase difference signal at the grid of V206A, the voltage at the wiper of potentiometer RP251 adjusts to null or zero volts. This voltage changes proportionally with the grid signal from the sampling circuit, and hence represents the phase difference between propellers. The following paragraphs discuss the effect of this voltage on synchrophaser output.

OFF-SPEED CIRCUITS. —When the propeller goes off-speed, the sampling circuit senses the condition as a sharp voltage change. (When the slave propeller is on-speed, the slave pulses occur at the same time interval in each successive sawtooth cycle.) When an underspeed or overspeed condition develops, the slave pulse occurs at a different position for each sawtooth cycle. At one point, the slave pulse falls up or down the sawtooth (fig. 5-22). Think of this as a phase error that occurs too rapidly for the phase-error circuit to compensate. During an underspeed condition, the voltage going to the phase difference tube suddenly changes from positive to negative (fig. 5-22). For an overspeed condition, the voltage suddenly changes from a negative to a positive.

As you read this paragraph, refer to figure 5-20. The action of the off-speed circuit is as follows. The underspeed voltage change, registered in the plate circuit of the phase difference tube, couples to the off-speed circuit through capacitors C253 and C254. The voltage change in the plate circuit is positive and the reverse bias on diode CR251 is reinforced. However, the reverse bias on diode CR252 is momentarily overcome, allowing capacitor C255 to charge positively. Capacitor C255 discharges slowly through its parallel resistive network and maintains a grid bias on the off-speed tube V206B. (For an overspeed, diode CR251 conducts and charges capacitor C255 negatively.) Successive sharp voltage changes add to the charge on capacitor C255 until correction of the off-speed condition occurs. Like the phase difference circuit, the off-speed circuit has a zero-volt adjustment potentiometer in the cathode circuit.

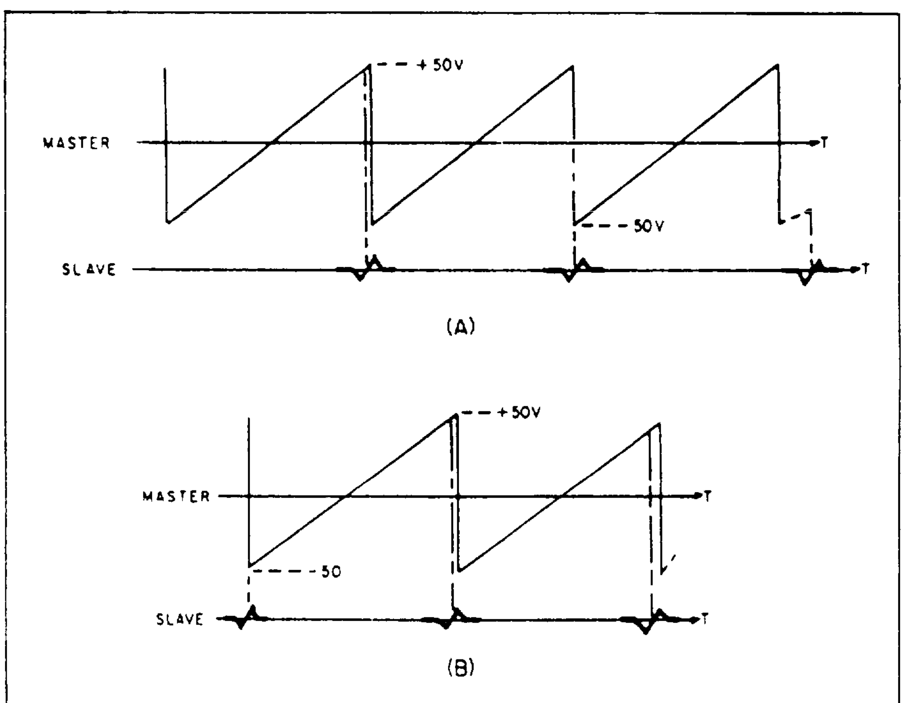


Figure 5-22.-Off-speed pulse comparison: (A) slave underspeed; (B) slave overspeed.

The pulsating voltage generated at the wiper by the changing grid bias on the tube is the speed-error voltage. The effect of this voltage is discussed later.

SIGNAL SUMMING. —As you can see by looking at figures 5-20 and 5-23, the phase-difference and speed-error voltages couple to the signal summing point. Also connected to this point are the limiting circuit, the phase-control potentiometer, and magnetic modulator signal winding number 2. Any difference in potential between the signal summing point and the feedback potentiometer causes a current in the modulator winding. This results in motor movement, which, in turn, causes the feedback potentiometer to null whatever potential is at the summing point.

PHASE-ERROR CORRECTION. —When the slave propellers aren't on-phase, phase-difference voltage acts through the averaging circuit to the summing point causing speed-bias servomotor rotation to correct the off-phase condition. This action occurs provided the phase control potentiometer (fig. 5-23) is set for zero volts. In this case, the phase difference voltage actually represents phase error. However, it is desirable to have a slave propeller maintain a specific angle of lead or lag to the master propeller. The phase control potentiometer then adjusts to cancel the phase-difference voltage at the summing point. For example, to maintain a slave lead of 10 degrees from the 180-degree position of the master pulse, the phase control potentiometer adjusts to cancel the phase-difference voltage. The phase-difference voltage is generated when the slave propeller leads the master propeller by 10 degrees. Thus, when the slave propeller leads by 10 degrees, net potential at the summing point is zero, and the speed-bias servomotor does not move. When the slave propeller changes from the 10-degree lead condition, the phase-difference voltage changes. The net potential at the summing point is the difference between the phase control

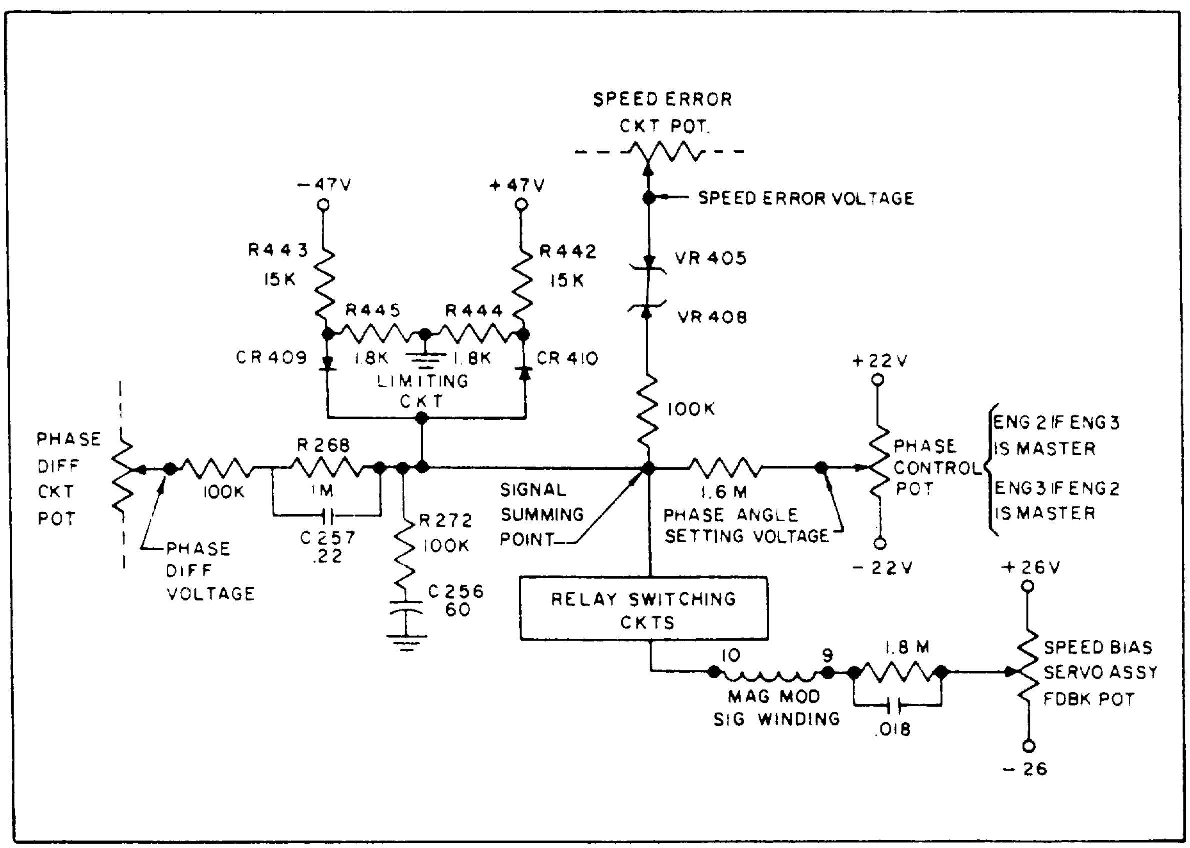


Figure 5-23.-Simplified schematic of signal summing.

potentiometer setting and the phase-difference voltage. This is how phase-error voltage and its size depend on the slave propeller's degree of lead or lag from the 10-degree lead condition. The manual phase control is adjustable to allow a slave lead or lag of 45 degrees.

SPEED-ERROR CORRECTION. —During the phase-error correction, Zener diodes VR405 and VR408 isolate the speed-error potentiometer from the signal summing point. When an off-speed occurs, these diodes conduct and connect the speed-error circuit to the summing point. For large speed errors, the speed-error signal is a pulsating dc of very low frequency. At the same time, the phase-error signal is a rapid dc step voltage consisting of sharp potential changes, which trigger the speed-error circuit. The dc step voltage changes developed in the cathode circuit of V206A (fig. 5-20) are averaged and effectively blocked by resistor R268 and capacitor C251. The sharp potential changes passing resistor R268 and capacitor C251 leak to ground by resistor R272 and capacitor C256, leaving the speed-error signal in control. When the engine reaches on-speed condition, but is still out of phase, the speed-error signal drops off until a point where the Zener diodes stops conducting and the phase-error signal assumes control.

TWO-PERCENT LIMITING. —The potential at the summing point has a limit of plus or minus 5 volts. The limiting circuit (R442, R443, R444, R445, CR409, and CR410 as shown in fig. 5-23) accomplishes this by clipping any signal outside of the range limit. In the off-speed circuit, this limited signal provides only enough output to drive the speed-bias servomotor to correct a two-percent speed change. This occurs because the motor movement results in a feedback voltage that cancels the speed-error signal. The slave propeller cannot follow large speed changes of the master engine. This prevents a slave from following an overspeeding or underspeeding master.

Resynchrophasing

The need for resynchrophasing arises from the nature in which phase angle correction circuits operate. As phase errors occur, the servomotor rotates to correct the error. At the same time, the feedback potentiometer moves and cancels a portion of the error signal. As the phase-error correction occurs, the phase-error signal decreases until it matches the feedback signal. When this occurs, the potential at the summing point is zero and the motor stops moving, leaving a portion of the error uncorrected. This is insignificant for errors that occur about a set point—leading and lagging errors. However, for errors that continually occur in one direction, the error accumulates, and can become large enough to reduce system efficiency. To overcome this, a procedure provides a lock on the mechanical governor bias, while the servomotor recenters at a zero-volt feedback position; this is *resynchrophasing.*

As you read this paragraph, refer to figure 5-19. While in synchrophasing mode, place the prop resynchrophase switch in the RESYNCH position. This energizes the electric clutch-brakes on the slave engine speed-bias servo assemblies. The brakes lock the output shafts and the clutches decouple the input and output shafts. This action leaves the input shafts free to turn. Locking the output shaft retains whatever mechanical bias is present on the mechanical governor. At the same time, relay K503 energizes. This opens the signal winding number 1 circuits on the magnetic modulators. (The master channel remains in normal governing mode through a parallel ground provided by the master relay to signal winding number 1 of the master channel modulator.) After a time delay sufficient to assure brake and clutch actuation before allowing the recentering action, relays de-energize, removing the phase- and speed-error circuits from the slave channel magnetic modulators and connecting the dummy loads. The only input to the slave channel magnetic modulators is now the feedback potentiometer acting into the dummy load through signal winding number 2. The generated signal then drives the motors until the feedback voltage is zero. Upon releasing the prop resynchrophase switch, all circuits return to the synchrophasing mode. Correction of the accumulated phase error can now occur.

TROUBLESHOOTING HINTS

When trouble occurs in the propeller system electrical controls, the first troubleshooting step you perform is determining which part of the system is malfunctioning. You can determine this by completing an operational check. The next step is to refer to the electrical schematic and the troubleshooting chart in the aircraft maintenance instructions manual, and then analyze the trouble.

REVIEW SUBSET NUMBER 9

Q1. What are the two ranges of propeller operation?

Q2. What mode of operation is the synchrophaser in when maintaining all propellers at the same RPM?

Q3. What unit provides a means of setting phase relationships between the master and slave propellers in the synchrophase system?

Q4. The synchrophaser speed derivative circuit is used to dampen changes in __________

____ .

Q5. The slave propellers are prevented from following an overspeed or underspeed master propeller by what synchrophaser circuit?

PROPELLER CONTROL SYSTEM

Learning Objective: *Recognize operating principles and features of aircraft propeller control systems.*

The propeller control system is similar to systems already discussed in this chapter. It is an integral part of, or works with, the propeller synchrophaser system and the propeller governing system. The discussion that follows concerns propeller pitchlock, the negative torque system, and feathering, unfeathering, and autofeathering operations. You should refer to figure 5-24 throughout this discussion of the components in and operation of the propeller control system.

PROPELLER

The four-bladed propeller converts engine shaft horsepower to thrust. The propeller consists of two principal sections—the rotating section and the nonrotating section. The rotating section consists of the blades, hub, spinner, and the dome that houses the pitch changing mechanism. The nonrotating section contains the pressure and scavenge oil pumps, the governor control mechanism, and the spinner afterbody. It is a constant-speed, full-feathering, reversing propeller, having the added features of pitchlock and a combination synchronizing and synchrophasing system.

Low-Pitch Stop Assembly

A mechanical stop assembly in the propeller dome limits low pitch blade angle to maintain a minimum blade angle. When the power levers position is below 28 degrees, a cam operated backup valve in the propeller housing collapses the low-pitch stop levers. The blades move toward the reverse position as directed by the power lever beta schedule.

Beta Follow-up System

The beta follow-up system provides a variable hydraulic low-pitch stop. At the FLIGHT IDLE power lever position, the beta follow-up stop is 10-degree blade angle; the mechanical low-pitch stop is 13 degrees. The purpose of the beta follow-up stop is to provide a secondary low-pitch stop. As the power lever moves toward the TAKEOFF position and the blade angle increases, the mechanical low-pitch stop remains at 13 degrees. The beta follow-up control programs the hydraulic stop in relation to power lever position to a maximum of 22.5 degrees of blade angle. If a sudden engine failure occurs and the negative-torque system fails to operate, beta follow-up prevents excessive reduction in blade angle and associated violent yawing.

Negative Torque System

The negative torque system (NTS) protects the aircraft from excessive drag by limiting the negative torque from the propeller to a predetermined value range of -150 to -500 shaft horsepower. During a negative torque condition, NTS provides a mechanical signal that overrides the propeller governing action to increase blade angle. When the propeller reaches a position where it is no longer developing negative torque, the propeller governor regains control of the propeller. If the negative torque condition persists, a cycling action continues from the mechanical

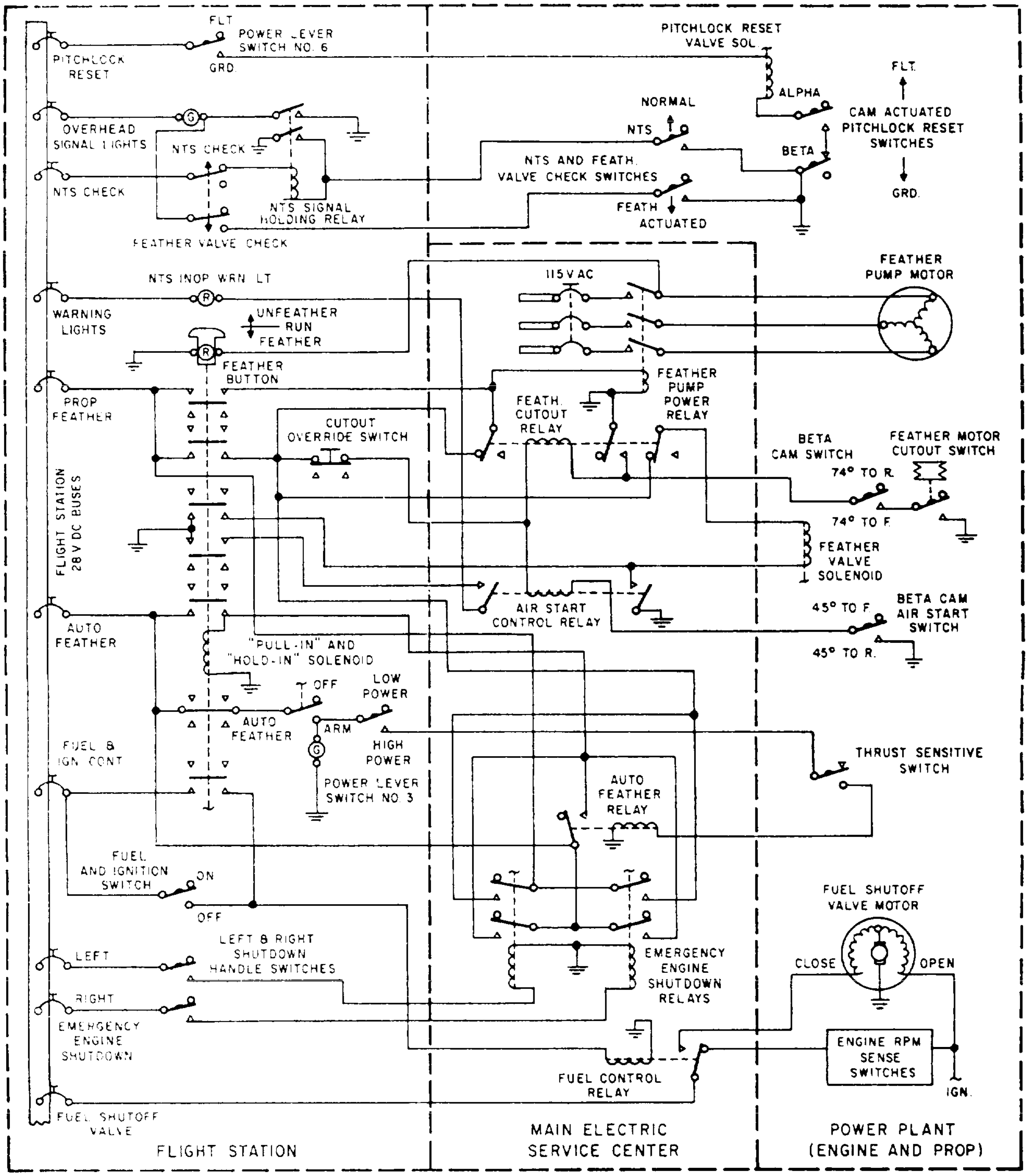


Figure 5-24.-Propeller control circuit.

signal to the propeller governor, and vice-versa, until some corrective action is taken.

ANTS INOP warning light illuminates when the 45-degree air start blade angle circuit energizes. The air start blade angle system limits negative horsepower during in-flight restart operations if NTS fails. The blades, upon reaching 45 degrees, energize the air start blade limit circuit, which drives the feather valve to the feather position. The blades moving toward the feather position open the circuit, de-energizing the feather solenoid valve. The result of this action is a cycling of the blades around the air start blade angle switch. For ground unfeather operation, bypass the air start blade limit switch by actuating the feather pump pressure cutout override switch while unfeathering the propeller.

Pitchlock

A hydraulic, speed-sensitive pitchlock mechanism is in the propeller assembly to prevent overspeeding. It is completely automatic and prevents further decrease in blade angle when engaged. Automatic engagement occurs in two ways: by loss or control oil pressure and when RPM exceeds 103.5 percent. The pitchlock governor, sensing the overspeed, allows the pitchlock teeth to engage, which prevents further decrease in blade angle. Due to teeth design, the blade angle can increase if the normal governing control is restored.

BLOCKOUT RANGES. —There are two blade angle ranges where pitchlock does not operate. One range is from plus 17 degrees to minus 14 degrees. This allows for RPM surges as blade angles reduce during approach and landing. The second is blade angles between 57 degrees and 86 degrees (full feather). This is necessary to decrease blade angle for air starting. Blade angles will be less than 57 degrees at 405 knots or limit Mach speed.

PITCHLOCK RESET. —A reset system will reset pitchlock up to 109 percent RPM at blade angles above 10 degrees with the power lever below 28-degree coordinator position. This 109 percent RPM setting of the pitchlock is momentary. It is necessary when the power lever moves very rapidly into the beta range and blade angle reduction is not quick enough. Pitchlock reset comes into use during an aborted takeoff or landing. In this condition the increase in fuel scheduled will cause engine speed to increase above 103 percent RPM.

FUEL GOVERNOR AND PROPELLER PITCHLOCK TEST SWITCH. —Four two-position (TEST-NORMAL) switches, one for each propeller, are on the engine check panel. Upon placing a switch to TEST, the propeller speed-bias servomotor receives a continuous overriding signal. The signal drives the mechanism full travel toward decrease pitch. This resets the propeller governor to a speed of 106 percent RPM, permitting a ground check of the pitchlock and fuel governor functions.

Propeller Feathering

Feathering aligns the propeller to the airstream to minimize drag during engine shutdown conditions. Feathering is started by pulling the engine emergency shutdown handle, autofeathering, or depressing the feather switch button. The feather valve ports hydraulic fluid to increase pitch on the propeller blades. This action bypasses all other control functions.

NORMAL FEATHERING. —To accomplish normal feathering, pull the engine emergency shutdown handle. Pulling the handle mechanically positions the feather valve and electrically energizes the feather button solenoid. Also, current goes to the auxiliary pump and to the feather valve solenoid, which hydraulically positions the feather valve to feather the propeller. When the propeller fully feathers, oil pressure buildup operates a pressure cutout switch, causing the auxiliary pump and feathering solenoid to de-energize. The feathering button light then goes out.

Feather Pump Pressure Cutout Override Switch. —There is a push-button switch next to each feather button. Actuating the override switch bypasses the feather pump pressure cutout switch. This permits continued operation of the feather pump if the feather pump operation finishes before the propeller reach the full feather.

Feathering Switches (Buttons). —Four guarded feather switches (buttons), one for each engine, provide an alternate method for feathering the propellers. Pressing a button to FEATHER cuts off fuel electrically, and energizes the feather solenoid and the feather pump motor to feather the propeller. The propeller unfeathers when the button goes to the unfeather position. The center position is for normal propeller operation. A light in the feather button illuminates when the circuit to the feather pump is energized.

AUTOMATIC FEATHERING. —The automatic feathering system performs its function by energizing the feathering button holding coil (pulling in the feathering button). This occurs when the autofeather arming switch is in the ARMED position and the engine loses power, which results in a large decrease in propeller thrust. This system is for use during takeoff only, and it functions above 60°±2° coordinator setting. Only one propeller will feather automatically.

Autofeather Arming Switch. —There is an autofeather ARMED-OFF switch on the autofeather and RPM control panel. It provides the control for the autofeather system. During normal operations and when the switch is in the ARMED position, all power plants have autofeather protection. With the switch in the ARMED position and electrical power to the power lever quadrant, autofeather arming switches close and the autofeather armed lights illuminate. Both the arming switch and power lever quadrant switch (activated at 60 degrees) must close before the thrust-sensitive signal device can cause propeller autofeathering.

Autofeather System Indicators. —Four green indicator lamps, one for each propeller, illuminate to show the arming of each individual propeller autofeathering circuit. The lights are on the pilot's overhead control panel. Also, should a propeller autofeather, its light will remain on and the others will go out.

UNFEATHERING ON THE GROUND. — The propeller is unfeathered by holding the feathering button in the unfeather position. The air start switch (in the propeller) limits the blade angle decrease to 45 degrees. For further blade angle decrease, you hold the pressure cutout override button in.

PROPELLER CONTROL OPERATION

In this section, you will read about a typical propeller control operation. Before the operation is presented, you are given the following conditions:

- The engines are running.
- The engines are operating in the taxi range (power levers between 0 degree and 34 degrees on the coordinator).

Each power lever controls the propeller blade pitch and engine fuel flow through hydromechanical linkages. If a power lever is below 28 degrees and the blade pitch angle is above 10 degrees, the pitchlock reset valve solenoid (fig. 5-24) activates, resetting pitchlock up to 109 percent RPM.

As the power levers advance above 34 degrees into the flight-idle range, the flyweight propeller governor assumes propeller pitch control. This governor increases or decreases blade pitch to maintain 100 percent RPM by directing fluid through the feather valve. The temperature datum system controls proper engine temperature operation.

When ready for takeoff, the pilot places the AUTOFEATHER switch in the ARMED position. As the power levers advance beyond 60 degrees, the number 3 power lever switches close to the HIGH POWER position. If a propeller's thrust drops below 500 pounds, the thrust-sensitive switch closes. This energizes the autofeather relay. Power goes through the autofeather relay contacts to energize the feather switch pull-in and hold-in solenoid. The autofeather relay loses its power from the feather switch, but the feather switch remains energized through a holding circuit. Power runs from the energized feather switch through the contacts of the feather cutout relay to the feather pump power relay, to the feather pump motor. Power also goes to the feather valve solenoid through the feather cutout relay. The feather valve solenoid moves the feather valve, which ports oil to increase pitch, causing the propeller to feather. The fail-safe-type fuel control relay activates by power from the feather switch, causing the engine fuel shutoff valve to close.

As the propeller feathers, the beta cam switch closes when the blade angle goes past 74 degrees. The feather motor cutout switch closes when the propeller reaches full feather and the oil pressure increases. This completes a circuit that causes the feather cutout relay to energize, de-energizing the feather valve solenoid. Besides cutting out the feather pump power relay, the energized feather cutout relay maintains its own holding circuit. This completes the autofeathering cycle.

When shutting down the engine with the EMERGENCY ENGINE SHUTDOWN handle, power from the emergency engine shutdown relays is directed to the feather switch pull-in and hold-in solenoid. Each emergency shutdown handle has two switches and two relays to make sure the electrical systems energize. The engine is shutdown and feathered as described above. Also, pressing in the feather switch causes the feather cycle operation to take place.

When the flight crew restarts an engine during flight, pull the feather switch out to the UNFEATHER position and hold it there. The feather cutout relay is de-energized, and power goes to the feather pump power relay. The feather pump motor pressure builds up and oil flows to the decrease pitch side of the propeller dome, causing the propeller to start unfeathering. During restarts the feather valve solenoid energizes during NTS inoperative conditions only.

When blade angle decreases to less than 45 degrees, the beta cam air start switch closes, completing the path for current through the air start control relay. The air start control relay energizes the feather valve solenoid. This causes the propeller blades to increase toward the feather position. The beta cam air start switch opens at 48-degree blade angle, causing the air start control relay and feather solenoid valve to de-energize. This causes cycling of blade angle around the air start beta cam switch (45 degrees) and causes the NTS INOP warning light to flash. The light blinks because of the blade angle cycling action. At this indication, the flight crew pulls the emergency shutdown handle to abort the restart.

REVIEW SUBSET NUMBER 10

Q1. The propeller is used to convert engine shaft horsepower to ________________________.

Q2. What mechanical unit maintains a minimum blade angle?

Q3. What does the beta follow-up system provide?

Q4. What system resets pitchlock RPM from 103.5 percent to 109 percent during an aborted takeoff?

Q5. What valve bypasses all other control functions to feather the propeller?

Q6. What propeller system is used only during takeoff?

Q7. During ground propeller unfeathering, how do you decrease blade angle below 45 degrees?

APPROACH POWER COMPENSATOR SYSTEM

Learning Objective: *Recognize operating parameters and features of aircraft approach power compensator systems.*

The approach power compensator (APC) system (fig. 5-25) automatically controls engine power to maintain the best angle of attack during landing approaches. This permits the pilot to direct most of his attention toward flying the approach. During an APC approach in light to moderate turbulence, the set can maintain airspeed within a range of ±4 knots.

The major components of the system are a control panel, accelerometer, computer, control amplifier, a potentiometer to detect changes in elevator position, and a rotary actuator, which moves the throttle linkage. The aircraft angle-of-attack transducer supplies angle-of-attack signals to the computer. A compression switch on the landing gear breaks the APC circuit upon touchdown.

With the landing gear down and weight off the gear, the APC is energized by placing the engage switch to ON. The switch is magnetically held on until the aircraft touches down, the throttle overrides the system, or the pilot places the engage switch to OFF. The APC will also release automatically if either the override switch or the compression switch fails.

With the set engaged, the accelerometer, angle-of-attack transducer, and the ambient temperature selector switch supply information to the computer. The APC computer also receives elevator position signals from a potentiometer mounted in the control valve linkage of the elevator actuator. When normal acceleration is 1 g and the angle of attack is optimum for a landing approach, the computer sends no corrective signal and the throttle position does not change. The computer interprets deviations from these values as either offsetting each other or as

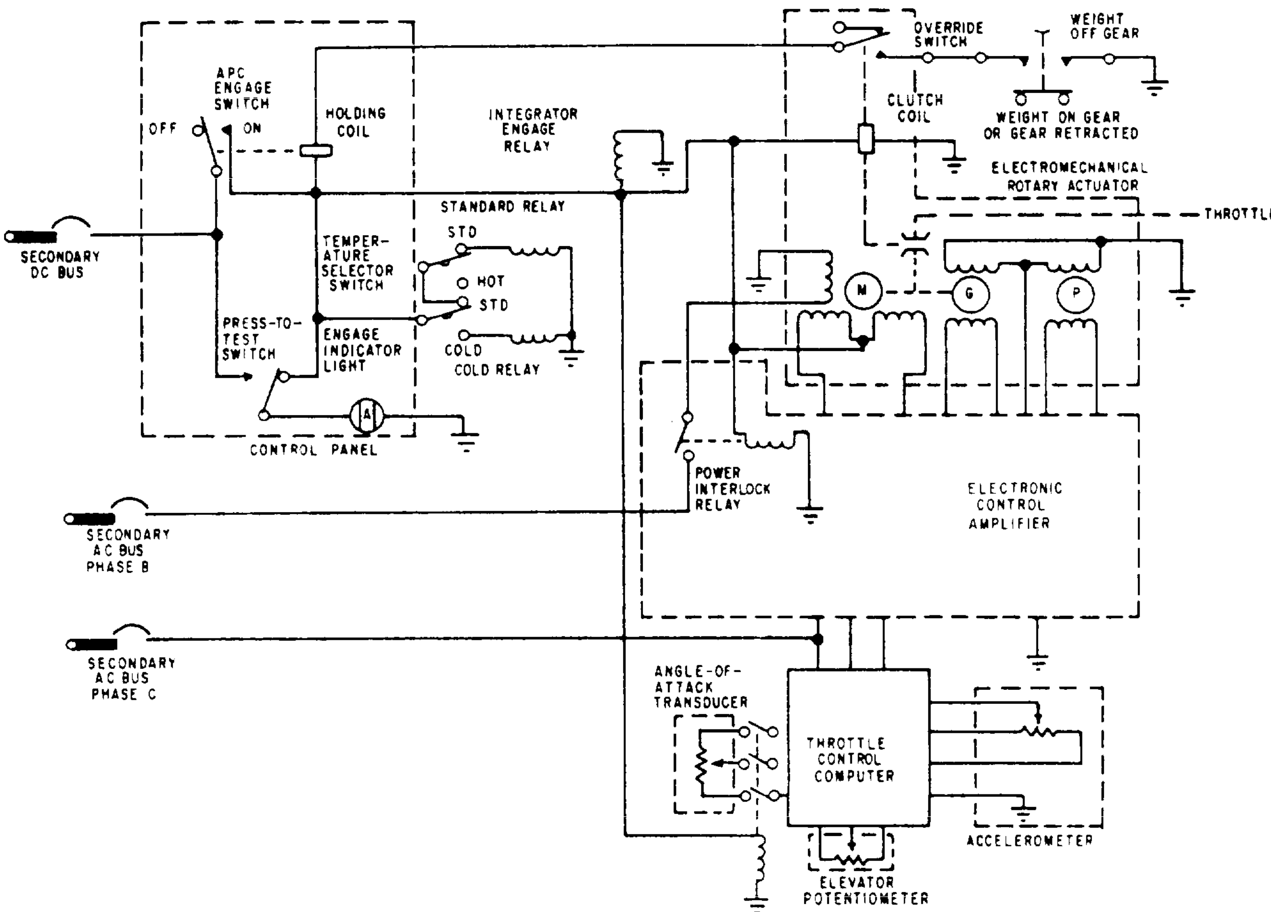


Figure 5-25.-Approach power compensator simplified schematic.

requiring a change of power setting. When a power change is necessary, the computer sends an electrical signal to the rotary actuator through the control amplifier. The rotary actuator motor then drives the engine control linkage to accomplish the required power change. The system is capable of driving the throttle linkage at speeds up to 25 degrees per second. The APC can vary the engine RPM from full throttle to 67 percent RPM at temperatures above 0°F, or to 58 percent RPM at temperatures below 0°F.

Since engine performance varies with ambient air temperature, the APC includes a three-position temperature switch to compensate for this effect. At low ambient air temperatures, the thrust change per degree of throttle movement is greater than at high ambient air temperatures. When the APC temperature switch is in COLD, the APC operates with a 15 percent reduction in gains from those with the switch in standard (STD). Conversely, with the temperature switch in HOT, the APC operates with an approximate 11 percent increase in gains from STD. This results in APC performance that is essentially the same regardless of ambient air temperature, with the following temperature settings: COLD below 4°C (40°F), STD from 4°C to 27°C (80°F), and HOT above 27°C.

REVIEW SUBSET NUMBER 11

Q1. To maintain the best angle-of-attack during landing approaches, the approach power compensator automatically controls

______________________________.

Q2. The approach power compensator circuit de-energizes when the pilot turns it off, the aircraft touches down, and __________.

Q3. What does the approach power compensator use to compensate for differences in ambient temperatures?

BLADEFOLD SYSTEM

Learning Objective: *Recognize operating principles and characteristics of helicopter bladefold systems.*

Bladefold on the H-60 helicopter is an electromechanical system. The bladefold index drive unit positions the main rotor head before folding. There are four bladefold actuators—one for each blade. A tail rotor blade positioner actuator positions the tail rotor for pylon and stabilator folding. The blade deice distributor assembly on the main rotor contains sequencing electronics and power switching circuits for bladefold and pitchlock actuators.

Power goes to the main rotor distributor through the main rotor slip ring. The bladefold control panel contains system operating controls and status/cue light capsules.

You can manually fold the pylon by using a folding pole. A lockpin switch on the pylon indicates when the pylon is locked in flight position. The tail cone-pylon fold point has a crack open switch. This switch indicates pylon disconnection from the tail cone. Two stabilator lockpin switches indicate when stabilator lockpins are locking the stabilator panels in flight position.

In addition, switches on each rotor hub indicate fold or spread status, and pitchlock engage or disengaged status. The switch signals go to the bladefold control panel and distributor.

MASTER POWER DISTRIBUTION

DC power for the system is from the No. 2 dc primary bus. This power goes through the weight-on-wheels and low oil pressure relays. Bladefold cannot operate unless the helicopter is on the ground and the rotor head not moving.

The transmission pressure switch energizes the transmission low oil pressure relay. With both weight-on-wheels and rotor head stopped, the 28-Vdc master power goes to the blade deice junction box.

The 28 Vdc at the blade deice junction box goes to two hydraulic system interlock relays. These relays actuate by pressure switches in the No. 1 and No. 2 hydraulic systems.

To protect the flight controls, pressure can go to only one stage of the main rotor servos during fold operation. One hydraulic system must be shut off by the SERVO switch on either collective stick grip. Pressure switches operate relays to ensure that only one hydraulic system is on. Relay operation permits master power to the bladefold control panel only when one hydraulic system is on.

The 28-Vdc rotor brake pressure switch senses rotor brake condition. The pressure switch actuates a relay, which applies a signal to the bladefold control panel. This signal is for the bladefold control panel indexing logic. The ROTOR BREAK-APPLY-RELEASE indicators on the bladefold control panel advise pilots when to apply or release the rotor brake.

FOLD SEQUENCE

The first step in folding the main rotor blades is to index the rotor head to a known position. The bladefold index drive unit accomplishes this task. A de-operated linear actuator in the unit engages the indexing motor output gear to the rotor brake disc gear. An index command from the bladefold index drive unit drives rotor head to indexed position. A 2.5-degree maximum cutaway segment of an index slip ring in the slip ring assembly senses this position.

With the BLADEFOLD switch in the FOLD position, and the rotor brake disengaged, the rotor can drive in either the clockwise or counterclockwise direction. The rotor will drive in the direction of the shortest distance to the index position. To do this, index drive slip ring construction is in two segments separated at the index position, 180 degrees from index position, and by providing a reversing relay in the index drive unit.

The index motor rotates at 0.5 RPM. As the rotor head reaches the 1.0-degree index position, index drive motor power switches off and the drive motor brake de-energizes, applying the brake. Power removal and brake application prevent the rotor head from overshooting the index position.

When rotor head position is on the insulated area between index drive slip ring segments 180 degrees from the index position, head rotation will be counterclockwise toward the index position.

The index unit can also act as a backup system to the rotor brake. You can use the index unit to engage the brake disk and to hold the rotor head stationary when performing maintenance on the rotor brake. To do this, use the GUST LOCK-LKD-UNLKD switch on the miscellaneous switch panel. The switch enables the index unit to extend and engage the rotor brake disk, without applying power to the index motor. A brake and gear train inside the motor prevents motor output shaft rotation with no power to the motor. The index unit effectively acts as a lock to hold the rotor head in place.

Power goes to the GUST LOCK switch from No. 2 dc primary bus interlocked through weight-on-wheels and transmission low oil pressure relays, so the GUST LOCK can only engage on the ground. When the index unit actuator retracts fully, a limit switch within the actuator activates a second relay inside the panel. This relay turns on a GUST LOCK caution light on the caution advisory panel.

DC power extends or retracts the index unit. Three-phase ac power operates the index motor.

When the rotor head is indexed, logic circuits in the bladefold control panel turn on an INDEXED status light. The logic also senses the condition of the main rotor blades, tail pylon, stabilator, and rotor brake. If main rotor blades are spread and indexed, pylon and stabilator are in flight position. With the rotor brake on, a pitch blades command goes to the DAFCS computer.

The computer flashes the BAR ALT push-button legend on the AFCS CONTROL panel. When the operator presses this push-button for 2 seconds, the TRIM push-button legend goes on. This causes the computer to send flight control positioning signals to the pilot-assist servos. The pilot-assist servos move the flight controls to a computer memorized position.

With controls positioned, the computer sends an enable signal to the pitchlock logic in the bladefold control panel indicated by the flashing TRIM push-button legend. The control panel delivers a pitchlock command through the slip ring to the bladefold deice distributor. This power goes to the distributor for pitchlock actuators and bladefold actuators. This 115-Vac power also goes to the pitchlock actuator on each rotor blade hub. Each actuator advances a Iockpin that locks each blade pitch control horn.

When all control horns lock, a signal goes through the slip ring to the bladefold control panel. This turns on a PITCH LOCKED status light.

As each blade's pitch lockpin engages its respective pitch control horn, the bladefold actuator operates. Each actuator, through gearing, unlocks its respective blade by pulling out two blade lockpins.

Once the blade lockpins pull out, worm gearing drives a segment gear, which folds back each blade. Switches on each blade sense when the blade lockpins pull out and each blade reaches a folded position. When all four blades actuate the bladefold switches, a signal goes from logic in the distributor. This signal flows through the slip ring to the bladefold control panel, bringing on a FOLDED status light.

Each blade has individual logic circuits in a bladefold module. Should any individual logic circuit fail, the associated blade will not fold. This does not affect the other blades in the system, and they will fold normally. A spread blade can fold manually.

If a loss of command signals or power occurs, this will prevent all blades from folding. A cycle caution logic circuit incorporated in the distributor monitors failures that are common to all blades. The cycle caution output goes to test points in the bladefold module for troubleshooting and fault isolation of the system.

SPREAD SEQUENCE

You accomplish main rotor blade spreading by setting the BLADEFOLD switch to SPREAD. The switch routes a spread command through the slip ring to the blade deice distributor. The spread command also goes to the junction box and energizes a relay. This causes the power to the distributor circuits to reverse phase, allowing the bladefold actuators to run in the spread direction, spreading each rotor blade. As each blade reaches the full spread position, two blade lockpins drive into the blade hinge lugs.

Two switches sense lockpin positions. When both switches actuate, a relay in the distributor energizes and reverses the phase of power to the actuators. The actuators run in the fold condition again for a brief period. This relieves stresses built up on the segment gear in each bladefold actuator.

Running the actuators in the fold direction causes the blade lockpins to back slightly out of the hinge lugs. One of the blade lockpin switches actuates before the other. This switch remains actuated even though the lockpins are backing out of the hinge lugs. The other switch deactuates when the lockpins back out. When one lockpin switch actuates, and the other is deactuated, distributor logic determines achievement of the full spread condition. This de-energizes the bladefold motor actuator on each blade.

Because the lockpins pull out only a short distance, they still safely lock the blades in flight position. Logic circuits in the distributor sense the fully spread conditions, spread command, and pitch lockpin IN condition for each blade. At this point, a relay actuates that pulls out the pitch lockpin in each blade pitch control horn. Simultaneously, a signal goes to a control panel spread complete logic circuit. This circuit actuates a 2-second time-delay relay. The relay shuts off hydraulic pressure to the pilot-assist servos and provides a logic signal to the DAFCS computer.

The logic signal to the DAFCS computer tells the computer to update flight control position information from the transducers for 2 seconds. This is accomplished when one stage of hydraulic pressure is off, preventing preloading of the flight controls. Any preloading of the controls would cause an error in position information to the computer.

After the 2-second delay, the computer blinks the RDR ALT push-button legend on the AFCS CONTROL panel. This informs the operator that the computer has accepted the flight control position update. The computer will place the flight controls in the new memorized position during the next fold cycle.

PYLON AND STABILATOR FOLD

The first step in manually folding the pylon is to complete bladefold operation. By doing this, you prevent rotor blade and pylon damage.

The crack open switch receives 28 Vdc, which comes through contacts of the weight-on-wheels relay. When the pylon opens about 5 degrees, the crack open switch applies power to the tail rotor blade positioner actuator. The actuator extends, indexes, and gust locks the tail rotor. It extends until the internal extend limit switch disconnects power. At the same time, another internal switch applies an actuator extended signal to the bladefold control panel logic circuits.

If main bladefolding is operating at the same time as pylon folding, the actuator extended signal stops main fold. This prevents the main blades from striking the pylon.

Two stabilator lockpin switches close when the stabilator locks in the flight (spread) position. This applies 28 Vdc to the automatic engagement circuit in the stabilator amplifier.

With the stabilator lockpin switches in nonflight position, power is removed from the No. 1 and No. 2 stabilator amplifier auto engage circuitry. The auto engage circuitry engages when the stabilator AUTO CONTROL PUSH TO RESET pushbutton is depressed. **DAMAGE MAY OCCUR TO THE FUSELAGE IF THE STABILATOR IS IN THE FOLD POSITION.** At the same time, the bladefold control panel logic circuits receives a ground signal.

With the main rotor blades properly folded, the bladefold control panel logic circuitry causes the SPREAD INCOMPLETE caution capsule to light under the following conditions:

- Power goes to the fold or spread relays without being commanded by the bladefold control panel.
- Pylon or stabilator panel spread but not locked.
- Tail rotor blade positioner actuator extends with the pylon in the flight condition.

REVIEW SUBSET NUMBER 12

Q1. In the H-60 bladefold system, the transmission low oil pressure relay is energized by a ______________________.

Q2. When the rotor head is on the insulated area between index drive slip ring segments 180 degrees from the index position, in what direction will the rotor head travel towards index?

Q3. During bladefold operations, if one blade fails to fold, will the other blades fold?

Q4. During blade spread operations, the actuators run in the fold condition after lockpin position switches activate to

______________________________.

Q5. During pylon and stabilator fold, at what point does the crack open switch power the tail rotor blade position actuator?

VARIABLE INLET DUCT RAMP SYSTEM

Learning Objective: *Recognize operating principles and features of variable inlet duct ramp systems.*

High-speed aircraft usually operate in predetermined Mach numbers instead of specific airspeeds. The Mach number is the ratio of the speed of an object to the speed of sound in the same medium and at the same temperature. Sonic velocity and Mach number vary with air temperature; therefore, at standard day conditions, the airspeed that corresponds to a given Mach number varies with changes in altitude.

In aircraft that fly at speeds of Mach 2.0 and greater, the air velocities at the inlet duct are much higher than the engine can efficiently use. The velocity of the air at the inlet duct entrance must be decreased before entering the engine to prevent engine stall. Some aircraft accomplish this by using a variable inlet duct ramp. The duct ramp is a moving part of the surface attached to the leading edge of the engine inlet duct. It positions the supersonic shock waves to allow only subsonic air to enter the duct. Through wind tunnel tests, the exact ramp position necessary at any particular speed is determined.

ENGINE INLET BLEED AIR SYSTEM

Learning Objective: *Recognize operating principles and characteristics of aircraft engine inlet bleed air systems.*

The engine inlet bleed air system of the F/A-18 provides the best inlet airflow for subsonic and supersonic flight. The inlet bleed air doors control inlet airflow by opening at 1.33 Mach to bleed boundary layer air off the compression ramp and close at 1.23 Mach. This makes sure the doors will not oscillate when the aircraft travels at 1.33 Mach. A bleed air channel controls the fuselage boundary layer airflow near the wing roots.

The bleed air doors open when three-phase, 115-Vat power is applied, and the controlling FLIGHT CONTROL COMPUTER (FCC) has a loss of power. After normal engine shutdown, the bleed air doors normally close. In some models of the F/A-18 aircraft when external power is on or the APU is operating in the ground maintenance mode and FCCs off, the bleed air doors will open. When FCCs are turned on, the bleed air doors will close. The FLT CONTR GND PWR RELAYS No. 11 and No. 12 prevent the cycling of the bleed air doors during ground operations.

The Air Data Sensor, DT-600/ASW-44, computes the free air Mach number and sends the signal to FCCA and FCCB. When the Mach number is below 1.23, the FCCs supply a ground, energizing the retract circuits. Each actuator torque motor energizes, and the actuator brakes release. The torque motors retract the bleed air doors (if doors are not retracted) until the actuator retract limit switches close. The retract limit switches de-energize the retract circuits, and the actuator brakes are applied by spring pressure.

When the Mach number is above 1.33, the FCCs remove the ground, de-energizing the control relays and energizing the extend circuits. Each actuator's torque motor energizes and the actuator brakes release. The torque motors extend the bleed air doors (if doors are not extended) until the actuators extend limit switches close. The extend limit switches de-energize the extend circuits, and the actuator brakes are applied by spring pressure.

The extend limit and retract limit switches in each bleed air door actuator makes a ground to signal the signal data converter when the inlet bleed door fully extends or retracts. When ground is removed, the signal data converter measures the time in transient until the other limit switch closes. If the time in transient exceeds 8 seconds, the signal data converter signals the digital computer. The digital computer commands the cockpit DDI to display a caution.

REVIEW SUBSET NUMBER 13

Q1. The ratio of the speed of an object to the speed of sound in the same medium and at the same temperature is known as

______________________ .

Q2. The F-18 engine bleed air system duct doors are controlled by ______________________ .

CHAPTER 6

AIRCRAFT INSTRUMENTS

When the first aircraft came into existence, the main goal was to launch the aircraft and keep it airborne as long as possible. At first, it was not possible to keep the aircraft in the air for longer than a few minutes. However, as engines and aircraft structures were improved, the aircraft was able to remain aloft for a longer time. Along with these improvements came the need for instruments. The first aircraft instruments were fuel and oil pressure instruments. These instruments warned the pilot of engine trouble so the aircraft could be landed before the engine failed. Later, when the aircraft could fly over considerable distances, weather became a problem. This led to the development of instruments that helped pilots fly through snowstorms, thunderstorms, and other bad weather conditions.

The instruments used in aircraft years ago are reasonably simple compared with those in current aircraft. The jet aircraft has brought many complex problems to instrument engineering.

Instrumentation is basically the science of measurement. Measurements that are common on all aircraft are posit ion, direction, speed, altitude, engine condition, fuel on board, and fuel consumption. In addition, jet aircraft instruments include Mach number, angle of attack, and tail pipe temperature indicators.

There are two ways of grouping aircraft instruments—by their operating principles and by the job they perform. Instrument operating principles include gyroscopic, pressure or temperature sensing, magnetism, electrical energy, or a combination of any of these. This chapter deals with instruments and indicating systems in relation to the jobs they perform—flight, engine, and equipment instruments. The flight instruments discussed are those instruments that provide aircraft performance information to the pilot. These instrument systems include the airspeed, altimeter, vertical speed, attitude, turn and bank, and angle-of-attack. Along with the heading indicator, these instruments provide primary flight reference to the pilot. The heading indicator is a flight instrument, which is discussed in the inertial navigation systems chapter.

FLIGHT INSTRUMENT SYSTEMS

Learning Objective: *Recognize operating principles and features of various aircraft flight instrument systems, including the pitot-static, airspeed indicator, angle-of-attack, gyroscope, and miscellaneous flight instrument systems.*

To maintain instruments properly, you, as an AE, must know the basic principles of the flight instrument systems. AEs frequently work with equipment and systems that use the principles of density and pressure.

You must consider density and pressure when discussing altimetry and airspeed. Although very light, air has weight and is affected by gravity. By its weight, air exerts pressure on everything it touches. Since air is a gas, it exerts pressure in all directions. The weight of the air pressing down from above determines the air pressure at any given altitude.

The weight of the atmosphere presses the molecules closer together, making them more numerous per unit of volume. This action takes place at the bottom of the atmosphere, or where it rests upon the earth's surface. Therefore, the air at the bottom of the atmosphere is more dense than at higher altitudes. Air pressure at sea level on an average day will support a column of mercury 29.92 inches high (fig. 6-1).

Atmospheric pressure is a force per unit area, and force is equal to mass multiplied by acceleration. Therefore, a pressure change occurs if either the mass of the atmosphere changes or the molecules within the atmosphere accelerate. Although altitude exerts the dominant control, temperature and moisture alter pressure at any

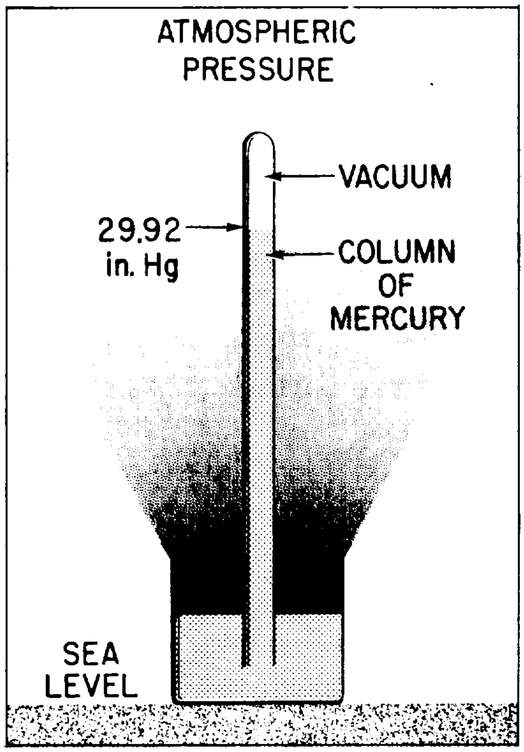


Figure 6-1.-Mercurial barometer.

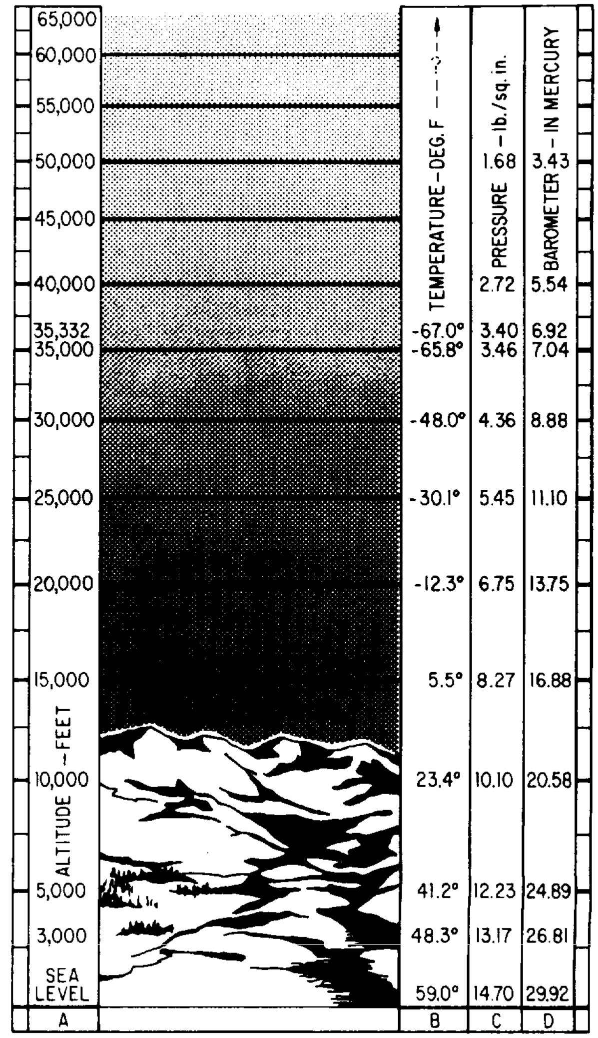


Figure 6-2.-The standard atmosphere.

given altitude. Figure 6-2 shows the standard pressure and temperature at given altitudes.

Conditions are very seldom *standard* for temperature or pressure; therefore, you must correct the formula to find density altitude or true airspeed. Let's consider an airfield under the influence of a low-pressure climatic condition, where the temperature is very hot. Together, these two conditions may reduce the density of the air to such an extent that it affects aircraft engine performance. This makes takeoff capability marginal, especially for a helicopter. The density of air also directly affects aircraft movement through the air, and thus the true airspeed of the aircraft. The denser the air, the more difficult it is for the aircraft to move through it.

PITOT-STATIC SYSTEM

The aircraft pitot-static system (fig. 6-3) includes instruments that operate on the principle of the barometer. The system consists of a pitot tube, static air vents, and three indicators, which connect with pipelines that carry air. The three indicators are airspeed, altimeter, and the vertical speed indicator (VSI).

The airspeed indicator shows the speed of the aircraft through the air and the altimeter shows the altitude. The VSI indicates how fast the aircraft is climbing or descending. They all operate on air that comes in from outside the aircraft during flight.

The pitot tube mounts on the outside of the aircraft (fig. 6-3) at a point where the air is least likely to be turbulent. The tube points in a forward direction parallel to the aircraft's line of flight. One general type of airspeed tube mounts on a streamlined mast extending below the nose of the fuselage. Another type mounts on a boom extending forward of the leading edge of the wing, Although there is a slight difference in their construction, they operate identically.

Pitot stands for impact pressure, the pressure of the outside air against the aircraft flying through it. The tube that goes from the pitot tube to the airspeed indicator applies the outside air pressure to the airspeed indicator. The airspeed

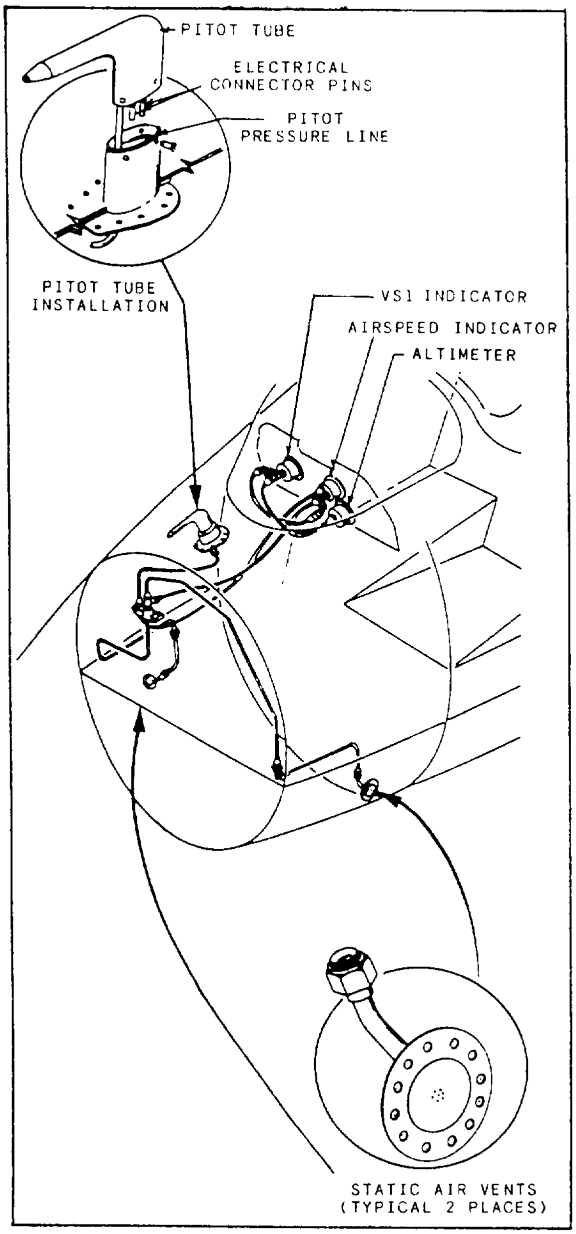


Figure 6-3.-Pitot-static system.

indicator calibration allows various air pressures to cause different readings on the dial. The purpose of the airspeed indicator is to interpret pitot air pressure in terms of airspeed in knots.

Generally, static air vents (fig. 6-3) are small calibrated holes in an assembly mounted flush with the aircraft fuselage. Their position is in a place with the least amount of local airflow moving across the vents when the aircraft is flying.

Static means stationary or not changing. The static part of the pitot-static system also introduces outside air. However, it is at its normal outside atmospheric pressure as though the aircraft were standing still in the air. The static line applies this outside air to the airspeed indicators, the altimeter, and the vertical speed indicator.

Airspeed Indicators

Readings from an airspeed indicator are useful. They are used to estimate ground speed and to determine throttle settings for the most efficient flying speed. These readings also provide a basis for calculating the best climbing and gliding angles. They warn the pilot if diving speed approaches the safety limits of the aircraft's structure. Since airspeed increases in a dive and decreases in a climb, the indicator is an excellent check for maintaining level flight. Figure 6-4

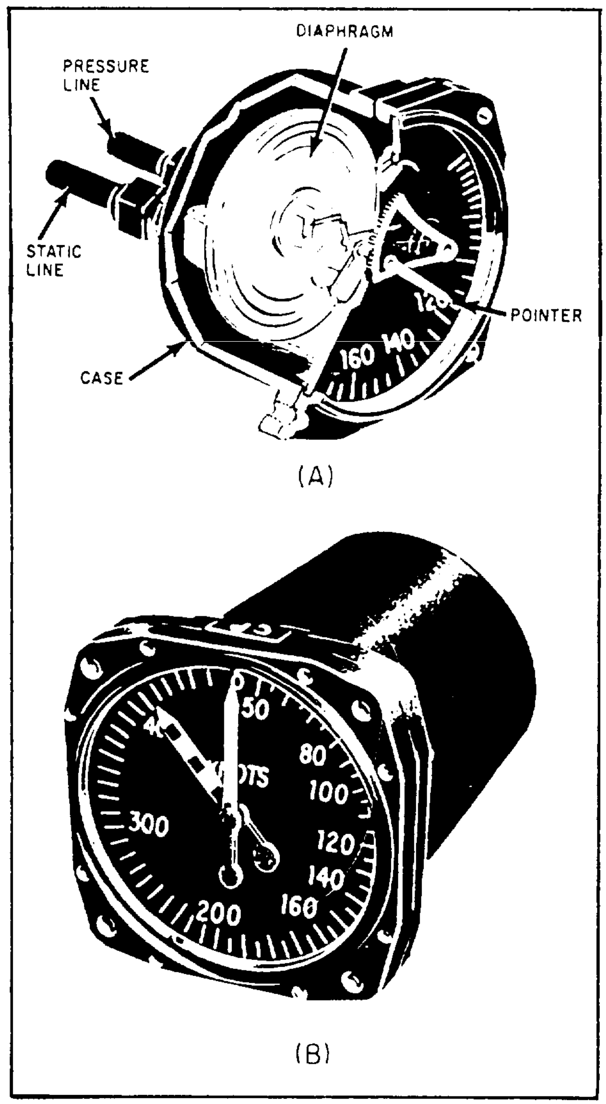
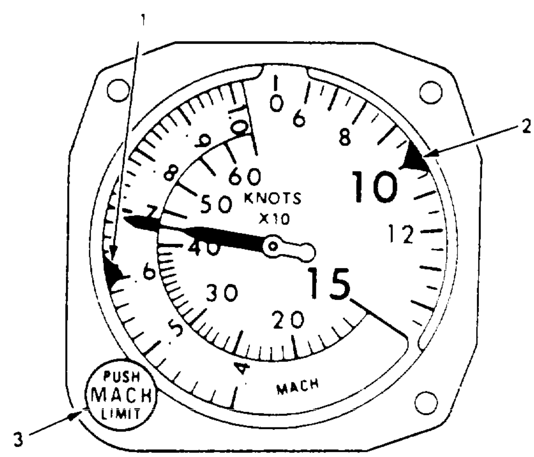


Figure 6-4.-(A) Airspeed indicator; (B) maximum allowable airspeed indicator.

shows a cutaway view of a typical airspeed indicator.

An airspeed indicator has a cylindrical, airtight case that connects to the static line from the pitot-static tube. Inside the case is a small aneroid diaphragm of phosphor bronze or beryllium copper. The diaphragm is very sensitive to changes in pressure, and it connects to the impact pressure (pitot) line. This allows air from the pitot tube to enter the diaphragm. The side of the diaphragm fastens to the case and is rigid. The needle or pointer connects through a series of levers and gears to the free side of the diaphragm.

The airspeed indicator is a differential pressure instrument. It measures the difference between the pressures in the impact pressure line and in the static pressure line. The two pressures are equal when the aircraft is stationary on the ground. Movement through the air causes pressure in the impact line to become greater than that in the static line. This pressure increase causes the diaphragm to expand. The expansion or contraction of the diaphragm goes through a series of levers and gears to the face of the instrument to regulate needle position. The needle shows the pressure differential in MPH or knots. (All speeds and distances are in nautical miles.)



INDEX	CONTROL/INDICATOR	FUNCTION
1	Mach index	Provides a reference mark along the mach scale
2	Airspeed index	Provides a reference mark along the airspeed scale
3	MACH PUSH LIMIT knob	When pressed and rotated it causes the mach index to move along the mach scale from 0.4 to 2.0 mach. When rotated (not pressed) it causes the airspeed index to move along the airspeed scale from 0 to 150 knots **CAUTION** To set mach limit, turn knob counterclockwise only.

Figure 6-5.-Airspeed/Mach indicator.

MAXIMUM ALLOWABLE AIRSPEED INDICATOR. —Figure 6-4, view B, shows the face of a maximum allowable airspeed indicator. The dial face measurements are in knots from 50 to 450 with an expanded scale below 200 knots. The dial has an indicating pointer and a maximum safe airspeed pointer. The maximum safe airspeed pointer moves as the maximum safe airspeed changes because of static pressure changes at different altitudes.

No matter where the pitot-static tube is located, it is impossible to keep it free from all air disturbances set up by the aircraft structure. You must make allowances for this *installation error* when reading the indicator. Temperature is another cause of error. Also, imperfect scaling of the indicator dial with respect to the air-speed-differential pressure relationship will cause an error in reading. You can make simple adjustments to the instrument mechanism to correct the tendency to read fast or slow.

MACH NUMBER INDICATORS. —In some cases, the term *Mach number is* used to express aircraft speed. The Mach number is the ratio of the speed of a moving body to the speed of sound in the surrounding medium. For example, if an aircraft is flying at a speed equal to one-half the local speed of sound, it is flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is Mach 2. (The term *Mach number* comes from the name of an Austrian physicist, Ernest Mach, pioneer in the field of aerodynamics.)

Figure 6-5 shows the front view of a typical airspeed and Mach number indicator. The instrument consists of altitude and airspeed mechanisms incorporated in a single housing. This instrument gives the pilot a simplified presentation of both indicated airspeed and Mach number. Both indications are read from the same pointer. The pointer shows airspeed at low speeds, and both indicated airspeed and Mach number at high speeds. Pitot pressure on a diaphragm moves the pointer, and an aneroid diaphragm controls the Mach number dial. The aneroid diaphragm reacts to static pressure changes because of altitude changes. Figure 6-6 is a mechanical schematic of an airspeed and Mach indicator.

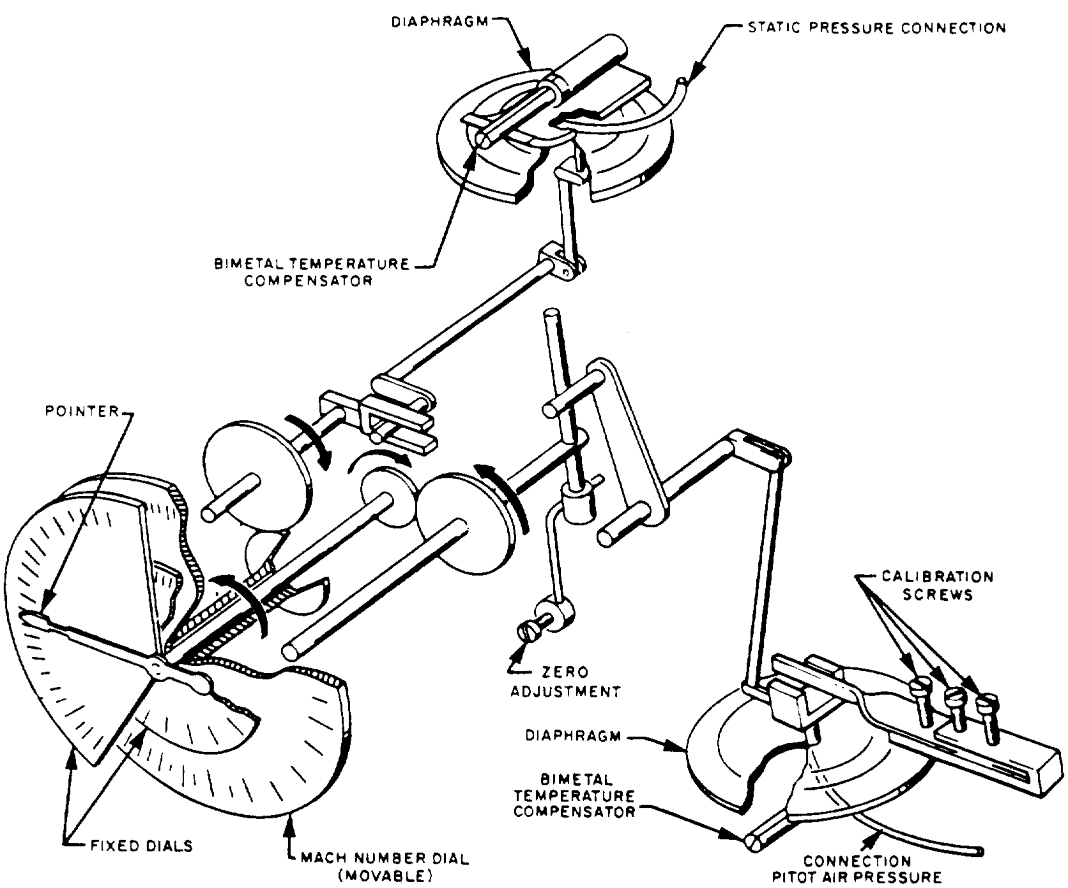


Figure 6-6.-Airspeed/Mach number indicator mechanical schematic.

The range of the instrument is 80 to 650 knots indicated airspeed and from 0.5 to 2.0 Mach number. Its calibrated operating limit is 50,000 feet of altitude. A stationary airspeed dial masks the upper range of the movable Mach dial at low altitudes. The stationary airspeed dial is graduated in knots. The instrument incorporates a landing speed index and a Mach number setting index. You can adjust both indexes by a knob on the lower left-hand corner of the instrument. You can adjust the landing speed index over a range of 80 to 150 knots. The index operates with the knob in its normal position. You may adjust the Mach number index over the entire Mach range. The index adjusts by depressing the knob and turning it.

Altimeter

An altimeter is an instrument that measures static pressure. Before you can understand how the altimeter works, you need to understand altitude. Remember, even though the altimeter reads in feet, it is actually measuring pressure.

The word *altitude* is vague, so it needs further defining. The term *altitude* includes altitude above mean sea level (MSL) and altitude above ground level (AGL). It also, includes pressure altitude, indicated altitude, density altitude, and elevation.

MEAN SEA LEVEL. —Since about 80 percent of the earth's surface is water, it is natural to use sea level as an altitude reference point. The pull of gravity isn't the same at sea level all over the world because the earth isn't perfectly round and because of tides. To adjust for this, an average (or mean) value is set; this is the mean sea level. Mean sea level is the point where gravity acting on the atmosphere produces a pressure of 14.70 pounds per square inch. This pressure supports a column of mercury in a barometer to a height of 29.92 inches. This is the reference point from which you measure all other altitudes. See figures 6-1 and 6-2. The altitude you read from an altimeter refers to MSL.

ELEVATION AND TRUE ALTITUDE. —Elevation is the height of a land mass above mean sea level. Elevation is measured with precision instruments that are far more accurate than the standard aircraft altimeter. You can find elevation information on charts or, for a particular spot, painted on a hangar near an aircraft ramp or taxi area.

True altitude is the actual number of feet above MSL. A ruler or yardstick is used to measure the altitude. In standard day conditions, pressure altitude and true altitude are the same.

ABSOLUTE ALTITUDE —Absolute altitude is the distance between the aircraft and the terrain over which it is flying. It is referred to as the *altitude above ground level* (AGL). AGL is usually useless information because of variations in the terrain. However, it is useful when flying near the ground; for example, in a takeoff or landing pattern. You find AGL by subtracting the elevation of the terrain beneath the aircraft from the altitude read on the altimeter (MSL). A radar altimeter indicates actual altitude above the terrain; you call this indication *radar altitude.*

PRESSURE ALTITUDE. —It is not possible to have a ruler extending from an aircraft and reaching to sea level to measure altitude. To measure altitude, instruments sense air pressure and compare it to known values of standard air pressure at specific, measured altitudes. The altitude you read from a properly calibrated altimeter referenced to 29.92 inches of mercury (Hg) is the *pressure altitude.*

Refer back to figure 6-2. If a pressure altimeter senses 6.75 pounds per square inch pressure with the altimeter set to sea level and barometric pressure 29.92 inches of mercury, the altimeter indicates 20,000 feet. This does not mean that the aircraft is exactly 20,000 feet above mean sea level. It means the aircraft is in an air mass exerting *a* pressure equivalent to 20,000 feet on a standard day. You can see that pressure altitude is not true altitude.

INDICATED AND CALIBRATED ALTITUDE. —Unfortunately, standard atmospheric conditions very seldom exist. Atmospheric conditions and barometric pressure can vary considerably. A pressure change of one-hundredth (0.01) of an inch of mercury represents a 9-foot change in altitude at sea level. Barometric pressure changes between 29.50 and 30.50 are not uncommon (a pressure change of about 923 feet). Indicated altitude is the uncorrected reading of a barometric altimeter. Calibrated altitude is the indicated altitude corrected for inherent and installation errors of the altimeter instrument. On an altimeter without such errors, indicated altitude and calibrated altitude are identical. Assume that this is the case for the rest of this discussion.

When flying below 18,000 feet, the aircraft altimeter must be set to the altimeter setting (barometric pressure corrected to sea level) of a selected ground station within 100 miles of the aircraft. Altitude read from an altimeter set to local barometric pressure is indicated altitude. The accuracy of this method is limited because you must assume a standard lapse rate; that is, for a given number of feet of altitude, an exact change in pressure occurs. This seldom happens, which limits the accuracy of the altimeter. Above 18,000 feet, all altimeters are set to 29.92 (pressure altitude). Although the altimeter is not accurate, as long as all aircraft have the same barometric pressure setting, aircraft vertical separation is controlled.

DENSITY ALTITUDE. —A very important factor in determining the performance of an aircraft or engine is the density of the air. The denser the air, the more horsepower the engine can produce. Also, there is more resistance to the aircraft in flying through the air, and the airfoils produce more lift. Pressure, temperature, and moisture content all affect air density. Measurements of air density are in weight per unit volume (for example, pounds per cubic foot). However, a more convenient measurement of air density for the pilot is density altitude. This is the altitude assigned to a given density in the standard atmosphere.

Density altitude does not show on an instrument. It is usually taken from a table or computed by comparing pressure, altitude, and temperature. Although moisture content affects air density, its effect is negligible.

Figure 6-7 shows the different types of altitude. At Navy Memphis, the field elevation is

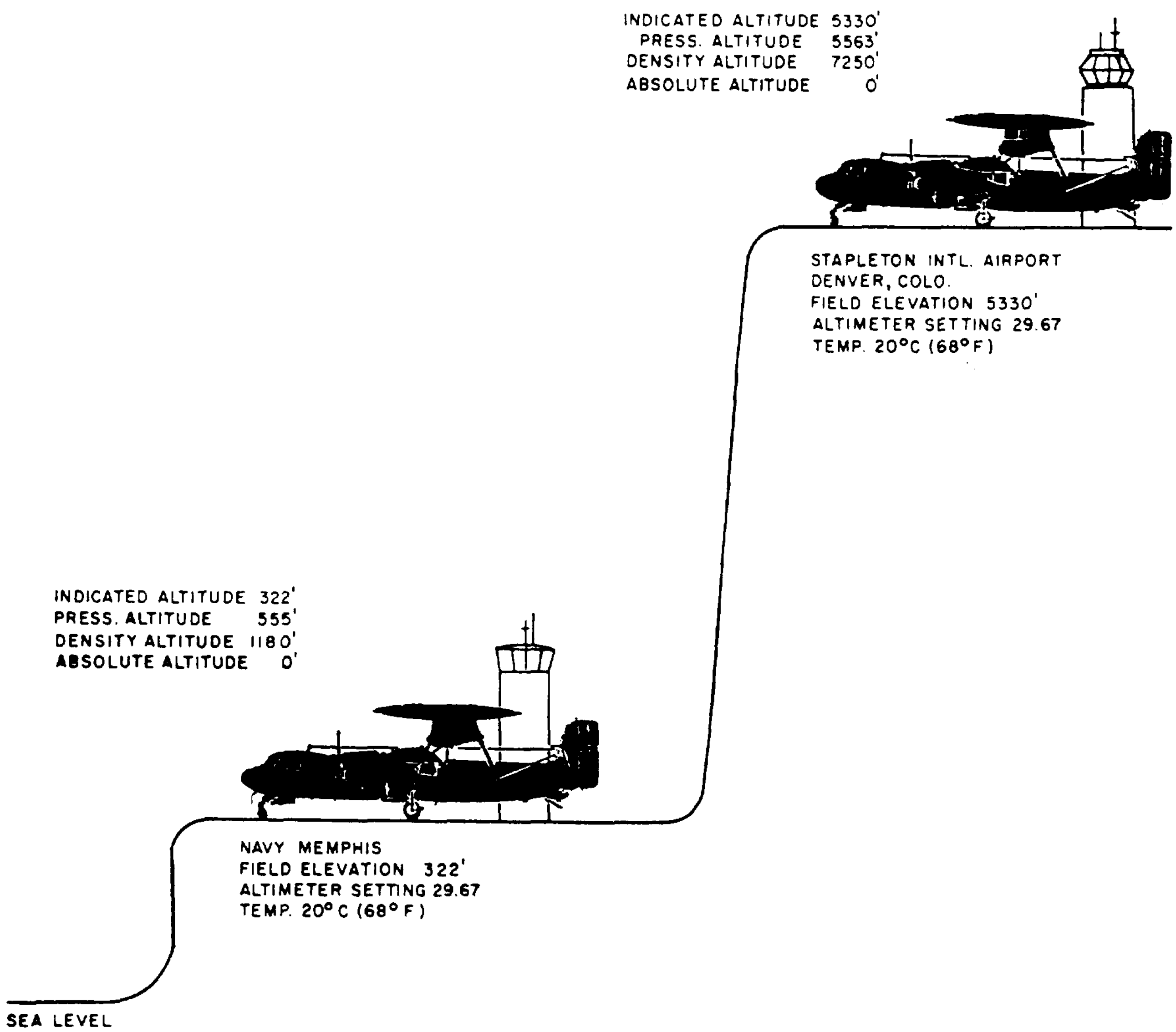


Figure 6-7.-Different types of altitude.

322 feet. The altimeter should read 322 feet when properly set to the local altimeter setting (in this case 29.67). If the altimeter is set to 29.92 (standard day pressure at sea level), the altimeter would read about 550 feet. The density altitude is such that the aircraft and engine perform the same as if they were at a standard day altitude of 1,180 feet. This means the distances required for takeoff and landing are longer for higher density altitudes (higher temperatures). The absolute altitude (AGL) for the aircraft at Memphis is zero feet because the aircraft is touching the surface.

Look at the altitude for Stapleton International Airport in Denver, Colorado (fig. 6-7). Notice that the difference between pressure altitude and indicated altitude remains the same as at Memphis. However, at the same temperature the density altitude is much greater at Denver.

Several kinds of altimeters are used today. They are all constructed on the same basic principle as an aneroid. They all have pressure-responsive elements (aneroid wafers) that expand or contract with the pressure changes of different flight levels. The heart of a pressure altimeter is its aneroid mechanism (fig. 6-8), which consists of one or more aneroid wafers. The expansion or contraction of the aneroid wafers with pressure changes operates the linkage. This action moves the indicating hand/counter to show altitude. Around the aneroid mechanism of most altimeters is a device called the bimetal yoke. As the name implies, this device is composed of two metals. It performs the function of compensating for the effect that temperature has on the metals of the aneroid mechanism.

The altimeter discussed in the following paragraphs is a simple one. Several complex altimeters are discussed later in this chapter, along with the automatic altitude system.

COUNTER POINTER PRESSURE ALTIMETER. —The purpose of the counter pointer pressure altimeter (fig. 6-9) is to show aircraft height. By studying the dial of the indicator, it is easy to understand the procedure for determining the height of the aircraft. A description of the mechanical operation of this altimeter follows. As you read about the operation, refer to figure 6-10.

Atmospheric changes cause movement of the two aneroid diaphragm assemblies (1). These assemblies move two similar rocking shaft assemblies (2) mutually engaged with the main pinion assembly (3). This movement goes to the handstaff assembly (4), which operates the hand assembly (5) and drives the counter mechanism (6) through a disk (7). Because of the special design of the hand assembly (5), the counter indication is never obscured. An internal vibrator (8) minimizes friction during the instrument's operation.

You make barometric corrections by turning the externally located knob (9). The knob engages the barometric dial (10) and the main plate assembly (11) that supports the entire mechanism. You make adjustments so the reading on the barometric dial corresponds to the area barometric conditions in which the aircraft is flying.

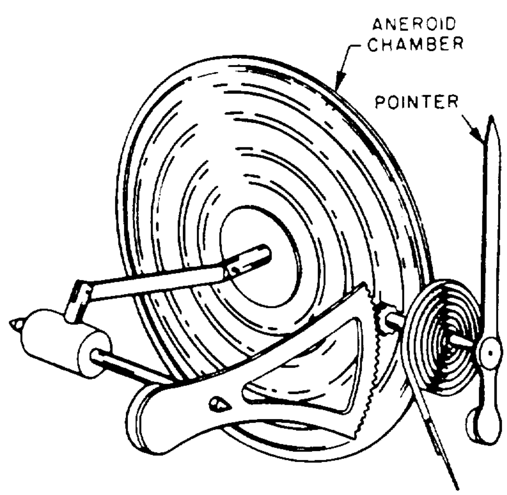


Figure 6-8.-Simplified aneroid mechanism.

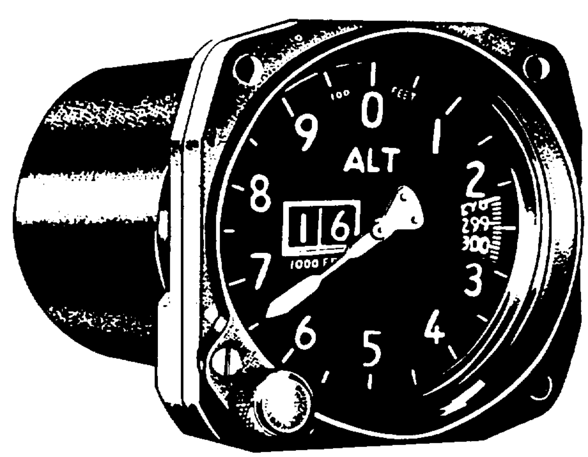
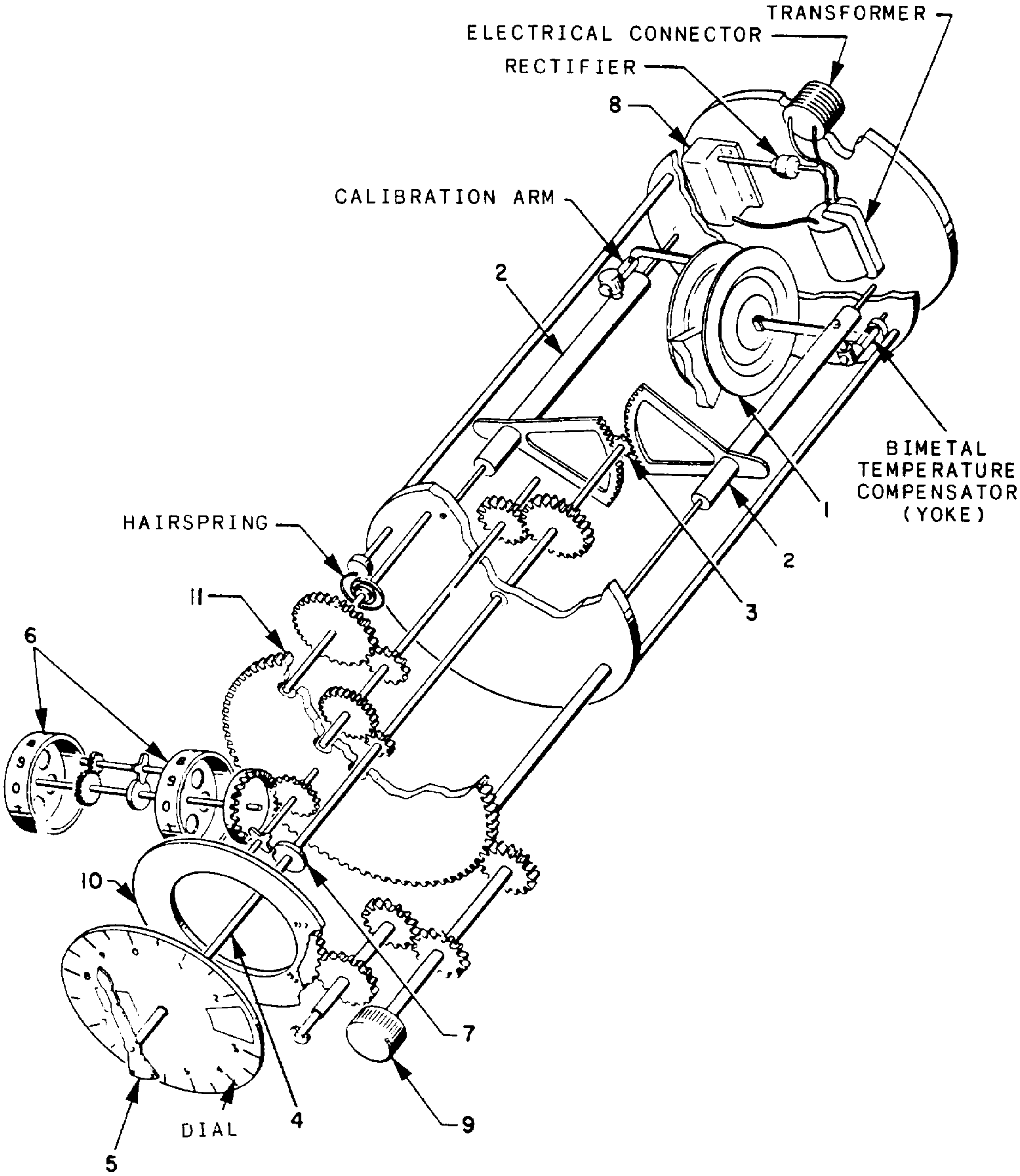


Figure 6-9.-Counter pointer pressure altimeter.



1. Diaphragm assembly
2. Rocking shaft assembly
3. Main pinion assembly
4. Handstaff assembly
5. Hand assembly
6. Counter mechanism
7. Disk
8. Internal vibrator
9. Knob
10. Barometric dial
11. Main plate assembly

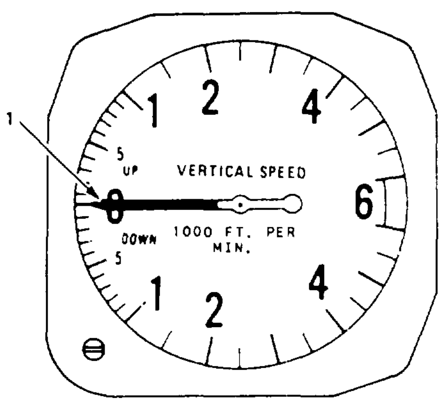
Figure 6-10.-Mechanical schematic of a counter pointer pressure altimeter.

Vertical Speed Indicators (VSI)

A vertical speed indicator shows the rate at which an aircraft is climbing or descending. It is very important for night flying, flying through fog, clouds, or when the horizon is obscured. Another use is to determine the maximum rate of climb during performance tests or in actual service.

The rate of altitude change, as shown on the indicator dial, is positive in a climb and negative in a dive or glide. The dial pointer (fig. 6-11) moves in either direction from the zero point. This action depends on whether the aircraft is going up or down. In level flight the pointer remains at zero.

The vertical speed indicator is contained in a sealed case, and it connects to the static pressure line through a calibrated leak. Look at figure 6-12. You can see that changing pressures expand or contract a diaphragm, which moves the indicating needle through gears and levers. The instrument automatically compensates for changes in temperature. Although the vertical speed indicator operates from the static pressure source, it is a differential pressure instrument. The difference in pressure between the instantaneous static pressure in the diaphragm and the static pressure trapped within the case creates the differential pressure.



INDEX	INDICATOR	FUNCTION
1	VSI POINTER	DISPLAYS VERTICAL VELOCITY IN FEET PER MINUTE

Figure 6-11.-Vertical speed indicator (VSI).

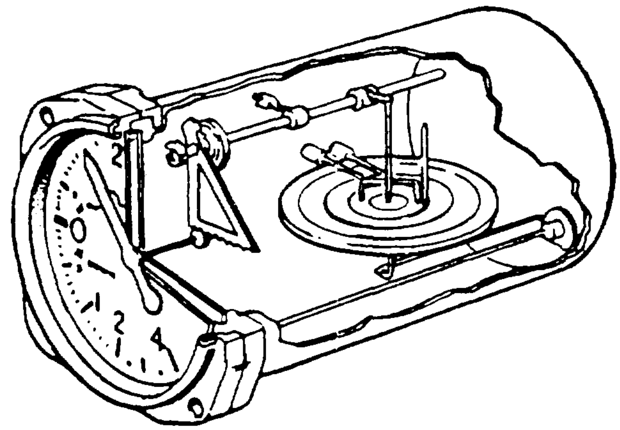


Figure 6-12.-Mechanical schematic of a VSI.

When the pressures equalize in level flight, the needle reads zero. As static pressure in the diaphragm changes during a climb or descent, the needle immediately shows a change of vertical speed. However, until the differential pressure stabilizes at a definite ratio, indications are not reliable. Because of the restriction in airflow through the calibrated leak, it requires a 6 to 9-second lag for the pressures to stabilize.

The VSI has a zero adjustment on the front of the case. You use this adjustment with the aircraft on the ground to return the pointer to zero. While adjusting the instrument, tap it lightly to remove friction effects.

AIR DATA COMPUTER SYSTEM (ADC)

Aircraft operating below 0.9 Mach airspeed use raw pitot and static pressures to develop accurate airspeed, altitude, and vertical speed indications. Aircraft operating in this speed range use the pressures that the pitot-static ports sense.

Modern supersonic aircraft operate in a higher speed range and require more accurate pressures. At high speed, pressures build upon the external skin of the aircraft. These pressures cause a distortion of the normal flow of air, causing the pitot-static system to sense false pressures. The system then supplies erroneous information to the flight instruments. The altimeter, for instance, may show an error of more than 3,000 feet. A 3,000-foot error in altitude is intolerable and could put an aircraft in an extremely dangerous position.

The system that compensates for altitude and other pitot-static errors is the air data computer system (ADC system). Many variations exist in both the name of the systems and the method of data development. The system in the F-14 is strictly a digital computer known as the *central air data computer (CADC)*. The system in the S-3 is an *airspeed altitude computer set (AACS)*. The AACS is a digital computer, but it is very different from the CADC used in the F-14.

Purpose

Many inputs are common to the various types of ADC systems. Air data computers differ in how they process input data and distribute output data to the various systems using the data. Data requirements vary with the type and mission of the aircraft.

The F-14 CADC system contains a single-processor digital computer with a separate independent analog backup wing sweep channel. The CADC can make yes and no decisions and solve mathematical problems. It converts outputs to either digital or analog form, depending on which aircraft system is to use the information. The CADC gathers, stores, and processes signals representing pitot pressure, static pressure, total temperature, and angle-of-attack data derived from the aircraft airstream sensors.

Figure 6-13 shows the functional relationship between the CADC (digital processor), its inputs, and the various functions in each aircraft system using the data. The digital processor performs wing-sweep, glove-vane, and flap-and-slat schedule computations. It also performs limit-control and electrical interlocks, failure detection,

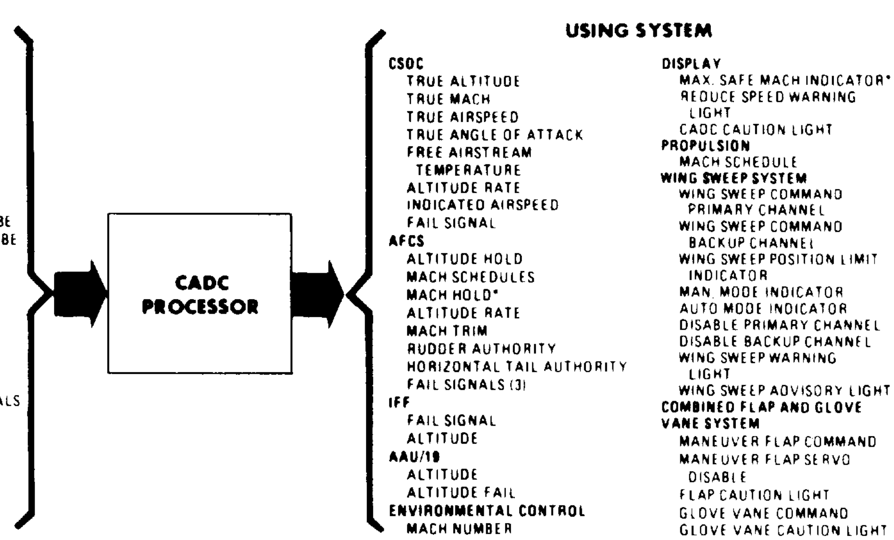


Figure 6-13.-F-14 air data computer system.

and systems test logic. Figure 6-14 shows inputs power. This power is from essential bus number to the CADC and the CADC outputs to the 2 (phases A, B, and C). The system also uses systems, which depend on or in part upon CADC single-phase, 115-volt ac, 400-hertz power. This functions. Notice in figure 6-14 that the CADC power is also from one phase of the essential bus system uses three-phase, 115-volt ac, 400-hertz and goes to the backup channel. *Cooling*

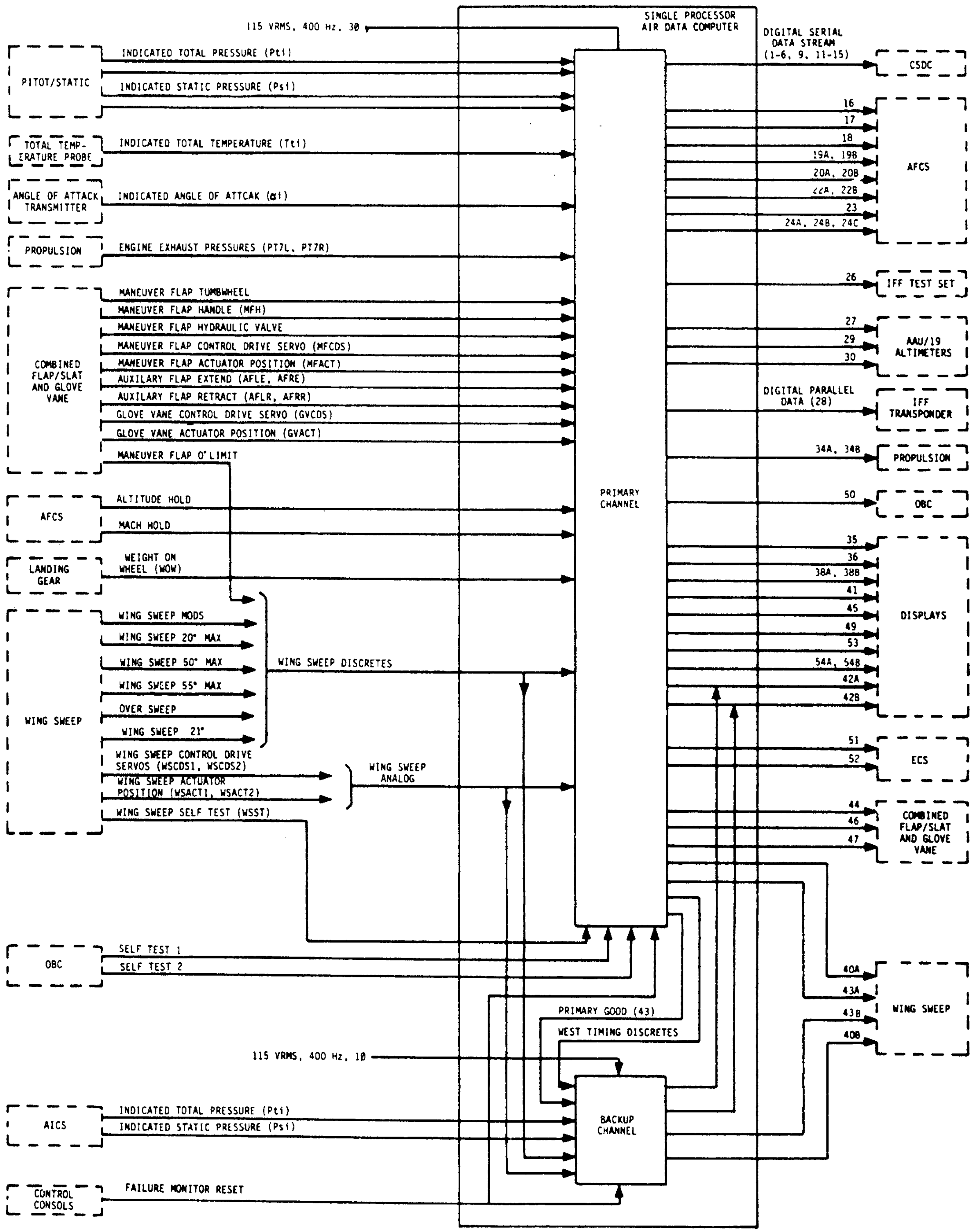


Figure 6-14.-Air data computer block diagram showing inputs and outputs.

equipment for the ADC system must be available when the system is operating.

NOTE: To understand air data computer maintenance in modern aircraft, you must have a knowledge of digital electronics, including logic diagrams and flow charts. Review Navy Electricity and Electronics Training Series (NEETS), module 13, NAVEDTRA 14155, and *Digital Computer Basics,* NAVEDTRA 10088, before continuing.

The air data computer receives information from pressure-sensitive and temperature-sensitive units mounted on external points of the aircraft. Then, it compensates for errors and sends the corrected information to other systems in the aircraft. Concurrently, it detects any changes in pressure and temperature information. It converts these changes into usable signals and sends them along with the pressure and temperature signals. The electrical signal outputs are representative of altitude, Mach number, true airspeed, angle of attack, total temperature, and impact pressure. There is also a pneumatic output of corrected static pressure. This output is used by the barometric altimeter, airspeed, and vertical speed indicators, and by some modules within the air data computer.

There are four data inputs to the ADC:

1. Total pressure (pitot)
2. Indicated static pressure
3. Indicated angle of attack
4. Total temperature

Command and test signal inputs use the available raw and corrected primary data for making functional tests of various ADC outputs.

Table 6-1 is a list of symbols and their respective definitions. Since these symbols are

Table 6-1.-Symbols Used with an ADC System

SYMBOL	DEFINITION
ADC	Air data computer
AOA	Angle of attack
BIT	Built in test
a i	Indicated angle of attack
a T	True angle of attack
B	Constant
Δ	Incremental change
CADC	Central air data computer
Hp	Barometric or pressure altitude
M	Mach number
PD	Pressure differential
Ps	Corrected static pressure
P	Indicated static pressure
Pt	Corrected total pressure
Pti	Indicated total pressure
QA	Actual impact pressure
Qc	Corrected impact pressure
θ R	Ramp angle
Ts	Free airstream temperature
Tt	Total temperature
Tti	Indicated total temperature
Va	True airspeed
Vc	Calibrated airspeed
Ws	Wing sweep

used many times in this section, you should refer to this table for symbol meanings.

Figure 6-15 shows the major distribution of systems that depend on all or part of the ADC. Notice that all inputs, such as pitot and static pressures, go to the digital processor. Signals resulting from the processing of the inputs go to the using systems. Although the diagram in figure 6-15 shows pneumatic inputs only, both pneumatic and electrical inputs are used.

Major Components

The four major components that collect and distribute information used in the air data computer system are listed below.

1. Angle-of-attack transmitter
2. Pitot-static system
3. Total temperature probe
4. Air inlet control system

As you know, the functions of these components are essentially the same on all aircraft. Only the processing and distribution of air data information varies from aircraft model to model. When performing maintenance on any ADC system, you should refer to the latest maintenance instructions manual (MIM) for that particular aircraft model. This way you will be sure the information on the ADC system is current.

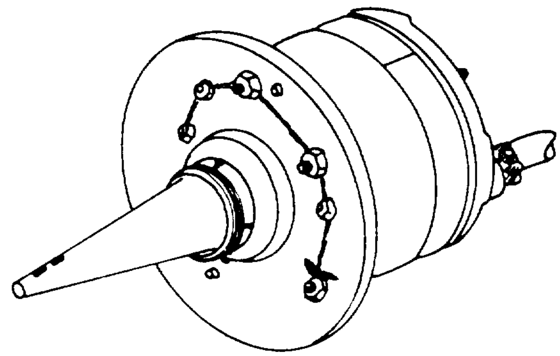


Figure 6-16.-Angle of attack transmitter (probe).

ANGLE-OF-ATTACK TRANSMITTER. — Forces vary with the angle of attack. The angle of attack is the angle between the relative wind and the chord of the wing. (The chord of the wing is a straight line running from the leading edge to the trailing edge.) Increasing the angle of attack increases the pressure felt under the wing and vice versa.

The angle-of-attack transmitter (fig. 6-16) detects changes in the aircraft's local angle of attack. It sends these changes, in the form of

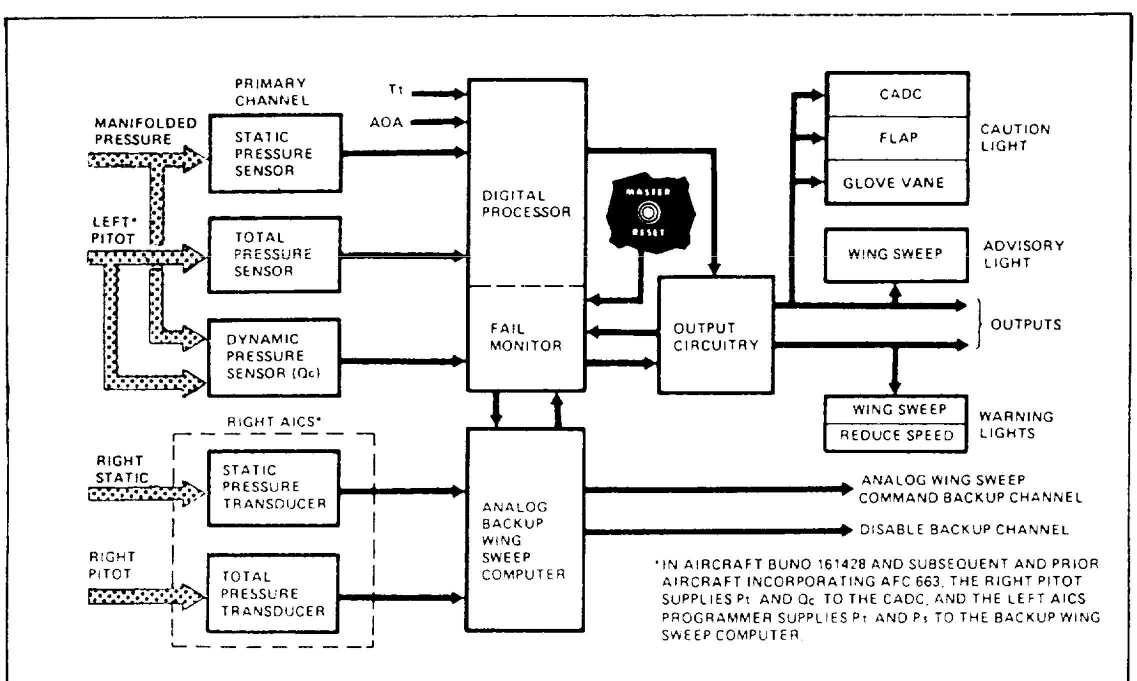


Figure 6-15.-ADC (digital processor) inputs and outputs.

mechanical motion, to potentiometers within the transmitter. These potentiometers convert the mechanical motion to proportional electrical voltages. These voltages go to associated angle-of-attack indicating and interface equipment.

The transmitter has a detector probe that senses changes in airflow. Changes in airflow cause the probe paddle to rotate. This, in turn, drives the wiper arms of the three internally mounted potentiometers.

The angle-of-attack system shows the pilot aircraft pitch attitude with respect to the surrounding air mass.

PITOT-STATIC SYSTEM. —Figure 6-17 shows the airstream sensors of the pitot-static

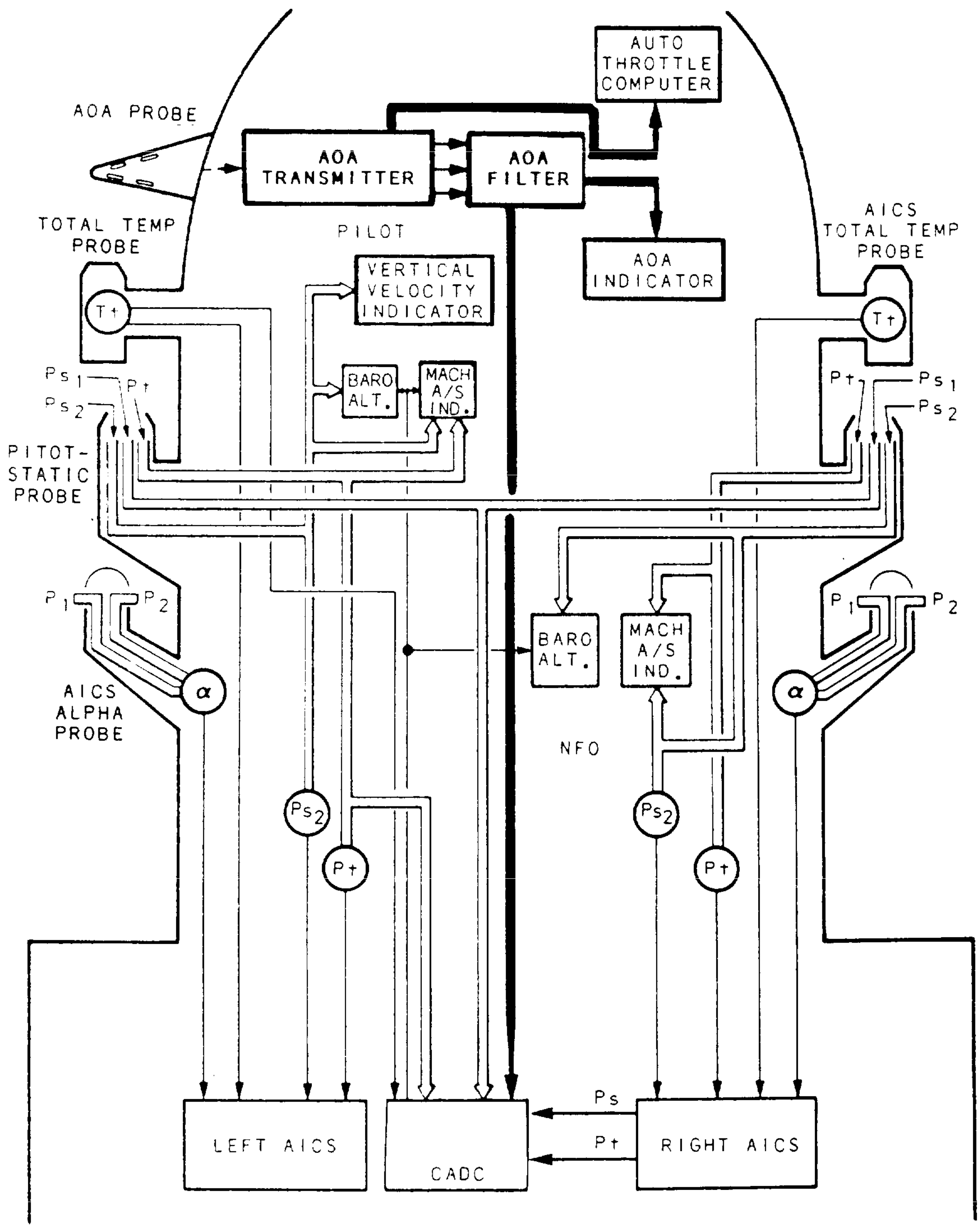


Figure 6-17.-ADC system airstream senors.

system. These sensors sense the air surrounding the aircraft and provide impact (pitot/Pt) pressure and atmospheric (static/Ps) pressure. These pressures go to the flight instruments, the air data computer, and the engine air inlet control system (AICS) programmers. The pitot-static system is actually two separate systems with individual pitot-static probes (fig. 6-18), one on each side of the forward fuselage. The ADC receives static pressure (Ps) from both probes. However, it receives total pressure (Pt) from only one probe.

Indicated Static Pressure. —This pressure (P) is the atmospheric pressure as sensed at a point on the aircraft that is relatively free from airflow disturbances. At subsonic speeds, static pressure error is small and of little significance. However, at transonic and supersonic speeds, the static ports sense extreme static pressure errors. Both Mach number and angle of attack can cause significant errors in the static pressure system. Indicated static pressure (P), as detected by the aircraft static ports, deviates from true static pressure. These deviations have a definite relationship to Mach number and angle of attack. The size of the error is the ratio of true static pressure to indicated static pressure, as related to Mach number and angle of attack.

Impact Pressure. —As implied, impact pressure (Qc) is the force of the air against the aircraft. Qc is measured directly by use of a pitot-static probe (fig. 6-18) or calculated from the outputs of the static and total pressure transducers. The ADC calculates actual impact pressure (QA) as a function of Mach number squared and static pressure.

Indicated Total Pressure. —This pressure (Pti) is the sum of static air pressure and the pressure created by aircraft motion through the air. The pitot tube senses Total pressure, which you also know by the familiar term *pitot pressure.*

Corrected Static and Corrected Total Pressures. —These pressures, Ps and Pt, contain errors that must be corrected to get true static and true total pressures. These errors are a result of slope

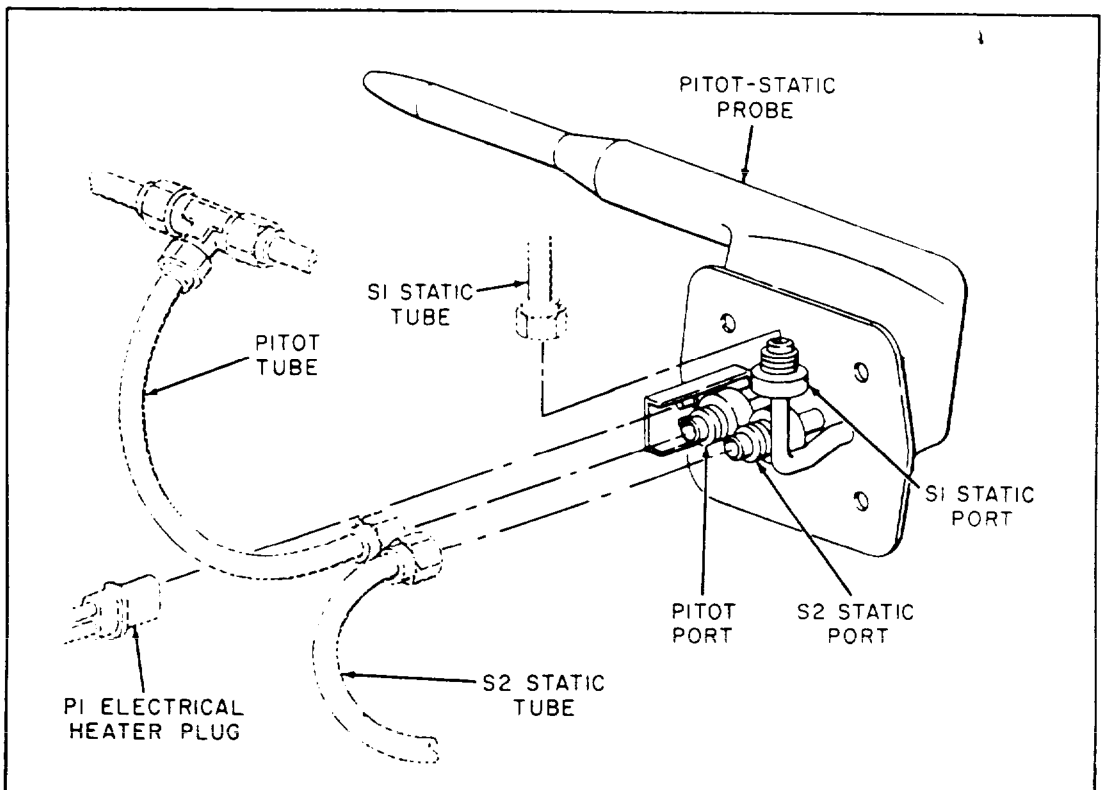


Figure 6-18.-Pitot-static probe.

and offset errors related to Mach speeds. The computer calculates the specified slope and intercept errors as functions of the indicated pressure ratio (Pti/P) and of the indicated angle of attack (ai).

CAUTION

Be sure to disable the pitot-static heater before working on this system. You may be seriously burned by touching the probes.

TOTAL TEMPERATURE PROBE.—Total temperature (Tt) is the temperature of ambient air plus the temperature increase created by the motion of the aircraft. Total temperature is sensed by a probe. This probe includes a platinum resistance element inside an aerodynamic housing placed in the airstream. The resistive element, whose resistance varies with temperature, acts as the variable portion of a bridge circuit.

The total temperature probe provides the ADC with accurate outside air temperature information. The raw information is the indicated total temperature (Tti). The computer smoothes and limits computations on the Tti before using the resultant output to calculate true total temperature (Tt). Figure 6-19 shows a typical temperature-sensitive bridge circuit that provides temperature data to the air data computer.

AIR INLET CONTROL SYSTEM.—The air inlet control system (AICS) decelerates supersonic air. It also provides even, subsonic airflow to the engine throughout the flight envelope. The AICS is similar to the variable inlet duct ramp system mentioned in chapter 5. Three automatically controlled hinged ramps on the upper side of the intake vary inlet geometry. The ramps position to decelerate supersonic air by creating a compression field

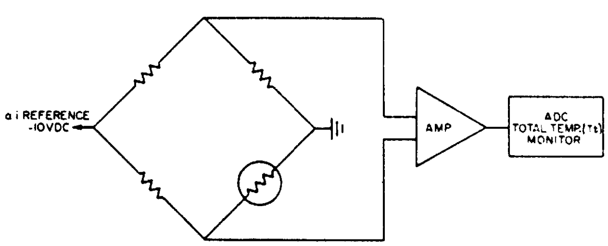


Figure 6-19.-Total temperature circuit.

outside the inlet. They also regulate the amount and quality of air going to the engine. Electrohydraulic actuators, which respond to fixed schedules in the AICS programmers, position the ramps.

An electrical total pressure (Pt) input from the right AICS programmer goes to the ADC backup channel as airspeed indications for wing sweep.

AUTOMATIC ALTITUDE SYSTEM

In the past, the air traffic control system radar presented azimuth and distance information to the controller on a horizontal radarscopes. Aircraft identification was primarily by voice radio, the use of position reports over definite fixes, making identifying turns of the aircraft to headings requested by the controller, or by a beacon identification signal. Altitude information was given over the voice radio. After this information-gathering process, the information was recorded on a flight strip by the controller and updated as required. When the aircraft moved into another controller's area, the handoff of the aircraft and the associated information was basically a manual process. Although the system was adequate, it became cumbersome during heavy traffic.

The increase in air traffic since 1950 has caused serious problems of vertical separation, terrain clearance, and collision avoidance. Because of these problems, improved air traffic control techniques were developed. These techniques included the use of altitude-coded transponders for automatic altitude and position reporting.

Automatic altitude reporting equipment that provides continuous automatic identification of aircraft on the ground controller's radarscopes has been developed. This equipment cuts out many of the manual steps required in the old air traffic control system. An air data computer corrects static pressure errors and provides synchro-driven altitude information to the pilot's altimeter. It also provides altitude in digital form to the aircraft transponder in high-performance aircraft. In low-performance aircraft, the equipment provides a direct readout of altitude to the pilot and digital altitude information to the aircraft transponder. The digital information then goes to the ground interrogator and shows on the radarscopes in alphanumeric form.

The automatic altitude system operation is discussed in the following paragraphs. An interrogation pulse group goes from the interrogator-transmitter unit through a directional interrogator antenna assembly. The pulse group triggers an airborne transponder, causing a multiple pulse reply group to be transmitted. The transponder transmission goes to the ground interrogator-receiver, which is processed through a computer. It is then displayed in alphanumeric form on the controller's radar screen. The length of the round-trip transit time determines the range of the replying aircraft. The mean direction of the main beam of the interrogator antenna during the reply determines the azimuth. The encoded signal from the transponder provides, via mode C, the aircraft's altitude in 100-foot increments.

Look at figure 6-20, which shows the automatic altitude reporting system. As you can see, a semiautomated air traffic control system includes the following improvements over the past system:

- It automatically provides the air traffic controller with a radar presentation. It identifies, in three dimensions, every properly equipped aircraft within his/her control area.

- As a result of the three-dimensional presentation, it greatly reduces the use of voice radio. It also eases the workload of the air traffic controller, thus increasing air traffic control efficiency.

- A transponder signal reinforces the radar signal normally seen on the radarscopes. It makes the signal stronger and much less susceptible to atmospheric interference.

- The beacon system altitude reporting feature may reduce vertical separation in the higher flight levels.

- It continuously updates aircraft altitude records in 100-foot increments. This permits more accurate traffic control when aircraft are changing altitude rapidly, as they do in terminal areas.

The AIMS Program

The AIMS Program, implemented by the Department of Defense, derives its name from the following acronyms:

ATCRBS (air traffic control radar beacon system)

IFF (identification friend or foe)

MARK XII Identification System

Systems (reflecting the many AIMS configurations)

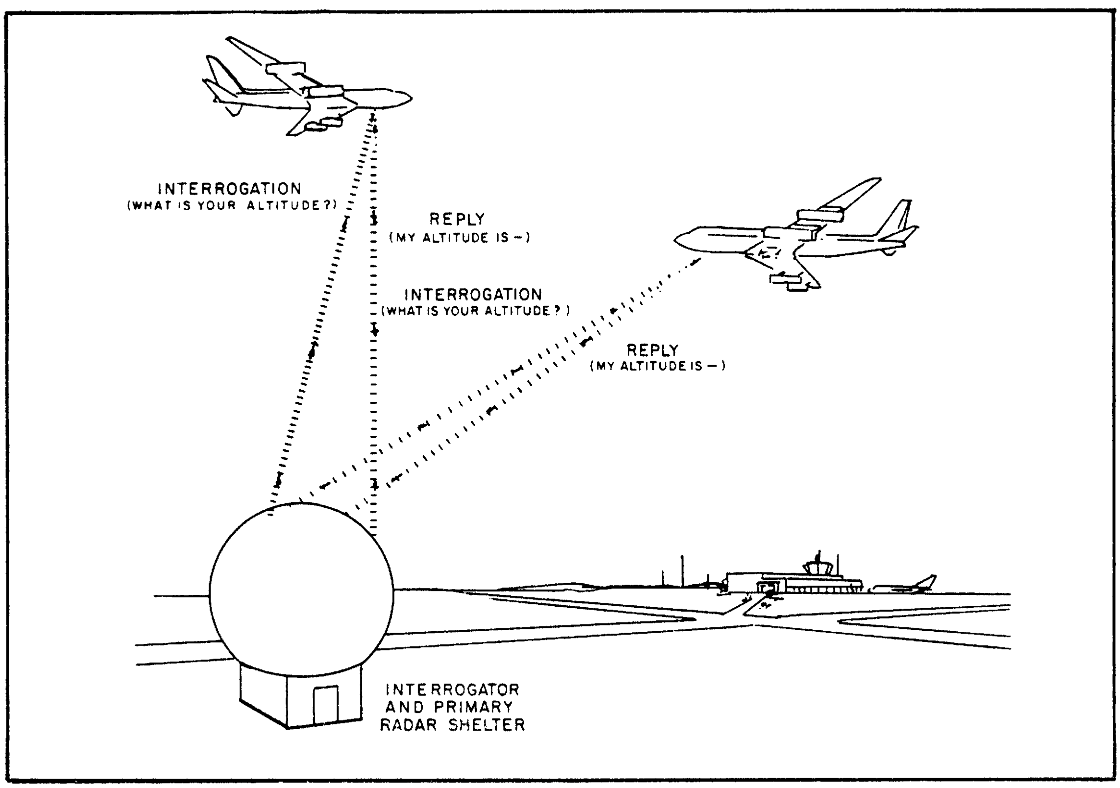


Figure 6-20.—The automatic altitude reporting system.

The primary goal of the AIMS program was to improve air traffic control within the United States. DoD participated in the first phase of the FAA plan. The plan was to upgrade peacetime operational use of the airspace. It included the provision of additional identification and altitude signals to ground air traffic control stations. Use of this plan resulted in a major improvement in military air traffic control. The secondary objective is to classify equipment configurations and capabilities.

The AIMS system consists of transponders, interrogators, computers, servoed altimeters, altimeter-encoders, control panels, and associated equipment. Interrogators are found in most AIMS-equipped ground and surface sites, tactical ground and surface systems, and certain special task airborne vehicles. To avoid misreadings and the friction problems associated with current aircraft altimeters, counter-drum-pointer altimetry displays are used.

Concurrent with the Department of Defense decision to use the AIMS, the following tolerances were established:

- Maximum difference between the pilot's and ground displays, ±125 feet.
- Maximum difference between the pilot's display and true altitude, ±250 feet.

Tolerances during takeoff, instrument approach, and landing remain within existing military/FAA standards.

Static-Pressure Errors

The altimeter system accuracy limitation of ±250 feet required the elimination of, correction of, or compensation for system errors. To achieve accuracy, each aircraft type was treated separately to determine what corrections its pressure system required within its flight envelope. Aircraft with small or negligible measured static-pressure defects required only an instrument. This instrument transforms a static-pressure input into a digital electrical output of pressure altitude.

High-performance, subsonic aircraft with large position errors require an instrument to correct the static-pressure error as a function of Mach number. To correct the pressure error, it must be known and be repeatable in aircraft of the same type. Since repeatability is a problem with flush static ports, the ports were replaced with a pitot-static tube.

High-performance, supersonic aircraft also require an instrument capable of correcting for pressure errors as a function of Mach number. Because of the greater size of errors met over a wider range of altitude and speed, the instrumentation in this type of high-altitude aircraft is more complex than that of subsonic aircraft.

You can place errors produced in the measurement and transmission of true pressure altitude into three groups—measured altitude, altitude transmission, and instruments (transducer or computer and digitizer).

ERRORS IN MEASURED STATIC PRESSURE. —Errors in measured static pressure result from many variables. Variables include the design of the pressure pickup, location of the pressure pickup on the aircraft, and the Mach number. The angle of attack and the aircraft configuration also contribute to errors. The static-pressure sensor can be either a flush fuselage vent or a static-pressure, L-shaped tube. When using a flush vent, the slightest surface irregularity or structure in the vicinity of the vent may deflect the perpendicular flow of air past the vent. With static-pressure tubes, you must give concern to other variables. Theses are the shape of the tube, the orifice configuration, and the type of structural support. In either case, there is a local pressure surrounding the pressure-sensing vent that differs from the free stream pressure.

ALTITUDE ERRORS. —Altitude errors are introduced by pressure lag, system leaks, and instrument error. Lag can cause errors of hundreds of feet, depending upon the rate of pressure change and the system volume. In level flight or during very low rates of ascent and descent (500 to 600 ft/min), the errors are small and almost negligible. Errors produced by system leaks can be significant if the leak is in a pressurized area of the aircraft.

INSTRUMENT ERRORS. —Instrument errors are the result of friction, hysteresis, temperature, acceleration, and design limitations. The overall accuracy of the instrument depends on the range of the instrument and complexity of the mechanism.

Equipment Requirements

Today, all naval aircraft have automatic altitude reporting. In most of the high-performance aircraft containing an ADC, the ADC automatically reports altitude. The modification also provides an output for the AAU-19/A servoed altimeter. Slower, low-flying aircraft, not requiring an ADC, have AAU-21A altimeter-encoders. The signal is based on the standard atmospheric pressure of 29.92 inches of mercury.

Air Data Requirements

The basic functions of the air data computer in the Air Traffic Control Radar Beacon System (ATCRBS) are to correct the sensed static pressure and the provision of appropriate outputs of altitude. The altitude outputs are usable in two forms—a digital output in 100-foot increments for wire transmission to transponders, and an analog synchro output for providing pressure altitude information to an AAU-19/A servoed altimeter. The system also includes a failure monitoring circuit. Table 6-2 gives the general computer requirements for the CPU-46/A and the CPU-66/A.

Air data computers consist of a pressure-sensing means, a computing mechanism, an error signal generator, a servo loop, and output devices. The output devices provide signals for both altitude indication and altitude reporting. The unit computes corrected pressure altitude from the inputs of indicated static pressure, total pressure, and information on the aircraft static-pressure error. All of this information in the computer is on a two-dimensional cam. The cam is readily replaceable if it should fail or if you must calibrate the unit for another type of aircraft.

Look at figure 6-21 as you read about system operation. A small step change in static pressure causes the aneroid capsule to deflect, rotating the rocking shaft assembly. The rotation makes the *Geneva* sector and locking disk rotate the microsyn rotor from its null position. Alternately, a correction for static-pressure defect can rotate the microsyn rotor. In either case, the error voltage generated is amplified and directed to the two-phase servomotor. The servomotor drives the

Table 6-2.-Computer Requirements

	CPU-46/A COMPUTER	CPU-66/A COMPUTER
RANGE	80,000 FT	50,000 FT
TOLERANCE	±20 FT OR ±0.2% OF ALTITUDE	±25 FT OR ±0.25% OF ALTITUDE
STATIC PRESSURE CORRECTION	0.2 to 2.5 MACH AT ALL ALTITUDES	0.2 to 0.95 MACH AT ALL ALTITUDES
INPUTS	STATIC PRESSURE TOTAL PRESSURE	STATIC PRESSURE TOTAL PRESSURE
OUTPUTS	TRUE ALTITUDE 1. SIGNAL TO TRANSPONDER ENCODED IN 100-FOOT INCREMENTS. 2. SYNCHRO SIGNAL USED TO DRIVE ALTIMETER INDICATOR.	TRUE ALTITUDE 1. SIGNAL TO TRANSPONDER ENCODED IN 100-FOOT INCREMENTS. 2. SYNCHRO SIGNAL USED TO DRIVE ALTIMETER INDICATOR.

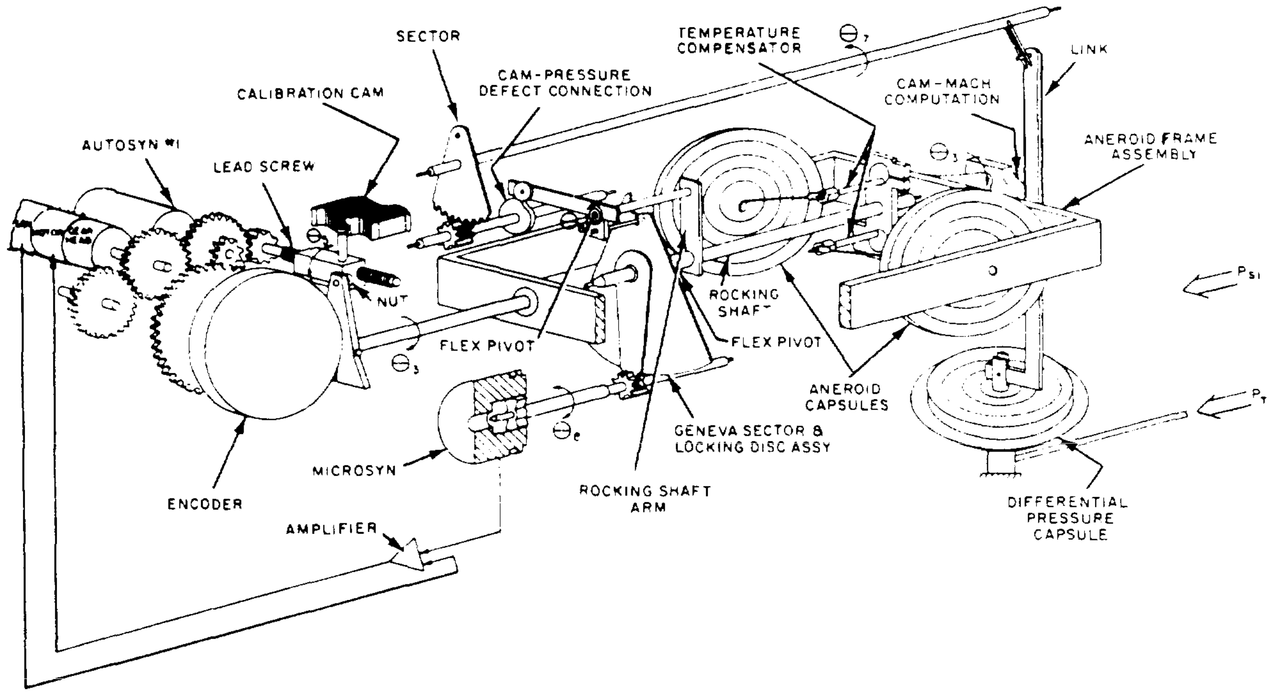


Figure 6-21.-CPU-66/A computer components.

output devices, lead screw, and frame until the microsyn is again in a null position. Thus, the angular rotation of the frame caused by the aneroid capsule displacement provides a change in the synchro and encoder outputs.

CPU-46/A SUPERSONIC ALTITUDE COMPUTER. —The CPU-46/A altitude computer (fig. 6-22) is used in high-performance,

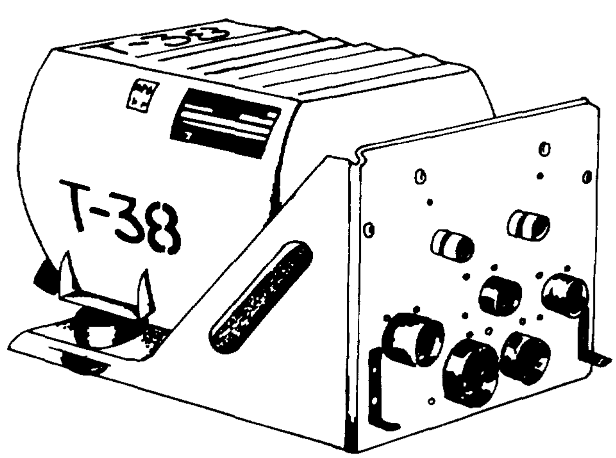


Figure 6-22.-CPU-46/A supersonic altitude computer.

supersonic aircraft. These aircraft have operational limitations of 80,000 feet of altitude and Mach 2.5. The CPU-46/A consists of pressure sensors, a computing system, an electronic package, and output devices. The unit receives pressure from the aircraft pitot-static system and requires a 115-volt, 400-hertz power source. It provides altitude information, corrected for static-pressure error, as follows:

- Two separate analog signals for positioning the remote AAU-19/A altimeters.

- An encoded binary signal to the airborne transponder for altitude reporting. The output of the encoder must agree with the output to the AAU-19/A to within ±20 feet. A mechanical cam compensates for static-pressure position error. Corrected pressure altitude is computed and provided as output signals.

If the computer fails, the AAU-19/A altimeter automatically reverts to a pneumatic standby mode, and the altitude reporting encoder deactivates. A standby flag appears on the AAU-19/A display to advise the pilot of the failure.

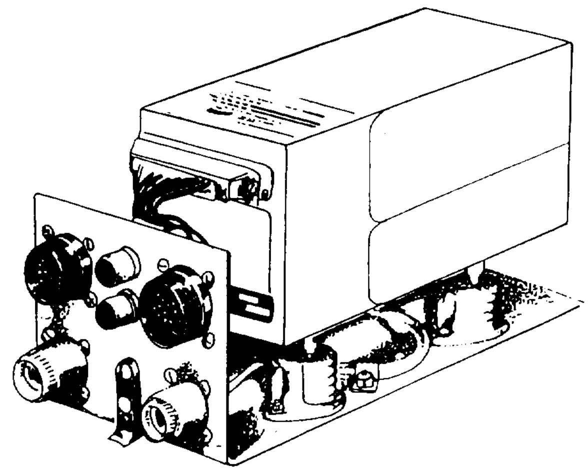


Figure 6-23.-CPU-66/A subsonic altitude computer.

CPU-66/A SUBSONIC ALTITUDE COMPUTER. —The CPU-66/A altitude computer (fig. 6-23) is used to altitudes of 50,000 feet and at speeds up to 0.95 Mach. Its operation is similar to that of the CPU-46/A.

The ADCs have been modified to have the same altitude output capabilities as the CPU-46/A or the CPU-66/A. The modification depends on the speed and altitude capabilities of the aircraft in which the unit is installed.

Altimetry

The three altimeters that work with the automatic altitude reporting system are the AAU-19/A, AAU-21/A, and AAU-24/A (fig. 6-24).

SERVOED BAROMETER ALTIMETER AAU-19/A. —The counter-drum-pointer servoed barometric altimeter (fig. 6-25) consists of a pressure altimeter combined with an at-powered servomechanism. The altitude display is in digital form, using a 10,000-foot counter, a 1,000-foot counter, and a 100-foot drum. Also, a single

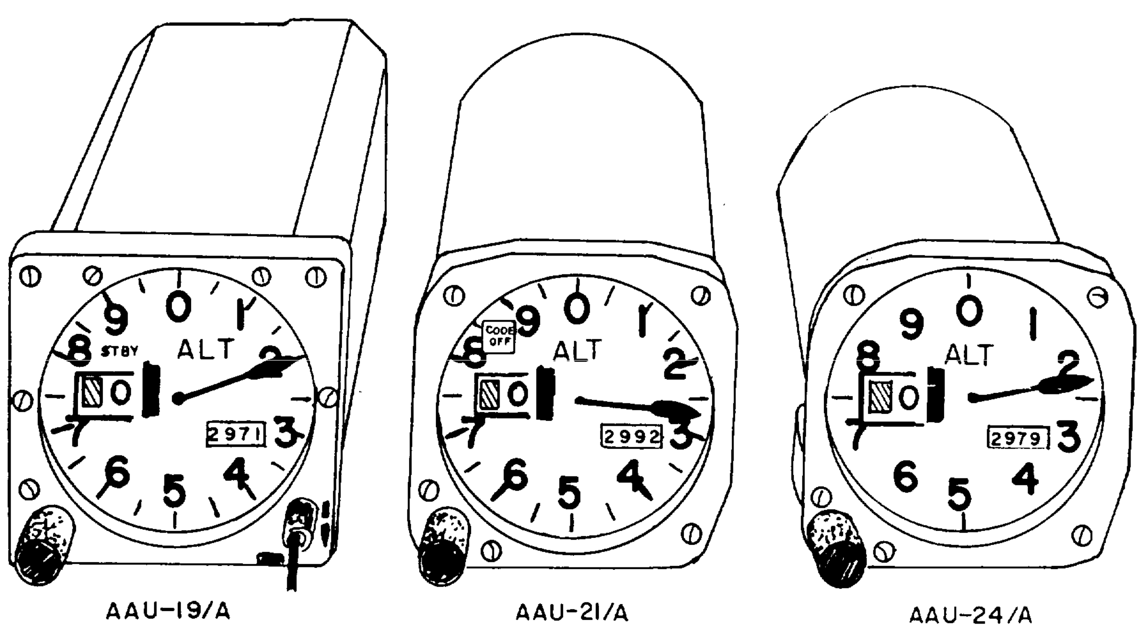
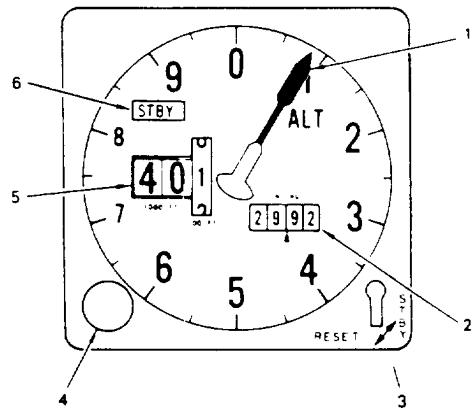


Figure 6-24.-AAU-19/A, AAU-21/A, AAU-24/A altimeters.



INDEX	CONTROL/INDICATOR	FUNCTION
1	Altimeter pointer	Indicates less than thousand-foot scale altitude in 50-foot increments
2	Barometric scale	Displays altimeter setting in inches of mercury
3	RESET/STBY selector	RESET—Altimeter is operated electrically through the AACS STBY—Altimeter is operated barometrically through the pitot/static system
4	Barometric pressure set knob	Sets barometric pressure in inches of mercury on barometric scale
5	Altitude counter-drum	Indicates altitude in thousands of feet and hundreds of feet
6	STBY warning flag	STBY flag denotes mode of altimeter operation: In/view (STBY)—operating barometrically Out-of-view—operating electrically through AACS

Figure 6-25.-AAU-19/A altimeter.

pointer shows hundreds of feet on a circular scale. The barometric pressure setting (baroset) knob is used to insert the local pressure in inches of mercury. The baroset knob has no effect on the digital output (mode C) of the ADC. This digital output is always referenced to 29.92 inches of mercury.

The altimeter has a servoed mode and a pressure mode of operation. The mode of operation is controlled by a spring-loaded, self-centering mode switch, placarded RESET and STBY. In the servoed mode, the altimeter displays altitude, corrected for position error, from the synchro output of the air data computer. In the standby mode, the altimeter operates as a standard altimeter. In this mode, it uses static pressure from the static system that is uncorrected for position error.

The servoed mode is selected by placing the mode switch to RESET for 3 seconds. The ac power must be on. During standby operation, a red STBY flag appears on the dial face. The altimeter automatically switches to standby operation during an electrical power loss or when the altimeter or altitude computer fails. The standby operation is selected by placing the mode switch to STBY. An ac-powered internal vibrator automatically energizes in the standby mode to lessen friction in the display mechanism.

With the local barometric pressure set, the altimeter should agree to ±75 feet of field elevation in both modes.

AAU-21/A ALTIMETER. —AAU-21/A altimeter is used in low/slow aircraft. It has a counter-drum-pointer display similar in appearance to the AAU-19/A. The altimeter contains a servo-driven encoder. The encoder provides an altitude signal to the aircraft transponder for transmission to a ground station.

AAU-24/A ALTIMETER. —The AAU-24/A altimeter (fig. 6-26) contains a precision pressure-sensing device, counter, and pointer drive mechanisms. It also contains a combination counter drum and pointer for altitude display. The counter displays two digits, showing multiples of 10,000 feet and 1,000 feet respectively, and moves intermittently. The drum shows multiples of 100 feet and moves continuously. The pointer travels one revolution for each increment of 1,000 feet of altitude. The pointer scale is from 0 to 9; each step representing an increment of 100 feet. Each 100-foot step is split into two increments of 50 feet each.

The barometric setting (baroset) knob is located in the lower left corner of the bezel. It protrudes a maximum of 0.73 inch in front of the bezel. The baroset knob works with a four-digit counter, designated IN Hg, to set the altitude indication to the prevailing barometric pressure. It is adjustable from 28 to 31 inches of mercury. There is a locking screw next to the baroset knob. This screw is used only during calibration procedures to align the barometric pressure (IN Hg) indication with altitude indication.

Two sets of internal lights, one red and one white, provide dial lighting. Each set consists of four lights. Controls for dial lighting are external to the altimeter.

To overcome the effects of stop and jump friction in altimeter mechanisms, the altimeter has an internal, electrically operated mechanical vibrator.

The block diagram, shown in figure 6-27, shows altimeter operation. Outside air pressure from the aircraft static-pressure system goes to the altimeter case. Two evacuated pressure-sensing element assemblies within the case expand as the case pressure decreases with increasing altitude. Expansion or contraction of each element sends movement to a rocker shaft assembly via a link-arm configuration. Pivots for the rocker shaft assemblies couple to a temperature compensating ring that changes the movement of the rocker shafts. This movement compensates for temperature changes. A differential gear assembly, coupled by segment gears to the rocker shafts, provides an output movement. This movement is proportional to the average expansion or contraction of the two sensing element assemblies.

The output gear of the differential gear assembly drives a gear train mechanism. This gear

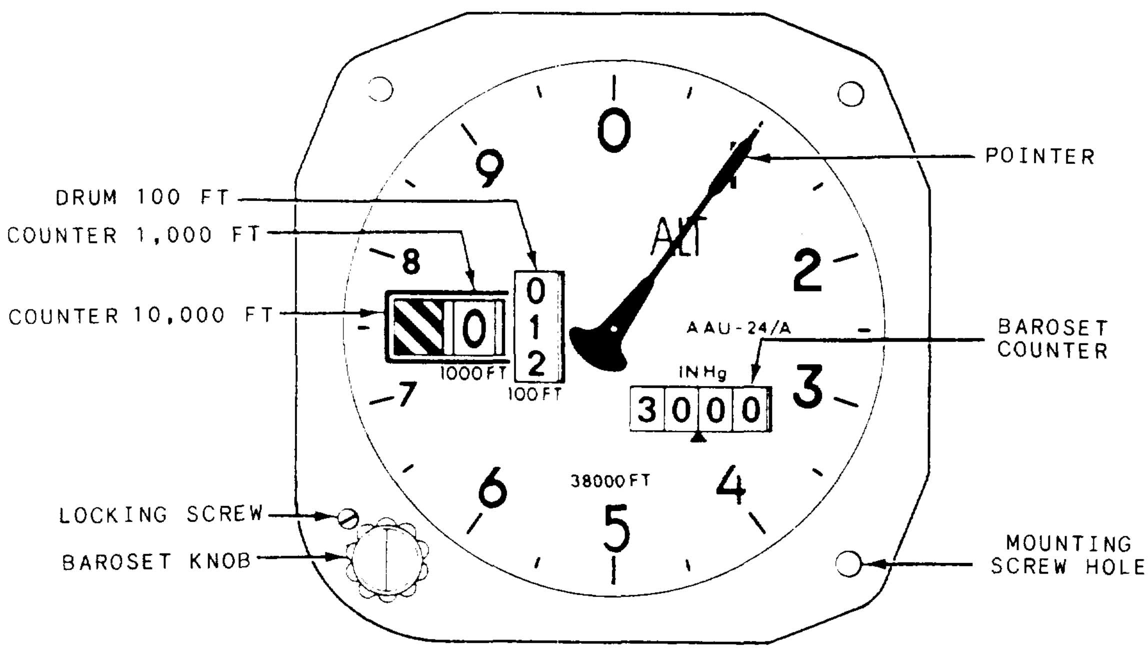


Figure 6-26.-AAU-24/A altimeter dial face.

train operates a counter-drum assembly and a pointer assembly that traverses the instrument dial. The counter/drum provides a numerical readout of altitude. The position of the pointer provides greater accuracy of readout.

The baroset knob is coupled, via a barometric setting shaft, to two spur gears that run on an idler shaft. One spur gear meshes with a gear that drives the barometric counter. The other spur gear meshes with the gear train mechanism that provides altitude indication. Thus, the pressure the barometric counter shows is tied to a particular indication of altitude.

To permit calibration of the pressure and altitude relationship, a device can disengage the normal barometric operation of the altimeter. Using a locking screw, you lock the device in the locked position. In this position, both spur gears on the idler shaft are actuated by the baroset knob. When calibrating, slacken the locking screw and move it toward the edge of the bezel. You can now withdraw the baroset knob by a small amount away from the bezel. This action disengages the knob from one spur gear so turning the knob now operates only the altitude indication.

The large increases in the speed and volume of air traffic caused the need for a more efficient, automated air traffic control system. The ATCRBS, which automatically provides the controller with a three-dimensional identified presentation, is a step toward the solution of the problems of vertical separation, terrain clearance, and collision avoidance. Automatic altitude reporting relieves both the pilot and the ground controller of much radio work. It also provides continuous monitoring of the altitude of properly equipped aircraft. This system results in increased efficiency in the air traffic control system. The system also gives pilots a more accurate altimetry system, reducing altimetry errors of 0.8 percent of altitude to 0.35 percent of altitude.

ANGLE-OF-ATTACK (AOA) INDICATING SYSTEM

The angle-of-attack indicating system detects aircraft angle of attack from a point on the side of the fuselage. It furnishes reference information for the control and actuation of other units and aircraft systems. It provides signals to operate an angle-of-attack indicator

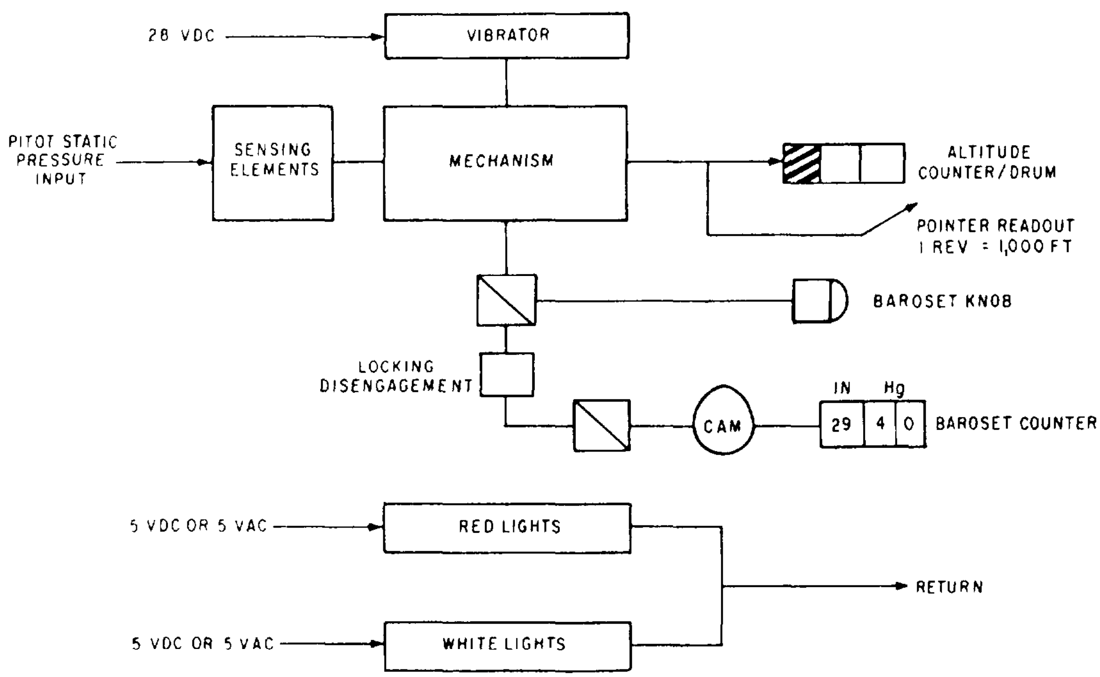


Figure 6-27.-Altimeter block diagram.

(fig. 6-28) on the pilot's instrument panel. This indicator displays a continuous visual indication of the local angle of attack. A typical angle-of-attack system provides electrical signals for operating the rudder pedal shaker. The shaker warns the pilot of an impending stall when the aircraft is approaching the critical stall angle of attack. Electrical switches in the AOA indicator operating at various preset angles of attack energize colored lights in the approach light system and an approach index light in the cockpit.

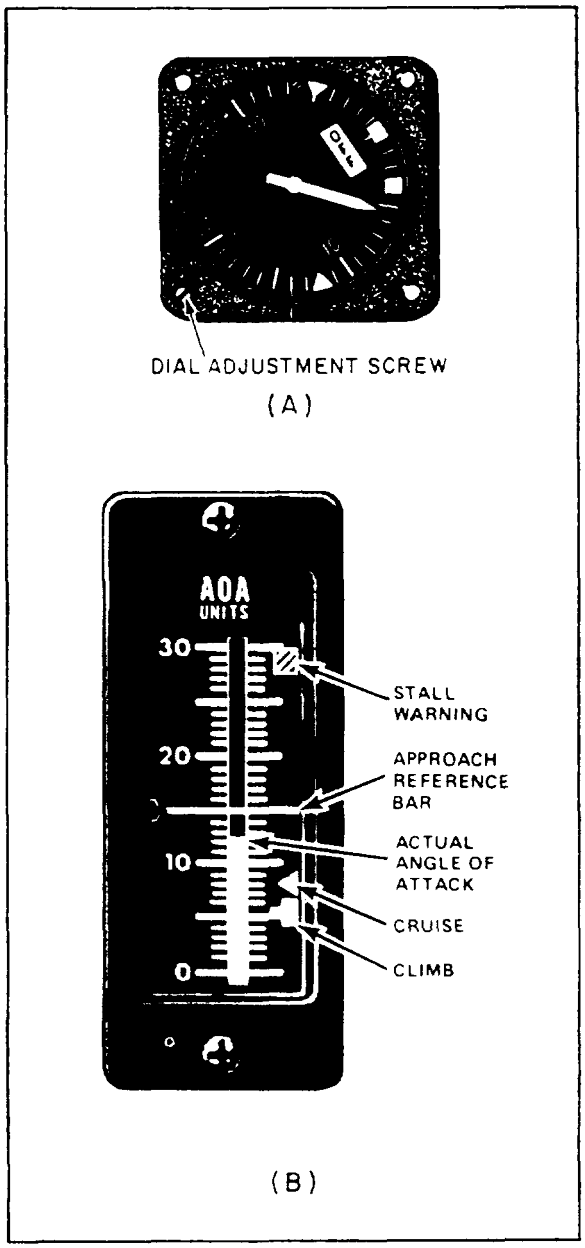


Figure 6-28.-AOA indicators: (A) radial; (B) vertical scale.

These lights furnish the landing signal officer and the pilot with an accurate indication of approach angle of attack during landing. An angle-of-sideslip system, consisting of an airstream direction detector, angle-of-attack, and angle-of-sideslip compensator, is installed on some aircraft. The outputs from these are used for controlled rocket firing.

The angle-of-attack indicating system consists of an airstream direction detector transmitter (fig. 6-29) and an indicator. The airstream direction detector measures local airflow direction relative to the true angle of attack. It does this by determining the angular difference between local airflow and the fuselage reference plane. The sensing element works with a servo-driven balanced bridge circuit, which converts probe positions into electrical signals.

The angle-of-attack indicating system operation is based on detection of differential pressure at a point where the airstream is flowing in a direction that is not parallel to the true angle of attack oft he aircraft. This differential pressure is caused by changes in airflow around the probe.

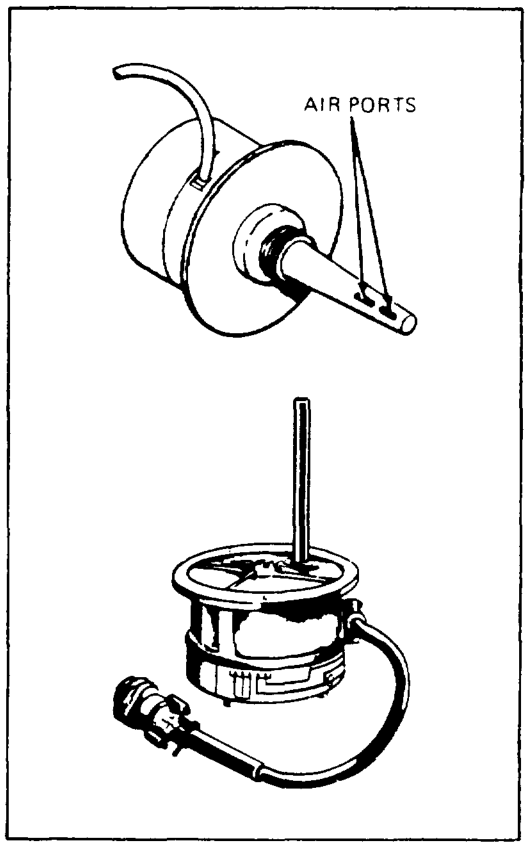


Figure 6-29.-AOA transmitter.

The probe extends through the skin of the aircraft into the airstream.

The exposed end of the probe contains two parallel slots (ports). These slots detect the differential airflow pressure (fig. 6-30). Air from the slots passes through two separate air passages to separate compartments in a paddle chamber. Any differential pressure, caused by misalignment of the probe to the direction of airflow, causes the paddles to rotate. The moving paddles rotate the probe, through mechanical linkage, until the pressure differential is zero. This occurs when the slots are symmetrical with the airstream direction.

Two potentiometer wipers, rotating with the probe, provide signals for remote indications. Probe position, or rotation, is converted into an electrical signal by one of the potentiometers that is the transmitter component of a self-balancing bridge circuit. When the angle of attack of the aircraft changes, the position of the transmitter potentiometer alters. This causes an error voltage to exist between the transmitter potentiometer and the receiver potentiometer in the indicator.

Current flows through a sensitive polarized relay to rotate a servomotor located in the indicator. The servomotor drives a receiver potentiometer in the direction required to reduce the error voltage. This action restores the circuit to a null or electrically balanced condition. The polarity of the error voltage determines the resultant direction of rotation of the servomotor. The indicating pointer is attached to, and moves with, the receiver potentiometer wiper arm to show on the dial the relative angle of attack.

Adjustable cam switches (fig. 6-31) control the approach light, approach indexer, and stall warning. The cams (switches) operate as the indicator responds to movement of the transmitter potentiometer. Figure 6-32 shows the relationship of the indicator to the lights and stall warning. The AOA indexer on the pilot's glare shield has two arrows and a circle illuminated by colored lamps to provide approach information. The cam-actuated switch contacts in the angie-of-attack indicator also control the angle-of-attack indexer. The upper arrow is for high angle of attack (green). The lower arrow is for low angle of attack (red). The circle is for optimum angle-of-attack (amber). An arrow and a circle together show an intermediate position.

The indexer lights function only when the landing gear is down. A flasher unit causes the indexer lights to pulsate when the arresting hook is up with the HOOK BYPASS switch in the CARRIER position.

STALL WARNING SYSTEM

Many aircraft have stall warning indicators to warn the pilot of an impending aerodynamic stall. In the past, stall warning indicators were of a pneumatic control type. These devices activated either warning horns or flashing lights. Later, research found that a stall relates directly to the angle of attack, regardless of airspeed, power setting, or aircraft loading. The stall warning devices of most aircraft now in the fleet operate at a specified angle of attack. The devices operate through cams in the angle-of-attack indicator. The cam-driven switch activates a vibrator motor connected to either a rudder pedal or the control

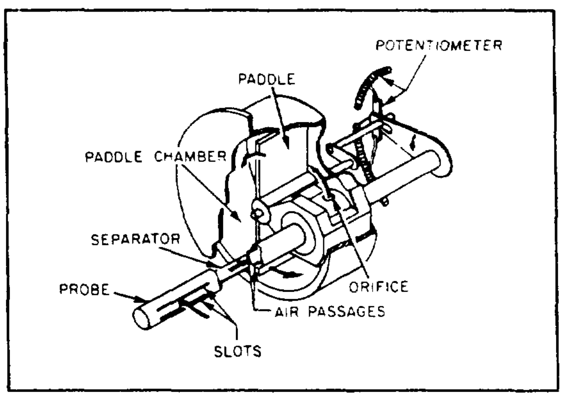


Figure 6-30.-Mechanical schematic of airstream direction detector.

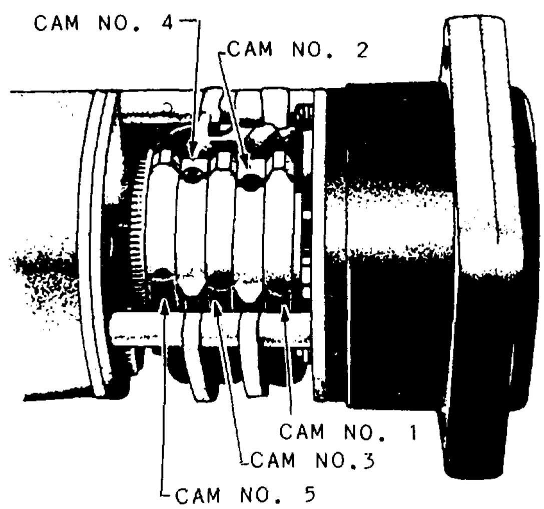


Figure 6-31.-Angle-of-attack indicator cams.

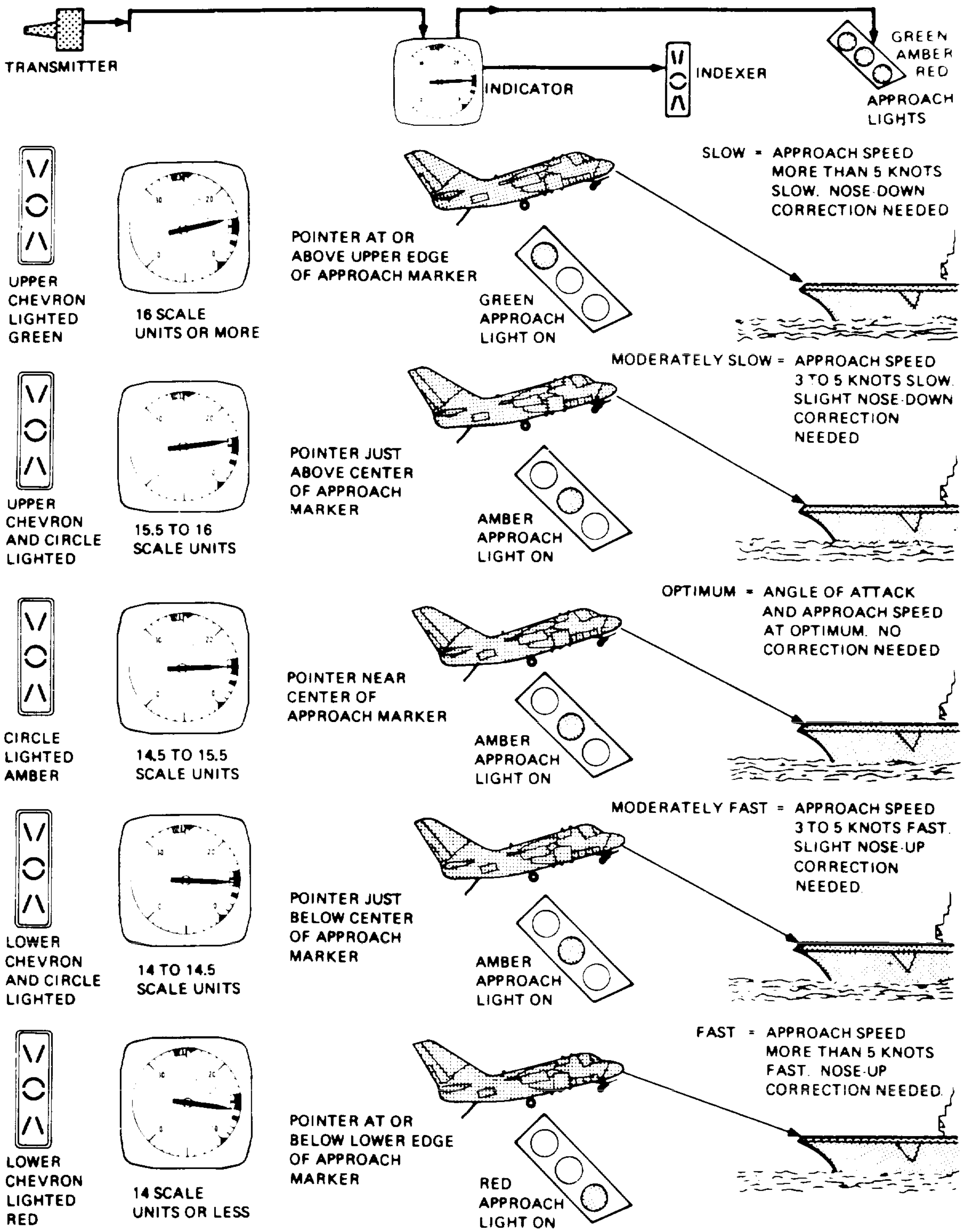


Figure 6-32.-Angle-of-attack (AOA) indications.

stick. Figure 6-33 shows a simplified schematic of the rudder shaker system. When the aircraft reaches stall angle of attack, the AOA indicator cam-actuated switch completes the rudder shaker motor circuit to ground. When the angle of attack returns below stall conditions, the cam deactuates the switch. The switch action removes the ground to the rudder shaker motor.

GYROSCOPIC INSTRUMENTS

Early aircraft were flown by visually aligning the aircraft with the horizon. With poor visibility, it was not possible to fly the aircraft safely. The need for flight instruments to correct this condition lead to the development of fyroscopic instruments. The gyroscopic properties of a spinning wheel made precision instrument flying, precise navigation, and pinpoint bombing practical and reliable. Some of the instruments that use this principle are the turn-and-bank indicator, directional gyro, gyro horizon, and the drift meter. Systems that use the gyroscopic principle include the AFCS, gyrostabilized flux-gate compass, and the inertial navigation system. The following paragraphs contain a brief review of gyroscopic principles.

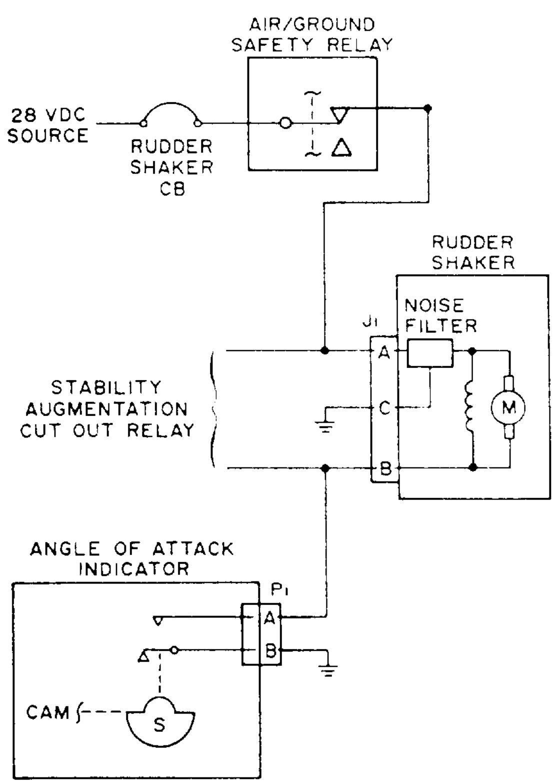


Figure 6-33.-Rudder shaker schematic (simplified).

NOTE: You should review Navy Electricity and Electronics Training Series (NEETS), module 15, *Principles of Synchros, Servos, and Gyros,* before continuing.

A gyroscope is a spinning wheel or rotor with universal mounting. This mounting allows the gyroscope to assume any position in space. Any spinning object exhibits gyroscopic properties. The wheel, with specific design and mounts to use these properties, is a gyroscope. The two important design characteristics for instrument gyros are

1. high density weight for small size, and
2. high speeds rotation with low-friction.

The mountings of the gyro wheels are gimbals. They can be circular rings or rectangular frames. However, some flight instruments use part of the instrument case itself as a gimbal. A simple gyroscope is shown in figure 6-34.

The two general types of mountings for gyros are the free or universal mounting and the restricted or semirigid mounting. The type of mounting the gyro uses depends on the gyro's purpose.

A gyro can have different degrees of freedom. The degree of freedom depends on the number of gimbals supporting the gyro and the arrangement of the gimbals. Do not confuse the term *degrees of freedom,* as used here, with an angular value as in *degrees of a circle.* The term *degrees*

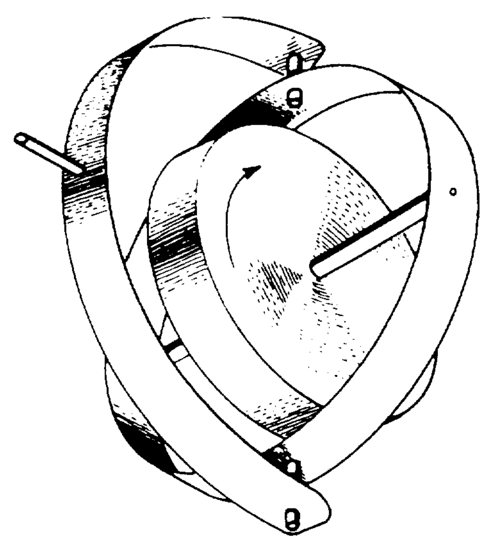


Figure 6-34.-Simple gyroscope.

of freedom, as used with gyros, shows the number of directions in which the rotor is free to move. (Some authorities consider the spin of the rotor as one degree of freedom, but most do not.)

A gyro enclosed in one gimbal, such as the one shown in figure 6-34, has only one degree of freedom. This is a freedom of movement back and forth at a right angle to the axis of spin. When this gyro is mounted in an aircraft, with its spin axis parallel to the direction of travel and capable of swinging from left to right, it has one degree of freedom. The gyro has no other freedom of movement. Therefore, if the aircraft should nose up or down, the geometric plane containing the gyro spin axis would move exactly as the aircraft does in these directions. If the aircraft turns right or left, the gyro would not change position, since it has a degree of freedom in these directions.

A gyro mounted in two gimbals normally has two degrees of freedom. Such a gyro can assume and maintain any attitude in space. For illustrative purposes, consider a rubber ball in a bucket of water. Even though the water is supporting the ball, it does not restrict the ball's attitude. The ball can lie with its spin axis pointed in any direction. Such is the case with a two-degree-of-freedom gyro (often called a free gyro).

In a two-degree-of-freedom gyro, the base surface turns around the outer gimbal axis or around the inner gimbal axis, while the gyro spin axis remains fixed. The gimbal system isolates the rotor from the base rotation. The universally mounted gyro is an example of this type. Restricted or semirigid mounted gyros are those mounted so one plane of freedom is fixed in relation to the base.

Practical applications of the gyro are based upon two basic properties of gyroscopic action:

1. Rigidity in space

2. Precession

Newton's first law of motion states "A body at rest will remain at rest, or if in motion will continue in motion in a straight line, unless acted upon by an outside force." An example of this law is the rotor in a universally mounted gyro. When the wheel is spinning, it stays in its original plane of rotation regardless of how the base moves. Figure 6-35 shows this principle. The

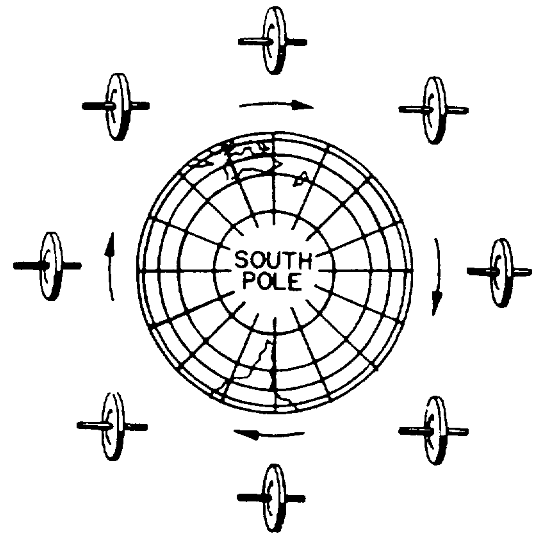


Figure 6-35.-Action of a freely mounted gyroscope.

gyroscope holds its position relative to space, even though the earth turns around once every 24 hours.

The factors that determine how much rigidity a spinning wheel has are in Newton's second law of motion. This law states "The deflection of a moving body is directly proportional to the deflective force applied and is inversely proportional to its mass and speed." To obtain as much rigidity as possible in the rotor, it has great weight for size and rotates at high speeds. To keep the deflective force at a minimum, the rotor shaft mounts in low friction bearings. The basic flight instruments that use the gyroscopic property of rigidity are the gyro horizon, the directional gyro, and any gyrostabilized compass system. Therefore, their rotors must be freely or universally mounted.

Precession (fig. 6-36) is the resultant action or deflection of a spinning wheel when a deflective force is applied to its rim. When a deflective force is applied to the rim of a rotating wheel, the resultant force is 90 degrees ahead of the direction of rotation and in the direction of the applied force. The rate at which the wheel precesses is inversely proportional to rotor speed and directly proportional to the deflective force. The force with which a wheel precesses is the same as the deflective force applied (minus the friction in the gimbal ring, pivots, and bearings). If too great a deflective force is applied for the amount of

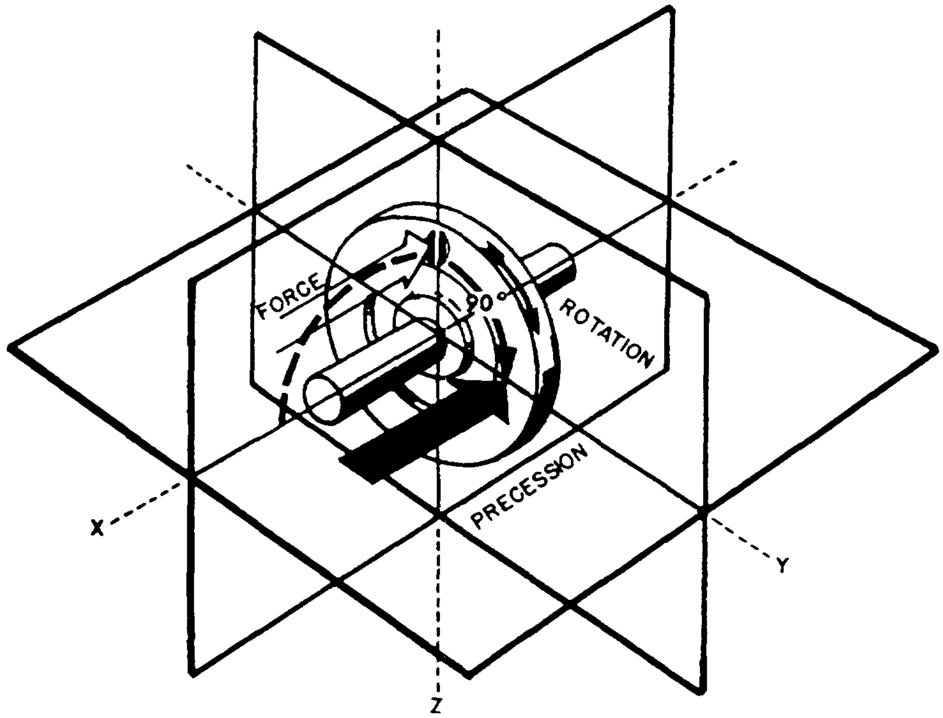


Figure 6-36.-Precession resulting from deflective force.

rigidity in the wheel, the wheel precesses and topples over at the same time.

Any spinning mass exhibits the gyroscopic properties of rigidity in space and precession. The rigidity of a spinning rotor is directly proportional to the weight and speed of the rotor speed and inversely proportional to the deflective force.

Attitude Indicator

Pilots determine aircraft attitude by referring to the horizon when they can see it. Often, however, the horizon is not visible. When it is dark or when there are obstructions to visibility such as overcast, smoke, or dust, the pilot cannot use the earth's horizon as a reference. When this condition exists, they refer to an instrument called the *attitude indicator.* This instrument is also known as a *vertical gyro indicator (VGI), artificial horizon,* or *gyro horizon.* From these instruments, pilots learn the relative position of the aircraft with reference to the earth's horizon.

The attitude indicator gyro rotor revolves with its spin axis in a vertical position to the earth's surface. This vertical position is rigidly maintained as the aircraft pitches and rolls about the space-rigid gyro (fig. 6-37). The case of the gyro identically duplicates aircraft movement. The case is free to revolve around the stable gyro because of the mounting of the gyro rotor in gimbals. It follows, therefore, that the aircraft itself actually revolves around the rotor and is the complementing factor in establishing the indications of the instrument.

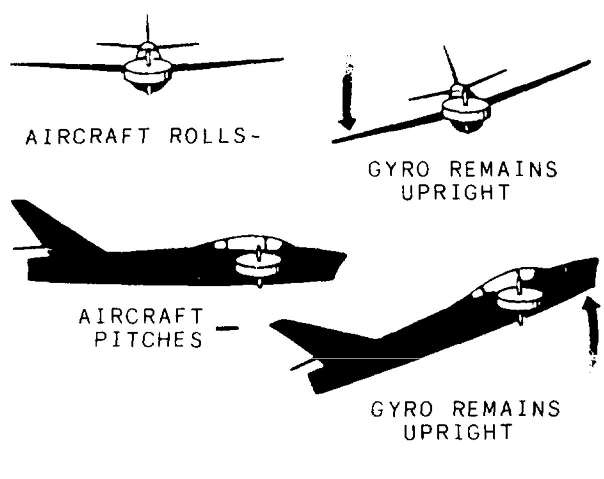


Figure 6-37.-Aircraft reference and gyro stability.

Although attitude indicators (fig. 6-38) differ in size and appearance, they all have the same basic components and present the same basic information. There will always be a miniature aircraft on the face of the indicator that represents the nose (pitch) and wing (bank) attitude of the aircraft. The bank pointer on the indicator face shows the degree of bank (in 10-degree increments up to 30 degrees, then in 30-degree increments to 90 degrees). The sphere is always light on the upper half and dark on the lower half to show the difference between sky and ground. Calibration marks on the sphere show degrees of pitch in 5- or 10-degree increments. Each indicator has a pitch trim adjustment for the pilot to center the horizon as necessary.

Some attitude indicators have a self-contained gyro. Other more modern indicators use pitch and roll information from the inertial system or the attitude heading reference system. These systems are accurate and reliable. They gain their reliability and accuracy from being larger since size is not limited by the space of an instrument panel. Electrical signals from the remote gyro travel via synchros. The signal is amplified in the indicator to drive servomotors and position the indicator sphere. This positioning is exactly as the vertical gyro position in the gyro case. In the newer attitude indicators, the sphere is gimbal-mounted and capable of 360-degree rotation. In contrast, the older gyros could only travel 60 degrees to 70 degrees of pitch and 100 degrees to 110 degrees of roll. Some aircraft incorporate an all-attitude

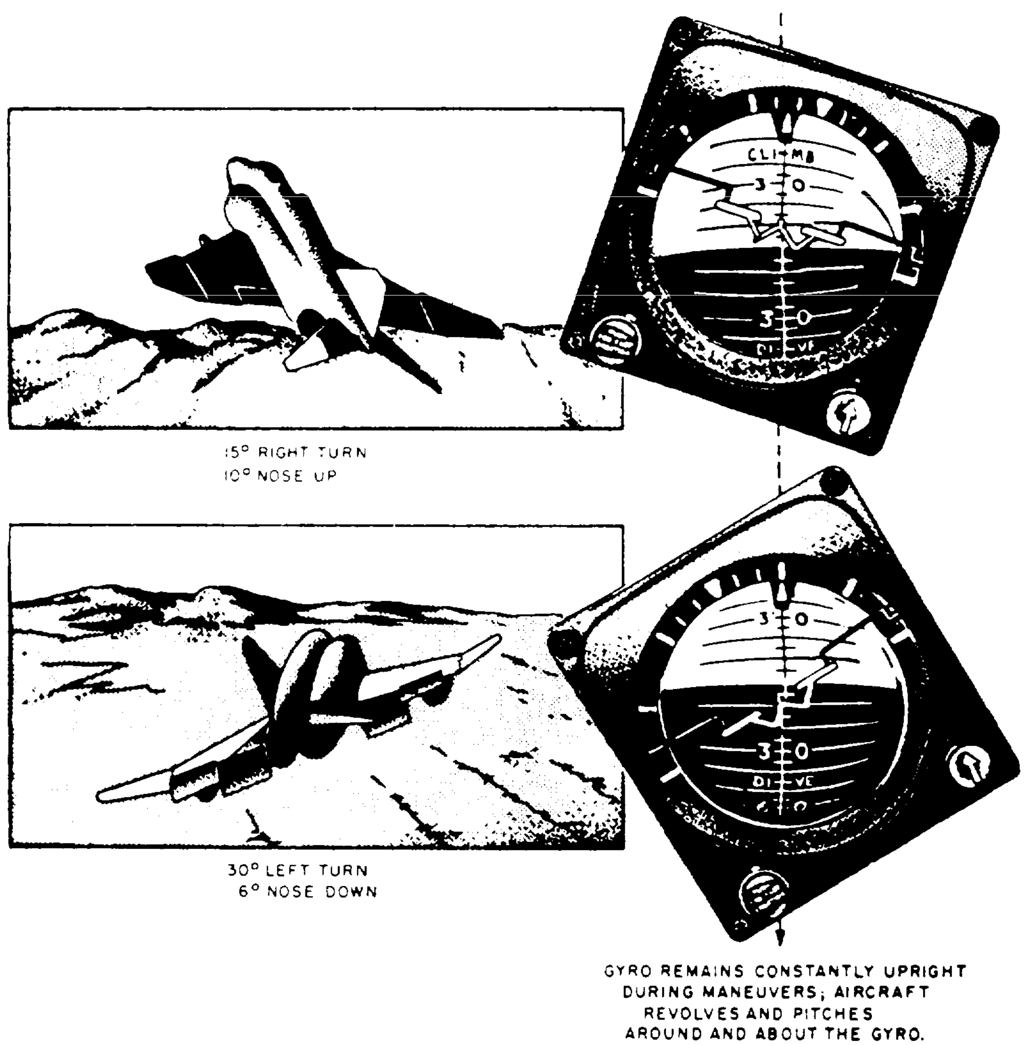


Figure 6-38.-Roll and pitch indications on the attitude indicator.

indicator (fig. 6-39). In addition to pitch and roll, this indicator shows compass information along the horizon bar. It also shows turn-and-bank information on the bottom. An even more sophisticated instrument, the *flight director,* displays the above information plus radio navigation information, all on one instrument.

NOTE: Because of close association and interface with inertial navigation systems, chapter 7 of this TRAMAN contains information about attitude indicating systems.

Turn-and-Bank Indicator

The turn-and-bank indicator (fig. 6-40), also called the *turn-and-slip indicator,* shows the lateral attitude of an aircraft in straight flight. It also provides a reference for the proper executions of a coordinated bank and turn. It shows when the aircraft is flying on a straight course and the direction and rate of a turn. It was one of the first modern instruments for controlling an aircraft without visual reference to the ground or horizon.

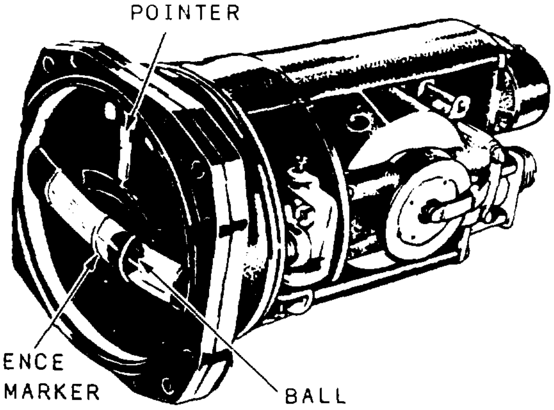


Figure 6-40.-Turn-and-bank indicator.

The indicator is a combination of two instruments—a ball and a turn pointer. The ball part of the instrument operates by natural forces (centrifugal and gravitational). The turn pointer depends on the gyroscopic property of precession

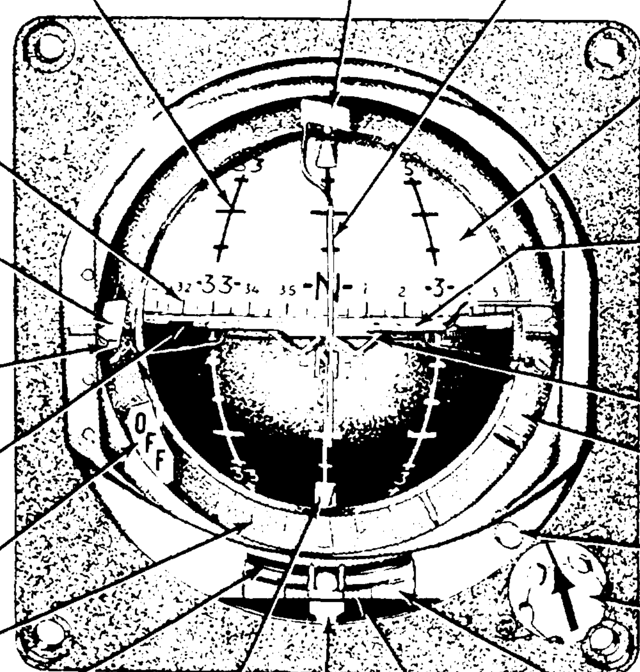


Figure 6-39.-All-attitude indicator (AAI).

for its indications. The power for the turn indicator gyro is either electrical or vacuum.

BALL. —The ball portion of a turn-and-bank indicator (fig. 6-40) consists of a sealed, curved, glass tube. The tube contains water-white kerosene and a black or white agate or common steel ball bearing. The ball bearing is free to move inside the tube. The fluid provides a damping action and ensures smooth and easy movement of the ball. The curved tube allows the ball to seek the lowest point when in level flight. This is the tube center. A small projection on the left end of the tube contains a bubble of air. The bubble lets the fluid expand during changes in temperature. There are two markings or wires around the center of the glass tube. They serve as reference markers to show the correct position of the ball in the tube. The plate that holds the tube and the references are painted with luminous paint.

The only force acting on the ball during straight flight (no turning) with the wings level is gravity. The ball seeks its lowest point and stays within the reference marks. In a turn, centrifugal force also acts on the ball in a horizontal plane opposite to the direction of the turn.

The ball assumes a position between the reference markers when the resultant of centrifugal force and gravity acts directly opposite to a point midway between the reference markers. When the force acting on the ball become unbalanced, the ball moves away from the center of the tube.

In a skid, the rate of turn is too great for the angle of bank. The excessive centrifugal force moves the ball to the outside of the turn. The resultant of centrifugal force and gravity is not opposite the midpoint between the reference markers. The ball moves in the direction of the force, toward the outside of the turn. Returning the ball to center (coordinated turn) calls for increasing bank or decreasing rate of turn, or a combination of both.

In a slip, the rate of turn is too slow for the angle of bank. The resultant of centrifugal force and gravity moves the ball to the inside of the turn. Returning the ball to the center (coordinated turn) requires decreasing the bank or increasing the rate of turn, or a combination of both.

The ball instrument is actually a <u>balance</u> indicator because it shows the relationship between angle of bank and rate of turn. It lets the pilot know when the aircraft has the correct rate of turn for its angle of bank.

TURN POINTER. —The turn pointer operates on a gyro. The gimbal ring encircles the gyro in a horizontal plane and pivots fore and aft in the instrument case. The major parts of the turn portion of a turn-and-bank indicator are as follows.

- A frame assembly used for assembling the instrument.
- A motor assembly consisting basically of the stator, rotor, and motor bearings. The electrical motor serves as the gyro for the turn indicator.
- A plate assembly for mounting the electrical receptacle, pivot assembly, and choke coil and capacitors for eliminating radio interference. It also mounts the power supply of transistorized indicators.
- A damping unit that absorbs vibrations and prevents excessive oscillations of the needle. The unit consists of a piston and cylinder mechanism. The adjustment screw controls the amount of damping.
- An indicating assembly composed of a dial and pointer.
- The cover assembly.

The carefully balanced gyro rotates about the lateral axis of the aircraft in a frame that pivots about the longitudinal axis. When mounted in this way, the gyro responds only to motion around a vertical axis. It is unaffected by rolling or pitching.

The turn indicator takes advantage of one of the basic principles of gyroscopes—precession. Precession, as already explained, is a gyroscopes's natural reaction 90 degrees in the direction of rotation from an applied force. It is visible as resistance of the spinning gyro to a change in direction when a force is applied. As a result, when the aircraft makes a turn, the gyro position remains constant. However, the frame in which the gyro hangs dips to the side opposite the direction of turn. Because of the design of the linkage between the gyro frame and the pointer, the pointer shows the correct direction of turn. The pointer displacement is proportional to the aircraft rate of turn. If the pointer remains on center, it shows the aircraft is flying straight. If it moves off center, it shows the aircraft is turning in the direction of the pointer deflection. The turn needle shows the rate (number of degrees per minute) at which the aircraft is turning.

By using the turn-and-bank indicator, the pilot checks for coordination and balance in straight flight and in turns. By cross-checking this instrument against the airspeed indicator, the relation between the aircraft lateral axis and the horizon can be determined. For any given airspeed, there is a definite angle of bank necessary to maintain a coordinated turn at a given rate.

MISCELLANEOUS FLIGHT INSTRUMENTS

The pilot uses several other indicators to control the aircraft. These indicators are not always useful, but they come into play under special flight conditions. As you read this section, look at figure 6-41.

Accelerometer Indicators

The pilot must limit aircraft maneuvers so various combinations of acceleration, airspeed, gross weight, and altitude remain within specified

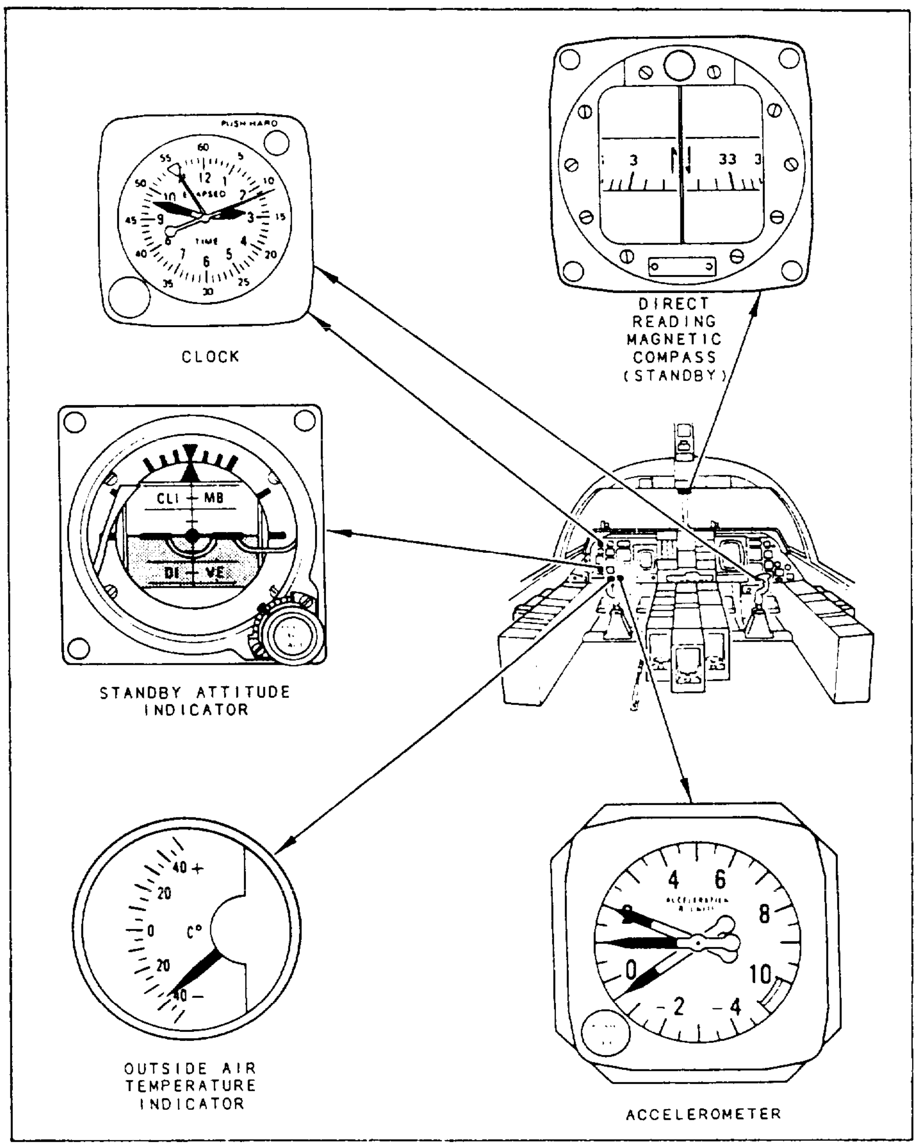


Figure 6-41.-Miscellaneous flight instruments.

values. This cuts out the possibility of damaging aircraft as a result of excessive stresses. The accelerometer shows the load on the aircraft structure in terms of gravitation (g) units. It presents information that lets the aircraft be maneuvered within its operational limits.

The forces sensed by the accelerometer act along the vertical axis of the aircraft. The main hand moves clockwise as the aircraft accelerates upward and counterclockwise as the aircraft accelerates downward.

The accelerometer indications are in g units. The main indicating hand turns to +1 g when the lift of the aircraft wing equals the weight of the aircraft. Such a condition prevails in level flight. The hand turns to +3 g when the lift is three times the weight. The hand turns to minus readings when the forces acting on the aircraft surfaces cause the aircraft to accelerate downward.

The accelerometer operates independently of all other aircraft instruments and installations. The activating element of the mechanism is a mass that is movable in a vertical direction on a pair of shafts (fig. 6-42). A spiral-wound main spring dampens the vertical movement of the mass. The force of the mass travels by a string-and-pulley

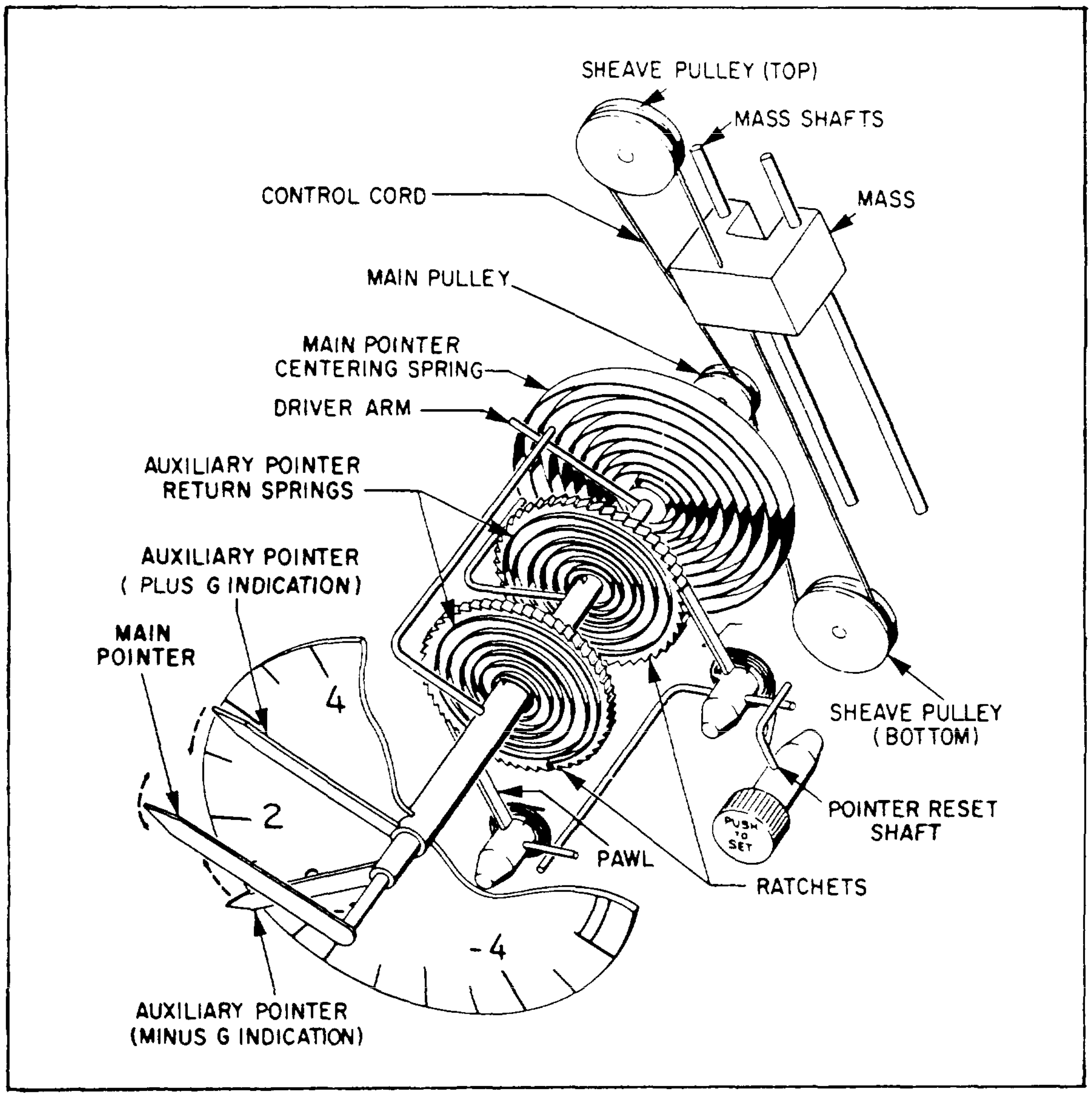


Figure 6-42.-Accelerometer mechanical schematic.

system to the main spring and main shaft. From here, it goes to the plus and minus assemblies. The hand assemblies mount on the plus and minus assemblies. Changes in vertical acceleration cause movement of the mass on the shafts, which translates into a turning motion of the main shaft. The turning motion pivots the indicating hands around the dial. The hand travels a distance equivalent to the value, in g units, of the upward or downward acceleration of the aircraft.

The accelerometer operates on the principle of Newton's Law of Motion. During level flight, no forces act to displace the mass from a position midway from the top and bottom of the shafts. Therefore, the accelerometer pulley system performs no work, and the indicating hands remain stationary at +1 g. When the aircraft changes from level flight, forces act on the mass. This action causes the mass to move either above or below its midway position. These movements cause the accelerometer indicating hands to change position. When the aircraft goes nose down, the hands move to the minus section of the dial. When the nose goes up, they move to the plus section.

The main hand continuously shows changes in loading. The two other hands on the accelerometer show the highest plus acceleration and highest minus acceleration of the aircraft during any maneuver. The indicator uses a ratchet mechanism to maintain these readings. A knob in the lower left of the instrument face is used to reset the maximum- and minimum-reading hands to normal. Thus, the accelerometer keeps an indication of the highest accelerations during a particular flight phase or during a series of flights.

Clocks

The standard Navy clock is a 12-hour, elapsed-time, stem-wound clock with an 8-day movement. This type of clock is in the cockpit for use by the pilot or copilot. Clocks maybe located elsewhere for use by other crew members as well. The pull-to-set winding stem is at the lower left of the dial. The dial has 60 divisions, which you read as minutes or seconds, as appropriate. The face has standard minute and hour hands, a sweep-second hand, and an elapsed-time minute hand. You may start, stop, or reset the elapsed-time minute hand by pressing a single button at the upper right of the dial.

Direct-Reading Magnetic Compasses

During the early days of aviation, direction of flight was determined chiefly by direct-reading magnetic compasses. Today, the direct-reading magnetic compass (fig. 6-41) is used as a standby compass. Direct-reading magnetic compasses used in Navy aircraft mount on the instrument panel for use by the pilot. It is read like the dial of a gauge.

A nonmagnetic metal bowl, filled with liquid, contains the compass indicating card. The card provides the means of reading compass indications. The card mounts on a float assembly and is actually a disk with numbers painted on its edge. A set of small magnetized bars or needles fasten to this card. The card-magnet assembly sits on a jeweled pivot, which lets the magnets align themselves freely with the north-south component of the earth's magnetic field. The compass card and a fixed-position reference marker (lubber's line) are visible through a glass window on the side of the bowl.

An expansion chamber in the compass provides for expansion and contraction of the liquid caused by altitude and temperature changes. The liquid dampens, or slows down, the oscillation of the card. Aircraft vibration and changes in heading cause oscillation. If suspended in air, the card would keep swinging back and forth and be difficult to read. The liquid also buoys up the float assembly, reducing the weight and friction on the pivot bearing.

Instrument-panel compasses for naval aircraft are available with cards marked in steps of either 2 degrees or 5 degrees. Such a compass indicates continuously without electrical or information inputs. You can read the aircraft heading by looking at the card in reference to the lubber line through the bowl window.

Standby Attitude Indicator

The standby attitude indicator (fig. 6-41 on the pilot instrument panel) consists of a miniature aircraft symbol, a bank angle dial, and a bank index. It also includes a two-colored drum background with a horizon line dividing the two.

The indicator roll index is graduated in 10-degree increments to 30 degrees, with graduation marks at 60 degrees and 90 degrees. The indicator is capable of displaying 360 degrees of roll, 92 degrees of climb, and 79 degrees of dive. Because of the high spin rate of the gyro, the indicator displays accurate pitch-and-roll data for 9 minutes after electrical failure. The attitude indicator incorporates a pitch trim knob to position the miniature aircraft symbol above or below the horizon reference line. The pitch trim knob also cages the gyro. When the pitch trim knob is pulled out, the gyro will cage. Rotating the knob clockwise while extended will lock in the extended position. The attitude indicator also incorporates an OFF flag. The flag appears if electrical power fails, or if you cage the gyro.

Outside Air Temperature Indicator

An indicator displaying uncorrected outside air temperature is located on the pilot's instrument panel (fig. 6-41). A temperature-sensitive resistor (temperature bulb) is exposed to the slipstream. This resistor measures changes in temperature. The temperature of the air measurement is in the form of changing resistance. The outside air temperature indicator displays this change in resistance. The graduated indicator dial is marked in Celsius, from +50 degrees to –50 degrees.

REVIEW SUBSET NUMBER 1

Q1. List the two ways of grouping aircraft instruments.

Q2. What determines the air pressure at any given altitude?

Q3. What is the standard atmospheric pressure at 5,000 feet of altitude?

Q4. Name the three indicators that use pressures from the pitot-static system.

Q5. What instrument uses both pitot and static air pressure?

Q6. What is the Mach number for an aircraft flying at twice the speed of sound?

Q7. Define the terms "AGL" and "MSL."

Q8. Define the term "absolute altitude."

Q9. What is the name for the aneroid mechanism used in most altimeters?

Q10. Name the four inputs to the air data computer system.

Q11. Define the term "impact pressure."

Q12. What is the operational limit of aircraft using the CPU-46/A supersonic altitude computer?

Q13. What system actuates the rudder pedal shaker to warn the pilot of an impending stall?

Q14. What determines the degrees of freedom for a gyro?

Q15. Name the two basic properties of gyroscopic action.

Q16. What indicator shows the lateral attitude of an aircraft?

ENGINE INSTRUMENT SYSTEMS

Learning Objective: *Recognize the operating principles and characteristics of various engine instrument systems, including tachometer, temperature indicating, fuel flow, oil pressure, fuel pressure, oil temperature, exhaust-nozzle indicating, and torquemeter systems.*

Engine instruments provide indications of tail pipe temperature, oil and fuel pressure, engine RPM, oil temperature, and fuel flow rate. The pilot must be aware of engine operation at all times. If oil pressure falls below the normal operating limit or tail pipe temperature becomes excessively high, the engine instruments provide these indications to the pilot.

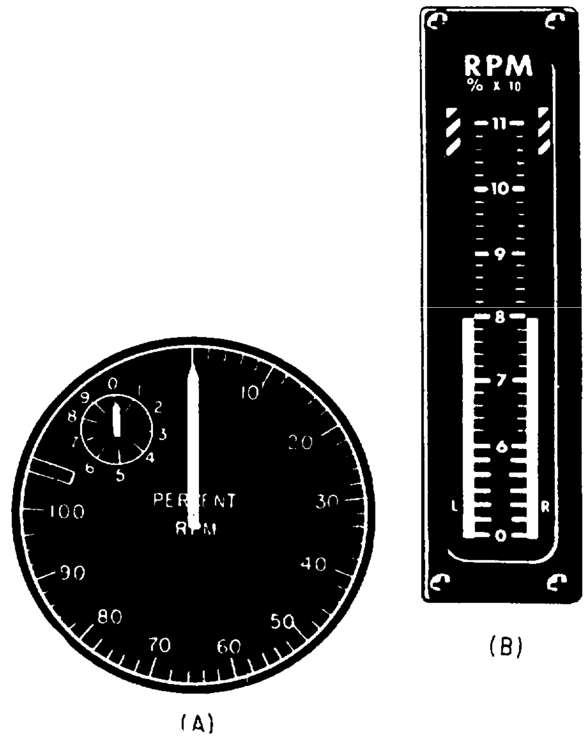


Figure 6-43.-Tachometer indicators: (A) jet engine (radial); (B) jet engine (vertical scale).

TACHOMETER SYSTEMS

The tachometer indicator is an instrument that shows the speed of a gas turbine engine (jet) main rotor assembly. Figure 6-43 shows tachometer indicators for various types of engines. The dials of tachometer indicators used with jet engines are shown in percentage of revolutions per minute (RPM), based on takeoff RPM.

Several types and sizes of generators and indicators are used in the tachometer systems of naval aircraft. As a rule, they all operate on the same basic principle. This section introduces you to information on tachometer systems. A typical generator and a typical indicator are described because it is not practical to describe all the generators and indicators. For detailed information on a particular system, you should refer to the manufacturer's manuals.

Essentially, the tachometer system consists of an ac generator coupled to the aircraft engine and an indicator consisting of a magnetic-drag element on the instrument panel. The generator transmits electric power to a synchronous motor, a part of the indicator. The frequency of this power is proportional to the engine speed. An accurate indication of engine speed is obtained by applying the magnetic-drag principle to the indicating element. The problem of changes in generator output voltage is cut out by the generator and synchronous-motor combination. These units make a frequency-sensitive system for sending an indication of engine speed to the indicator with absolute accuracy.

For many installations, it is desirable to send a single engine-speed indication to two different stations in the aircraft. The frequency-sensitive system is ideal for this application because there is no change in indication when a second indicator connects in parallel with the first. Synchronous-motor operation in each indicator depends only on the availability of enough power in the generator to operate both indicator motors.

Tachometer Generator

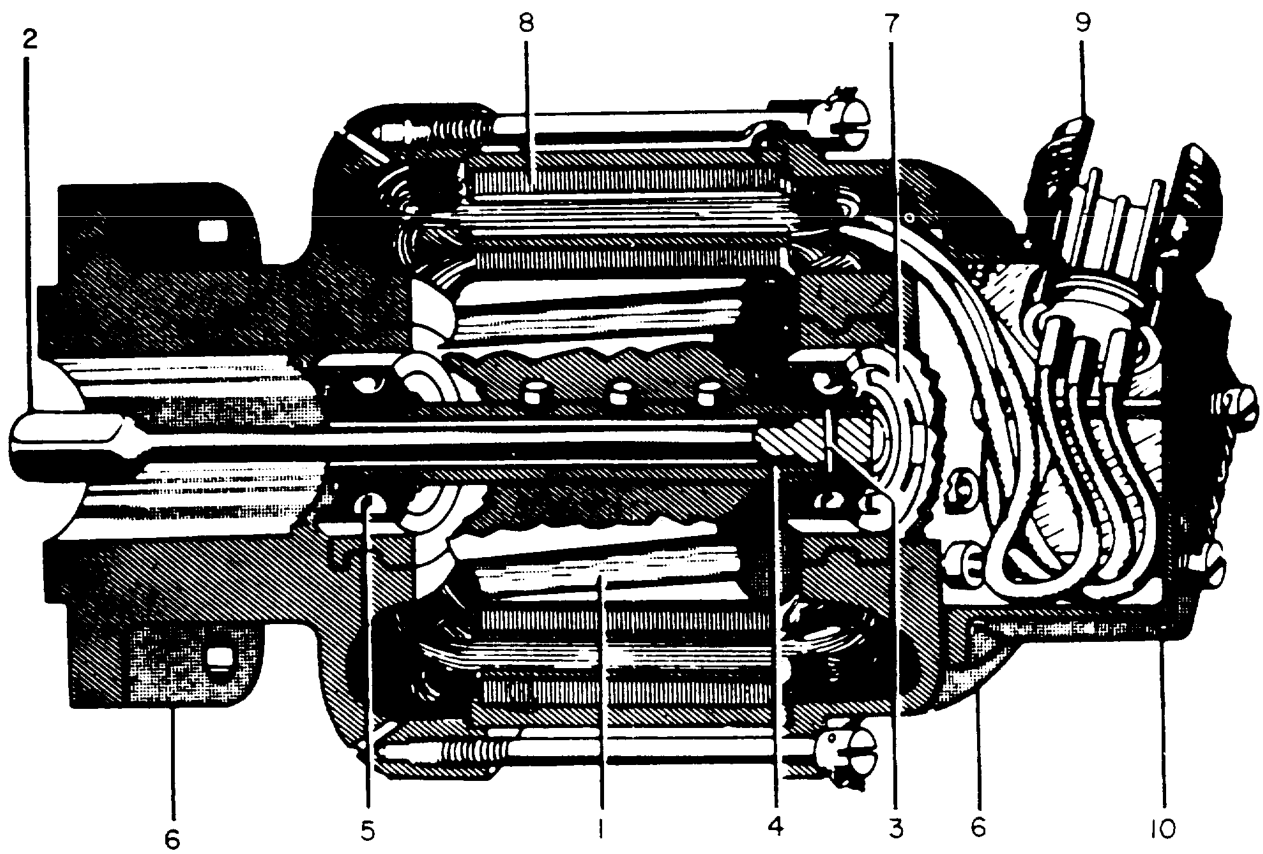
Tachometer generator units are small and compact (about 4 inches by 6 inches). The generator is constructed with an end shield designed so the generator can attach to a flat plate on the engine frame or reduction gearbox, with four bolts.

Figure 6-44 shows a cutaway view of a tachometer generator. You should refer to it while you read this section. The generator consists essentially of a permanent-magnet rotor (callout 1) and a stator (callout 8) that develop three-phase power as the rotor turns.

The armature of the generator consists of a magnetized rotor. The rotor is cast directly onto the generator shaft. The generator may be of either two- or four-pole construction. The two- and four-pole rotors are identical in appearance and construction. They differ in that the two-pole rotor is magnetized north and south diametrically across the rotor, while the four-pole rotor is magnetized alternately north and south at each of the four pole faces.

The key (callout 2) that drives the rotor is a long, slender shaft. It has enough flexibility to prevent failure under the torsional oscillations originating in the aircraft drive shaft. It will also accommodate small misalignments between the generator and its mounting surfaces. This key goes into the hollow rotor shaft. A pin (callout 3) at the end opposite the drive shaft secures the key in place. An oil-seal ring (callout 4) is located inside the hollow shaft and over this key. This seal prevents oil from leaking into the generator through the hollow shaft. The shaft runs in two ball bearings (callout 5) set in stainless steel inserts. The inserts are cast directly into the generator end shields (callout 6). An adjusting spring (callout 7) at the receptacle end of the shaft maintains the proper amount of end play.

The stator consists of a steel ring with a laminated core of ferromagnetic material. A three-phase winding goes around this core and is insulated from it. The winding is adapted for two- or four-pole construction, depending on the



1. Rotor
2. Drive key
3. Pin
4. Oil-seal ring
5. Ball bearing
6. End shields
7. Adjusting spring
8. Stator
9. Receptacle
10. Junction box

Figure 6-44.-Cutaway view of a tachometer generator.

generator in which it is used. The two end shields are of die-cast aluminum alloy. They serve to support the generator stator and rotor by means of a receptacle (callout 9). The receptacle attaches to the junction box (callout 10) of the generator.

Tachometer Indicators

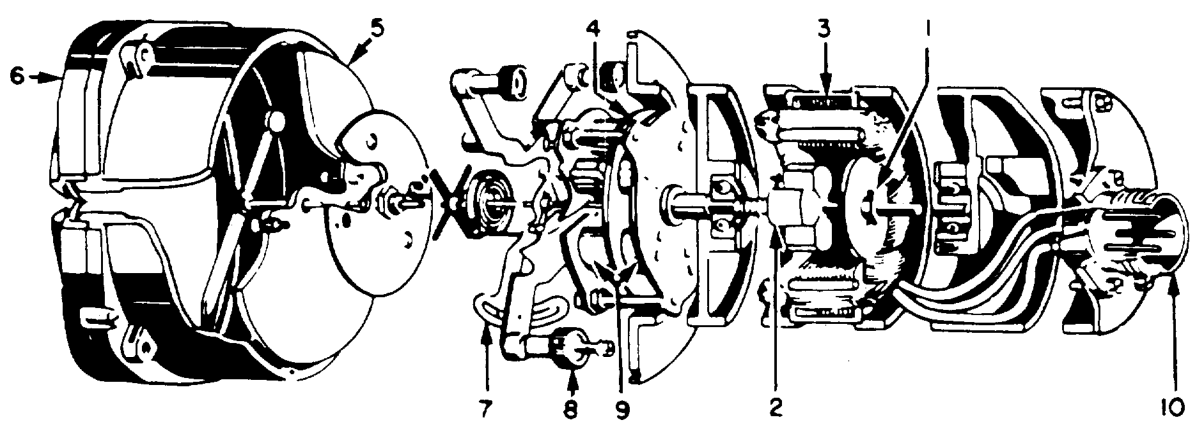
Tachometer indicators mount on the cockpit instrument panel. They are relatively small in size. The type of unit varies. Depending on the particular installation, some are single element and others are dual element, The operating principles of the two types are basically the same.

Figure 6-45 shows a cutaway view of a single-element tachometer (radial) indicator. The unit consists essentially of two parts a synchronous motor and an indicating element. The motor runs in synchronism with the tachometer generator. It also drives the indicating element through a magnetic-drag coupling. The indicating element indicates the speed of the synchronous motor, and, therefore, the speed of the aircraft engine.

The synchronous motor (callout 3) consists of a three-phase stator winding that goes in, and is insulated from, a laminated circular core. Within the circular core is a shaft. The rotating parts attach to this shaft. A cotter pin secures a hysteresis disk (callout 1) to the shaft. A permanent magnet rotor (callout 2) is free to move on the shaft. The hysteresis disk at one shaft end and a spring at the other restrain longitudinal motion of the permanent magnet rotor. The spring is secured to the shaft to transmit torque from the rotor to the shaft. Ball bearings in the motor end shields support the shaft. These end shields also serve to locate the stator. This lets all parts of the motor maintain their proper position with respect to each other.

The armature of the synchronous motor consists mainly of the permanent magnet and the hysteresis disk. The purpose of the permanent-magnet material is to provide starting and running torque at low speeds. The hysteresis disk provides starting torque at high speed. This is necessary because the magnitude of flux is great, but the permanent magnet, by itself, cannot pull into step. At the higher speeds, the hysteresis disk moves the rotor up to near synchronism, and then the permanent magnet pulls it into exact synchronism.

One end of the motor shaft extends through the front end shield and supports the drag-magnet assembly (callout 9). The drag-magnet assembly, which is driven by the synchronous motor, consists of two plates to which small permanent magnets attach. The arrangement of the magnets concentrate the flux near the outside edge of the drag disk. This arrangement obtains maximum torque with minimum weight. Between the two, plates carrying the magnets is a disk (callout 4) of conducting material. This material is an alloy having a low-temperature coefficient. This prevents temperature changes from affecting the material's resistance. The magnet assembly



1. **Hysteresis disk**
2. **Rotor**
3. **Motor**
4. **Drag disk**
5. **Scale plate**
6. **Cover assembly**
7. **Adjusting arm**
8. **Adjusting nut**
9. **Magnet assemblies**
10. **Receptacle**

Figure 6-45.-Cutaway view of a tachometer indicator (radial).

spinning around the disk of conducting material produces torque on the disk.

The drag disk connects to the lower end of the indicator assembly shaft. When the disk rotates, the indicator pointer moves to show the speed of the aircraft engine. The indicating element is supported by three posts. These post have adjustable nuts (callout 8) for leveling the assembly as necessary. You can obtain further positioning by the adjusting arm (callout 7).

The scale plate (callout 5) is calibrated either in RPM or percentage and shows engine speed. The cover assembly (callout 6) serves as a protective container for the mechanism. Electrical connection to the tachometer generator is by the receptacle (callout 10) at the rear of the indicator.

Dual Indicators

With the increasing requirement for more instruments for efficient flight, the combination of several instruments in one has become very common. The dual tachometer is an example of a combination of instruments. Some multi-engine aircraft use dual tachometers.

The dual tachometer consists of two synchronous-motor magnetic-drag tachometer indicators housed in a single case. The indicators show the speed of rotation of the engines simultaneously on a single dial. There is one tachometer indicator for each pair of engines on the aircraft.

Vertical Scale Indicators

Vertical scale indicators are used on some models of naval aircraft. A vertical scale shows engine performance data such as fuel flow, engine speed, exhaust gas temperature, and accelerometer readings. Vertical scale indicators are compact, light in weight, and easily read.

Basically, all vertical scale indicators consist of a vertical tape that operates by an amplifier, motor, gears, and sprockets. These systems (fig. 6-46) are basically the same as systems used on other aircraft. There may be possible changes in nomenclature due to the various aircraft and engine manufacturers.

The engine indicating groups consist of cockpit indicators and associated sensing devices required to monitor left and right engine performance. Dual indicators display percentage of engine N_2 rotor speed (RPM indicator), turbine inlet temperature (TIT indicator), and engine fuel flow (FF indicator). Individual indicators display engine power trim (PT indicator) and N_1 overspeed caution (L or R N_1OVSP caution indicator light),

TACHOMETER INDICATOR. —The electrical tachometer (RPM) indicator displays percentage of engine N_2 rotor speed on two vertical scales. One each for the left and right engines. The indicator scales are linear from 0 to 6, and from 6 to 11 multiplied by 10 to get percent of RPM. Upper left and right limit range markers and OFF failure flags appear between the 10.4 and 11 points of the scales. The absence of the OFF failure flags confirms the indicator channels are receiving power. The indicator receives variable-frequency signals proportional to N_2 compressor speed from each engine tachometer generator. The signals go to solid-state circuitry to produce a proportional drive signal for a servomotor. The servomotor drives gears and sprockets to position a tape on the indicator face, showing percentage of engine N_2 rotational speed.

The test selector switch on the MASTER TEST panel is used to test the indicators. It disconnects a self-test circuit in the indicators from the tachometer-generator input circuits. The self-test circuit then connects with the appropriate test signal within the two indicator channels. The channel circuitry processes the test signal and drives the indicator tapes to show 80 percent of RPM.

N_1, N_2 TACHOMETER GENERATORS. —The N_1 and N_2 tachometer generators are identical two-phase alternator types. They supply electrical signals directly proportional to engine-compressor rotational speed. The N_1 tachometer generator for the left and right engines is driven by the N_2 low-pressure compressor rotor. An output from this generator goes to the engine rotor overspeed detector. The signals represent N_1 compressor revolutions per minute (RPM). The N_2 tachometer generator is driven by the N_2 high-pressure compressor through the engine accessory gearbox. Signals from this generator go directly to the electrical tachometer indicator (RPM indicator) at the pilot station. The indicator displays percentage of N_2 rotor speed.

ENGINE ROTOR OVERSPEED DETECTOR. —The engine rotor overspeed detector receives electrical signals from the left and right N_1 tachometer generator. The detector consists of three solid-state circuit boards—a crystal oscillator (clock) board and two identical gated counter boards, one for each engine, The detector receives a 0- to 33-volt, 0- to 70-hertz signal from each N_1 tachometer generator. In the detector, the voltage is cut to a constant 5 volts. The normal frequency signal is reshaped and processed through the counter circuit to establish a signal period. The clock sets up a reference period for each counter. The counters measure the period for their respective tachometer-generator signal. Then, they compare the tachometer-generator signal period with the established clock reference period. If the incoming generator signal period is shorter than the clock reference period, the counter energizes a switching relay. The relay

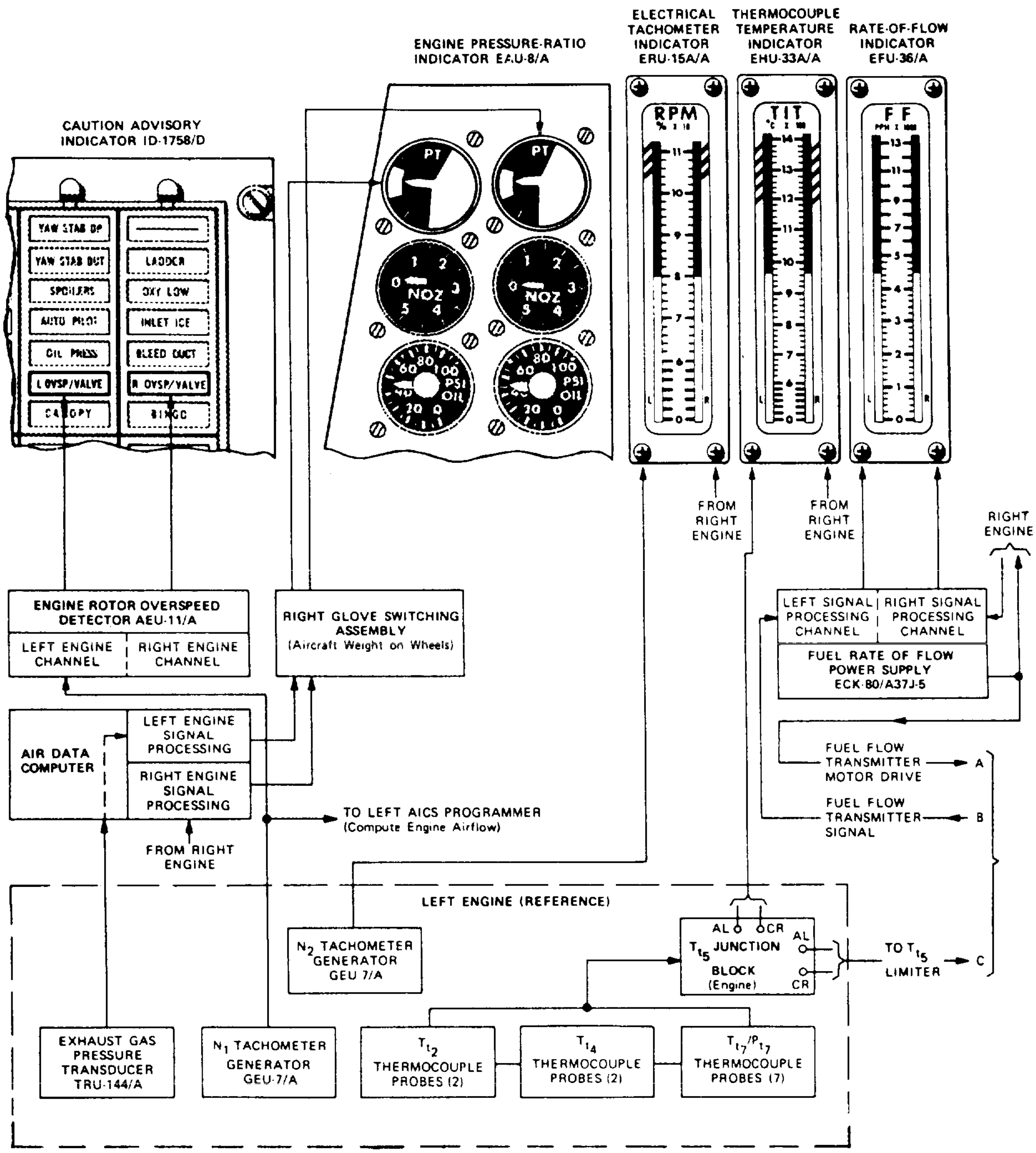


Figure 6-46.-F-14 engine instrument indicating group.

completes a circuit to power its respective caution indicator light on the pilot CAUTION ADVISORY indicator.

TEMPERATURE INDICATING SYSTEMS

To properly monitor the operation of an aircraft engine, you must know various temperature indications. Some of the more important indications include the temperatures of the engine oil, free air, and exhaust systems of jet engines. Various types of thermometers, such as the bimetal and resistance types, collect and present this information.

The main parts of resistance thermometers are the indicating instrument, the temperature-sensitive element (resistance bulb), and the connecting wires leading from the bulb.

The indicator dials of resistance thermometers are calibrated according to the range of temperature to be measured. Figure 6-47 shows a resistance thermometer indicator. The indicators are self-compensating, allowing for the changes in cockpit temperatures.

Wheatstone Bridge System

A schematic diagram of a Whetstone bridge thermometer circuit is shown in figure 6-48. You should refer to it as you read this section. The resistance bulb element is one side of the Wheatstone bridge circuit. The other three sides are resistors in the indicating meter. The circuit receives voltage from the aircraft dc power supply.

When the temperature bulb senses a temperature of 0°C, its resistance is 100 ohms. The resistance of arms X, Y, and Z are also 100 ohms each. At this temperature the Wheatstone bridge is in balance. This means the sum resistance of X and Y equals the sum resistance of the bulb and Z. Therefore, the same amount of current flows in both sides of this parallel circuit. Since all four sides are equal in resistance, the voltage drop across side X equals the drop across the bulb. Since these voltages are equal, the voltage from A to B is zero, and the indicator reads zero.

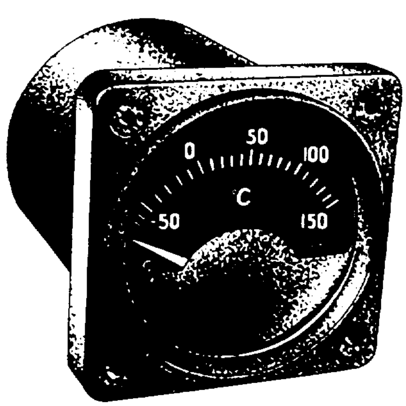


Figure 6-47.-Indicator of a resistance thermometer.

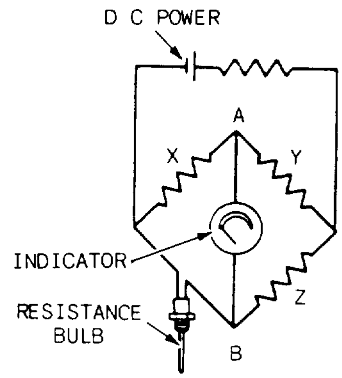


Figure 6-48.-Wheatstone bridge thermometer.

NOTE: If there is an open in the voltage supply circuit, the galvanometers will also read zero.

When the temperature of the bulb increases, its resistance also increases. This unbalances the bridge circuit causing the needle to deflect to the right. When the temperature of the bulb decreases, its resistance decreases. Again the bridge circuit goes out of balance. However, this time the needle swings to the left.

The galvanometers is calibrated so the amount of deflection causes the needle to point to the number of the meter scale. This number corresponds to the temperature at the location of the resistance bulb.

This instrument requires a constant and steady supply of dc voltage. Fluctuations in the power supply affect total bridge current, which can cause an unbalanced bridge. Unless excessive heat damages the bulb, it will give accurate service indefinitely. When a thermometer does not operate properly, check carefully for loose wiring connections before replacing the bulb.

Radiometer System

The radiometer is a temperature indicator that uses two coils in a balanced circuit. In some instruments, the coils turn between the poles of a permanent magnet. In other instruments, a small permanent-magnet rotor turns between stationary coils. Radiometer circuits vary in design, but the principle of operation is very much the same for all.

Figure 6-49 shows a simplified circuit with a permanent-magnet rotor. The two coils are stationary in the instrument, and the indicator needle fastens to the permanent-magnet rotor. The needle position is determined by how the permanent magnet aligns itself with the resultant flux of the two coils.

For an understanding of how the circuit operates, let's trace the current through the circuit. Starting at ground, current flows up through the bulb, centering potentiometer R5 and R6, to point D. Current through the left leg of the bridge is from ground through R1 to point A. Current then goes from point A through the lower part of the expansion and contraction potentiometer R2. It also goes from pin 2 of R2 through R4 to point D. Here, the currents of the two legs combine and flow through R7 to the positive 28 volts.

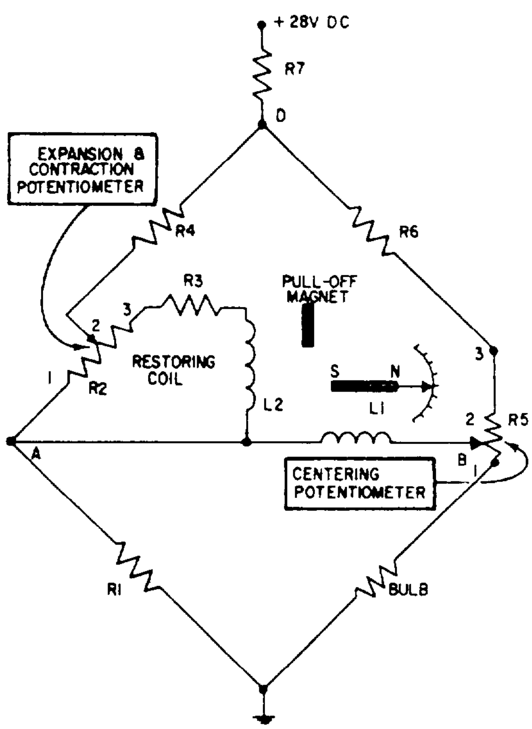


Figure 6-49.-Radiometer type temperature indicator.

Note that restoring coil L2, resistor R3, and upper part of potentiometer R2 forms a parallel path for current flow from point A to pin 2 of R2. Deflection coil L1 connects between points A and B. Therefore, any difference in potential between these two points will cause current to flow through L1.

The radiometer temperature indicator uses a fixed permanent magnet to pull the pointer to an off position when the indicator is not operating. Thus, current through restoring coil L2 must compensate for the pulloff magnet when the indicator is operating. Variations in the resistance of the bulb, because of temperature changes, cause a change in voltage at point B. It also causes the resulting change in current through deflection coil L1.

Thermocouple System

Thermocouple temperature indicators show the air temperatures in the heater duct of anti-icing systems and in the exhaust systems of jet engines.

A thermocouple is a junction or connection of two unlike metals; such a circuit has two junctions. When one of the junctions becomes hotter than the other, an electromotive force is produced in the circuit. By including a galvanometers in the circuit, this electromotive force can be measured. The hotter the high-temperature junction (hot junction) becomes, the greater the electromotive force. By calibrating the galvanometers dial, in degrees of temperature, it becomes a thermometer. The galvanometers contains the *cold* junction.

The thermocouple thermometer systems used in naval aircraft consist of a galvanometers indicator, a thermocouple or thermocouples, and thermocouple leads. Some thermocouples consist of a strip of copper and a strip of constantan pressed tightly together. Constantan is an alloy of copper and nickel. Other thermocouples consist of a strip of iron and a strip of constantan. Others may consist of a strip of Chromel and a strip of Alumel.

The *hot* junction of the thermocouple varies in shape, depending on its application. Two common types—gasket and rivet—are shown in figure 6-50. In the gasket thermocouple, the rings of two dissimilar metals are pressed together, forming a spark plug gasket. Each lead that connects back to the galvanometers must be of the same metal as the thermocouple part to which it connects. For example, a copper wire connects to the copper ring, and a constantan wire connects to the constantan ring. Thermocouple leads are critical in makeup and length because the galvanometers are calibrated for a specific set of leads in the circuits.

TURBINE INLET TEMPERATURE (TIT) INDICATOR SYSTEM. —Some aircraft have an engine turbine inlet temperature indicator system (fig. 6-51) to provide a visual indication of temperatures entering the turbine. The temperature of each engine turbine inlet is measured by 18 dual-unit thermocouples in the turbine inlet casing. These dual thermocouples are connected in parallel. One set sends signals through a harness and aircraft wiring to an indicator. The other set of thermocouples provides signals to the temperature datum control. Each circuit is electrically independent and provides dual system dependability.

All parts of the engine temperature measurement system are made of Chromel and Alumel material, including welds. Special wiring and wire identification are in the aircraft from

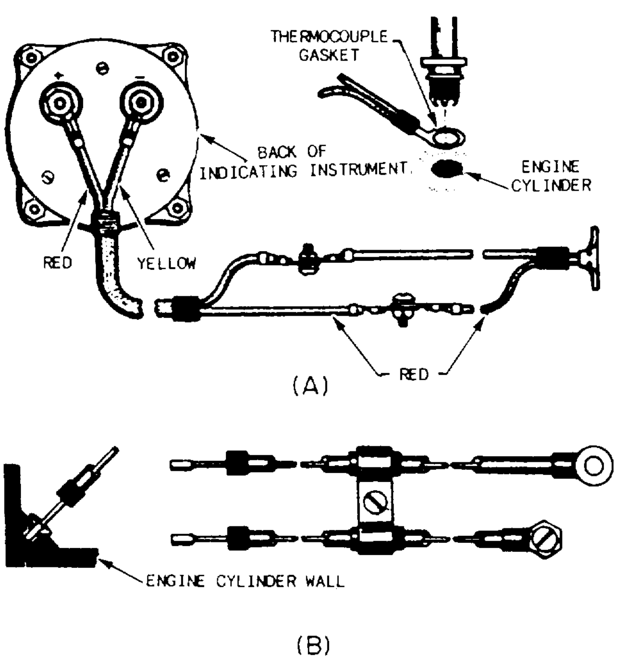


Figure 6-50.-Thermocouples: (A) gasket type; (B) rivet type.

the thermocouple harness terminal block to the indicator. Plugs in the thermocouple circuits are also of a special type. The thermocouple harness mounts on the turbine unit aft of the thermocouple. The harness includes separate leads for each of the 18 thermocouples, and it maintains two electrically separate circuits. The harness is located inside a rigid metal, channel type of housing and cover. The leads and terminals project through holes in the front side of the housing wall. Electrical signals from the 18 dual-junction thermocouples are averaged within the harness.

The thermocouple assemblies mount on pads provided around the turbine inlet case. Each thermocouple incorporates two electrically independent junctions within a sampling type probe. AL identifies Alumel terminal studs, and CR identifies Chromel terminal studs.

Since the average voltage of the thermocouples at the thermocouple terminal blocks represents the turbine inlet temperature, it is necessary that no interference with the signal take place while the signal goes to the indicator. Therefore, the wiring from the thermocouple terminal block to the indicator goes through the harness. The harness wiring goes separately from other interference-producing wiring.

The indicator contains a bridge circuit with cold junction compensation, a two-phase motor to drive the pointer, and a feedback potentiometer. Also included in the indicator is the Zener voltage reference circuit, a chopper circuit, an amplifier, power supply, a power-off flag, and an overtemp warning light.

Output of the bridge circuit goes to the chopper circuit, so the bridge circuit isn't loaded. The chopper output goes to the amplifier. Output of the amplifier feeds the variable field of a two-phase motor. This field positions the indicator main pointer and the digital indicator, The motor also drives the feedback potentiometer to provide a nulling signal. The signal is relative to the temperature signal and stops the drive motor upon reaching the correct pointer position.

The Zener diode circuit protides a closely regulated reference voltage in the bridge, This signal avoids the error caused by voltage variation from the indicator power supply. The indicator power supply powers the Zener circuit, the chopper, and the amplifier. It also powers the power off warning flag and the fixed field of the two-phase motor.

The overtemperature warning light in the indicator comes on when the turbine inlet

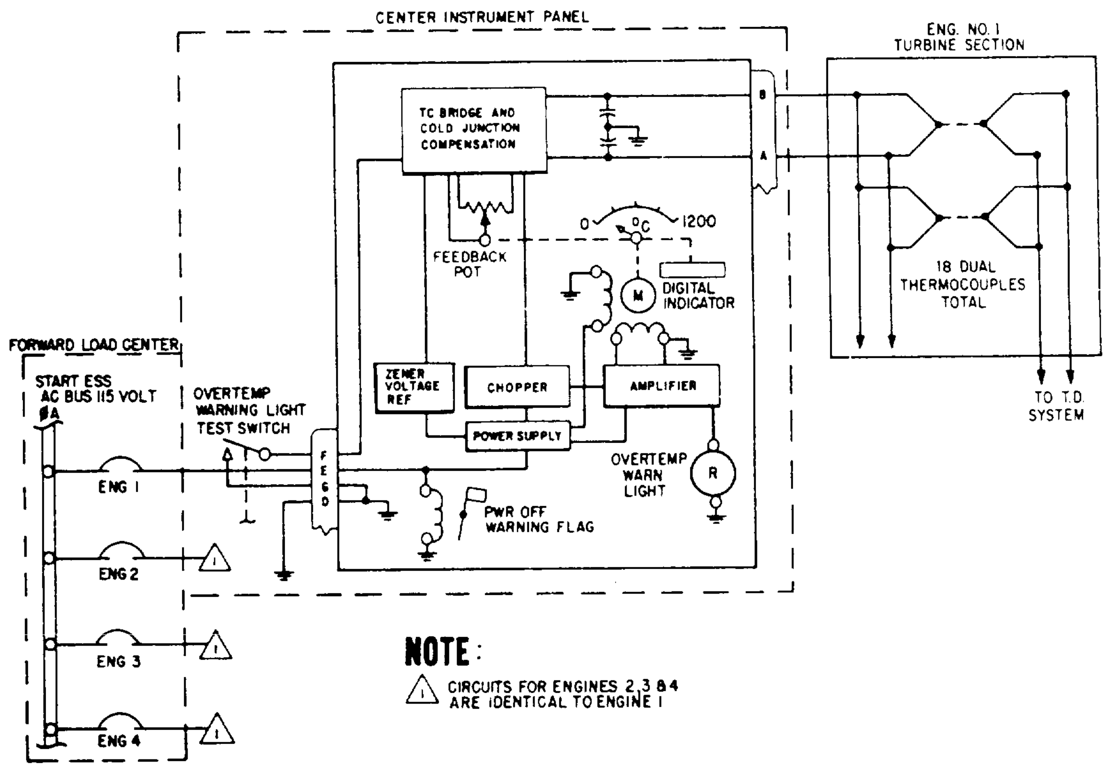


Figure 6-51.-Turbine inlet temperature indicator system.

temperature (TIT) reaches 1,082°C. At this point, a switch in the indicator closes to energize the warning light. One test switch installed external to the indicators lets the crew test all the indicator overtemperature warning lights at once. The test switch simulates an overtemperature signal in each indicator's temperature control bridge circuit.

When power to an indicator fails, a red warning flag becomes visible. Also, the indicator pointers maintain their position, and the overtemperature warning light becomes inoperative.

The indicator scale is calibrated in degrees Centigrade from 0 to 12 (times 100°C). The digital indicator goes from 0°C to 1,200°C in 2-degree increments.

The F-14 aircraft also used the thermocouple principle for indicating engine turbine inlet temperatures. Each engine has 10 thermocouple probes, distributed at three stations on the engine. They measure and average engine turbine inlet temperature. There are three types of thermocouple probes—compressor inlet temperature (T_{t2}), compressor discharge temperature (T_{t4}), and exhaust gas temperature thermocouple pressure ($T_{t7}-P_{t7}$). Each thermocouple probe has one or more Alumel-Chromel junctions. When the junctions become hot, a reaction between the dissimilar metal generates a dc voltage. A thermocouple harness connects the thermocouples in parallel to provide an average heat signal from each station.

The thermocouple temperature indicator (fig. 6-46) displays turbine inlet gas temperature on two vertical scales, one for each engine. The scales are linear from 0 to 6; segmented in tens, from 6 to 14 and multiplied by 100°C when read. OFF failure flags appear at the upper left and right of the indicator to show loss of signal input or electrical power.

Internally, the indicator has two channels, one for each engine. The channels basically consist of a cold junction compensator, rebalance potentiometer, chopper, servo amplifier, servomotor, and gear train. Thermocouple signal voltage from the engines goes to the cold junction compensator in each channel. The compensator provides corrective voltages to counteract the effect of secondary thermocouple junctions in the indicator when Alumel and Chromel leads connect to copper ones. A stable voltage goes to the old junction compensator and rebalance potentiometer.

The feedback of the potentiometer and output of the compensator go to the chopper, where it compares the inputs. The chopper provides a 400-hertz error signal to the servo system. The chopper output (signals relative to temperature change and potentiometer versus compensator difference) goes to a servo amplifier. The servo amplifier modifies the signals to drive the servomotor. The shaft of the motor couples to the rebalance potentiometer and indicator tape through the gear train.

As the amplifier error drives the motor, the rebalance potentiometer goes in a direction that reduces the error signal, nullifying the condition. The tape shows temperature, on the front scale of the indicator, relative to thermocouple output. When supplied with 28 volts dc, a test circuit in the indicator energizes a relay, disconnecting the thermocouple input. Then, it substitutes a test signal of specific value to be processed and to drive the indicator tape.

EXHAUST GAS TEMPERATURE INDICATING SYSTEM. —The exhaust gas temperature (EGT) indicating systems provide a visual temperature indication in the cockpit of the engine exhaust gases. The following is a discussion of a typical exhaust gas temperature indicating system.

The aircraft contains two separate but identical exhaust gas temperature indicating systems (fig. 6-52), one for each engine. Each system has 12 dual thermocouples, a combination indicator and transistorized amplifier, and the interconnecting Chromel and Alumel leads. Power for the indicator-amplifier is from the essential 115-volt ac bus.

Both exhaust gas temperature indicators are on the pilot's main instrument panel. They provide a visual indication of the engine exhaust temperatures. Each instrument is a hermetically sealed unit with a single receptacle for a mating plug electrical connection. The instrument scale ranges from 0°C to 1,200°C. There is a vernier dial in the upper right corner of the instrument face. A power-off warning flag is in the lower portion of the dial.

Internally, the indicator contains a simulated thermocouple cold junction with compensating resistors, a reference voltage source, and a dc-to-ac modulator. It also contains a transistor power output stage, miniature ac servomotor, and the power-off warning flag. The temperature indicator contains range markings on the instrument face.

The thermocouples convert engine exhaust gas temperature into millivolts. The voltage from the thermocouples go directly to the indicator-amplifier through the Chromel and Alumel leads. The voltage is amplified and drives a small servomotor. The motor, in turn, drives the indicator pointer. The thermocouple harness consists of two halves, each containing six dual-loop thermocouples. The assembled halves make up two independent thermocouple systems, each consisting of 12 thermocouples connected in

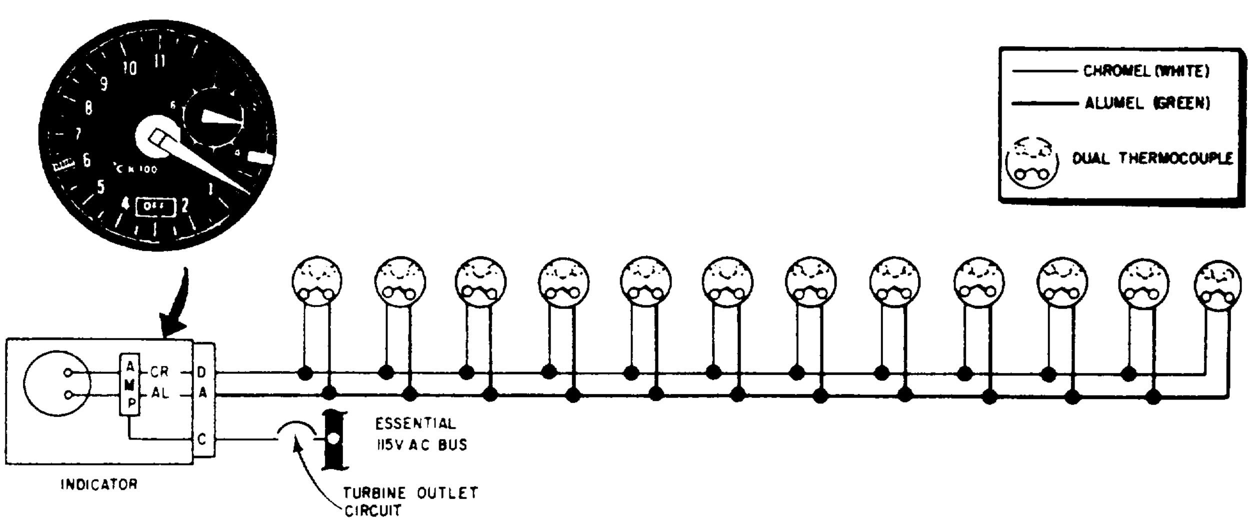


Figure 6-52.-Exhaust gas temperature indicating system.

parallel. The harness mounts on the turbine frame aft of the turbine rotor.

FUEL FLOW SYSTEMS

Fuel flow indicating systems provide a continuous indication of the rate of fuel delivery to the engine. The rate of flow is in pounds per hour. In some systems, the indicator also shows the amount of fuel remaining in the tanks. A typical flowmeter consists of two units—a transmitter and an indicator. The measurements are transmitted electrically to the panel-mounted indicator. Thus, use of electrical transmission ends the need for a direct fuel-filled line from the engine to the instrument panel. This minimizes the chance of fire and reduces mechanical failure rate.

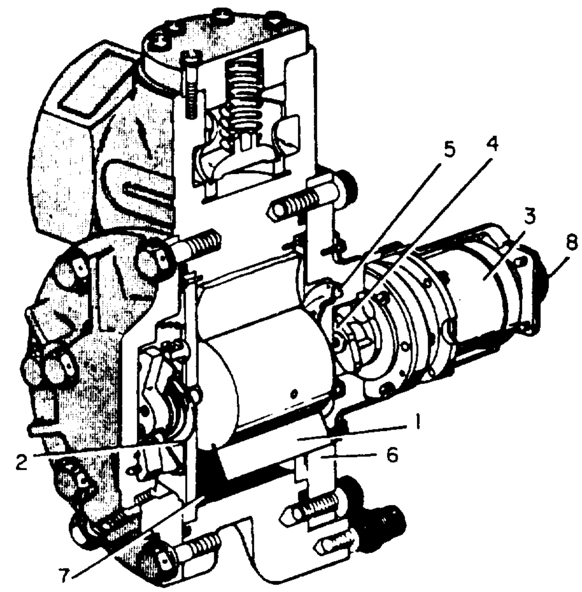
The fuel flowmeter system is quite similar to other synchro systems discussed in Navy Electricity and Electronics Training Series (NEETS) course. The following discussion describes a typical fuel flow indicating system to acquaint you with flowmeters in general. However, you should always refer to the manuals for the particular system you are maintaining.

Fuel Flow Transmitter

Figure 6-53 shows a cutaway view of a fuel flow transmitter. It is a two-in-one unit—a fuel-measuring mechanism (or meter) and a synchro transmitter. You can separate these parts from one another for maintenance purposes, but they join as a single assembly for installation.

The fuel enters the inlet port of the transmitter and flows against the vane (callout 1), causing the vane to swing. The spiral fuel chamber design allows the distance between the vane and chamber wall to become increasingly larger as fuel flow increases. A calibrated hairspring (callout 2) retards the motion of the vane. The vane ceases motion when the forces exerted on it by the hairspring and by the fuel are equal.

The rotor shaft of the synchro transmitter (callout 3) connects to a bar magnet (callout 4). Attached to the vane shaft is a ring magnet (callout 5). The ring magnet moves as the vane shaft moves. The transmitter mounting frame is between the bar magnet and the ring magnet, forming a liquid-tight seal. This is the seal between the fuel-metering section of the mechanism and the synchro. However, the bar magnet moves in unison with the ring magnet because the two magnets are magnetically coupled. The south pole of the ring magnet is opposite the north pole of



1. Vane
2. Hairspring
3. Synchro transmitter
4. Bar magnet assembly
5. Ring magnet assembly
6. Transmitter mounting frame
7. Fuel chamber
8. Electrical connector

Figure 6-53.-Cutaway view of a fuel flow transmitter.

the bar magnet. The two magnets send vane movement, caused by the fuel flow, to the synchro rotor. This action results in a corresponding movement of the rotor. Therefore, the angular displacement of the vane in relation to the fuel chamber housing determines the synchro rotor movement with respect to the stator.

The fuel flow transmitter has a relief valve, which automatically opens and bypasses the instrument when the fuel flow exceeds the capacity of the instrument. At such time, only part of the fuel flows through the metering portion. As the pressure across the instrument falls below the value at which the relief valve opens, the valve closes. This lets the flowmeter again operate normally. The transmitter unit location is in the fuel line between the fuel pump and fuel nozzle.

Fuel Flow Indicator

The fuel flowmeter indicator is located on the instrument panel. It is a remote-indicating instrument. This indicator consists of a synchro

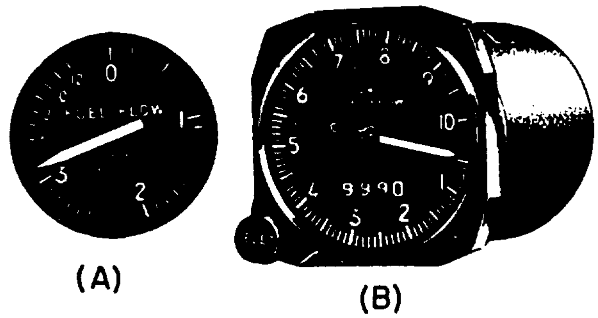


Figure 6-54.-(A) Fuel flow indicator; (B) fuel flow totalizer indicator.

receiver, a step-up gear train, a magnetic drag cup, and a calibrated spring. When fuel flows through the fuel flow transmitter, an electrical signal goes to the indicator receiver. This signal drives the synchro rotor to the proper position. Thus, the indicator pointer shows the rate of fuel flow.

Figure 6-54, view A, shows the face of the single flow indicator. To determine the amount of fuel consummation per hour, multiply the scale reading by 1,000. Figure 6-55 shows a schematic diagram of the single fuel flow indicator.

The following discussion uses the F-14 system as an example of a fuel flow system. Other aircraft fuel flow systems operate in a similar way.

The fuel flow transmitter consists of a synchronous motor, drum assembly, impeller assembly, spiral spring, and pickup coils. The transmitter housing has fuel inlet and outlet attachment flanges. The drum and impeller assemblies have two miniature permanent magnets, 180 degrees apart. The motor runs at a constant 120 RPM. The motor connects through a shaft to the drum assembly.

The impeller assembly rotates over the motor-drum shaft and mechanically couples to the drum with the spiral spring. The pickup coils, one for each assembly, are in line with the drum and impeller assembly magnets. As the motor rotates the drum, the impeller also rotates. When there is no fuel flow, the magnets of the drum and impeller assemblies align. As they pass their respective coil, they generate simultaneous output signals.

As fuel flow starts and increases through the transmitter housing, it goes through straightening vanes. These vanes eliminate the swirling motion of fuel. The fuel then passes through straight drilled passages of the rotating impeller. As fuel flow increases through the impeller, a proportional drag factor, or resistance to rotation, is imposed on the impeller assembly. This resistance causes the spring to deflect, equalizing the loading. The impeller magnets then deflect out of alignment. This action produces a later signal than that of the drum magnets and coil. Thus, an increased time span between signals of the rotating assemblies becomes relative to increased fuel flow.

The fuel rate-of-flow power supply consists of a power transformer and power supply, two signal-conditioning channels, and a motor driver. The transformer receives 115 volts ac, 400 Hz, and it feeds the power supply. The power supply provides low dc voltage to operate the

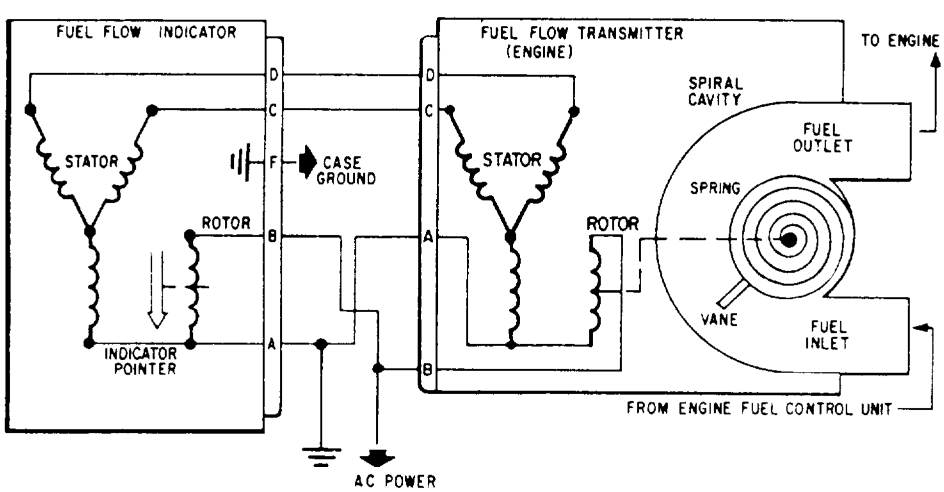


Figure 6-55.-Single fuel flow indicating system.

motor-driven logic and signal-conditioning channels. Using a stepping signal to drive control logic, the motor driver controls positive and negative 8-Hz ac signals between phases of both fuel rate-of-flow transmitter motors.

The signal-conditioning channel for each engine system receives pulses from the coils of its transmitter. A pulse shaper, for each channel, converts the time between transmitter drum and impeller coil pulses into a rectangular pulsewidth signal. An averaging filter processes this converted signal, which provides a low-ripple dc signal input to the fuel rate-of-flow indicator. The size (0 to 5 volts dc) of this signal is proportional to flow rate. A test circuit permits testing the power supply. A tap-off motor, phases A and B from the motor driver, routes an 8-hertz signal through an external test switch to the signal-conditioning channels for processing. The results of the processed signal are displayed on the indicator.

The fuel rate-of-flow indicator, a vertical scale indicator, displays rate of fuel flow for each engine on parallel scales. The scales are from 0 to 13. The scale reading, multiplied by 1,000, show the rate (pounds per hour) at which the engine is consuming fuel. The upper left and right OFF failure flags show a loss of power, or signal to the indicator. The indicator has two separate channels, one for each engine. The channels include a control transformer servo amplifier, servomotor, gears, and sprockets. The indicator channels receive 115 volts of ac for signal processing. An input of 0 to 5 volts dc from the fuel rate-of-flow power supply produces an output. This output is from the control transformer rotor winding to the servo amplifier.

The servo amplifier modifies the signal to the proper impedance and power level to drive the channel servomotor. Shaft rotation controls transformer output, and the rotation reduces transformer output voltage. When the output is null, the motor, gear train, and sprockets come to rest at a rate equivalent to the input.

The test selector switch on the MASTER TEST panel tests the indicators. The self-test circuit in the indicators disconnect the fuel rate-of-flow transmitter input circuits. It then connects to an appropriate test signal within the two indicator channels. The channel circuitry processes the test signal and drives the indicator tapes to indicate 4,200 to 4,400 pounds per hour.

Fuel Flow Totalizing Systems

Figure 6-54. view B, shows the indicator of a fuel flow totalizing system. The pointer of this instrument usually shows the combined rate of fuel flow into two or more engines. Also, if only one engine is operating, the pointer gives a true indication. A continuous reading of the pounds of fuel remaining in the aircraft fuel cells appears in the small window. Before starting the engines, you set the total amount of fuel in the aircraft on the pounds-fuel-remaining indicator by using the reset knob on the front of the instrument. As soon as the engines are running, the fuel flow pointer shows the rate of fuel consummation. The fuel remaining indicator starts counting toward zero, giving a continuous reading of fuel remaining in the cells. Numbers rotate past the window like those of the mileage indicator of an automobile speedometer.

The entire fuel flow totalizing system consists of two or more fuel flow transmitters, an amplifier, and an indicator.

FUEL FLOW TRANSMITTERS. —The fuel flow transmitters are almost identical to those already discussed in the single system. In the fuel flow totalizing system, the transmitters connect electrically, so their combined signals go into the fuel flow amplifier as one.

FUEL FLOW AMPLIFIER. —The fuel flow amplifier is an electronic device that supplies power of the proper size and phasing to drive the indicator. The speed at which the indicator motor runs depends on the transmitter signal going into the amplifier.

FUEL FLOW TOTALIZER INDICATOR. — The fuel flow totalizer indicator contains a two-phase variable speed induction motor. This motor travels in one direction only; however, the speed varies. As the rate of fuel consumption increases, more and more power goes to the indicator motor. This causes the speed of the motor to increase proportionally to the rate of fuel consumption. The motor turns a magnetic drum-and-cup linkage (similar to the tachometer indicator hysteresis cup), which causes pointer deflection. The deflection is proportional to the motor speed, and thus proportional to the rate of fuel consumption. At the same time, a linkage having a friction clutch drives the pounds-fuel-remaining indicator. The clutch is disengaged when using the reset knob to set the reading on the pounds-fuel-remaining indicator.

OIL PRESSURE SYSTEM

Oil pressure instruments show that oil is or is not circulating under proper pressure. An oil pressure drop warns of impending engine failure due to lack of oil, oil pump failure, or broken lines. Oil pressure shows on an engine gauge unit (fig. 6-56). This unit consists of three separate gauges in a single case—oil pressure, fuel pressure, and oil temperature. The gauge has a Bourdon tube mechanism for measuring fluid under pressure (fig. 6-57). The instrument's oil pressure range is from 0 to 200 PSI. You read the scale in graduations of 10 PSI. There is a single connection on the back of the case leading directly into the Bourdon tube.

In some aircraft, the oil pressure gauge is a separate instrument (fig. 6-58). This instrument operates on the Bourdon tube principle.

The synchro system is another method of measuring oil under pressure. This type of oil pressure system is used on most modern aircraft. Essentially, it is a method of directly measuring engine oil pressure. After taking the measurements, they go electrically from the point of measurement to the synchro indicator on the instrument panel. The synchro system ends the need for direct pressure lines from the engine to the instrument panel. It also reduces the chances

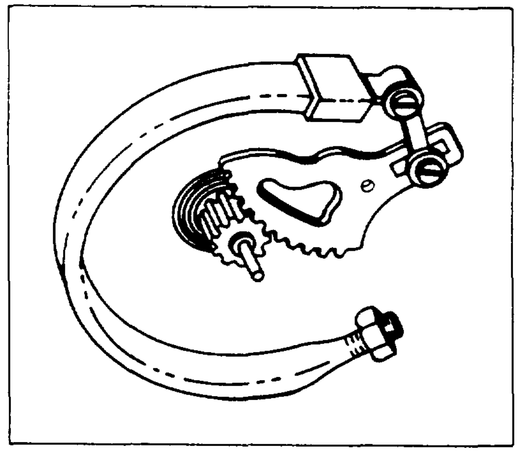


Figure 6-57.-Bourdon tube oil pressure gauge.

of fire, loss of oil or fuel, and mechanical difficulties.

The synchro system consists of a synchro indicator and transmitter. The synchro transmitter consists of a permanent magnet moving within a stator. The stator is a circular core of magnetic material wrapped with a single, continuous toroidal winding. Taps divide the winding into three sections. Voltages in each of the sections vary with the position of the permanent magnet. As the magnet moves, the ratio between the three signal voltages varies accordingly.

Look at figure 6-59. Here, you can see the transmitter and indicator connect in parallel. When excited by the same fundamental source, the signal voltages in corresponding sections of the two stators are equal and balanced. The signal voltages remain equal and balanced as long as the

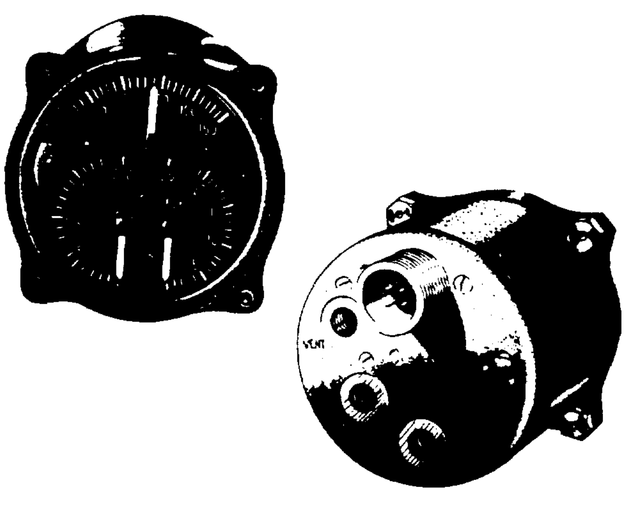


Figure 6-56.-Engine gauge unit.

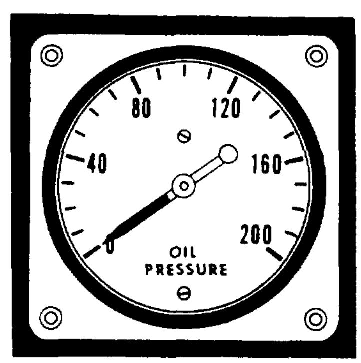


Figure 6-58.-Bourdon tube oil pressure instrument.

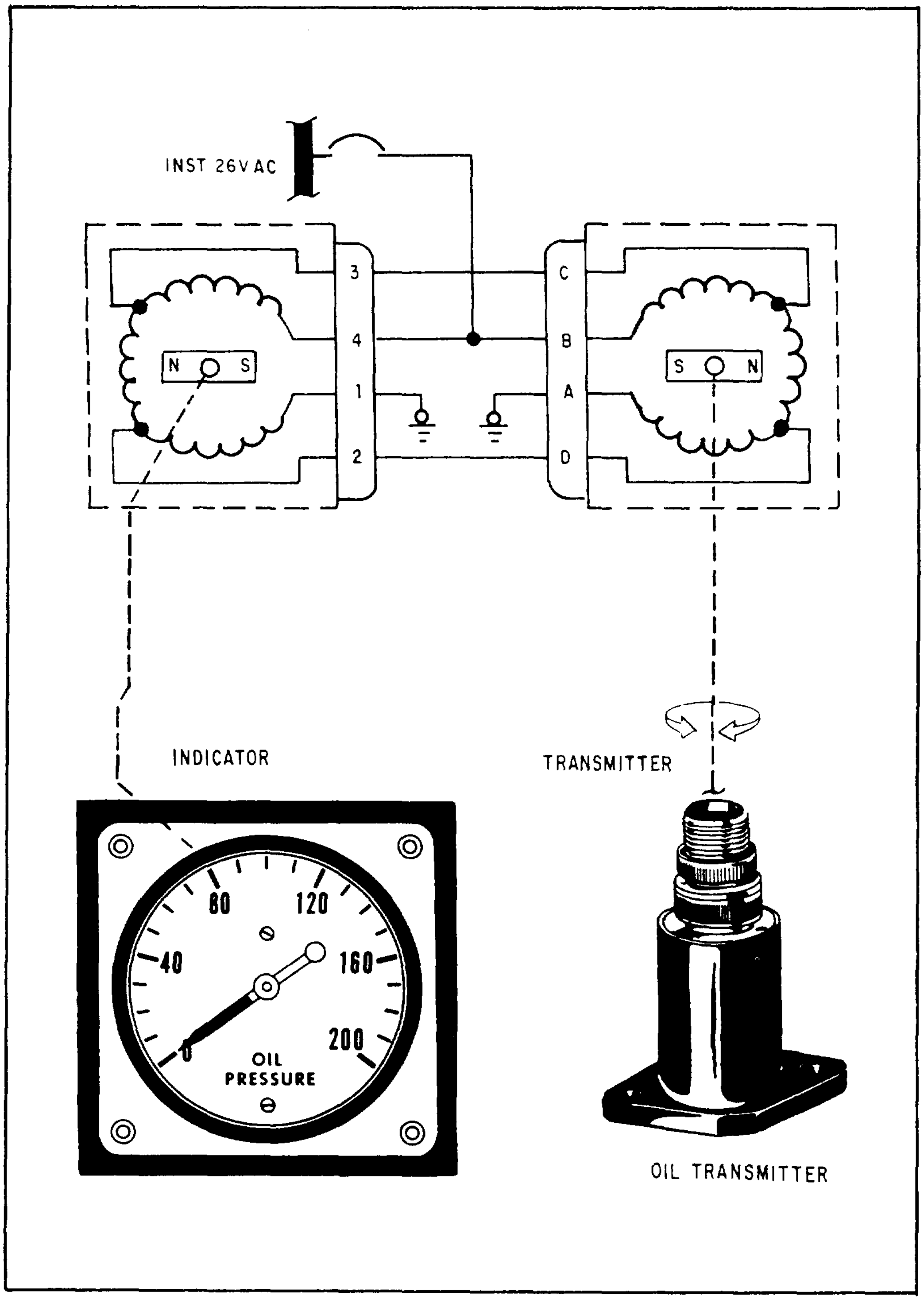


Figure 6-59.-Schematic of a synchro oil pressure indicating system.

magnets are in the same relative positions. However, if the transmitter magnet moves to a new position, the voltages in the three sections of the transmitter are no longer the same. They now differ from the voltages in the corresponding sections of the indicator. Because of this imbalance, current flows between the two units. This circulating current sets up additional magnetic lines of force in each stator, which establishes a magnetic force between the stator and the magnet of each unit. Since the indicator magnet is free to turn, it moves to a position corresponding to the position of the transmitter magnet. The indicator magnet connects to the indicator pointer by a shaft to provide a visual indication. The electrical leads between the transmitter and the indicator may be any reasonable length without noticeable effect on the indication.

FUEL PRESSURE SYSTEM

The fuel pressure gauge provides a check on the operation of the fuel pump and fuel pressure relief valve. The pilot must check the gauges often to ensure that the fuel pressure is correct. With the fuel pressure correct, the engines have a full range of power at all altitudes. The fuel pressure gauge operates on the same principle as the oil pressure gauge.

Fuel pressure indicators may be located in the cockpit by means of synchro systems. This type of system is the same for both fuel and oil pressure indications. However, the oil system transmitter is **not** interchangeable with the fuel system transmitter.

Look at figure 6-60. This synchro system is used to show fuel pressure. A change in fuel pressure introduced into the synchro transmitter causes an electrical signal to go through the interconnecting wiring to the synchro receiver. This signal moves the receiver rotor and the indicator pointer a distance proportional to the amount of pressure exerted by the fuel.

NOTE: You can see in figure 6-60 that the transmitter has a vent to the atmosphere. This allows the transmitter to accurately measure the differential between pump pressure and atmospheric pressure.

OIL TEMPERATURE SYSTEM

Two types of oil temperature gauges are available for use in the engine gauge unit. One unit consists of an electrical resistance type of oil thermometer, supplied with electrical current by the aircraft dc power system. The other unit, the capillary oil thermometer, is a vapor pressure

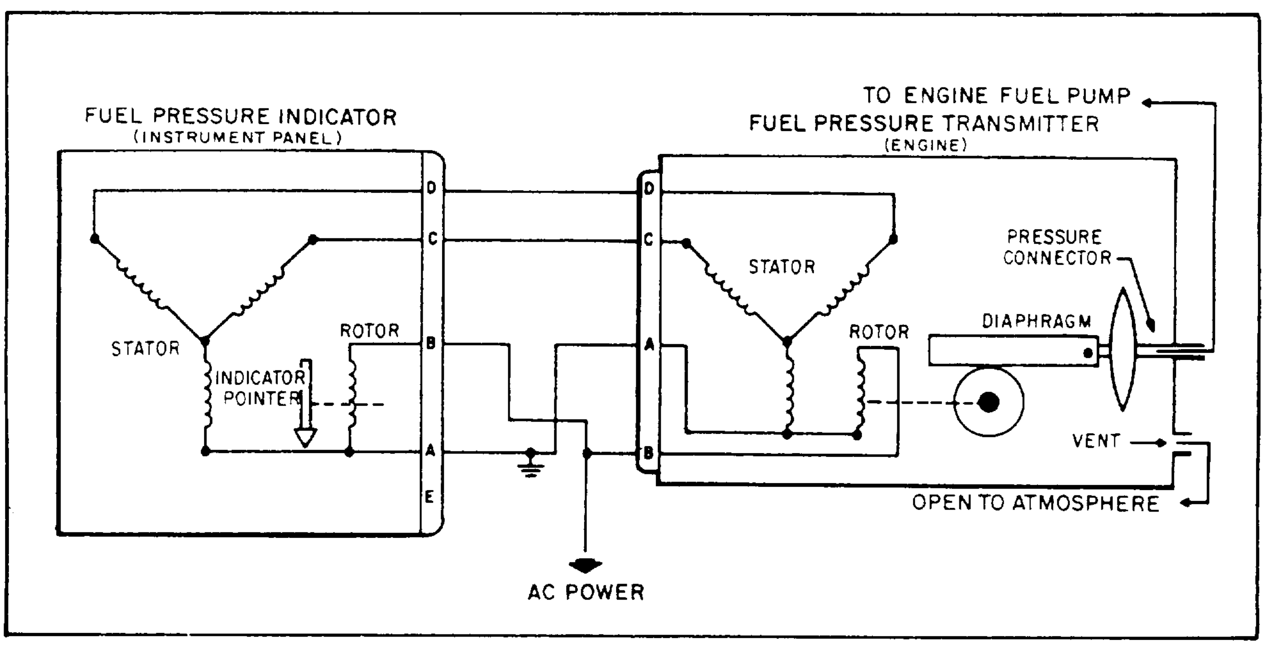


Figure 6-60.-Fuel pressure synchro system.

thermometer. It consists of a bulb connected by a capillary tube to a Bourdon tube and a multiplying mechanism connected to a pointer. The pointer shows the oil temperature on a dial.

EXAUST NOZZLE INDICATING SYSTEM

The exhaust nozzle position indicating system shows the pilot engine variable exhaust nozzle position. This, in turn, provides a measure of percentage of afterburning, since constant temperatures are held throughout the afterburner range.

Each engine has a separate but identical nozzle position indicating system. Each system consists of a transmitter potentiometer in the nozzle area control unit and an indicator on the main instrument panel. Power for the system is from the essential 28-volt dc bus.

Each indicator is a hermetically sealed unit containing a single receptacle for a mating plug electrical connection. The instrument scale ranges from OPEN to CLOSE, with markings at the 1/4, 1/2, and 3/4 positions (fig. 6-61).

The transmitter potentiometer consists of a resistance winding with a movable brush. This brush connects to a linkage within the nozzle area control and moves in relation to the variable exhaust nozzle. Current in the resistance winding is picked up by the movable rush, and it varies according to the location of the brush. Then, this signal current goes to one of the indicator field coils.

The indicator contains two field coils and a rotor. The polarized rotor mounts on a free-moving shaft. The shaft is located in the center of the magnetic field created by the two coils. One coil connects to the transmitter potentiometer in the nozzle area control. The second receives a constant current to give smooth indicator operation. The rotor aligns itself with the magnetic field. The magnetic field varies as the signal received from the potentiometer varies. A pointer mounted on the rotor shaft shows rotor position in relation to nozzle position.

TORQUEMETER SYSTEMS

The electric torquemeter system in turboprop aircraft measures the torque (horsepower) produced by the engine at the extension shaft. Each system consists of a transmitter (part of the engine extension shaft), a phase detector, and an

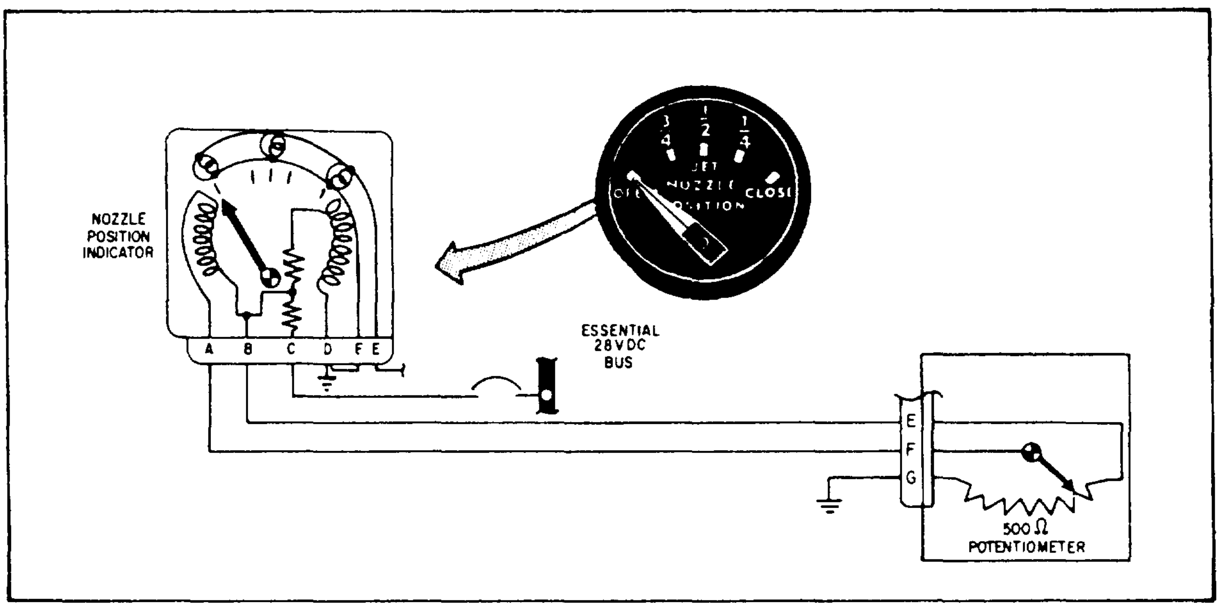
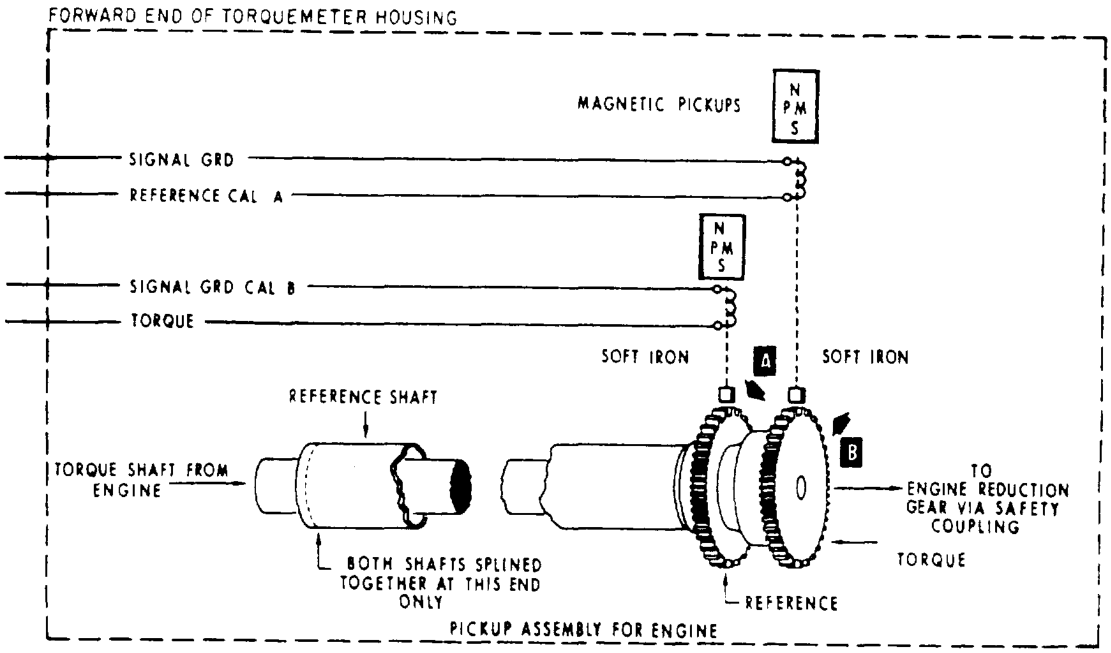


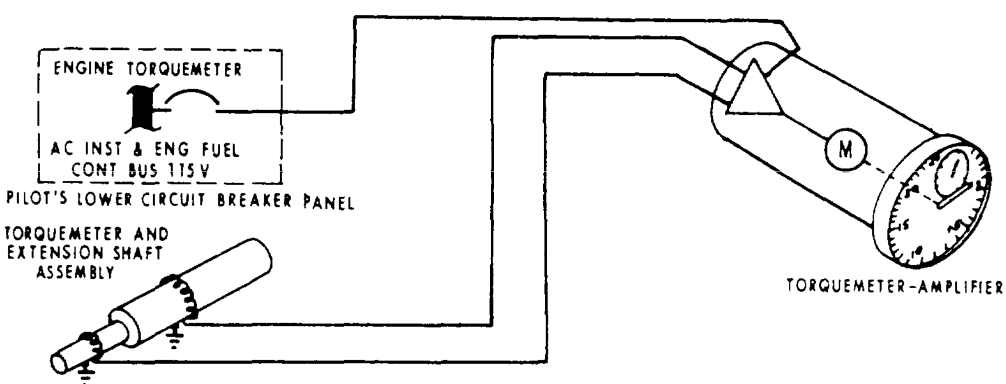
Figure 6-61.-Exhaust nozzle position indicating system.

indicator (fig. 6-62). The system measures the torsional deflection (twist) of the extension shaft as it sends power from the engine to the propeller. Magnetic pickups detect and measure this deflection electronically. The indicator registers the amount of deflection in shaft horsepower.

The extension shaft of the engine consists of two concentric shafts. The inner shaft is the power transmitting shaft. The outer shaft attaches to the inner shaft at the rear end. Toothed flanges on the front end of each shaft rotate in the field of magnetic pickups. When the engine is running, the teeth on the flange of the driving (inner) shaft move in relation to the teeth on the flange of the outer reference shaft, The displacement between the shafts is proportional to the torque load on the driving shaft. This displacement causes a phase displacement between the pickup signals. The phase angle of the resultant signal is linearly proportional to the shaft deflection. The phase detector and amplifier in the indicator converts the signal to current. The current goes to a servomotor, which drives the indicator pointers. The servomotor also drives the rotor of a synchro control transformer in the indicator. The synchro control transformer balances the synchro system when the pointer registers the measured torque.



(A)



(B)

Figure 6-62.-Torquemeter system: (A) pickup assembly; (B) indicating system.

REVIEW SUBSET NUMBER 2

Q1. What tach generator output is proportional to the engine speed?

Q2. When there is an open in the voltage supply circuit, what will the galvanometer of a Wheatstone bridge read?

Q3. In a radiometer-type temperature indicator, what component determines needle position?

Q4. What is a thermocouple?

Q5. In the fuel flow transmitter, what component senses vane movement and sends it to the synchro motor?

Q6. Name two ways of indicating oil pressure.

Q7. In the torquemeter system, what shaft is the reference shaft?

MISCELLANEOUS INSTRUMENT SYSTEMS

Learning Objective: *Recognize the operating principles and characteristics of miscellaneous aircraft instrument systems, including fuel quantity, hydraulic pressure, and position indicating systems.*

There is another group of instruments found on most Navy aircraft that does not come under flight instruments or engine instruments. It is a group usually referred to as *miscellaneous instruments.* This group consists of instrumentation for such systems as fuel, hydraulics, flap and gear positions, and cabin pressure.

CAPACITIVE-TYPE FUEL QUANTITY INDICATING SYSTEM

The capacitive-type fuel quantity system electronically measures fuel weight (not gallons) of the fuel in the tanks of an aircraft. The main units of the system are an indicator, tank probes, a bridge unit, and an amplifier. In some systems, the bridge unit and amplifier are one unit mounted in the same box. In the design of newer systems, the bridge and a transistorized amplifier are contained in the indicator.

Fuel Quantity Indicator

The fuel quantity indicator (fig. 6-63) is a hermetically sealed, self-balancing, motor-driven instrument. It contains a motor, pointer assembly,

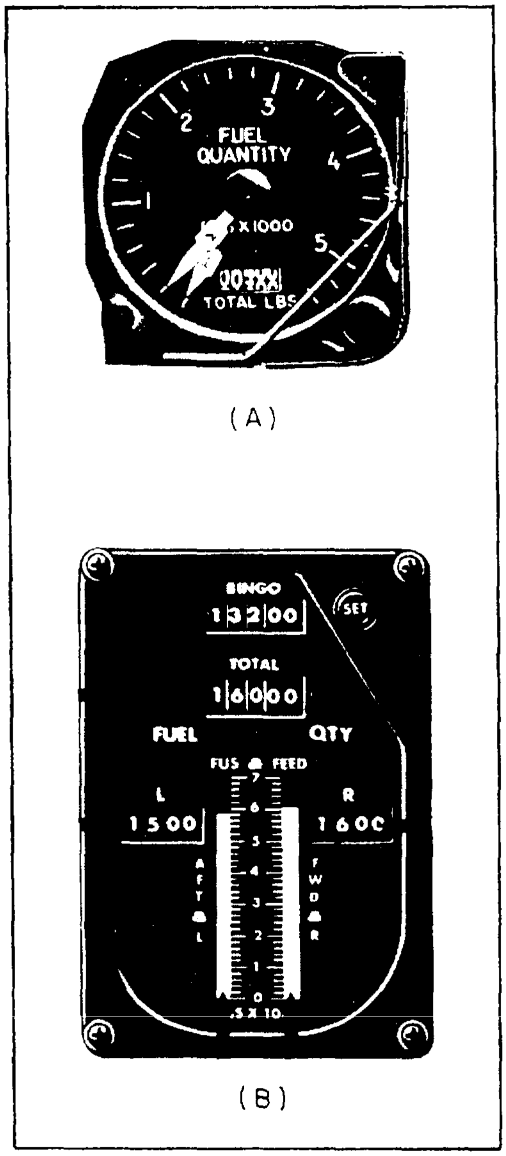


Figure 6-63.—Fuel quantity indicator: (A) Radial; (B) vertical scale.

transistorized amplifier, bridge circuit, and adjustment potentiometers. As the quantity of fuel in the tank changes, the capacitance value of the tank probe changes proportionately. The tank probe is one arm of a capacitance bridge circuit. The change of capacitance of the probe unbalances the bridge circuit of the amplifier power unit. The unbalance in the circuit causes an error voltage. The amplified error voltage goes to the motor. The motor drives the pointer mechanism and the rebalancing potentiometers to restore the bridge to a balanced condition. The direction of change in the capacitance of the probe unit determines the phase of the error voltage. The phase determines the direction of motor rotation and, therefore, the direction of pointer movement.

Tank Probe

A tank probe and a simplified version of a tank circuit are shown in figures 6-64 and 6-65. The capacitance of a capacitor depends upon three factors—the area of the plates (A), the distance between the plates (d), and the dielectric constant (K) of the material between the plates, or

$$C = \frac{KA}{d}$$

where A = the area of the plates,

d = the distance between the plates, and

K = the dielectric constant of the materials between the plates.

The only variable factor in the tank probe is the dielectric of the material between the plates. When the tank is full, the dielectric material is all fuel. Its dielectric constant is about 2.07 at 0°C, compared to a dielectric constant of 1 for air. When the tank is empty, there is only air between the plates, and capacitance is less. Any change in fuel quantity between full and empty produces a corresponding change in capacitance.

System Operation

Look at figure 6-66, which shows a simplified capacitance bridge circuit. The fuel tank capacitor and a fixed reference capacitor connect in series across a transformer secondary winding. A voltmeter connects from the exact center of the transformer winding to a point between the two capacitors. If the two capacitance are equal, the voltage drops across them are equal. Therefore, the voltage between the center tap and point P is zero. As the fuel quantity increases, the capacitance of the tank unit increases. This increase causes more current to flow in the tank unit leg of the bridge circuit. A voltage, which is in phase with the voltage applied to the transformer, now exists. As the quantity of fuel in the tank decreases, there is less current in the bridge tank unit leg. The voltage across the

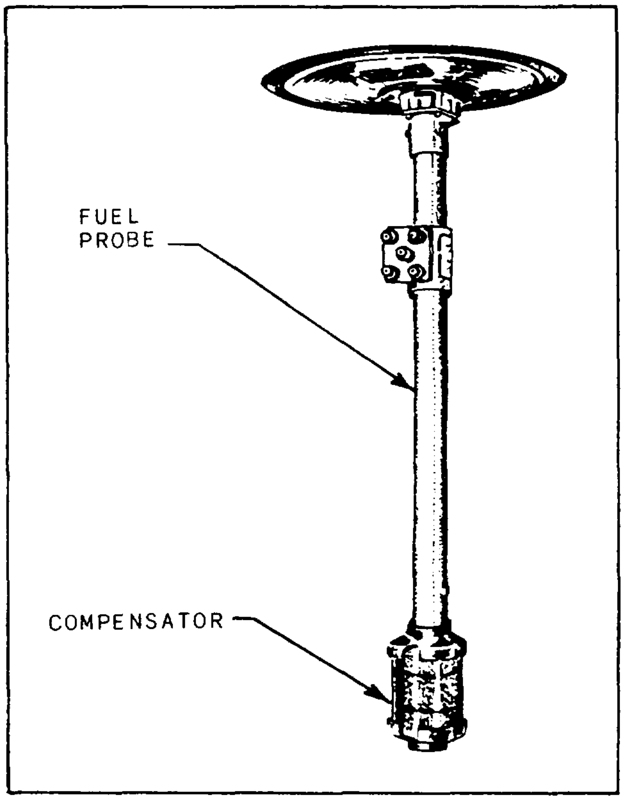


Figure 6-64.-Fuel quantity transmitter.

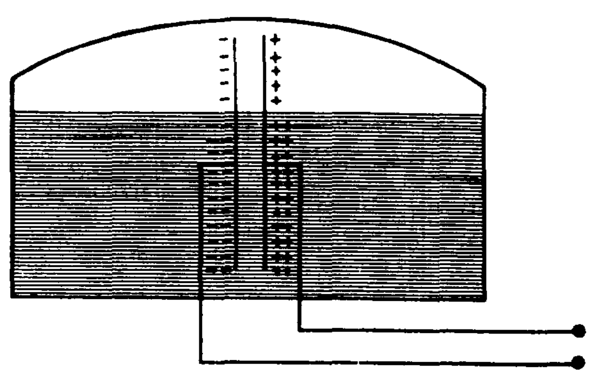


Figure 6-65.-Simplified tank circuit.

voltmeter is now out of phase with the voltage applied to the transformer.

In an actual capacitive-type fuel gauge, the input to a two-stage amplifier takes the place of the voltmeter. It amplifies the signal resulting from an imbalance in the bridge circuit. The output of the amplifier energizes a winding of the two-phase indicator motor. The other motor winding is the line phase winding. It receives constant power from the same voltage that powers the transformer in the bridge circuit. However, a series capacitor shifts its phase by 90 degrees. As a result, the indicator motor is phase sensitive. This means that the indicator motor will operate in either direction, depending on whether the tank unit capacitance is increasing or decreasing.

Look at figure 6-67. As the tank unit capacitance increases or decreases, it is necessary to maintain the bridge circuit in a balanced condition. This prevents the indicator motor from

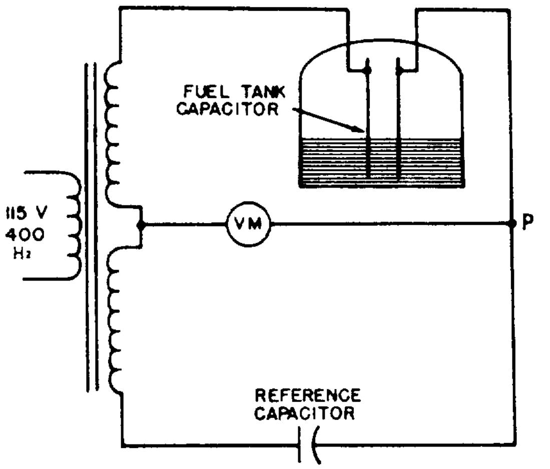


Figure 6-66.-Simplified capacitance bridge circuit.

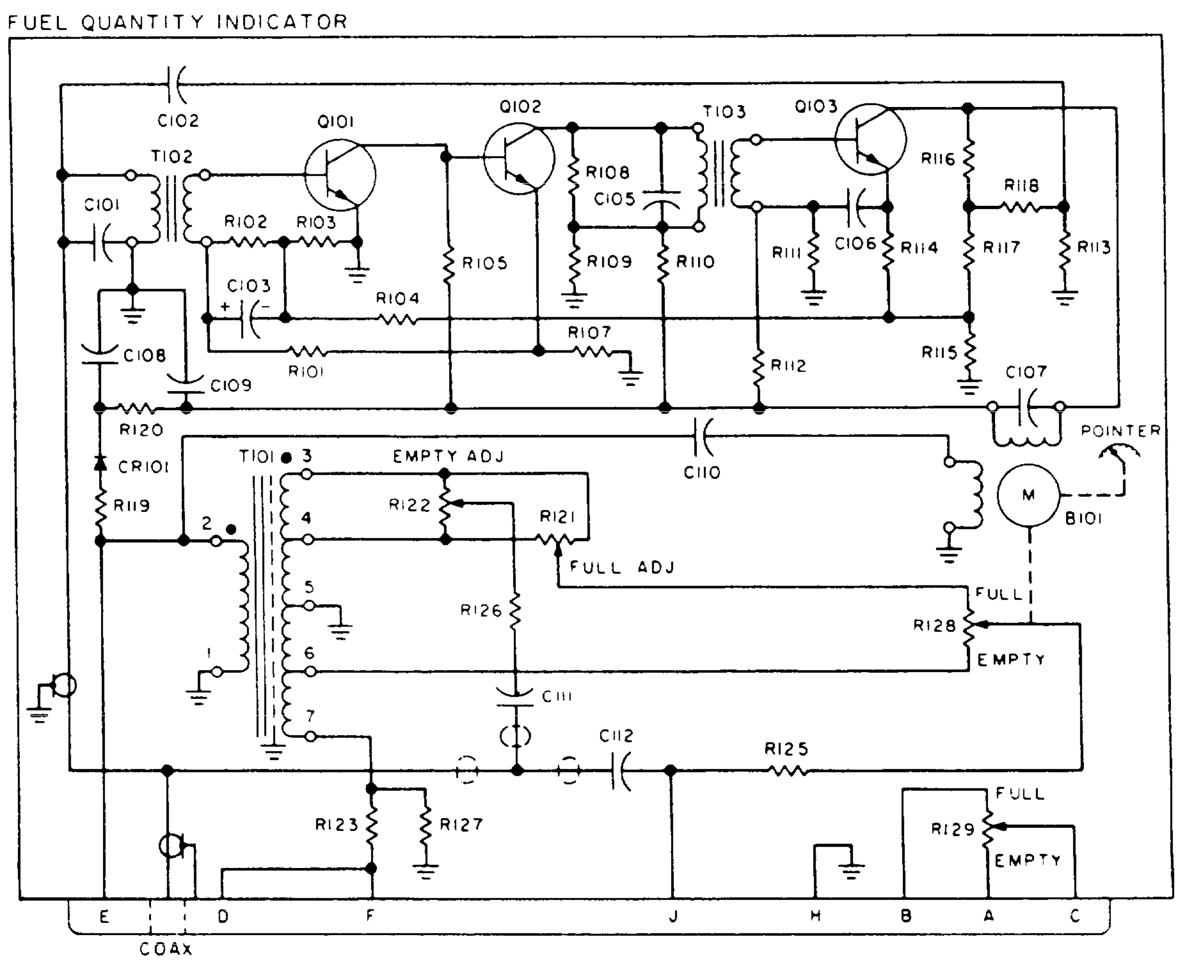


Figure 6-67.-Fuel quantity indicator schematic.

continually changing the position of the indicating needle. To do this, a balancing potentiometer (R128) connects across part of the transformer secondary. The indicator motor drives this potentiometer wiper in the direction necessary to maintain a continuous balance in the bridge.

The circuit shown in figure 6-67 is a self-balancing bridge circuit. An empty-calibrating potentiometer and a full-calibrating potentiometer connect across portions of the transformer secondary winding. You can adjust these potentiometers so the bridge voltage balances over the empty-to-full capacitance range of a specific system.

A test switch (not shown) unbalances the bridge circuit momentarily when checking the operation of the system. When the switch actuates, pin F connects to ground, unbalancing the circuit. As a result, the indicator drives toward the empty end of the dial. Opening the switch should restore the bridge to balance and return the indicator pointer to its original position. This proves that the system is operating correctly.

In installations where the indicator shows the contents of one tank, and the tank is fairly symmetrical, one probe is sufficient. However, for increased accuracy in peculiarly shaped fuel tanks, use two or more tank units in parallel. This configuration minimizes the effects of changes in aircraft attitude and sloshing of fuel in the tanks.

There are two classes of tank units (fig. 6-68) used in a typical capacitance fuel quantity measuring system—noncharacterized and characterized.

Noncharacterized tank units are variable capacitors, vertically mounted in the fuel cell. As the fuel level changes, the capacitance of the tank unit changes. This change in capacitance is uniform the entire length of the tank unit.

Characterized tank units are similar in construction and mounting to the noncharacterized tank units. As the fuel level changes, the capacitance of the tank unit changes. This change in capacitance is NOT uniform the entire length of the tank unit.

Since neither electrode of the tank unit goes to ground, and one lead to the amplifier is shielded, capacitance to ground does not enter into the circuit. Therefore, the length of the tank unit leads does not affect the accuracy of the system.

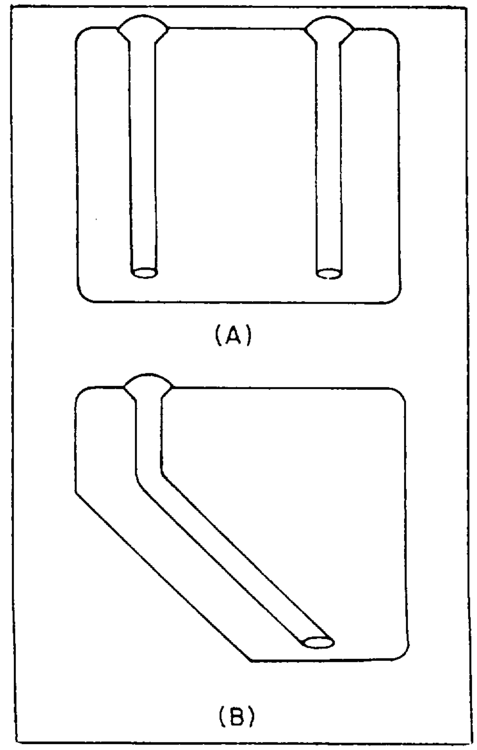


Figure 6-68.-Fuel quantity tank units: (A) Noncharacterized; (B) Characterized.

FUEL CHARACTERISTICS. —The characteristics of fuel are such that the dielectric constant and density deviate because of temperature change. Also, the variable factor in the fuel composition changes the dielectric constant and density. The weight by volume of aircraft fuel depends on its density, which, in turn, depends on its temperature. As the temperature of the fuel goes down, the density increases. As the temperature of the fuel goes up, the density decreases. Any change in the dielectric constant or density of the fuel affects the movement of the indicator pointer. For example, assume that the indicating system is at balance with the tank unit immersed to a given depth. The fuel it is immersed in has the density and dielectric constant of the fuel for which the system is calibrated. The indicator pointer will then reflect the correct amount of fuel in terms of pounds. Then, the tanks are drained and then refilled to the same level. This time the fuel has a greater density and higher dielectric constant, which causes the pointer to show a greater weight. The new reading is correct **only** if the effect of the changes in density and dielectric constant are proportional.

However, the effect of the increase in dielectric constant is greater than the effect of the increase in density. The results are an incorrect indication. The system reduces this error by varying the capacitance of the reference capacitor in the bridge leg opposite the immersed tank unit.

COMPENSATION. —The reference capacitor is varied by connecting a compensator unit in parallel with it. The compensator, like the tank probe, is a variable capacitor. However, the compensator mounts at the lowest level of fuel so it is completely immersed until the tank is almost dry. Its capacitance depends on the dielectric content of the fuel rather than the quantity. The compensator connects into the common reference leg for both phases of the bridge circuit. This allows it to become a part of the reference capacitance. A change in the dielectric constant of the fuel affects both the tank probe and the compensator capacitance. Therefore, the current change in the tank probe leg of the bridge is counteracted by a similar change in the reference leg of the circuit.

There are various capacitor-type fuel quantity systems that operate on the principle just described. Indicators, tank probes, and power units may differ as to shape, size, and specifications from system to system. For this reason, you should always consult the manufacturer's manuals for specific information on a particular system.

HYDRAULIC PRESSURE INDICATORS

In most naval aircraft, the hydraulic system operates the landing gear, flaps, speed brakes, bomb bay doors, and certain other units. Aircraft hydraulic pressure gauges show either the pressure of the complete system or the pressure of an individual unit in the system. A typical direct reading gauge contains a Bourdon tube and a gear-and-pinion mechanism. The mechanism amplifies and transfers the tube's motion to the pointer. The position of the pointer on the calibrated dial shows the pressure in pounds per square inch.

The pumps supplying pressure for operating the aircraft's hydraulic units are driven by an aircraft engine, an electric motor, or by both. Some installations employ a pressure tank or *accumulator* to maintain a reserve of fluid under hydraulic pressure. In such cases, the pressure gauge registers continuously. With other installations, operating pressure builds up only when needed, and pressure registers on the gauge only during these periods.

The pressures of hydraulic systems vary for different models of aircraft. In older pressure systems, the gauges registered from 0 to 2,000 PSI. With later model aircraft, the pressure ranges have increased. Some aircraft have systems with pressure ranges as high as 4,000 PSI. The trend is away from the direct reading pressure gauge and towards the synchro (electric) type of gauge.

Figure 6-69, view A, shows the hydraulic pressure indicator of a late model naval aircraft. This aircraft has three hydraulic systems. The indicating system shows the No. 1 and No. 2 flight control systems and the utility hydraulic system pressures. The indicating system consists of three remote pressure transmitters, a hydraulic pressure selector switch, and a dual pointer indicator. The system uses 26-volt, 400-hertz, single-phase alternating current from the 26-volt, single-phase bus.

Each hydraulic pressure system line contains a Bourdon tube type of pressure transmitter. Expansion and contraction of the Bourdon tube travels by mechanical linkage to the rotor of the

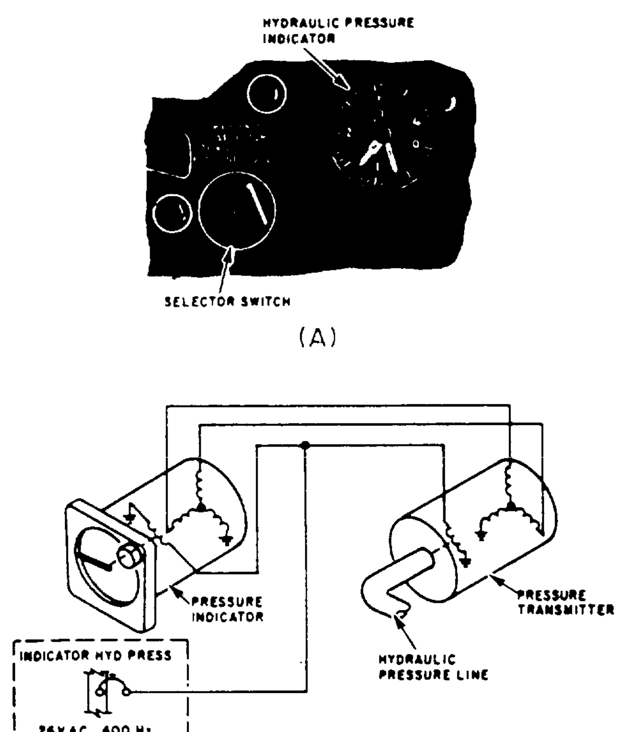


Figure 6-69.-(A) Hydraulic pressure indicator; (B) hydraulic pressure indicating schematic.

transmitter synchro. The pressure transmitter synchro sends an electrical signal to the receiving synchro within the indicator. The receiving synchro's rotor links mechanically to the indicator pointer. The pressure indicator contains two synchros that attach mechanically to two separate pointers. When the HYD PRESS SELECTOR switch is in the No. 1 and No. 2 FLT CONT position, the pointers indicate the pressure of each system. When the HYD PRESS SELECTOR switch is in the UTILITY position, the synchros connect in electrical parallel. This causes the pointers to act as one. This type of arrangement saves instrument panel space.

PNEUMATIC PRESSURE SYSTEMS

The cabin pressure altitude indicator (fig. 6-70) is a sensitive altimeter that measures cabin pressure. The instrument contains a sensitive diaphragm that expands or contracts with changes in cabin pressure. The altitude equivalent of cabin pressure shows on the dial, in increments of 1,000 feet. The range is from 0 to 50,000 feet. An opening in the back of instrument case allows it to sense cabin pressure. You can also use this instrument to reflect pressure suit altitude rather than cabin altitude when wearing a pressure suit.

CAUTION

Remove the cabin pressure altitude indicator if the aircraft is to undergo a cabin pressurization test on the ground. Failure to remove the indicator will result in damage to the instrument from excessive pressure.

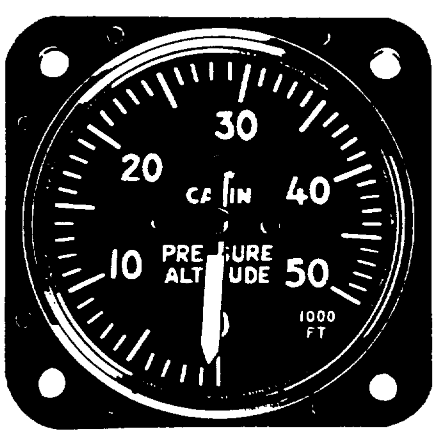


Figure 6-70.-Cabin pressure altitude indicator.

POSITION INDICATING SYSTEM (DC SYNCHRO SYSTEM)

A dc synchro system is a method of showing a remote mechanical condition. Specifically, these systems show movement and position of wing flaps, cowl flaps, oil cooler doors, or similar movable parts of the aircraft.

The system consists of a transmitter, an indicator, and connecting wires. A dc voltage from the aircraft's electrical power system supplies the voltage to operate the system. The transmitter mechanically connects to the movable device that is actually supplying the positioning data. The indicator repeats this information on a properly calibrated scale in the indicator on the instrument panel. Figure 6-71 illustrates a complete three-wire system.

Transmitter

The three-wire system transmitter consists of a continuous circular toroidal resistance winding with two diametrically opposite brushes continuously touching the winding. These brushes apply dc to the winding. The brushes rotate with the movement of the aircraft part to which they are mechanically attached.

Indicator

The three-wire system indicating element consists of an annular core, a permanent magnet rotor, a damping cylinder, and three field coils. The leads between the coils connect to the three taps of the transmitter winding. As voltages at the transmitter taps vary through brush rotation, the distribution of current in the indicator coils varies. This causes the resulting magnetic field of the three coils to position the pointer's permanent-magnet rotor.

A copper cylinder provides a damping effect. The induced eddy currents in this cylinder oppose movement of the rotor. This reduces the tendency of the pointer to oscillate.

Landing Gear

An example of a position indicating system is a wheel position indicator. The system consists of three back-mounted indicators. A series of limit switches in the landing gear control circuit control these indicators. The wheel instrument (fig. 6-72, view A) gives a ready indication of the landing gear position. There are three positions on a drum that move about an axis. One position of the drum has a landing gear wheel symbol. The center position has a diagonal barber pole (black and yellow warning lines). The other position has the word UP. The miniature wheel shows that the wheel is down and locked. The UP indicator shows the wheel is up and locked. The barber pole shows the wheel is somewhere between up and down, or not locked in position.

The position indicator operates through the landing gear limit switches in the wheel wells of the aircraft. When the landing gear moves the contact of S1 (fig. 6-72, view A) to the up position, the indicator shows the wheel is up and locked. When the landing gear moves the contact of S2 to the down position, the indicator shows the landing wheel. This says the wheel is down and locked. Each switch connects to a solenoid in the indicator. As the solenoids energize, the indicator element moves to reveal the position of the aircraft landing gear. When the landing gear is moving, both the up lock and down lock switches release. This opens both circuits to the corresponding indicator, causing the black and yellow barber pole to show. It also causes the warning light in the landing gear handle to illuminate. Figure 6-72, view B, shows a schematic for a complete aircraft landing gear position indicating system.

Flaps

You can show the aircraft flap position in a manner similar to the landing gear. These

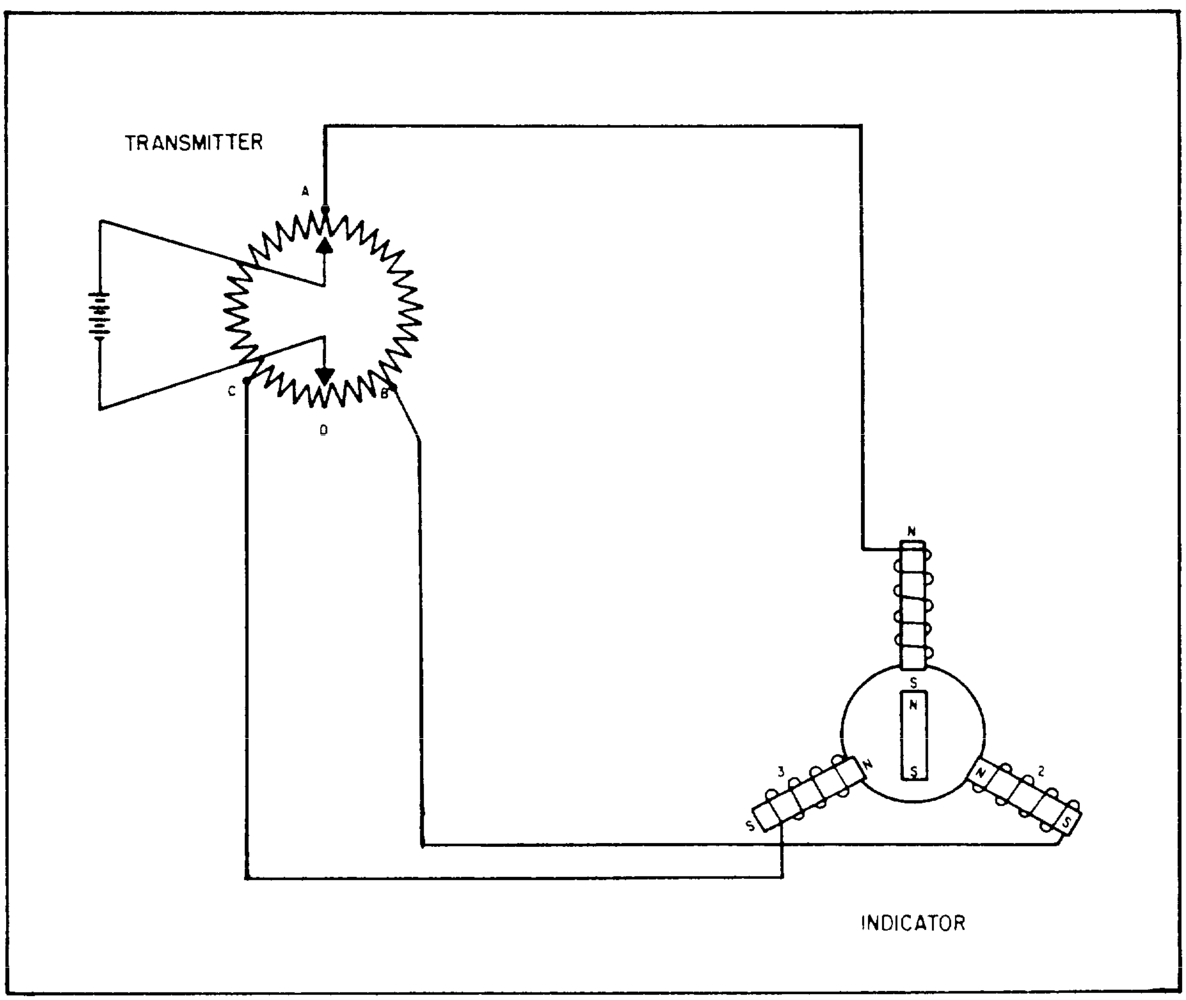


Figure 6-71.-Three-wire dc synchro system.

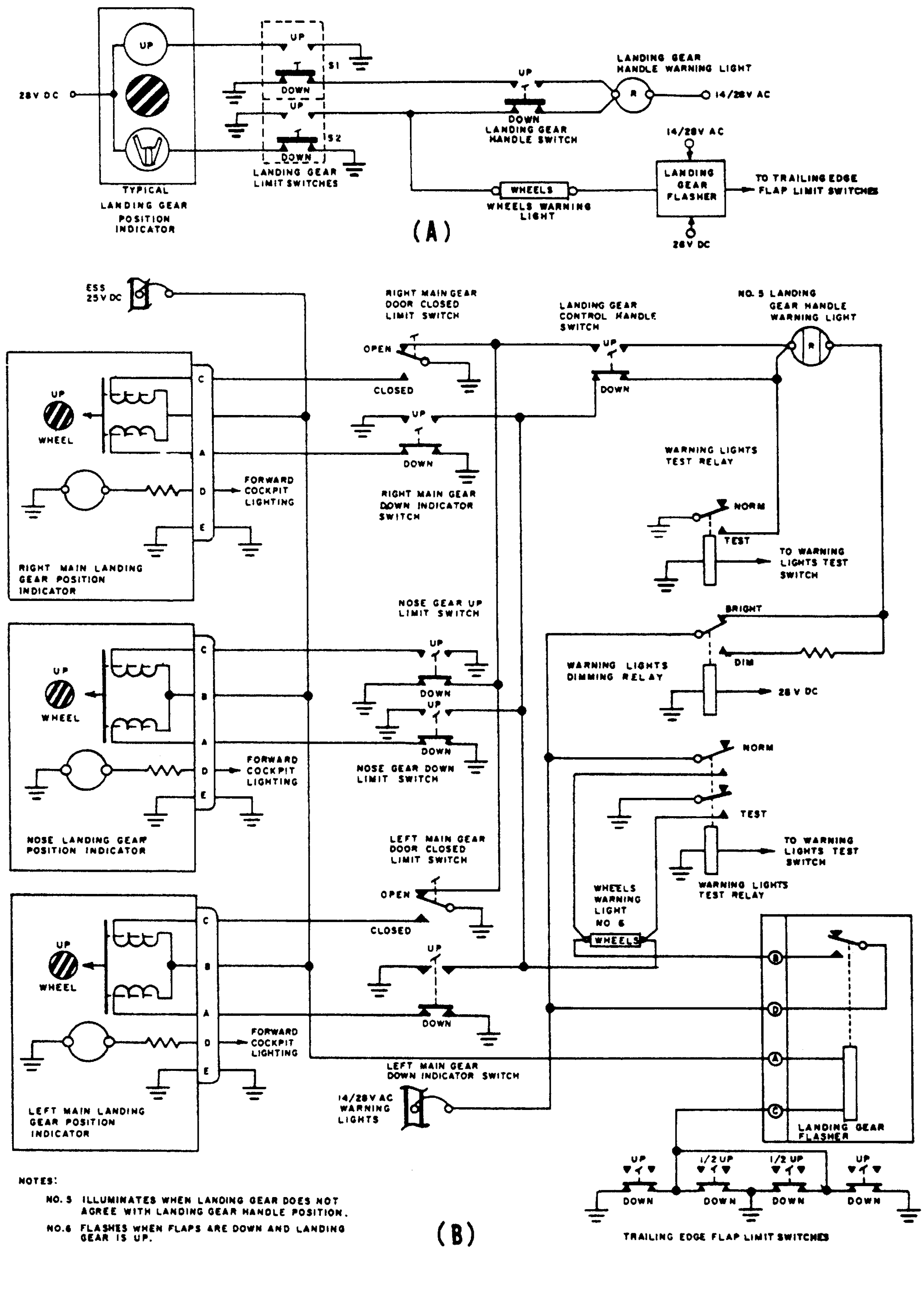


Figure 6-72.—Landing gear position indicating system: (A) typical; (B) system schematic.

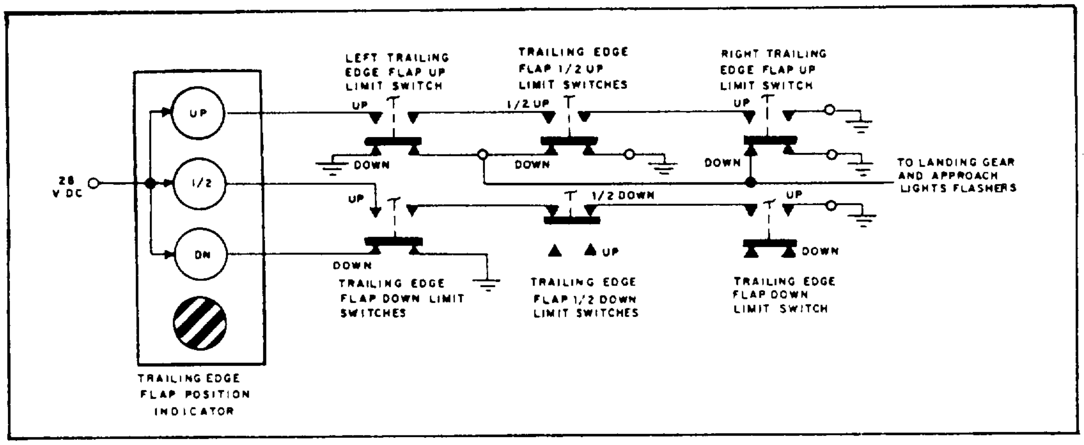


Figure 6-73.-Flap position indicating system.

indicators show UP, 1/2, DN (down), and barber pole. The indicator (fig. 6-73) energizes through limit switches.

Other aircraft show the position of the flaps using the dc synchro system of remote indication. This system consists of a transmitter and an indicator (fig. 6-74). A change in flap position moves the transmitter rotor, and a similar rotor movement occurs in the indicator on the instrument panel. A pointer attached to the indicator rotor shows the amount of travel of the flaps in percent of full extension. The transmitter mounts on the flap drive control unit and actuates by the control actuating mechanism.

Integrated Position Indicator

In many jet aircraft, the design of position indicators combines various systems into one instrument. This instrument is the integrated

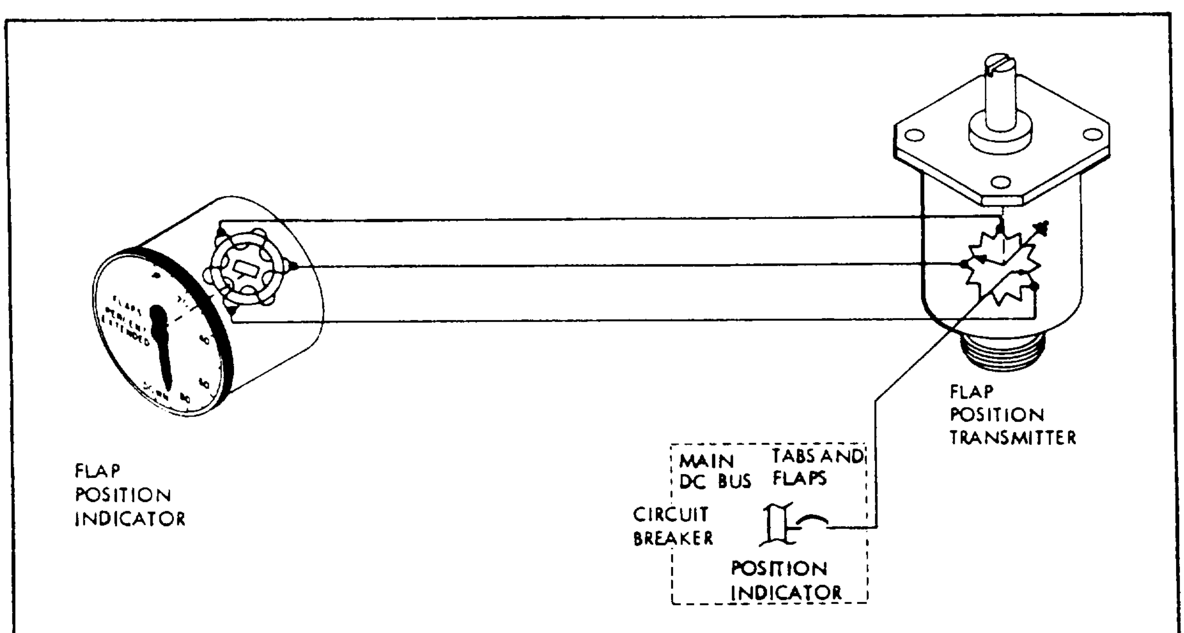


Figure 6-74.-Dc synchro flap position indicating system.

position indicator (IPI) (fig. 6-75). This IPI is from the A-6A *Intruder,* all-weather attack aircraft.

Figure 6-75 shows the IPI in four different configurations—power off, transient, clean, and dirty. The power off and transient positions are self-explanatory. The term *clean* describes an aircraft that has all of its gear up or in, and the aircraft profile is as free of parasitic drag as possible. The term *dirty* means the opposite of clean—that units are protruding out or down, and that resulting drags exist. These are not the only aircraft configurations possible. Most of the individual systems (stabilizer, flaps, speed brakes, etc.) are capable of independent action. All the systems do not function simultaneously as shown in the figure.

Views A and B of figure 6-75 show a transitional period that appears the same as power off—barber poles.

For specific operation and exact position indications of these instruments, refer to the MIM for the specific aircraft. There are many possible sets of indications. Briefly, however, slats usually position in conjunction with flap movements. The stabilizer shows pitch trim control (nose up, nose down). The speed brakes, which are for reducing airspeed, show either as in or out, with no midposition.

REVIEW SUBSET NUMBER 3

Q1. Name the two types of fuel probes.

Q2. Upon what does the density of fuel depend?

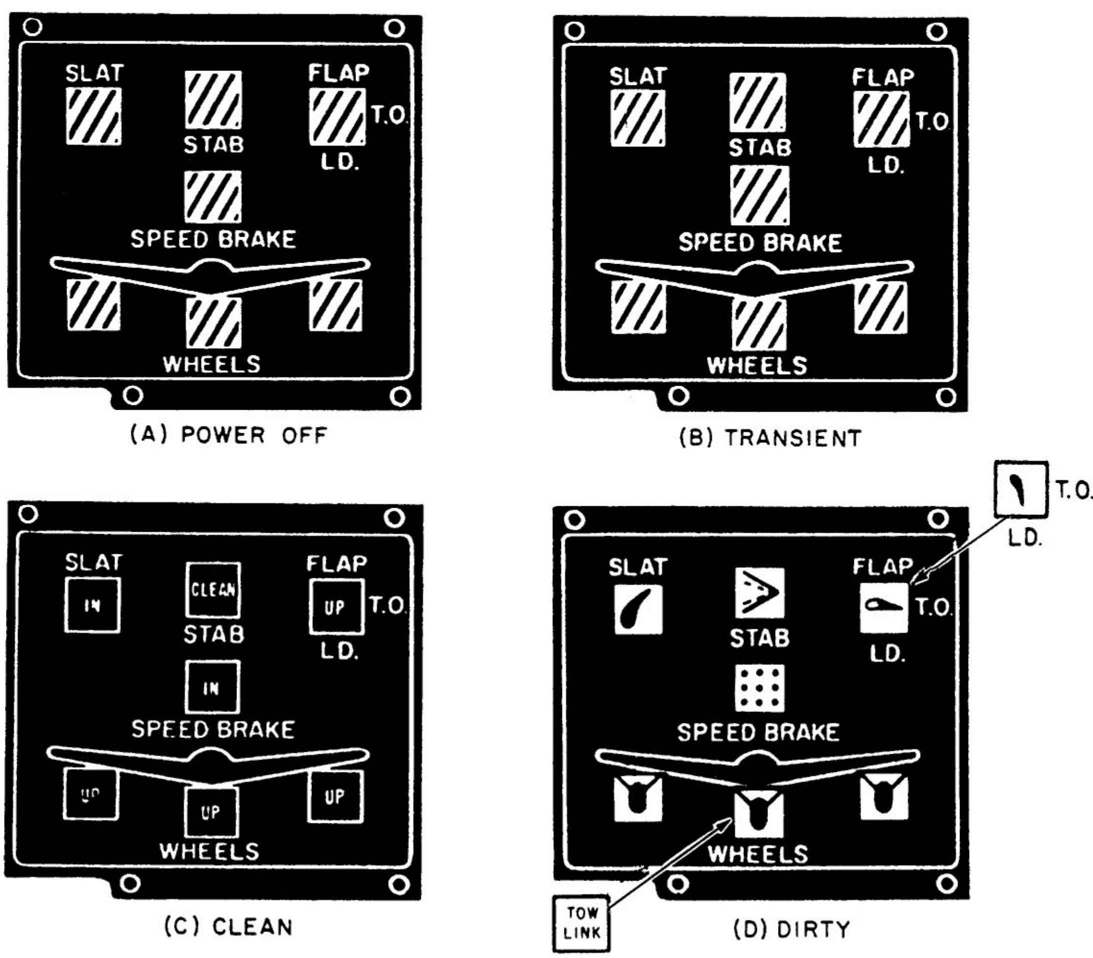


Figure 6-75.—Integrated position indicator (IPI).

Q3. What unit in the fuel quantity system depends on the dielectric content rather than the quantity?

Q4. Name the position indicator that combines various systems into one instrument.

INSTRUMENT SYSTEM MAINTENANCE

Learning Objective: *Relative to aircraft instrument system maintenance, identify the various procedures used to maintain, troubleshoot, test, interchange, protect, ship, and handle aircraft instruments.*

You need a wide variety of skills to maintain aircraft instruments and their associated equipment. It is important for you to check, inspect, and maintain these instruments because the aircraft will not perform properly unless the instruments present reliable information.

Instruments used in high-speed aircraft must give correct indications. The accuracy of instruments such as percent-type tachometers, tail pipe temperature indicators, and gyro attitude indicators require preventive maintenance. The existence of excessive errors in instrument systems directly relates to flight safety and efficient aircraft performance. You cannot assume that borderline instrument errors are acceptable. This is particularly important in high-speed aircraft.

As an AE, you will perform functional tests on aircraft instruments to make sure they give accurate indications. Operational and functional tests take time. When you perform an inspection, you need to know how the particular aircraft instrument operates. Also, you need to know what tools and test equipment you will need. Without these knowledge and skills, you can't properly perform the tasks assigned to your rating.

GENERAL MAINTENANCE

General maintenance of instruments fall into two categories—scheduled and unscheduled maintenance. The material condition of the systems and reliability of instruments are ensured by the day-to-day maintenance routine.

Cases

Instruments come in one of four different kinds of cases.

1. One-piece phenolic composition cases
2. Two-piece phenolic composition cases
3. Nonmagnetic all-metal cases
4. Metallic-shielded cases

The cases come in several different sizes so instruments can be easily removed and maintenance simplified. Special instruments that centain mechanisms too large for adaption to a standard case come in specially designed cases.

Instruments easily mount on the instrument panel with locking devices molded into the instrument flange assembly, by spring locknuts, or mounting clamps. You can easily remove instruments that use a mounting clamp by unscrewing the tension screw in the instrument's lower right corner. You do not have to remove the tension screw to release the tension on the clamp assembly.

Markings and Graduation

Markings on the glass instrument face cover help flight personnel confirm instrument operation to within the prescribed ranges of the equipment. The markings usually consist of a white arc on the outer edges of the instrument glass. They show the normal operating range. A red mark shows the operating limit that should not be exceeded.

WARNING

An index marking of white paint, not over one-sixteenth inch wide by three-sixteenths inch long, is at the bottom center of all instruments color-marked for operating ranges. Place this index mark at the point between the glass and the case. This mark will show whether or not the glass cover moves at any time after marking the ranges. Obtain the proper range markings for the aircraft instruments from the flight manual (NATOPS) for the particular aircraft.

Panels

Instrument panels are made from sheet aluminum alloy, with sufficient strength to resist flexing. The panel is nonmagnetic and painted a dull black to eliminate glare and reflection. Some panels are constructed in two layers, and the instrument faces are flush with the rear panel. The front panel is a reflector panel that mounts over the rear panel with sufficient clearance to supply an indirect lighting effect. The indirect lighting system is not standard for all aircraft. Some aircraft have spotlights, edge lighting, or a combination of these. Some instruments have their own internal lighting system.

Instrument panels are shock-mounted to absorb low-frequency, high-amplitude shocks. The mounts consist of square-plated absorbers in sets of two, each secured to separate brackets. You should inspect the mounts periodically for deterioration; if the rubber is cracked, replace the pair.

As an AE, your instrument maintenance duties include certain inspections that you should conduct at regular intervals. During a daily inspection, you inspect the following Items:

- Check pointers for excessive errors. Some indicators should show existing atmospheric pressure, existing temperatures, etc. Others should indicate zero.
- Check instruments for loose or cracked cover glasses. Replace pitot-static instruments if damaged.
- Check instrument lights for proper operation.
- Check caging and setting knobs for freedom of movement and correct operation.
- Carefully investigate any irregularity the pilot reports.

When performing a phase/calendar inspection, make the following checks:

- Check the mounting of all the instruments and their dependent units for security.
- Check for leaks in instrument cases, lines, and connections.
- Check for dull or marred luminous paint on dial markings and pointers.
- Check the condition of operation and limitation markings. Also, check their condition.
- Check for contact and condition of bonding on instruments.
- Check shock mountings for condition of rubber and security of attachment.
- Check for freedom of motion of all lines and tubing behind the instrument panel. Also, check that they are properly clamped or taped to avoid chafing, and free from moisture, crimps, etc.

After starting the engine, check the instrument pointers for oscillation. Also, check the readings for consistency with engine requirements and speeds. On multiengined aircraft, check the instruments for the various engines against each other. Investigate any inconsistency; it may indicate a faulty engine, component, or instrument.

After you have diagnosed a particular trouble and found the instrument to be faulty, remove and turn it into supply. Remember, the following precautions when removing and installing instruments:

- Handle instruments carefully at all times. Additional damage may result if you abuse the instrument.
- Do not change the location of an indiator.
- Do not force the mounting screws. If the screw is cross-threaded, replace it. Do not draw the screws up too tight against the panel. This may distort the case enough to affect the operation of the instrument, crack the case, or break off the mounting lugs.

- When removing or installing tubing of a pressure-operated instrument, use a backup wrench to avoid twisting the tubing or fitting. Do not exert undue force while tightening the connection.
- Install all electrical plugs hand tight.
- Before connecting an electrical plug to an instrument, check the plug for bent or broken pins.
- Cap the open electrical receptacles, plugs, and hose connections to prevent foreign material from entering the instrument or system.

Lubrication

Most instruments require little or no lubrication in the field. The shafts and bearings or instruments are lubricated before assembly. No further lubrication is necessary until the instrument goes to a NADEP for overhaul. Only specially trained personnel perform overhaul operations for aircraft instruments.

Aircraft Plumbing

Rigid and flexible tubing is extensively used in aircraft. These tubes come in many different sizes. Sizing is usually determined by the outside diameter of the tube and ranges from one-eighth inch to 2 inches in diameter. The type of material and wall thickness determine the amount of pressure that a tube can safely withstand. When replacing or repairing tubing, you should use caution to make sure that you use the proper type. You can find detailed information on tubing and tubing repairs in *Aircraft Structural Hardware,* NAVAIR 01-1A-8.

RIGID TUBING. —Rigid metal tubes are widely used in aircraft for fuel, oil, coolant, oxygen, instrument, and hydraulic and vent lines. Corrosion-resistant steel (stainless steel) and aluminum alloy tubing are the most commonly used tubing. You may identify the basic tube material by either visual inspection or by the alloy designation stamped on the tubing.

Tube fittings connect tubes together and connect tubes to instruments. The shape of the fitting is determined by the particular installation—some are straight, while others have various angles. The fittings secure to the tube by a beaded or flared joint. The beaded or upset joint is used in low-pressure lines. Systems that use low-pressure lines include vacuum, deicer, and oil systems that use rubber hose fittings. All high-pressure and some low-pressure lines use flared joints. Grip dies and flaring or beading tools are used to form flared and beaded joints. When working rigid tubing, you should consult the manuals on the beading and flaring tools to use the tools properly.

If piping and lines are damaged, you should replace them with new parts. To repair tubing, you must determine how much tubing to remove. Some things you need to consider when deciding how much tubing to remove include the following:

- Location of the tubing
- The extent of damage
- The most convenient location for tool manipulation

There is a tendency to overtighten tubing nuts to prevent high-pressure fluid from escaping. Such overtightening may severely damage or completely cut off the tube flare. When you remove a tube, check the flare. If you find a flare with less than 50 percent of its original wall thickness, reject the tube.

In bending tubing, you must be careful to prevent collapsing of the tube at the bend. When making bends for fluid tubing, make sure that you use the proper bending radius. These specifications can be found in NA 01-1A-8.

Bands of paint or strips of tape around the line near each fitting identify each rigid line in the aircraft. There is **at least one** identifying marker in each compartment.

All lines less then 4 inches in diameter have identification tape on them. The exceptions to this are cold lines, hot lines, and lines in an oily environment. Another except ion is any line in engine compartments where there is a chance of the tape going into the engine intake. In these cases, and all others where you do not use tape, use paint to identify the lines.

Identification tape codes show the function, contents, hazards, direction of flow, and pressure in the fluid line. When applying these tapes, refer to MIL-STD-1247. MIL-STD-1247 standardizes rigid line identification throughout the Department of Defense (fig. 6-76).

The function of the line is identified by a 1-inch-wide tape that contains printed word(s), color(s), and geometric symbols. Functional identification markings (see MIL-STD-1247) are the subject of an international standardization agreement. Three-fourths of the total width on the left side of the tape is a color or color code. This code shows one function only per color or colors. The function of the line is printed in English across the colored portion of the tape. A non-English-speaking person can troubleshoot or maintain the aircraft if he/she knows the color code. The right-hand one-fourth of the functional identification tape contains a geometric symbol. This symbol is different for every function. This allows a colorblind person to identify the line function by means of the geometric design rather than by the color. Look at figure 6-77. Here, you see a listing of the functions and their associated identification media as used on the tapes.

The identification-of-hazards tape shows the hazard associated with the contents of the line. Tapes that show hazards are one-half inch wide, with the abbreviation of the hazard printed across the tape. There are four general classes of hazards found with fluid lines.

1. Flammable material (FLAM). The hazard marking FLAM identifies all materials ordinarily known as *flammable or combustibles.*

2. Toxic and poisonous materials (TOXIC). TOXIC identifies lines containing materials that are extremely hazardous to life or health.

3. Anesthetics and harmful materials (AAHM). AAHM identifies all materials producing anesthetic vapors and all liquid chemicals and compounds hazardous to life and property. However, they do not normally produce dangerous quantities of fumes or vapors.

4. Physically dangerous materials (PHDAN). PHDAN marks a line carrying material that is not dangerous within itself. However, the material is asphyxiating in confined areas or is generally handled in a dangerous physical state of pressure or temperature.

Table 6-3 lists some of the fluids that you may work with and the hazards associated with each.

Table 6-3.-Hazards Associated With Various Fluids

CONTENTS	HAZARD
Air (under pressure)	PHDAN
Alcohol	FLAM
Carbon dioxide	PHDAN
Freon	PHDAN
Gaseous oxygen	PHDAN
Liquid nitrogen	PHDAN
Liquid oxygen	PHDAN
LPG (liquid petroleum gas)	FLAM
Nitrogen gas	PHDAN
Oils and greases	FLAM
JP-4	FLAM
Trichlorethylene	AAHM

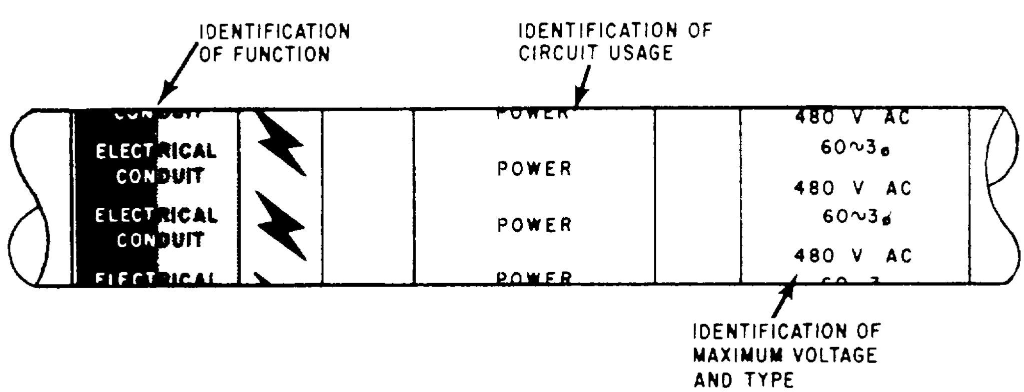


Figure 6-76.-Electrical line identification application.

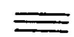
FUNCTION	COLOR	SYMBOL
Fuel	Red	
Rocket oxidizer	Green, Gray	
Rocket fuel	Red, Gray	
Water injection	Red, Gray, Red	
Lubrication	Yellow	
Hydraulic	Blue, Yellow	
Solvent	Blue, Brown	
Pneumatic	Orange, Blue	
Instrument air	Orange, Gray	
Coolant	Blue	
Breathing oxygen	Green	
Air conditioning	Brown, Gray	
Monopropellant	Yellow, Orange	
Fire protection	Brown	
De-icing	Gray	
Rocket catalyst	Yellow, Green	
Compressed gas	Orange	
Electrical conduit	Brown, Orange	
Inerting	Orange, Green	

Figure 6-77.-Functional identification tape data.

FLEXIBLE TUBING (HOSE). —Flexible hose assemblies consist of lengths of hose coupled with threaded end fittings. There are two classes of flexible tubing—high pressure and low pressure.

You can get the specifications for flexible hose by interpreting the identification code on the hose. This identification, a series of dots and dashes, gives hose size, temperature range, and date of manufacture. The date of manufacture is in quarter of year and year. Refer to NA 01-1A-8 for a detailed discussion of flexible hose identification.

You **cannot** construct high-pressure flexible hose at the organizational level. You **must** order it through supply, as organizational maintenance cannot perform high-pressure tests.

You can order the parts for a low-pressure flexible hose through supply and make the hose locally. You can reuse fittings from a damaged hose if they meet the required specifications.

When you install hose, make sure it will not twist under any operating condition. This type installation lessens the tendency for connecting fittings to loosen. When you replace hose in hydraulic, fuel, oil, alcohol, and pneumatic systems, make sure the new hose is an exact duplicate of the old hose. By this, the length, outside diameter, inside diameter, material, type, and shape (except on directed modifications) must be the same as the old hose.

If a bend is necessary when installing hose in fluid systems, the radius must not be smaller than the minimum specified in NA-01-1A-8. This publication shows the minimum bend radii for flexible hose. When practical, it is desirable to use a radius that is larger than the specified minimum.

When you install hose through holes in brackets and when using supporting clips, there can be no reduction in hose diameter. If these conditions are present, they reduce flow, and damage to the hose may occur.

The hose must have support every 24 inches. Closer supports are desirable when practical. The flexible line support should never cause deflection of the rigid connecting lines under any possible relative motion that may occur. Flexible hose between two rigid connections may have excessive motion restrained where necessary, but should never be rigidly supported. To avoid chafing use suitable bulkhead-type grommets or cushioned clips.

Protect hose installations from excessive temperature, such as exhaust blasts, supercharger ducts, and the like, either by shrouding or relocation. Use flame-resistant hose forward of the firewall on certain aircraft or as NAVAIR instructions may direct.

Where hoses connect to an engine or to engine-mounted accessories, provide 1 1/2 inches of slack between the last point of support and engine attachment. This prevents the chance of the hose pulling off the nipple due to engine movement, Whenever possible, install the hose so all hose markings are visible.

All hose materials deteriorate from exposure to heat, sunlight, excessive moisture, and ozone. Therefore, you should stow hoses in a cool dry place and away from electrical equipment. You can obtain age limits of shelf items based on the manufacturer's code from current accessory bulletins. Stow hose in straight lengths to prevent it from setting in a curved position. Replace the hose if cover material is peeling or flaking, or the braid reinforcement is open to the elements.

PITOT-STATIC INSTRUMENT MAINTENANCE

Maintenance of the pitot-static system consists of checking the lines for integrity, water, and miscellaneous obstructions. A pressure check is of the utmost importance as any slight leak will result in erroneous indications of the instruments during flight. You should also check the pitot heater for proper operation. You can do this by monitoring a voltage drop when the heat is turned on, or by checking the pitot tube for the presence of heat.

CAUTION

Do not touch the pitot tube with your bare hand with the heat on. The extreme heat may cause your skin to stick to the surface.

The following is an outline for water and debris removal from the pitot-static system.

For specific procedures, you should refer to the MIM.

1. Disconnect all altimeters, airspeed, and rate-of-climb indicators, and any other systems receiving information from the pitot-static system. Disconnect the lines from pitot or pitot-static tubes.

2. Remove all drain caps in the system.

3. Circulate a stream of clean, dry, filtered air at medium pressure through the complete system. Be careful not to include the cabin pressurization system static vent. Be certain that air is flowing from the exit end of each line.

4. Inspect all static vents and the pitot tube water removal drain holes for damage and evidence of foreign matter and obstructions. Check all low points in the lines for possible cracks due to icing in the lines.

5. Replace and secure all system drain caps.

6. Reconnect all instruments. Tighten connections properly; do not kink or bend the lines.

7. Using a field test set or other approved tester, thoroughly check the system for proper operation and leaks.

The maintenance of the pitot-static system is relatively simple when compared to more complex systems. However, its maintenance is **not** a minor task.

INSTRUMENT TESTING

Operation of most aircraft instruments is entirely automatic. Once installed, the units require no further maintenance or servicing other than routine and periodic inspections. If a system or instrument malfunctions, you must first localize the source of trouble. Develop a systematic troubleshooting procedure. The procedure should include the possible service troubles and their remedies for each type of instrument. You will find most of this information in applicable aeronautic publications, such as the MIM for specific aircraft and the service instruction manual for specific instruments.

An instrument that doesn't function properly or that is suspected of being unserviceable must first be checked to determine if the instrument or the installation is at fault. Usually, instrument problems fall into three groups—trouble in the power supply, trouble in the unit, or trouble in the connections to units, either electrical or mechanical. If the installation is faulty, line maintenance can correct the problem. If the instrument is the fault, you can remove and replace it with a serviceable unit. The defective unit goes to a qualified instrument overhaul depot for detailed inspection, overhaul, and repair.

Only authorized instrument shops can open instrument cases and make repairs or adjustments.

When making ground tests of electrical instruments, you should connect an external power supply to the aircraft. Do **not** use the battery when conducting ground tests of equipment.

When performing ground testing, you should use portable field test sets, such as the TTU-205C/E pressure-temperature tester and the TTU-27/E tachometer tester. Test sets are discussed in chapter 2 of this TRAMAN.

Always use a precision voltmeter to check instrument power. You can check most electrical instruments with a test indicator to determine where the trouble lies. For example, you can check synchro indicators using a synchro test indicator.

TROUBLESHOOTING

The manuals you use for instrument maintenance contain troubleshooting charts. These charts help you determine what is wrong with an instrument system. When you know what the problem of a particular instrument or system is, refer to the troubleshooting chart for the particular instrument. The chart gives a listing of the common troubles, probable causes, and remedies.

Efficient troubleshooting calls for an orderly, systematic plan of attack and a good understanding of the theory of equipment operation. A visual inspection should be made first; this will frequently pinpoint the trouble. When making this inspection, look for discolored or burned wires and terminal boards and corroded switch contacts. Also look for broken or frayed wires, loose connector plugs, and loose mechanical assemblies. Tables 6-4 and 6-5 are typical troubleshooting charts.

INTERCHANGEABILITY OF INSTRUMENTS

You need to be careful when substituting aircraft instruments. Check the illustrated parts breakdown (IPB) manual for the specific aircraft for the correct type of instrument. This manual lists the part number of the instrument.

If you cannot find an exact replacement for an instrument, an interchangeable instrument may sometimes be used to prevent delay in returning an aircraft to service. Aviation supply items with the same stock numbers are operationally interchangeable, regardless of the manufacturer or the manufacturer's part number. An

Table 6-4.-Troubleshooting Chart—Airspeed Indicator

TROUBLE	PROBABLE CAUSE	REMEDY
Pointer does not move.	Pitot pressure connection not connected properly to line from pitot tube.	Check tubing and connections for leaks.
	Pitot or static pressure line clogged.	Disconnect pitot and static pressure lines from all instruments. Drain at lowest point of each tube line. Blow through tubing to remove obstructions.
	Defective indicator mechanism.	Replace indicator.
Inaccurate readings.	Leak in tubing from pitot or static pressure fittings.	Check lines to external fittings for leaks.
	Leak in indicator case.	Replace indicator.
	Defective indicator.	Replace indicator.
Pointer does not set on zero when airplane is on ground.	Defective indicator.	Replace indicator.
Pointer oscillates.	Leak in tubing from pitot or static pressure fittings.	Disconnect lines from indicator. Check lines for leaks.
	Leak in indicator case.	Replace indicator.
	Leak in rate of climb indicator or altimeter installations.	Check lines for leaks. If instrument is at fault, replace instrument.
	Moisture in pitot lines.	Drain moisture from lines.

Table 6-5.-Troubleshooting Chart—Fuel Flow Indicating System

TROUBLE	PROBABLE CAUSE	REMEDY
Sluggish pointer operation.	No power on one rotor. Defective indicator.	Check connections. Replace indicator.
Pointer 180 degrees in error.	No power on one rotor.	Check connections.
Pointer swings in limited arc at top of indicator.	Transmitter ground lead open. Reversed power leads.	Check connection to pin A of transmitter. Interchange power leads.
Pointer swings in limited arc at bottom of indicator.	Indicator ground lead open.	Check connection to pin A of indicator.
Pointer swings at side of indicator dial, audible squeal from instrument.	Short or reversed connection between power and stator leads.	Check for short. Interchange power leads.
Pointer swings at side of indicator dial, no audible squeal.	Open stator lead.	Replace lead.
Pointer rotates in reverse direction.	Reversed stator leads.	Interchange stator leads.
Slight movement of pointer.	Defective indicator. Defective transmitter. Clogged or dirty fuel or pressure lines to transmitter.	Replace indicator. Replace transmitter. Clean lines.
Pointer spins.	Power lead reversals, power and stator leads shorted or reversed or making intermittent contact. Defective indicator.	Check for continuity and shorts. If wiring is correct, replace indicator. Replace indicator.
Low fuel indication.	Defective indicator. Trouble in engine fuel regulation system or fuel system.	Replace indicator. Refer to fuel system.

instrument that has a stock number has at least one distinctive feature that lets you identify it individually. Normally, you will not substitute one instrument for another; however, in an emergency it may be necessary. Before you make a substitution, properly identify the instrument in the *Aviction Supply Catalog,* which pertains to instruments.

EMERGENCY PROTECTIVE TREATMENT

Aircraft instruments that were submerged in water must be given treatment to minimize corrosion as soon as practicable after immersion. Refer to *Avionic Cleaning and Corrosion Preventive Control Manual,* NAVAIR 16-1-540, for the correct procedures.

Many of the parts of instrument systems, such as amplifiers, transformers, and capacitors, have a protective treatment to inhibit fungus growth. This treatment consists of coating the components with a special type of fungus-resistant varnish or lacquer. The manufacturer or an aviation depot usually performs this operation. Some maintenance activities may do this job. Since the varnish and lacquer are poisonous, this is a dangerous operation. It requires special equipment and specially trained personnel.

SHIPPING AND HANDLING

You should handle non-RFI instruments with the same care you handle new instruments to avoid additional damage. To prevent damage in handling and storage, all instruments are stored and transported in individual metal containers and well-packed cartons. Use care in packing inoperative instruments so no additional damage occurs during shipment. Pack individual cartons for shipment in strong wooden boxes, except when prohibited.

Instruments that have a locking mechanism should be placed in the locked position before being shipped. Refer to the manufacturer's instructions for information regarding the locking of a particular instrument.

Cleaning

Clean all aircraft instruments after removal from the aircraft and before shipping to supply. Drain instruments that are fluid transmitters or pressure indicators to ensure that no fluid remains inside the instrument.

Be careful you don't contaminate instruments with perspiration. Thoroughly dry the instrument before wrapping it with moistureproof material.

Containers

All instruments and accessories coming from supply are in containers. There are two types of containers—nonmetallic and metallic.

The nonmetallic container is usually of a high-grade cardboard construction. It will not withstand the rough treatment that the metallic type container can endure. However, if they are not abused, they afford adequate protection for the instrument.

The metallic type is a heavy gauge metal and has a lid that secures to the can with a snap-ring fastener. You can open and close this container without damaging it.

Do not damage or throw away packaging material from both the nonmetallic and metallic containers. Make provisions for retaining this material in the electric shop since it may be used for returning equipment to supply. Many of these containers have labels stating REUSABLE CONTAINER—DO NOT DESTROY.

REVIEW SUBSET NUMBER 4

Q1. What type of marking is used to identify dial face slippage?

Q2. When installing rigid tube markings, what is the minimum number per compartment?

Q3. What is the color of the identfication tape on electrical conduits?

Q4. Name the four classes of hazards identified by identification of hazards tape.

CHAPTER 7

COMPASS AND INERTIAL NAVIGATION SYSTEMS

The material in this chapter is about aircraft navigation systems. The basic systems discussed are the aircraft compass system and inertial navigation system (INS). Also, this chapter presents a discussion of the calibration of these two systems.

The way electrical signals are detected, amplified, and delivered to various indicators and systems is highly sophisticated. Before you begin this chapter, you might need to read Navy Electricity and Electronics Training Series (NEETS), Module 15, *Principles of Synchros, Servos, and Gyros.*

NAVIGATION TERMS AND DEFINITIONS

Learning Objective: *Recognize the navigation-related terms and definitions basic to compass and inertial navigation system operation.*

Any purposeful movement in the universe involves an intention to proceed to a definite point. Navigation is the business of proceeding so you will arrive at that point. Air navigation is defined as the process of directing the movement of an aircraft from one point to another. The function of air navigation is to locate positions and measure distance and time along the intended direction of flight.

POSITION

Position is a point defined by stated or implied coordinates. You will frequently qualify this term by such adjectives as *estimated, dead reckoning, no wind,* etc. However qualified, the word *position* always refers to some place that you can identify. One of the basic problems of the navigator is that of *fixing* his position. If he does not know where he is, he can't direct the movement of the aircraft to its intended destination.

DIRECTION

Direction is the position of one point in space relative to another, without reference to the distance between them. Direction may be either three-dimensional or two-dimensional; the horizontal being the usual plane of the latter. For example, the direction of San Francisco from New York is approximately west (two-dimensional). However, the direction of an aircraft from an observer on the ground may be west and 20° above the horizontal (three-dimensional). Direction is not itself an angle (for example, the direction east), but it is often measured in terms of its angular distance from a reference direction.

COURSE

Course is the intended horizontal direction of travel. For example, the direction of NAS Jacksonville from NAS Pensacola is east. This should be the intended direction of flight. However, because of wind conditions aloft, the aircraft might not head straight toward Jacksonville, but somewhat to one side. No matter what the aircraft heading is, the course (the intended direction) is still east.

HEADING

Heading is the horizontal direction in which an aircraft is pointing. In the previous example, you can see the difference between course and heading. *Heading* is the actual orientation of the aircraft's longitudinal axis at any instant, while *course* is the direction of travel intended. *True* heading uses the direction of the geographic North Pole as the reference. *Magnetic heading* uses the direction of the earth's magnetic field at that location as the reference. Magnetic heading differs from true heading by the amount of magnetic variation (MAGVAR) at that location. *Compass heading* differs from magnetic heading by the amount of magnetic deviation. Compass heading differs from true heading by the amount of compass error (deviation ± variation).

BEARING

Bearing is the horizontal direction of one terrestrial point from another. Bearings can be expressed by two terms—true north or the direction in which the aircraft is pointing. If true north is the reference direction, the bearing is a true bearing. If the reference direction is the heading of the aircraft, the bearing is a relative bearing. If you get a bearing by radio, it is a radio bearing; if visual, it is a visual bearing. Thus, the direction between two objects on (or near) the surface of the earth can be described concisely by saying: THE (RADIO, VISUAL) BEARING OF A FROM B IS X ± (RELATIVE, TRUE).

DISTANCE

Distance is the separation between two points. To measure distance, you measure the length of a line joining the two points. This seems understandable enough. However, suppose that the two points are on opposite sides of a baseball. How do you draw the line? Does it run through the center of the ball, or around the surface? If around the surface, what path does the line follow? You must qualify the term *distance* used in navigation to show how to measure the distance. The shortest distance on the earth's surface from NAS San Diego to Sydney, Australia, is 6,530 miles. However, via Honolulu and Guam, a frequently used route, it is 8,602 miles. You can express the length of a chosen line in various units, such as miles, kilometers, or yards.

TIME

Time has many definitions. The two definitions used with navigation are as follows: (1) the hour of the day and (2) an elapsed interval. The first appoints a definite instant, as *takeoff time is 0214.* The second definition appoints an interval, such as *time of flight, 2 hours 15 minutes.*

POLES

The earth's geographic poles are the extremities of the earth's axis of rotation. Look at figure 7-1. Here, P_n, E, P_s and W represent the surface of the earth at sea level. Line P_nP_s is the axis of rotation. The earth's rotation is such that all points in the hemisphere, P_nWP_s, approach the reader. Those points in the opposite hemisphere will recede from the reader. The extremities of the axis, points P_n and P_s are the north and south poles, respectively. A man on the surface of the earth, facing in the direction of rotation, has the North Pole on his left. East will be in front of him, the South Pole on his right, and west behind him.

The earth has some of the properties of a bar magnet. The magnetic poles are the regions near

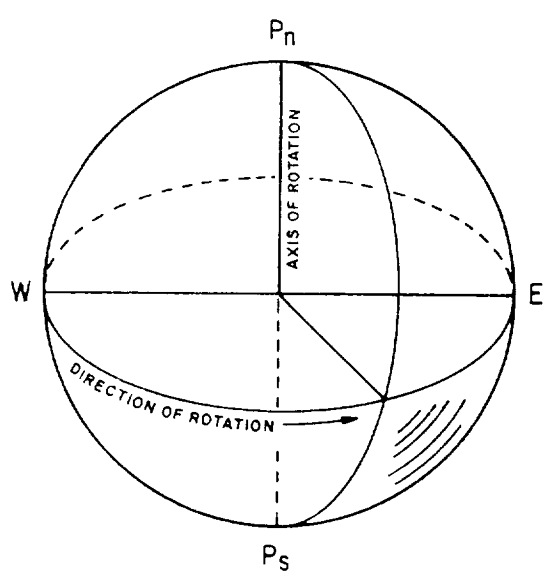


Figure 7-1.-Schematic representation of earth showing axis of rotation and equator.

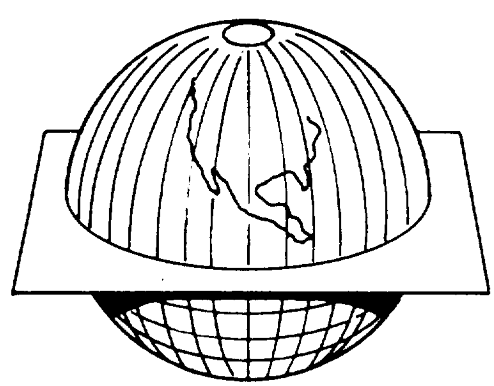


Figure 7-2.-The equator is a great circle whose plane is perpendicular to the polar axis.

the ends of the magnet. This is where the highest concentration of magnetic lines of force exist. However, the earth's magnetic poles are not at the geographic poles, nor are they antipodal (opposite) to each other.

GREAT CIRCLES AND SMALL CIRCLES

The intersection of a sphere and a plane is a circle. The intersection is a great circle if the plane passes through the center of the sphere. It will be a small circle if it does not.

PARALLELS AND MERIDIANS

Look at figure 7-2. Here, the earth's equator is a great circle. If a second plane (fig. 7-3) passes through the earth parallel to the equator, its intersection is a small circle. Small circles don't always have planes perpendicular to the polar axis. However, if they are perpendicular, then all points on the small circle are equidistant from the equator; that is, the circles are parallel to the equator. Such small circles, together with the equator, are PARALLELS. They provide one component of a system of geographical coordinates.

Now, suppose that planes pass through the earth's poles (fig. 7-4). Such planes contain the axis, and since they also contain the center, they form great circles at the surface. Great circles through the poles of the earth are MERIDIANS. All meridians are perpendicular to the equator. Meridians form the second part of a system of geographical coordinates commonly used by navigators.

LATITUDE AND LONGITUDE

You can identify any point on earth by the intersection of a parallel and a meridian. It is the same as an address *at the corner of Fourteenth Street and Seventh Avenue.* You are just using different names for identifying the parallels and meridians.

The circumference of a circle is divided into 360 units. This unit is the *degree.* It is the same unit you use to measure an angle. In figure 7-5,

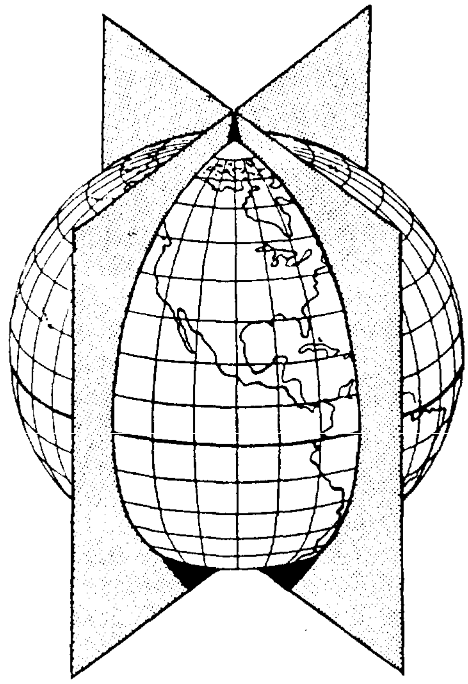


Figure 7-4.-Great circle through the poles form meridians.

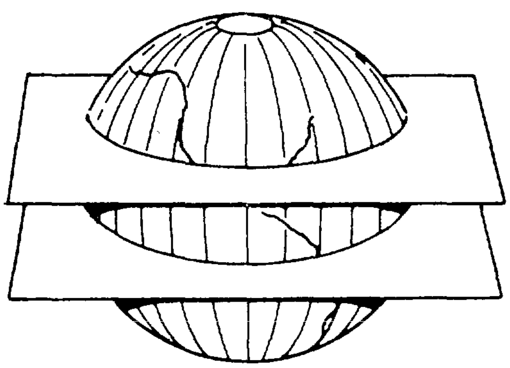


Figure 7-3.-The plane of a parallel is parallel to the equator.

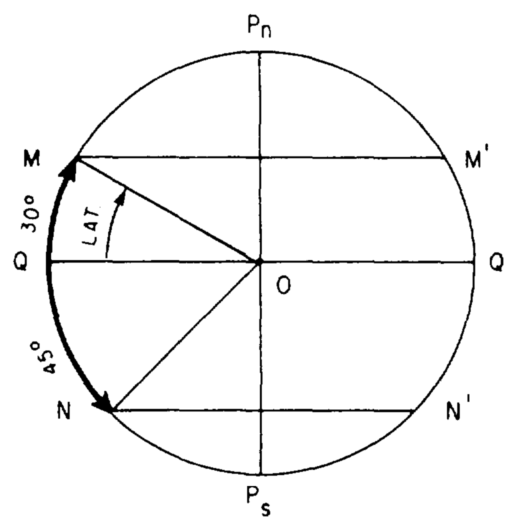


Figure 7-5.-Latitude of M is angle QOM or arc QM.

circumference QP_nQP_s represents a meridian. QQ´ represents the equator, whose plane passes through the axis of rotation. Let M be some position north of the equator on a meridian. The number of degrees in arc QM is the measure of angle QOM. If arc QM is 30°, then angle QOM is 30°. Thus, you measure a central angle by measuring its subtended arc.

Let MM´ be the plane of a small circle parallel to QQ´, the equator. Then arc QM measures the distance of any point on MM´ from the equator. You can describe the whole parallel MM´ by saying that it is 30° north of the equator. Similarly, you can say any point on NN´ is 45° south of the equator. The angular distance of a position north or south of the equator is the position's latitude. You measure latitude northward or southward through 90° and label it N or S to show the direction of measurement. You express latitude in terms of the angle at the center (see angle QOM in figure 7-5). Latitude, then, is the north-south geographical coordinate.

The east-west geographical coordinate is longitude. You can define longitude in three ways:

1. as an arc of the equator or a parallel,
2. as the angle at the pole or the angle at the center between the planes of the prime meridian, and
3. as the meridian of a point on earth. You measure this point eastward or westward from the prime meridian through 180°. Label it E or W to show the direction of measurement.

You measure latitude from a standard great circle (the equator). You also use a standard great circle when measuring longitude. This great circle is the meridian. The standard meridian is the *prime meridian.* By international agreement in 1884, the meridian adopted as the prime meridian was the one on which Greenwich Observatory (near London, England) was located. This is was the 0° longitude.

Figure 7-6 represents the earth. QQ´ is the equator, with its plane passing through the center, O. G is the position of Greenwich, and M is a position in north latitude west of Greenwich. P_nM' and P_nG' are portions of the meridians through M and G intersecting the equator at M´ and G´. The longitude of M includes

1. the arc of the equator G´M´,
2. the angle GP_nM formed by the meridional planes through G and M, and
3. the angle G´OM´ formed at the center between G´ and M´.

You should recognize that each of these expressions measures the same coordinate—longitude.

The longitude of a position is also described as being east or west of Greenwich. In figure 7-6, the longitude of M is west; the longitude of N is east. You can see that longitude east or west cannot exceed 180°.

You can subdivide the degree into smaller units, as in the decimal system. However, the more common method of subdivision is to divide each degree into 60 minutes (´) of 60 seconds (´´) each. Another method is to divide the degree into 60 minutes and tenths of minutes.

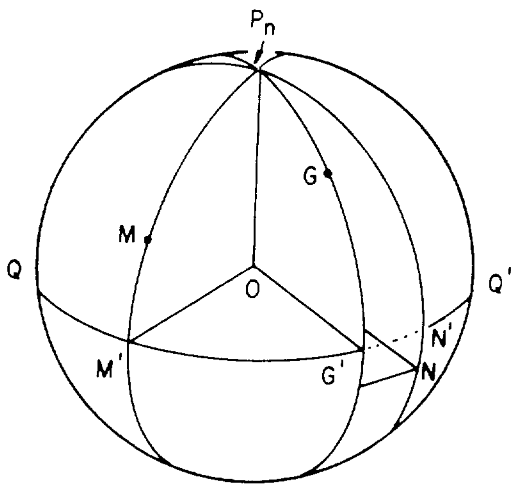


Figure 7-6.—Longitude is measured between meridians.

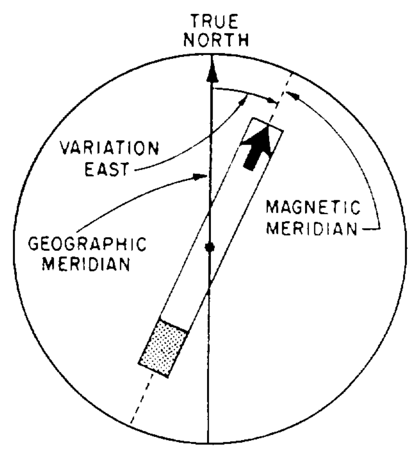


Figure 7-7.-Easterly magnetic variation.

To convert minutes into decimals of degrees, or to convert seconds into decimals of minutes, divide by 6. Thus: 15°30′ = 15.5′, and 15°30′24″ 15°30.4′.

VARIATION

As stated under the definitions of poles, the earth's true (geographic) poles and its magnetic poles are not at the same locations. Also, the location of the magnetic poles changes slightly over the years. In 1960, the north magnetic pole was at latitude 74.9°N and longitude 101.0°W. The southern pole was at latitude 67.1°S and longitude 142.7°E. Thus, a given line will have a different direction to the true North Pole than to the magnetic North Pole. In addition, lines of magnetic force are not generally straight lines because of irregular iron deposits near the earth's surface. Since a compass needle aligns to the lines of force at its location, it may not point to true or magnetic north. The locations on the earth where the compass does point to true north, when connected together, form an irregular line. This is the *agonic line.* At other locations, the angle between the direction of true north and the direction of the earth's magnetic field is the locations variation. The earth's magnetic field direction may not be the same as the direction of the magnetic poles. This same angle is also often called the *angle of declination.* You label variation (or declination) east or west as the magnetic field direction is east or west, respectively, of true north. (See figures 7-7 and 7-8.) Lines connecting locations having the same variation are *isogonic* lines.

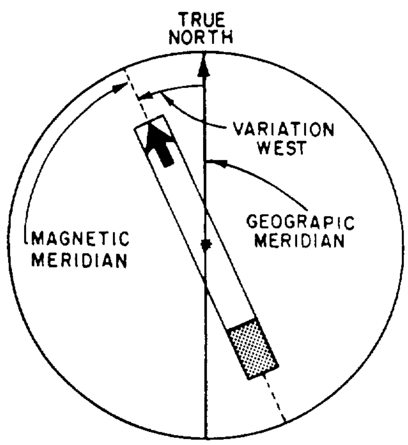


Figure 7-8.-Westerly magnetic variation.

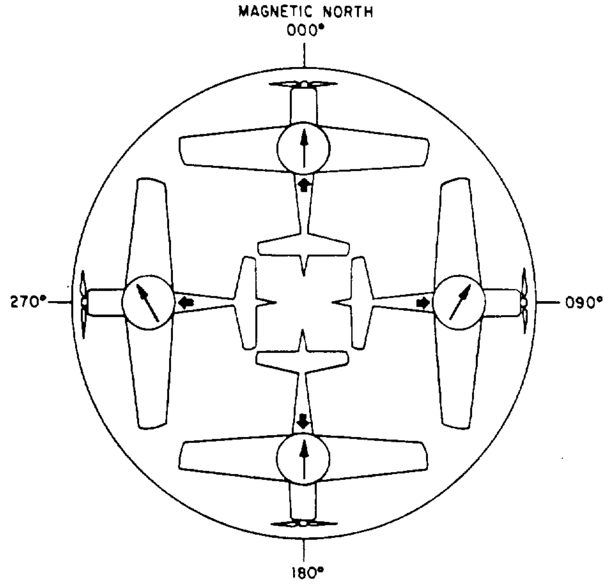


Figure 7-9.-Deviation changes with heading.

DEVIATION

Deviation is the error in a magnetic compass caused by nearby magnetic influences. These influences may relate to magnetic material in the structure of the aircraft and to electrical (electronic) circuits. These magnetic forces deflect a compass needle from its normal alignment with the earth's magnetic field. You express the amounts of such deflections in degrees. The deflection will be east or west as the compass points east or west, respectively, of the earth's magnetic lines of force. Deviation varies with the heading of the aircraft. Figure 7-9 shows one reason for this deviation.

For example, suppose that you represent the net result of all magnetic forces inherent in an aircraft by an arrowhead in the aircraft's longitudinal axis and aft of the compass. If the aircraft is heading toward magnetic north, the magnetic forces (arrowhead) attract the south-seeking end of the compass needle. However, they don't change the needle's direction because the inherent magnetism has the same polarity as the earth's field. Now, suppose that the aircraft takes an east magnetic heading. The aircraft's magnetic forces now repel the north end of the compass needle and attract the south end, causing easterly deviation. The figure also shows that the deviation when heading south is zero and when heading west is westerly. You can reduce deviation by changing the position of small compensating magnets in the compass case. However, it is usually not possible to remove all the deviation on all headings. You must determine the residual deviation for each compass installation and record it on a deviation card. The card shows the actual deviation on various headings or, more frequently, the compass headings for various magnetic headings. You can accomplish this using a process known as *compass swinging.*

COMPASS ERROR

The net result of both variation and deviation is the *compass error.* If variation and deviation have the same name (east or west), you add to get compass error. If they have different names, subtract the smaller from the larger. Give the difference given the name of the larger. (See fig. 7-10.) You can label variation and deviation plus (+) if east, and minus (–) if west. In this case the compass error is the algebraic sum of the two.

Example 1.

Given: Variation 7° west (W), deviation 2° west (W).

Required: Compass error.

Solution: 7°W + 2°W = 9°W. To fly a true course of 135°, this aircraft over this spot on the earth would fly a compass heading of 144°.

Example 2.

Given: Variation (–)2°, deviation (+)5°.

Required: Compass error.

Solution: (–)2° + 5° = (+)3°

MAGNETIC DIP

At the magnetic poles, the direction of the earth's magnetic field is vertical (perpendicular to the earth's surface). Along the *aclinic line* (sometimes called the magnetic equator), roughly half way between the poles, the field's direction is horizontal (parallel to the earth's surface). The difference between the direction of the earth's field and the horizontal at any location is the *magnetic dip.* The magnetic dip varies from very

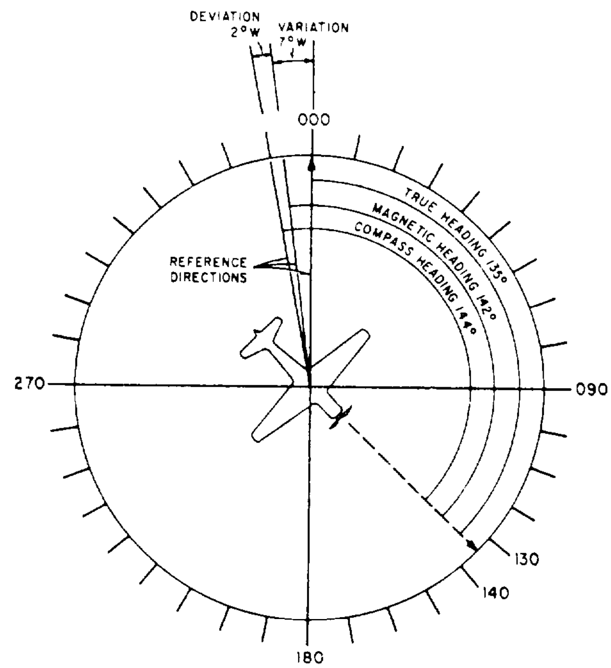


Figure 7-10.-Effect of compass error.

small angles near the equator to very large angles near the poles. You can measure the angles with a dip needle, which is a magnetic needle free to turn about a horizontal axis. At San Francisco the dip angle is about 62°. A line connecting all locations having equal dip angles is an *isoclinic line.*

The total intensity of the magnetic field is along the dip angle. However you can show it as two components—vertical and horizontal. (See fig. 7-11.)

Only the horizontal component is effective as a directive force for a magnetic compass (wet compass). It loses its effectiveness near the magnetic poles because of the weak horizontal component there. The vertical component causes errors in a magnetic compass during aircraft maneuvers that tilt the compass card east or west. If an aircraft heading east increases its speed, or when heading west decreases its speed, the compass card tilts. Also, when turning east from a north or south heading, the floating compass card will tilt. In both cases, the east side of the card sinks and the west side rises. The vertical component of the earth's field causes the compass card to rotate to the east when in the northern hemisphere. It will cause the card to rotate west when in the southern hemisphere. The amount of error is zero at the aclinic line, and it

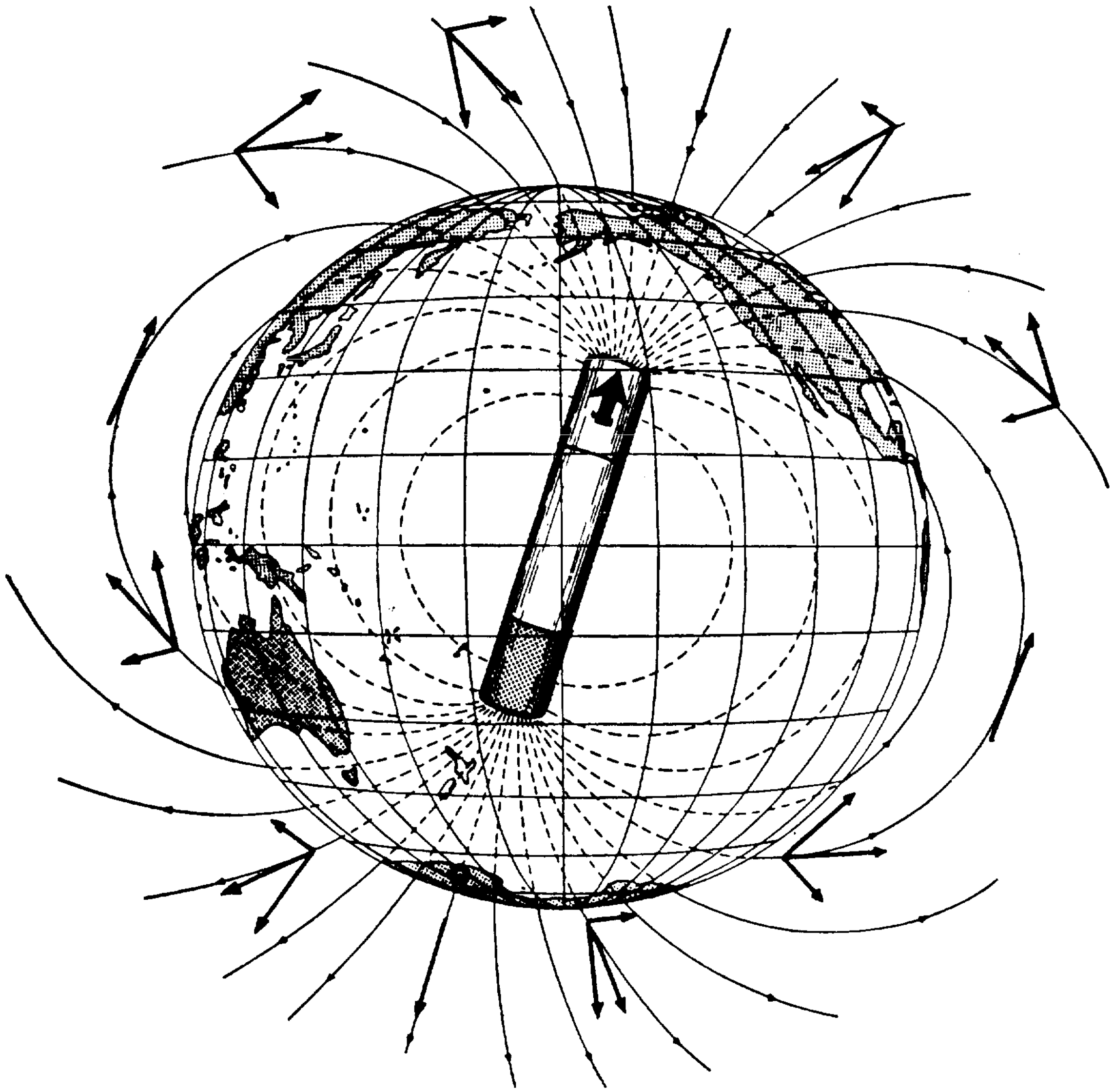


Figure 7-11.-The earth's magnetism.

increases toward the magnetic poles. It should be clear that precise turns are difficult if referenced to such a compass.

PILOTAGE

Pilotage is the directing of aircraft from point to point by visual or radar observation of landmarks. These landmarks are either previously known or recognized from a chart. It is similar to taking a trip by automobile where the highway is the course taken and the towns are the check points. This method has obvious limitations if the flight is made over a large body of water or poorly charted area. Also, if you make the flight using only visual observations, darkness, rain, or fog further limit its use. Therefore, whenever possible, use pilotage in conjunction with other methods of navigation.

DEAD RECKONING

Dead reckoning is the process of determining a position from the record of a previously known position, course, speed, and time traveled. To be accurate, you must consider every change of course and speed during the flight. It does not matter whether the pilot or the air mass (wind) through which the aircraft is flying makes the changes.

RADAR NAVIGATION

Modern radar can be a valuable aid to navigation. Some radars present a maplike display of the terrain around the aircraft on the screen of a cathode-ray tube (CRT). This allows pilotage to go beyond some of the limitations of visual observations.

Radar transponders are devices that do not operate until interrogated or triggered into action by a suitable signal from another radar transmitter. Then, they transmit their own signal, which the interrogating radar receives. These are used both for fixed navigational aids, such as radar beacon stations and for airborne identification friend or foe (IFF) systems.

Doppler radar can detect and show actual ground speed and drift of an aircraft, regardless of wind speed or direction.

Radar altimeters give the actual distance from the aircraft to the surface below. The surface below can be a body of water or land masses far above sea level.

RADIO NAVIGATION

Radio navigational aids vary from a fairly simple direction finding receiver to complex systems using special transmitting stations. These special stations make it possible to fix the position of an aircraft with considerable accuracy. The usable range varies according to its intended use and also with weather and ionospheric conditions. Beacon stations associated with an instrument landing system (ILS) are usually of low power. Long-range air navigation (loran) stations have a range extending to 1,400 miles under favorable conditions. Aviation Electronics Technicians (ATs) maintain the airborne portions of radio and radar systems.

CELESTIAL NAVIGATION

Celestial navigation is the method of fixing the position of the aircraft relative to celestial bodies. Since the earth is constantly revolving, an accurate time device is necessary. You may use a sextant to measure the angle of the celestial bodies with respect to the horizon. In marine navigation, the visible horizon is the reference. In air navigation, you use an artificial horizon as the reference point. Also, the navigator needs an almanac to determine the celestial equator system coordinates at the time of observation.

The usual method to show a line of position from celestial observation consists of (1) observation, (2) coordinate conversion, and (3) plotting. The navigator tries, whenever possible, to select three bodies about 1200 apart in azimuth. This not only results in lines of position that cross cleanly, it also minimizes the effects of a constant error in the observations.

INERTIAL NAVIGATION

Inertial navigation systems (INS) are dead-reckoning devices that are completely self-contained. They are independent of their operating environment, such as wind, visibility, or aircraft attitude. They do not radiate or receive RF energy; therefore, they are impervious to countermeasures. They make use of the physical laws of motion that Newton described three centuries ago. Of course, you must enter the starting position into the system. When known positions are available, you may correct or update the system if an error exists.

Another input to the system is from acceleration detectors that measure the rate of change in the motion of the aircraft. The first integral of acceleration is velocity. Velocity results when acceleration is integrated with respect to time. For example, a body starts from rest and constantly accelerates at 8 feet per second per second for 11 seconds. The velocity at the end of this time would be 88 feet per second (60 miles per hour). However, in actual practice, acceleration is not always this constant. The integration of acceleration is the process of summing all minute acceleration-time increments over a given amount of time.

By integrating velocity with respect to time, the result is displacement (distance). Therefore, the second integral of acceleration is displacement. The inertial navigator's purpose is to keep track of position and not the total distance traveled. This causes the system to integrate all values of acceleration (positive and negative) detected over the time involved.

If the earth were flat and vehicles traveled only on the earth's surface, a two-axes inertial navigation system could plot the position using two accelerometers. One accelerometer would be sensitive along the x-axis (E-W) and the other sensitive along the y-axis (N-S). The important point to note about detecting acceleration of a body is that each accelerometer detects only the component of the resultant acceleration along its sensitive axis. They have no way of telling whether the detected velocity change is due to a speed change or a direction change or both. It does not matter what forces cause the velocity change. Neither can the accelerometer distinguish between the acceleration of the vehicle and the pull of gravity. Therefore, if the accelerometer tilts off its level, its output will include a component of gravity as well as vehicle acceleration. To get the correct vehicle acceleration in the horizontal plane, the sensitive axis of the accelerometer must be perpendicular to the gravitational field.

Of course, the earth is not flat, and not exactly round either. Its radius at the poles is less than its radius at the equator. It also spins about its polar axis. A spinning gyro in gimbals tries to maintain a fixed direction in relation to space rather than to any point on earth. Consider a gyro at the equator with its spin vector direction east, toward the morning sun. After 6 hours of earth rotation, the spin vector would be up in relation to the earth's surface. After 12 hours it would be west. After 18 hours it would be down; and after 24 hours it would be east again. Also, consider a spinning gyro with its spin axis parallel with the earth's axis of rotation. At the equator it is parallel with the earth's surface. However, as it moves to the North Pole, it becomes vertical to the earth's surface. You must take all of these items into account and correct for them. So, to navigate on the earth requires a highly complex inertial system, each component of which is capable of extreme accuracy.

A four-gimbal system allows the platform to retain the original orientation regardless of what maneuvers the aircraft makes. This allows the platform to serve as a level mount for the accelerometers. The stable platform contains two identical floated, two-degree-of-freedom gyros. They mount with their spin axes horizontal and at right angles to each other. Using the gyroscopic principle of precession, it is possible to apply a continuous torque to the appropriate axes. This action reorients the gyros to maintain the stable platform horizontal to the earth's surface and pointed north. An electronic analog computer develops the signals necessary to properly torque the gyros. The correct ions for earth rate depend on the aircraft's position on the earth's surface.

Some system's use as many as three accelerometers. Two are horizontal with one sensitive to north-south acceleration and the other sensitive to east-west acceleration. The third accelerometer mounts to determine vertical acceleration. A computer subtracts the gravity component from the output of the vertical accelerometer. A more detailed description of an INS follows later in the chapter.

REVIEW SUBSET NUMBER 1

Q1. A point that is defined by stated or implied coordinates is known as a ____________ .

Q2. The intended horizontal direction of travel is known as ________________ .

Q3. *In what two reference directions can you express bearings?*

Q4. The east/west geographical coordinate is known as ____________________________ .

Q5. You measure longitude 180° east or west from what point?

Q6. The angle between true north and the direction of the earth's magnetic field is known as ____________________________ .

Q7. How do you label variation?

Q8. Magnetic influences cause what type of error in magnetic compasses?

Q9. The net result of both variation and deviation is known as ______________ .

Q10. When variation and deviation have the same name, do you add or subtract to obtain compass error?

Q11. You can determine a position from the record of a previously kno~w position, course, speed, and time traveled by what process?

Q12. What navigation system makes use of the physical laws of motion that Newton described three centuries ago?

AIRCRAFT COMPASS SYSTEMS

Learning Objective: *Recognize the operating principles and features of compass systems, the attitude reference system, and associated sensors and indicators.*

Countless navigational devices and methods have been invented and devised. In the present era, with its supersonic speeds, accurate determination of direction has become increasingly important. An error of only a few degrees in a space of minutes will carry the modern aviator many miles off course.

During the early days of aviation, direction of flight was determined within the aircraft chiefly by direct-reading magnetic compasses. Today the direct-reading magnetic compass still finds use as a standby compass should the more sophisticated compass systems fail.

COMPASS SYSTEM SENSORS AND INDICATORS

In chapter 6, the heading indicator is mentioned as a flight instrument. This instrument is part of the primary heading reference system. The heading indicator receives electrical/electronic signals from various components in the system and shows the pilot aircraft heading in degrees. Do not confuse this compass system with the standby compass system (wet compass) covered in chapter 6.

Sophisticated navigation systems and weapons delivery systems require aircraft heading information in electrical/electronic signal form. In this form, the information goes to computers,

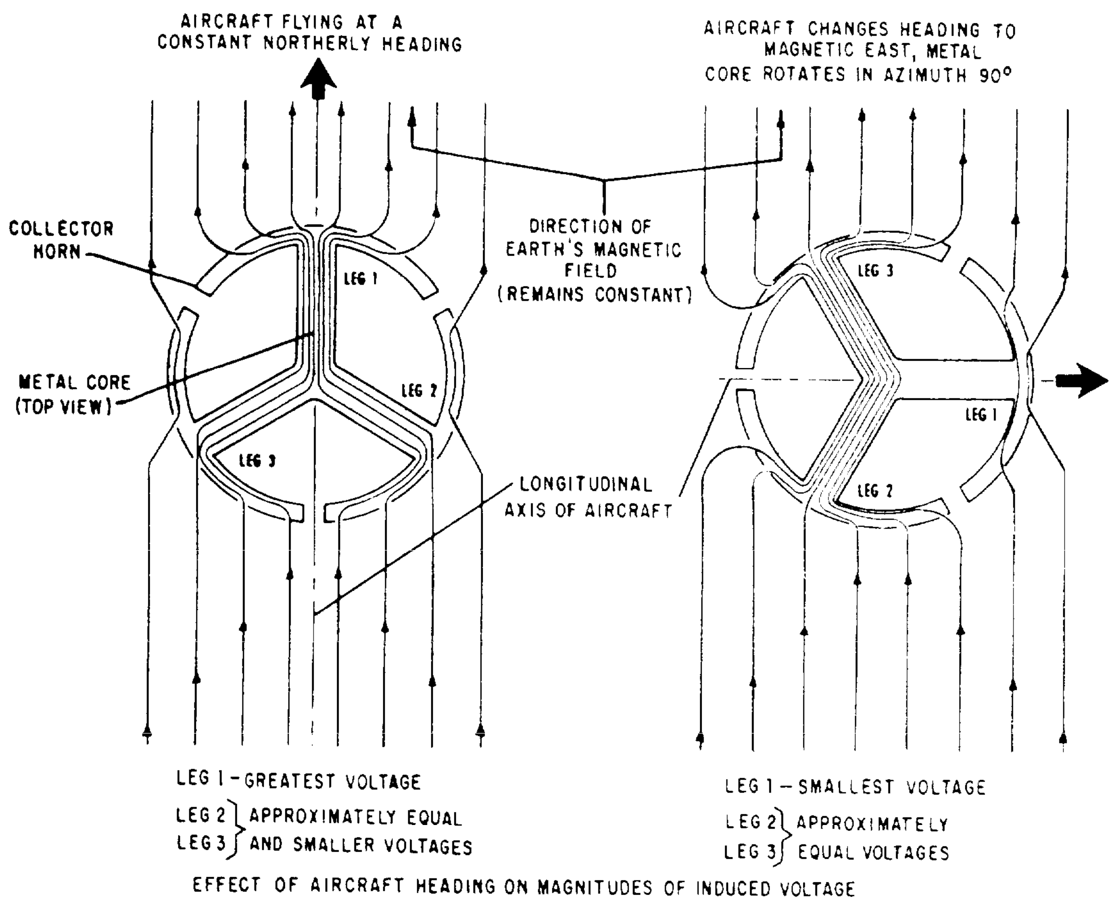


Figure 7-12.—Flux valve heading changes.

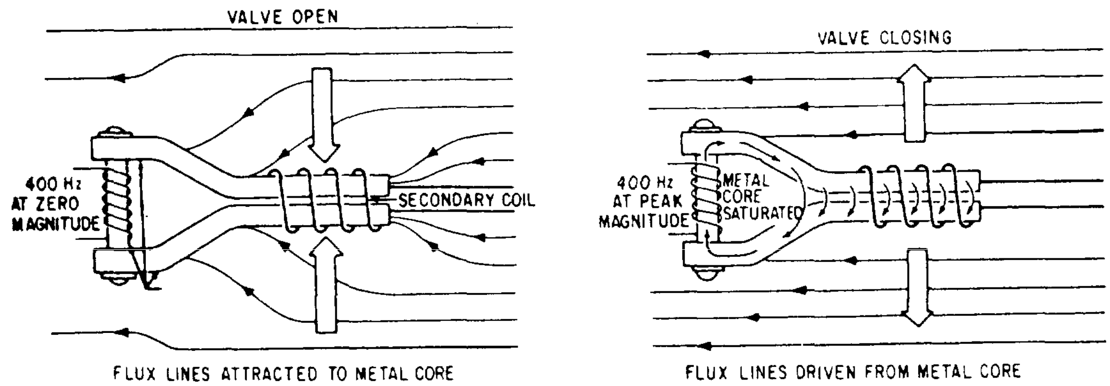


Figure 7-13.-Magnetic flux line movement.

indicators, and other components. Also, by using these signals, indicators can include aircraft heading along with other information in a single instrument.

Compass Transmitter

The compass transmitter, called a *flux valve,* detects the direction of the flux lines of the magnetic field of the earth. It electrically sends this information to a servo loop. The transmitter is only a few inches in height. It is usually mounted within the wing or tail of the aircraft as this area has the lowest magnetic disturbances in the aircraft. It consists of a hermetically sealed hemispherical bowl containing a pendulous sensing element in a damping fluid. A universal mounting permits the sensing element up to 30 degrees of freedom in roll and pitch, while prohibiting rotation about the vertical axis.

The laminated metal core of the flux valve is a good conductor of magnetic lines of force (high permeability). It is shaped like a three-spoked wheel with the rim split between the spokes, as shown in figure 7-12. The earth's magnetic lines of force will concentrate in these legs because they offer low reluctance to the flux. The amount of flux in any one leg is proportional to the angular position of the leg relative to the earth's magnetic lines of flux. The signal pickup coils are wound around these legs, one for each leg. The coils are 1200 apart in a horizontal plane. The coils connect electrically in a wye configuration.

The exciter coil is wound around the hub of the core, corresponding to the axle of a wheel. This coil receives 400-hertz ac power. This coil is the primary, and the signal pickup coil is the secondary. The design of the core and windings prevents transformer action between the coils. The purpose of the primary winding and its applied voltage is to produce a magnetic field. This magnetic field changes the reluctance of the core. When the 400-hertz ac goes to the primary coil, the current generates a magnetic field in the core. The magnetic field drives the core to saturation at the peak of each positive and each negative portion of the cycle. Figure 7-13 shows the side view of the center hub and one leg of the sensing element.

When the 400-hertz voltage is at zero, the reluctance of the core is low. This allows the maximum number of the earth's magnetic flux lines to concentrate in the core. As the primary sine wave builds up toward maximum, reluctance increases, making the core less attractive to earth's magnetic flux lines. As the magnetic flux lines move out, they cut through the secondary coil and induce a voltage (emf) in it. Refer to figure 7-14.

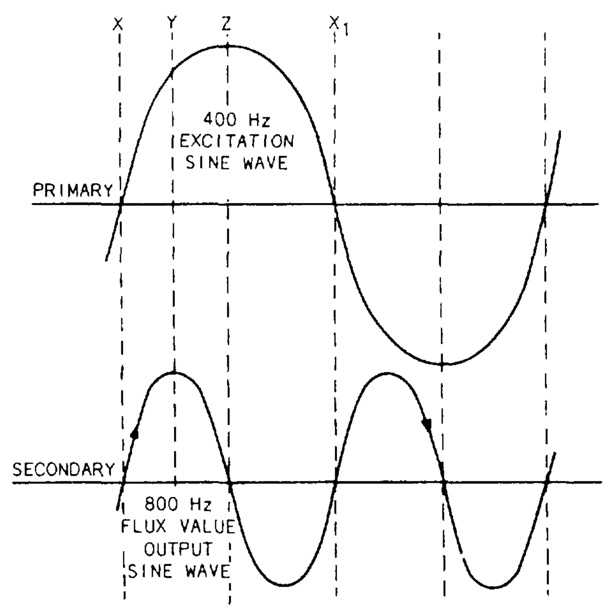


Figure 7-14.-Flux valve sine waves.

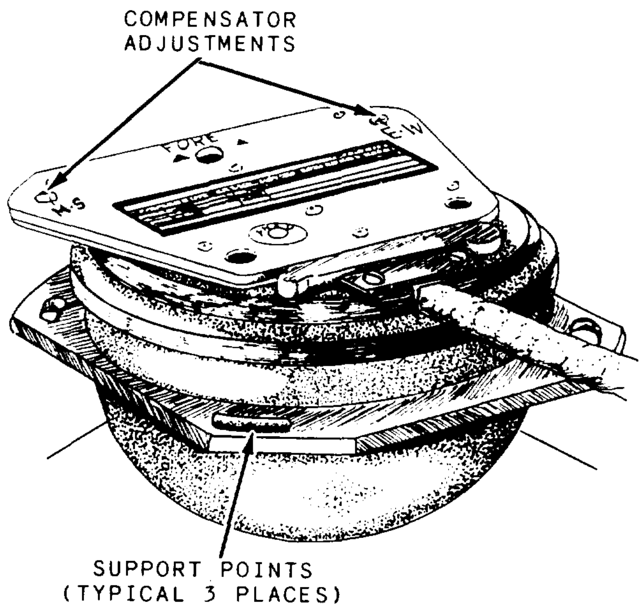


Figure 7-15.-Compass transmitter and compensator.

The movement of flux lines increases until point Y on the 400-hertz sine wave, and then the movement tapers off and stops moving at point Z. At this point no voltage is induced into the secondary winding. As the primary sine wave starts dropping toward X_1, the reluctance of the core decreases. The core now attracts more and more of the earth's flux lines. These lines of flux cut through the secondary coil in the opposite direction and induce a voltage of the opposite polarity. When the primary sine wave reaches X_1, the maximum number of the earth's flux lines again concentrate in the core. However, they are not moving, so the induced voltage in the secondary coils is zero.

The same action takes place during the negative half of the 400-hertz excitation current. This makes the resulting output of the flux valve an 800-hertz signal. The voltages of each of the three secondary coils pass through zero at the same instant. However, their polarity and amplitude depend on the heading of the aircraft. They vary in the same fashion as the stators of a synchro transmitter. This would allow you to use it to drive an 800-hertz synchro system. The original 400-hertz excitation is effectively cancelled by the special construction of the metal core and windings. This construction allows lines of flux produced by the primary coil to induce canceling voltages in the secondary coils.

Attached to the top of the compass transmitter is a compensator assembly (fig. 7-15). It consists primarily of two sets of two small permanent bar magnets. You can change the relative azimuth position of each set by rotating a screw on the outside of the unit. These screws position the magnets by a gear train. One adjusting screw adjusts for north-south compensation, and the other screw adjusts for east-west compensation.

Two wiring symbols for the flux valve are shown in figure 7-16. To distinguish them from synchro units, the words *compass transmitter* or *flux valve* are usually included in the drawing.

Displacement Gyroscope Assembly

The displacement gyroscope assembly (fig. 7-17) consists of a vertical gyro (VG) and a

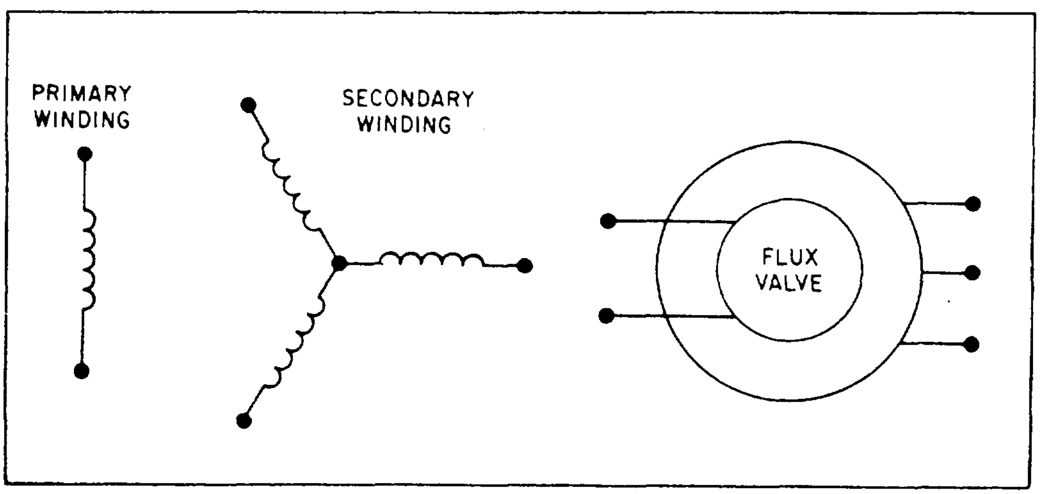


Figure 7-16.-Compass transmitter schematic and functional symbols.

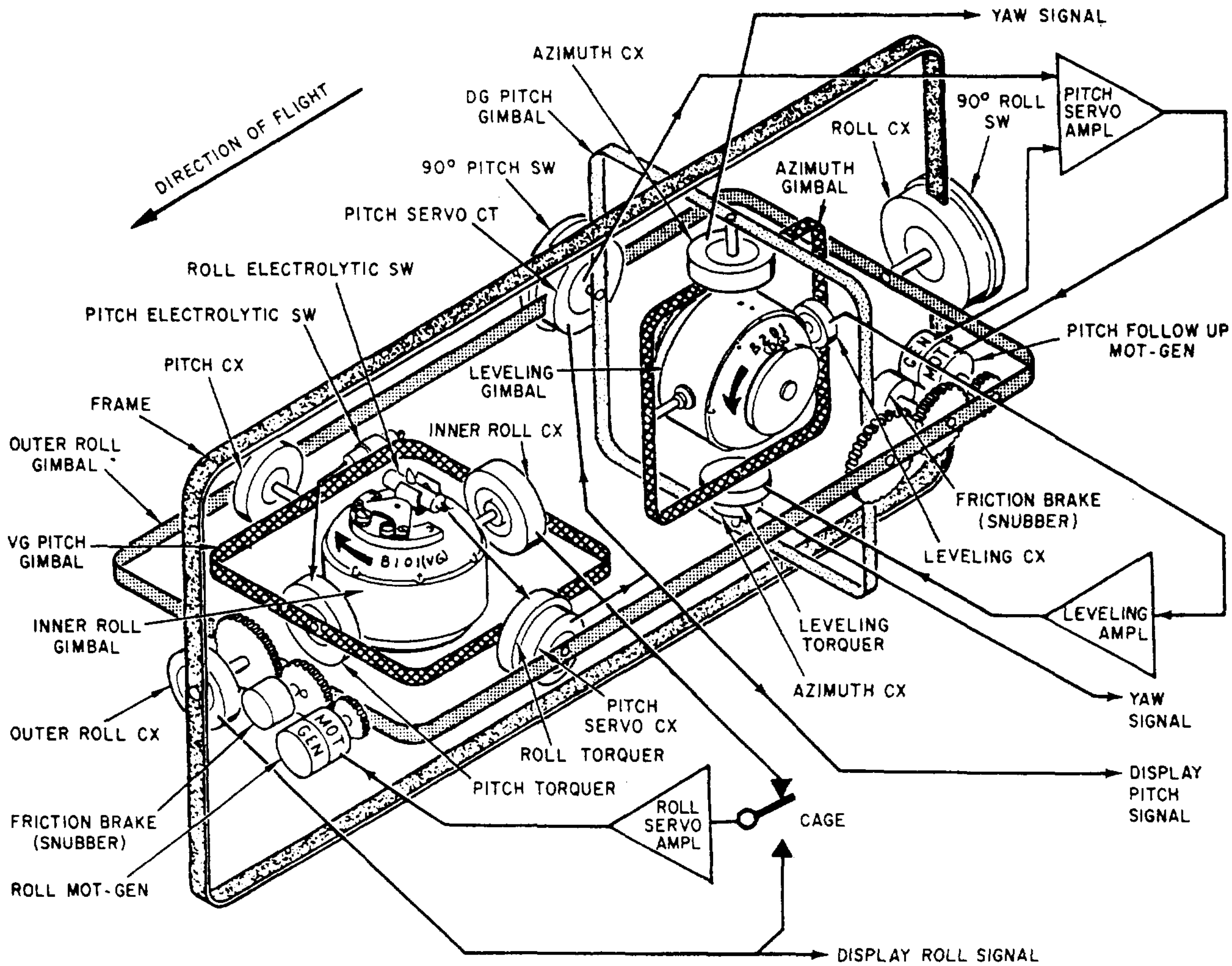


Figure 7-17.—Typical displacement gyro and servo loops.

directional gyro (DG). These gyros mount in a common outer roll gimbal. The vertical gyro provides pitch and roll signals and the directional gyro provides heading (azimuth) signals. Erection and leveling servo loops erect and maintain the spin axis of the vertical gyro gravity vertical and the directional gyro spin axis parallel to the earth. Roll, pitch, and azimuth control transmitters convert aircraft attitude and heading into electrical signals.

VERTICAL GYROSCOPE OPERATION. — Look at figure 7-17 as you read this section. The vertical gyro consists of gyro spin motor B101 (which is the inner roll gimbal) and the vertical gyro pitch gimbal. It also includes the outer roll gimbal and the frame. The frame mounts to the assembly case and follows all aircraft maneuvers. The outer roll gimbal mounts in the frame. It may rotate 360° about the roll axis but follows the aircraft in pitch and yaw.

The vertical gyro pitch gimbal mounts in the outer roll gimbal. This gimbal may rotate 360° about the pitch axis but follows the outer roll gimbal movements in roll and yaw. The gyro spin motor may rotate ±85° in roll but follows the vertical gyro pitch gimbal in pitch and yaw. Mechanical stops (not shown) limit inner roll gimbal movement to prevent B101's spin axis, aligning with the vertical gyro pitch gimbal axis. Such an alignment would cause the vertical gyro pitch gimbal to spin about its pitch axis (gimbal lock).

Leveling. —At power application, a friction brake (snubber) releases the outer roll gimbal from the frame. The gyro spin motor starts, and electrolytic switches sense unlevel conditions in pitch and roll. The output of the electrolytic switches activates the torquers. The gyro reacts to the applied torque and precesses until the electrolytic switches are level. The inner roll control transmitter is mounted between the vertical gyro pitch gimbal and the inner roll gimbal. This transmitter applies signals to the roll servo amplifier to drive the roll motor-generator. The roll motor-generator, in turn, drives the outer roll gimbal to the level of the inner roll gimbal.

Pitch Sensing. —As the aircraft pitches, the outer roll gimbal follows, but the vertical gyro pitch gimbal remains level. The pitch servo control transmitter detects the pitch attitude and applies pitch signals to the indicators and other aircraft systems. The pitch control transmitter applies pitch signals to the automatic flight control system (AFCS) control amplifier.

Roll Sensing. —As the aircraft rolls, B101 remains level, but the vertical gyro pitch gimbal rolls (with the outer roll gimbal). The inner roll control transmitter senses the difference. It then causes the roll amplifier to drive the roll motor-generator until the outer roll gimbal is level with B101. The outer roll control transmitter (on front end of frame) detects and applies roll signals to indicators and other systems. The roll control transmitter (on aft end of frame) applies roll signals to the AFCS control amplifier.

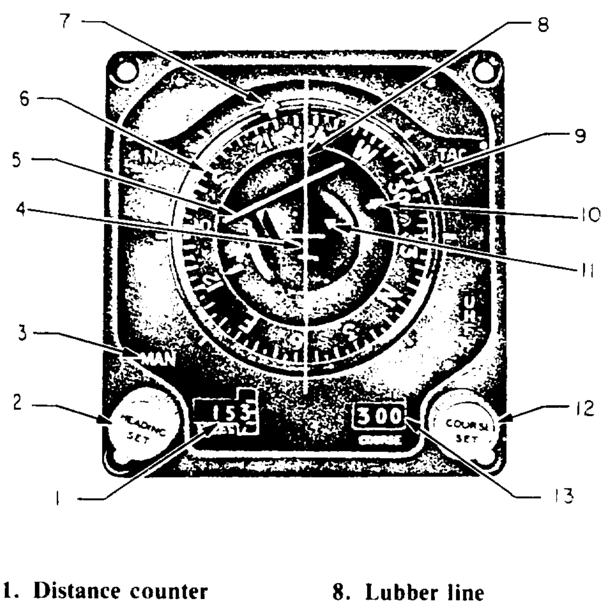
DIRECTIONAL GYROSCOPE OPERATION. —The directional gyro consists of gyro spin motor B201 (including a leveling gimbal), an azimuth gimbal, and a directional gyro pitch gimbal. The directional gyro pitch gimbal mounts in the outer roll gimbal. The pitch gimbal may move 3600 about the pitch axis, but it follows the outer roll gimbal in roll and yaw. The azimuth gimbal mounts in the directional gyro pitch gimbal. It may move 3600 about the yaw axis; however, it follows the directional gyro pitch gimbal in pitch and roll. B201 mounts in the azimuth gimbal. B201 is limited to ±85° by mechanical stops (not shown) to prevent gimbal lock.

Leveling. —The leveling control transmitter output goes to the leveling amplifier, which drives the leveling torquer. When the leveling torquer moves the azimuth gimbal, B201 precesses until the leveling control transmitter senses a level condition. The directional gyro pitch gimbal is servoed to the vertical gyro pitch gimbal and maintained perpendicular to the surface of the earth. The pitch servo control transmitter output, through the pitch servo control transformer, is amplified and drives the pitch follow-up motor-generator. The motor-generator positions the directional gyro pitch gimbal.

Azimuth Sensing. —The azimuth gimbal may settle at any random position in yaw. The only forces acting on the gimbal are gyro rigidity, apparent (earth rate) precession, and the leveling torquer. Azimuth sensing in the directional gyro operating mode is reliable only after setting the correct heading into the system with the SET HDG control. Two azimuth control transmitters sense any movement of the directional gyro pitch gimbal about the azimuth gimbal. The yaw signal of one azimuth control transmitter goes to the attitude indicator. The yaw signal of the other azimuth control transmitter is processed in the compass adapter-compensator and applied to other aircraft systems.

Horizontal Situation Indicator (HSI)

Aircraft, such as the P-3, use the horizontal situation indicator to provide the pilot with a



1. Distance counter
2. Heading set knob
3. Mode light
4. Aircraft symbol (fixed)
5. Course deviation bar
6. Compass card
7. Bearing pointer
8. Lubber line
9. Command heading marker
10. Course pointer
11. To-from pointer
12. Course set knob
13. Course counter

Figure 7-18.-Horizontal situation indicator.

visual indication of the navigational situation of the aircraft. The horizontal situation indicator (fig. 7-18) is on the pilot's main instrument panel. It provides a visual presentation of the horizontal or plane view of the aircraft relative to the navigation situation. It also provides an integrated display of navigation data from various sources. It presents this data to the pilot in a symbolic pictorial display for quick and easy assimilation. The center portion of the display contains an azimuth or compass card (callout 6). The card displays aircraft magnetic heading when read against the top of the lubber line (callout 8). You may also read the bearing pointer (callout 7), course pointer (callout 10), and command heading marker (callout 9) against the card.

The bearing pointer (outer pointer, shown at 2200, provides pictorial bearing information to a ground electronic station. It can also provide a bearing to a base or target (as computed by the navigational computer set). The course pointer (inside compass card, at 3000, shows the selected course to a ground electronic station, or aircraft magnetic ground track. The course deviation bar (callout 5) (center segment of this pointer) shows the aircraft's deviation from a selected course. It shows this pictorially with respect to the stationary miniature aircraft symbol (callout 4) at the center of the display.

A to-from pointer (callout 11) (just above the aircraft symbol) shows if the selected course leads to or from a ground electronic station. A command heading marker (callout 9) just outside the compass card (shown at 3000, shows the command magnetic heading. It also shows, by its angular displacement from the lubber line, the heading error angle. The course pointer and the command heading marker may be set manually by means of the COURSE SET (callout 12) and HEADING SET (callout 2) knobs. They can also be set remotely by external signals to the HSI course command and heading command servos. The selected course to a ground electronic station or aircraft magnetic ground track is also indicated on the course counter (callout 13). A distance counter (callout 1) at the lower left shows the distance in nautical miles. The distance may be to the ground electronic station, base, or target (as computed by the navigational computer set).

There are four mode-of-operation lights (callout 3) (TAC, UHF, MAN, NAV) that show around the display. They illuminate internally to show the selected operating modes. The unilluminated words remain practically invisible. The instrument uses integral lighting.

For detailed operation of the horizontal situation indicator system, refer to the applicable maintenance instructions manual.

Bearing-Distance-Heading Indicator (BDHI)

The BDHI is used with various navigation systems and provides information according to the mode selected. Some aircraft have more than one BDHI, with separate select switches for each instrument. The distance counter numerals may be in a vertical row or horizontal, as the ID-663A/U in figure 7-19.

The lubber index is a fixed reference mark at the top of the instrument face. The compass card (read under the lubber index) shows the aircraft heading (either true or magnetic, depending on the mode used). Two pointers, a single bar and a double bar, can indicate the following:

- Bearing to a ground electronic station
- Bearing to destination
- Aircraft ground track
- Aircraft drift angle
- Heading error

The BDHI select switch selects the available combinations of these indications in a given aircraft configuration.

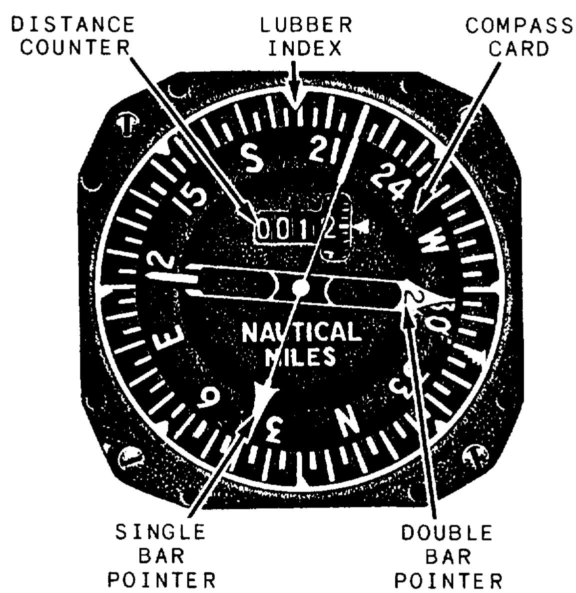


Figure 7-19.-Bearing-distance-heading indicator.

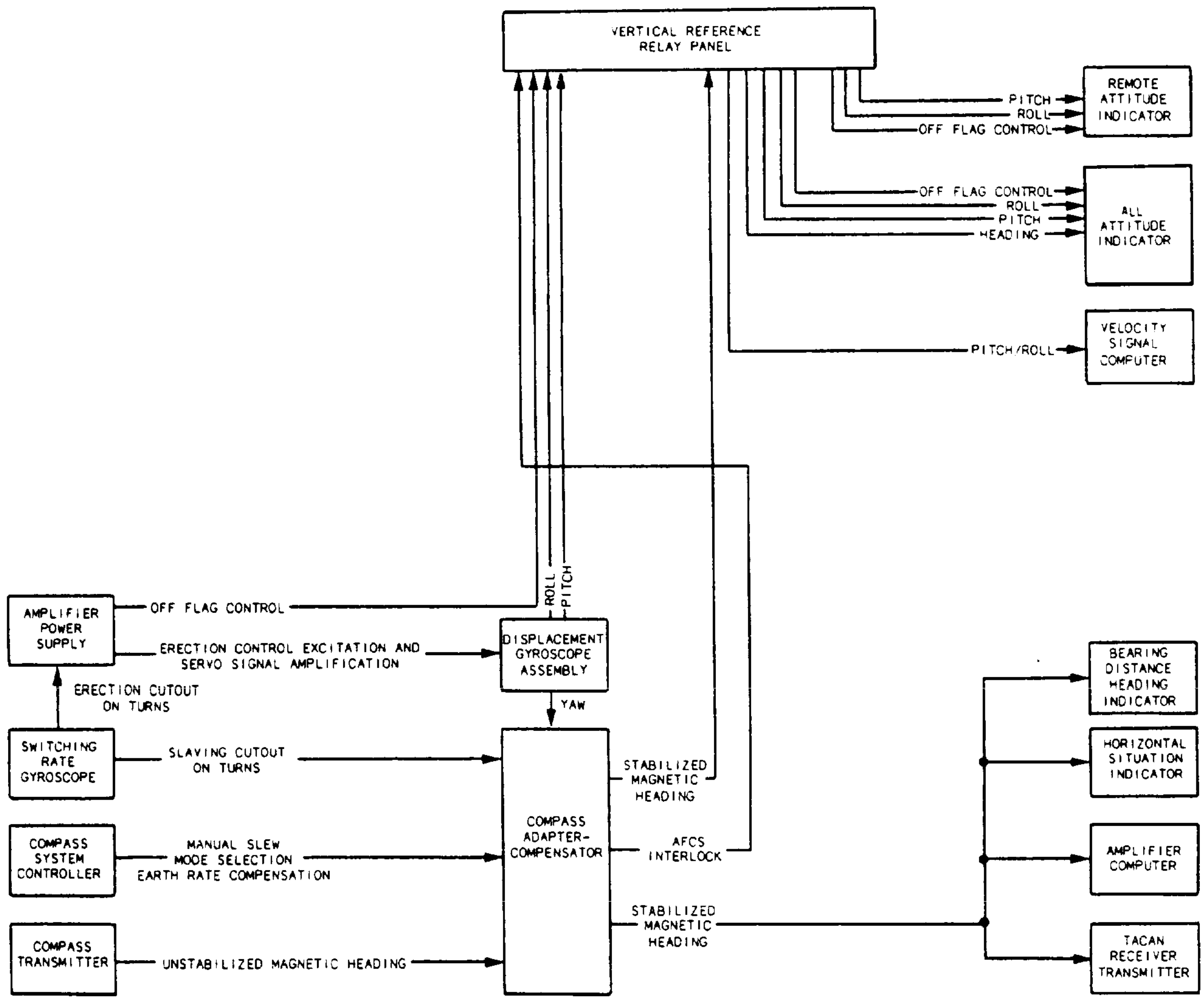


Figure 7-20.-Block diagram of the attitude heading reference system.

Electrical inputs for the compass card and pointers come from synchro transmitters located in other equipment. In the ID-663A/U, synchro torque receivers position the compass card and both pointers, In the ID-663 B/U and ID-663B/V, torque receivers position both pointers. These torque receivers contain a synchro control transformer, a transistor error signal amplifier, and a two-phase servomotor to position the compass card. In the ID-663C/U, the control transformer-amplifier srvomotor positions the compass card and both pointers.

The distance counter may display distance to base, target, or ground electronic station, depending on the mode selected. It consists of three synchro torque receivers to position the units, tens, and hundred numerals. It also has a 1,000 flag to place the numeral 1 preceding the hundreds numeral. This enables the counter to display distance up to 1,999 nautical miles.

The OFF flag covers the distance counter when distance information is not available. In the ID-663B/V, the 1,000 flag and OFF flag are positioned by separate coils, The ID-663A/U, ID-663B/U, and ID-663 C/U have a meter-type movement, which, when de-energized, shows OFF. Partial rotation moves the OFF flag out of view, and full rotation brings the 1,000 flag into view.

ATTITUDE HEADING REFERENCE SYSTEM (AHRS)

The AN/ASN-50 attitude heading reference system (fig. 7-20) generates and provides continuous roll, pitch, and heading signals. These signals go to the aircraft attitude indicator and other avionics equipment. Error signals develop in the displacement gyroscope as a result of displacement of synchro sensing devices from their null position. A remote compass transmitter supplies additional heading information to the system. For detailed information on the AN/ASN-50 system, you should refer to *Reference Altitude Heading,* NAVAIR 05-35LAA-1.

In the attitude heading reference system, roll and pitch information goes directly from the vertical gyroscope to the attitude indicator. The system supplies azimuth information in one of three modes selected on the compass controller—COMP (compass), SLAVE (slaved), or FREE (free).

The **compass mode** is an emergency mode used when the displacement gyroscope is malfunctioning. When operating in the compass mode, the magnetic heading signal from the flux valve integrates with a compensating signal. This integration corrects for magnetic field distortion around the aircraft.

The free mode is used at latitudes greater than 700. You can also use it in areas where the earth's magnetic field has appreciable distortion, and when the flux valve fails. When operating in the free mode, you manually set the initial heading reference, using the compass controller PUSH TO TURN control. After establishing the initial reference, heading information accuracy depends on the directional gyroscope's ability to maintain its position relative to earth.

The slaved mode is the normal operating mode. This mode uses both the flux valve and directional gyroscope signals. The directional gyroscope signal acts as a stabilizer for the flux valve data. Automatic fast synchronization to the magnetic heading occurs during the start cycle and upon switching to the slaved mode. A SYNC IND meter on the compass controller shows when a loss of synchronization occurs. The loss of synchronization occurs between the azimuth heading output and the flux valve. When such a condition exists, you may accomplish fast synchronization by momentarily pressing the compass controller PUSH TO SYNC switch.

Autopilot decoupling occurs whenever manual or automatic synchronization occurs. Circuitry compensates for apparent drift of the gyroscope resulting from rotation of the earth. Other circuitry provides means to interrupt slaving and erection voltages during turns of 15 degrees per minute or greater.

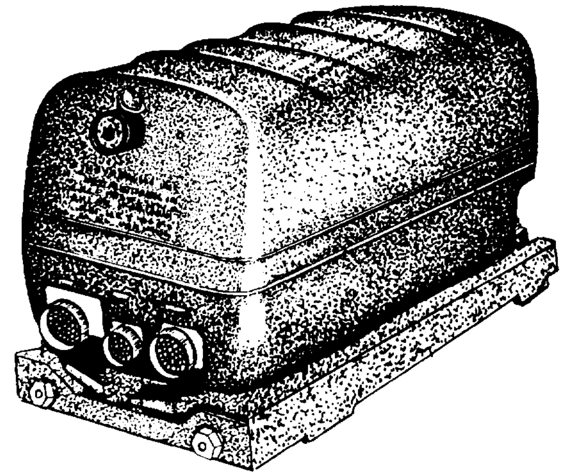


Figure 7-21.-Displacement gyroscope.

Displacement Gyroscope

The displacement gyroscope (fig. 7-21) is a hermetically sealed, two-gyroscope platform providing pitch, roll, and azimuth signals to the system indicating instruments. The vertical gyroscope provides a source of pitch and roll information, while the directional gyroscope provides azimuth (yaw, heading) information. Control transmitters (synchros) convert attitude changes into electrical signals that represent pitch, roll, and yaw. (The AN/ASN-50 displacement gyro is similar to the one discussed earlier in this chapter.)

Erection circuits maintain the spin axis of the vertical gyroscope in a gravity vertical position. These circuits consist of a roll electrolytic switch, with associated roll torquer, and a pitch electrolytic switch, with associated pitch torquer.

A servo loop maintains the spin axis of the directional gyroscope level. The loop consists of a leveling pickoff, an external leveling amplifier, and a leveling torquer.

The vertical gyroscope spin motor mounts in the inner roll gimbal, which is free to move in a roll direction. The freedom of movement in the roll direction is limited to ±82° by mechanical stops to prevent gyroscope gimbal lock. Gimbal lock would occur if the vertical gyroscope spin axis were to become aligned with the vertical gyroscope pitch gimbal. The directional spin motor mounts in the directional gyroscope leveling gimbal. This gimbal is free to move in a roll direction. Mechanical stops also restrict the freedom of the leveling gimbal to ±82°, preventing gimbal lock. These stops also prevent the inversion of the leveling and inner roll gimbal during gyroscope rotor coastdown after system shutdown.

The outer roll gimbal is the outermost gimbal for both the vertical and directional gyroscopes. Pitch control transmitters detect pitch movement of the outer roll gimbal about the vertical gyroscope pitch gimbal. The outer roll control transmitter and directional gyroscope control transmitter mount between the outer roll gimbal and gyroscope case (frame). However, they mount at opposite ends. They sense roll movement of the aircraft (and frame) about the outer roll gimbal.

The azimuth gimbal may settle at any random heading during power application. Therefore, you must slave the directional gyroscope's initial azimuth signal to the flux valve. Also, you can correct it manually to a known magnetic heading. You must do this so the azimuth signal reflects actual aircraft heading. The two azimuth control transmitters, between the azimuth gimbal and the directional gyroscope pitch gimbal, will then furnish information on any further change in aircraft heading.

The displacement gyroscope incorporates snubbers. They maintain the approximate normal position of the outer roll gimbal and the directional gyroscope pitch gimbal when power is removed. Upon application of power, the snubbers energize, removing their snubbing action. The motor-generator and gear assemblies that drive the gyroscope gimbals have enough power to override the snubbing action should a snubber failure occur.

Amplifier Power Supply

The amplifier power supply (fig. 7-22) contains the following components:

- An ac and a dc power filter
- Two power supply modules
- A roll driver amplifier
- Roll, pitch, and leveling servo amplifiers
- A leveling modulator
- A servo failure monitor module
- Two thermal relays
- Ten control relays

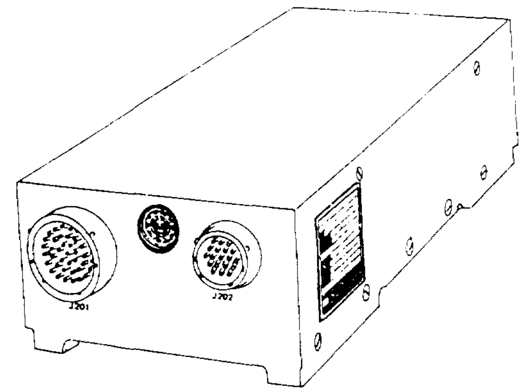


Figure 7-22.-Amplifier power supply.

The amplifier power supply provides the timing, switching, and voltages required for the start cycle; erection voltage control during system operation; monitoring roll and pitch signals and the neutral power lead of the vertical gyroscope motor; and the roll, pitch, and leveling amplifiers required for control of the displacement gyroscope gimbals.

Aircraft three-phase power goes to the amplifier power supply. It then routes through the ac power filter. The filtered three-phase power then goes to other system components. A power supply connected to all three legs of the three-phase power provides 28-volt dc, which goes to a filter. System components use both filtered and unfiltered dc.

The second power supply is a three-section supply. Each section is independent of the other and supplies 95 volts dc. The dc outputs connect to various control relays within the amplifier power supply.

The output from the displacement gyroscope photoelectric pickoff is a dc voltage. A leveling modulator converts it to a 400-hertz ac voltage. The amplitude and phase of the modulator output depends on the amplitude and polarity of the dc voltage from the photoelectric pickoff. The 400-hertz ac voltage goes to the leveling amplifier; then the amplified signal goes to the directional gyroscope leveling torquer control winding.

Roll and pitch error signals from the displacement gyroscope are amplified by the roll and pitch amplifiers. After amplification, the signals go to the displacement gyroscope for application to the roll and pitch motor-generator control windings. The roll and pitch motor-generators

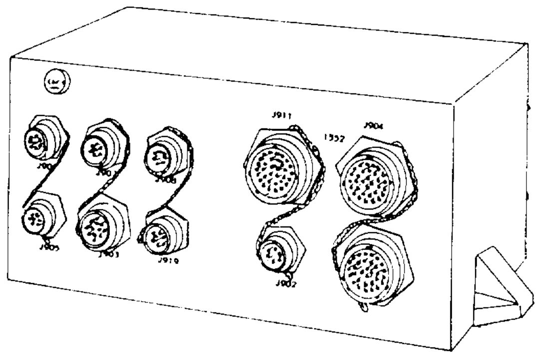


Figure 7-23.-Compass adapter compensator.

drive the displacement gyroscope roll and pitch gimbals.

Two thermal relays and nine control relays perform the timing and switching required for the start cycle. The start cycle is of 60 seconds duration. However, certain conditions change after the first 12 seconds. High pitch erection voltage goes to the pitch torquer for the complete start cycle. High roll erection voltage goes to the roll torquer after 12 seconds and continues until the completion of the start cycle. After the first 12 seconds, motor excitation voltage increases, and the gyroscope motors attain operating speed. After completion of the start cycle, two additional relays provide roll and pitch erection cutout during specific aircraft maneuvers.

Compass Adapter Compensator

The compass adapter compensator (fig. 7-23) receives heading information from the flux valve and the displacement gyroscope. It processes this information according to the azimuth mode selected by the compass controller. It then provides corrected heading signals to the heading indicator and other aircraft systems. The compass adapter compensator can operate in the following modes: free, compass, and slaved.

In the free mode of operation, you engage the PUSH TO TURN control on the compass cent roller to set actual aircraft heading. This establishes an initial azimuth reference. As aircraft heading changes, an azimuth synchro on the directional gyro measures the relative change between the aircraft and the directional gyroscope. The signal goes to the compass adapter, which makes corrections for real and apparent drift. The compensating signal for apparent drift is derived from a resolver in the compass controller. The EARTH RATE CAL variable resistor in the compass adapter adjusts this signal. Real drift is caused by mechanical imperfections in construction of the directional gyroscope. The compensating signal for real drift develops across the compass adapter GYRO DRIFT COMPENSATION POT variable resistor. This resistor has a dial calibrated in degrees per hour. The corrected information goes to external aircraft system components through five heading repeater synchros.

When operating in the compass mode, the 24-point compensation network corrects the flux valve signal for deviations. This signal goes as an error signal to the azimuth servo loop, resulting in corrected azimuth information (angle data shaft). Again, this information goes to external aircraft system components through five heading repeater synchros.

In the slaved mode, the directional gyroscope azimuth information and a compensated flux valve heading correction signal go to a differential synchro in the compass adapter. This slaves or synchronizes the gyroscope azimuth output to the flux valve heading, providing a heading output rather than a displacement output. Fast synchronization starts when the slaved mode is selected and is maintained until close alignment is achieved. Slow synchronization is applied continuously while operating in the slaved mode.

Compass Controller

The compass controller (fig. 7-24) provides switching functions, latitude compensation signals, and slew signals to the system compass

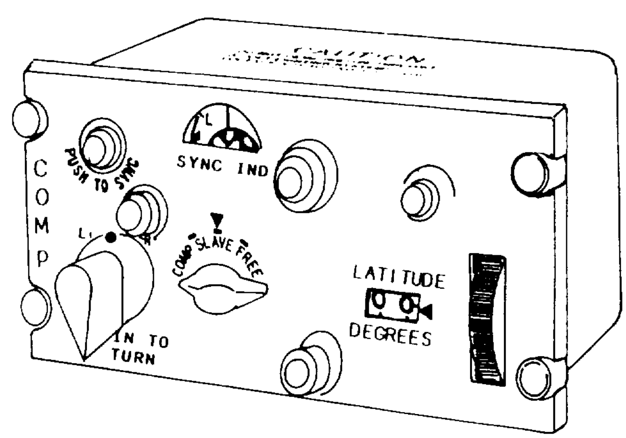


Figure 7-24.-Compass controller.

adapter. The compass controller also monitors and provides a visual display of the synchronization between the azimuth heading output and the flux valve.

The compass controller can operate in three modes—slaved, free, and compass. The compass controller contains a PUSH TO SYNC switch and SYNC IND meter. It also has a PUSH TO TURN control, mode switch (with COMP, SLAVE and FREE positions), and LATITUDE DEGREES control (counter assembly).

The mode switch selects the FREE (free), SLAVE (slaved), and COMP (compass) modes of operation. To accomplish this, it controls the mode-selecting relays in the system compass adapter. The mode switch also activates the SYNC IND meter during compass and slaved modes.

The PUSH TO TURN control (set heading) provides switching to decouple the autopilot. Also, it controls the direction and rate of slewing for alignment of the system to an azimuth heading. This switching action occurs when using the PUSH TO TURN control to reference the system output to the aircraft heading in the free mode.

The PUSH TO SYNC switch provides switching to synchronize azimuth heading output to the flux valve when operating in the slaved mode.

The LATITUDE DEGREES control, working with a resolver, provides a compensation signal for apparent drift of the directional gyroscope. Apparent drift results from earth rotation.

The hemisphere switch (N,S) selects the latitude correction signal for the Northern or Southern Hemisphere.

The SYNC IND meter shows the synchronization between the azimuth heading output and the flux valve.

The slaved mode is the normal operating mode except when in an area where the earth's magnetic field is distorted. The slaved mode synchronizes the directional gyroscope output to the flux valve heading. When initiating the slaved mode, fast synchronization occurs until close alignment with the flux valve heading is achieved.

Free mode is an alternate mode of operation. It is used in areas where the earth's magnetic field is distorted. When operating in the free mode, only the directional gyroscope output drives the system's azimuth indicators.

The compass mode is an emergency mode for use when the directional gyroscope fails. Only the flux valve output (compensated) provides heading information.

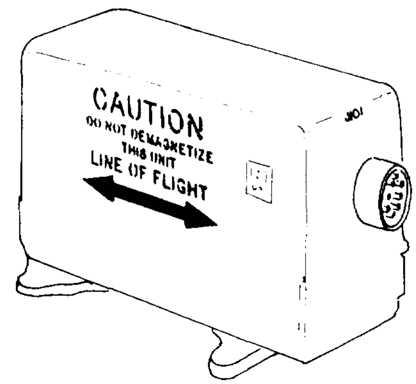


Figure 7-25.-Switching rate gyroscope.

Rate Gyroscope

The switching rate gyroscope (fig. 7-25) provides a means of interrupting the roll erection and slaving voltage. It is a single-degree-of-freedom gyroscope. It provides gyroscope sensitivity to rates of rotation about the yaw axis of the aircraft. When the aircraft turns at rates of 150 per minute or greater, the gyroscope precesses away from the normal condition. This causes the contacts of a magnetic reed switch to close, energizing a single-stage amplifier. Transistor switching action pulls in a relay, completing the 28-volt dc path to the turn cutout relay coil in the compass adapter.

Attitude Indicator

The attitude indicator (fig. 7-26) is a three-axis, servo-driven sphere that shows heading and relative roll and pitch attitude of aircraft. Vertical and horizontal pointers provide the pilot with aircraft deviation information from a desired flight path. Signals for operating servo systems of hermetically sealed units are from the displacement gyroscope. Aircraft rate of turn information and vertical displacement deviations from a desired glide path are displayed by a rate of turn pointer and displacement pointer, respectively. Loss of ac power is indicated by a display of a power failure warning flag. Inadequate current to vertical, horizontal, and displacement pointers results in display of respective warning flags. A pitch trim knob lets you adjust the sphere to varying aircraft configurations and reduce parallax error.

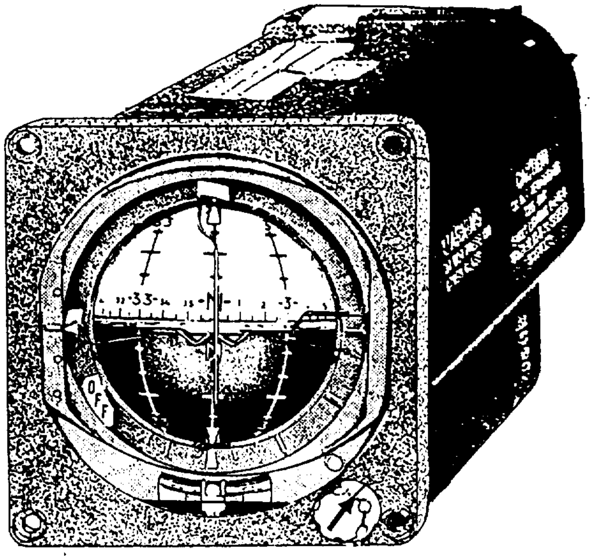


Figure 7-26.—Attitude direction indicator.

REVIEW SUBSET NUMBER 2

Q1. What is the purpose of the four-gimbal system in inertial navigation systems?

Q2. When operating the AN/ASN-50 attitude heading reference system, when do you use the compass mode?

INERTIAL NAVIGATION SYSTEM

Learning Objective: *Recognize the operating principles and characteristics of the inertial navigation system, to include Schuler loops and tuning; and identify navigation errors and aligning and calibration procedures.*

The following paragraphs describe a heading reference system found on the latest model high-speed aircraft and some patrol aircraft. The inertial navigation system (INS) is sometimes maintained by the Aviation Electronics Technician (AT) rating. Some squadrons use a concept called an integrated weapons team (IWT). It is composed of the three avionics/armament division (work center 200) ratings—AT, AO, and AE. Regardless of who maintains the INS, you, must be familiar with the theory and operating principles of such a system.

You may define navigation as the process of directing a vehicle from one point to another. Basically, navigation can be divided into two categories: (1) position fixing and (2) dead reckoning. In the first category, you determine your position relative to positions of known objects such as stars and landmarks. The most common example of navigation by position fixing is celestial navigation. Use of loran is another example of navigation by periodic position fixes. Dead reckoning, the second category, is the process of estimating your position from the following known information:

- Previous position
- Course
- Speed
- Time elapsed

Two examples of navigation by dead reckoning are Doppler radar and inertial navigation systems.

All navigation systems, except the inertial type, rely on some bit of information external to the vehicle to solve its navigational problem. In this respect, the inertial navigation system stands alone; it is completely self-contained within the vehicle. It is independent of its operating environment, such as wind, visibility, or aircraft attitude. It does not radiate RF energy; therefore, it is impervious to countermeasures. It does not depend on ground transmission or any other outside source to determine its instantaneous position. The inertial navigation system simply makes use of the physical laws of motion that Newton described three centuries ago.

BASIC PRINCIPLES

The operating principle of the inertial navigation system (INS) is Newton's first law of motion. This law states *"Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed on it."* In laymans terms, this law says that a body at rest tends to remain at rest. It also says a body in motion tends to remain in motion, unless acted upon by an outside force.

The full meaning of Newton's first law is not easy to visualize in the earth's reference frame because Newton's laws apply to an inertial reference system. You may define an inertial reference system as a nonrotating coordinate frame. It can be either stationary or moving linearly at a uniform speed, in which there are no inherent forces such as gravity.

You can make a simple test of whether you are in a true inertial system by releasing an object and observing its motion. If you release the object without imparting any acceleration to it, the object remains in its position relative to you. If you throw the object, it continues on an undeviating path at a constant speed. Such a system can exist only in empty space, far from any mass, for all masses contain gravitational forces. A reference system attached to the earth can closely approximate an inertial system. For this system to work, you must balance the gravitational force on a body by a second force. For example, an object sliding on a flat, frictionless plane on the earth's surface would move in a NEARLY straight line. The object will have a NEARLY constant speed, as you saw in the earth's coordinate system.

NOTE: The word *nearly is* emphasized because the object will deviate slightly from its straight-line motion. The cause of this deviation is the earth's rotation about its axis.

Newton's second law of motion shares importance with his first law in the inertial navigation system because the inertial navigation system works on Newton's second law. Newton's second law of motion states *"Acceleration is proportional to the resultant force and is in the same direction as this force."* Thus, the second law is written

$$F = ma$$

where

F = force

m = mass

a = acceleration

The physical quality in the above equation that pertains to the inertial navigation system is acceleration. You can derive velocity and displacement from acceleration. For example, consider this fact: Before an object can change its state of rest or state of motion, it must first experience an acceleration. Since acceleration is a change in velocity and velocity is a change in position, acceleration is a change in the change of position. However, before any change can have meaning, it must include the unit of time. Therefore, you can define a change per unit of time as a rate of change. Thus, a rate of change of displacement is velocity. A rate of change of velocity is acceleration. A rate of change of a rate of change of displacement is acceleration.

Differentiation is the process of investigating or comparing how one physical property varies with respect to another. *Integration,* the reverse of differentiation, is the process of summing all rate of changes that occur within the limits under investigation.

The inertial navigation system is not a differentiating system; it is an integrating system. However, before integration can be done, it must first have a rate of change. Therefore, the inertial navigation system, when stripped to its barest essentials, is a detector and an integrator. It first detects changes of motion. It then integrates these changes of motion with time to arrive at velocity, and again with time to arrive at displacement.

Fundamentals of Integration

Since an INS performs integration, the following is a review of integrating principles.

The equations for the integrals of acceleration and velocity are —

$$\int a\,dt = v$$

$$\int v\,dt = s$$

$$\int\int a\,dt\,dt = s$$

where,

s = displacement,

v = velocity,

a = acceleration,

$\int$ = integration symbol, and

dt = time differential.

When acceleration (a) is integrated ($\int$) over a specific period of time (dt), the result is velocity ($\int a\,dt = v$). When velocity (v) is integrated ($\int$) over a specific period of time (dt), the result is displacement (s). Therefore, when acceleration (a) is integrated twice($\int$) over a specific period of time (dt^2), the result is displacement (s).

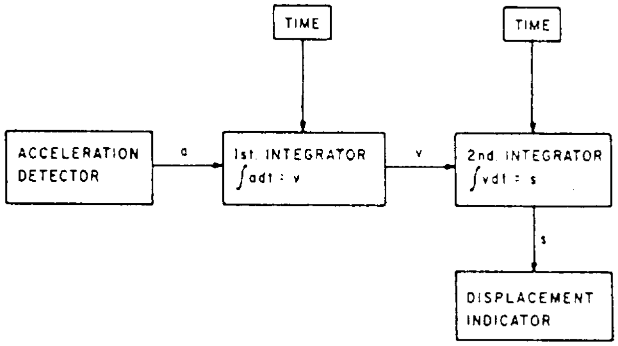


Figure 7-27.-Simple single-axis INS block diagram.

Remember from elementary physics that acceleration, whose units are ft/sec^2, multiplied by time in seconds is velocity in ft/sec. Also, that velocity (ft/sec) multiplied by time (sec) is displacement (ft). The integration of acceleration, for example, is the mathematical process of summing all minute acceleration-time increments over a given period. The result of the integration of acceleration is velocity over the same period. The same integration process performed on velocity gives displacement or distance traveled over the same period.

Simple Single-Axis Inertial Navigation System

An example of how a simple single-axis INS operates is illustrated as follows: Assume a person is on an INS-equipped train on railroad tracks at the equator. The tracks run in a straight line east and west only, The INS consists of an acceleration detecting device (accelerometer), an integrating device, and a displacement readout device. The accelerometer can sense movement in only one direction, along its sensitive axis. The sensitive axis is an imaginary line parallel to the movement of the mass within the detecting device. The acceleration detecting device is oriented in the train so that it detects accelerations when the train is moving forward or backward. Figure 7-27 is a block diagram of such a device.

If the train starts moving at point A, you will note a specific reading on the displacement readout device. When the train reaches point B and stops, the readout device will show the new position. The distance traveled from point A to point B added to the reference value noted at point A will show on the displacement indicator. The train returns to point A by traveling backwards. Thus, the simple inertial device is not disoriented. At point A the readout device shows the value that was chosen as a reference. This is the displacement at point B minus the distance traveled from point B to point A.

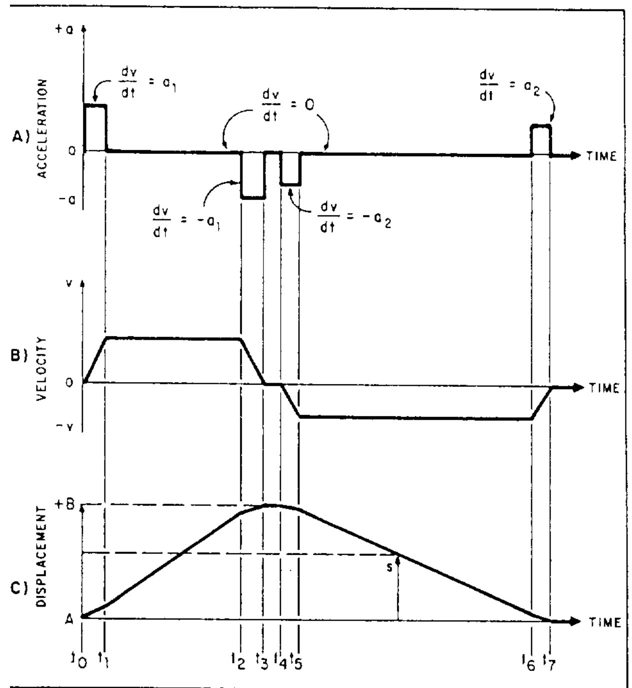


Figure 7-28.-Integration of acceleration and velocity: (A) acceleration, (B) velocity, (C) displacement.

Figure 7-28, view A, is a graph of the detected acceleration. View B is the velocity curve obtained by integrating the acceleration curve shown in view A. View C is the displacement curve obtained by integrating the velocity curve shown in view B. All three curves are plotted as a function of time.

The acceleration curve (fig. 7-28, view A) begins at time to as the train begins to travel from point A. Look at view C. The acceleration at time to has a value of al, and it remains at that value until t_1. At t_1 the train ceases to accelerate. Therefore, acceleration goes to zero. At this point, the train reaches a steady velocity. The train continues traveling at a constant velocity until time t_2 where the train begins to stop. The acceleration detector detects an acceleration equal in value to a_1, but its direction is opposite. This acceleration is constant from time t_2 to time t_3. At t_3 the acceleration goes to zero. The train is now stationary and standing at its destination—point B.

Look at the velocity curve for the time interval to to t_3 (fig. 7-28, view B). It is the result obtained when acceleration is integrated over the same interval. The velocity curve is the output of the first integrator from t_o to t_3. During the interval t_o to t_1, velocity is changing in an increasing or positive direction. This means that a positive acceleration is taking place. Velocity is constant during interval t_1 to t_2, which means acceleration is zero. At time t_2, velocity begins to decrease. This says that an acceleration is again taking place. In this case the acceleration is negative. At time t_3, both acceleration and velocity are zero.

The purpose of an INS is to keep track of position and not total distance traveled. To do this it integrates all values of acceleration (positive and negative) detected over the interval. Therefore, it is the net value of acceleration that interests the INS. For instance, in the interval t_o to t_3, all accelerations that occur over the interval are summed, giving a net value at time t_3. In this case, integration of acceleration (fig. 7-28, view A) is the process of summing the area bounded by the acceleration curve and the time axis. The area above the time axis is positive, and the area below the time axis is negative. Since the areas above and below the time axis are equal, the net value for interval to to t_3 acceleration is zero. The integral of acceleration for the interval to to t_3 is therefore zero. This means that the velocity at time t_3 is equal to the velocity at time to, in this case zero.

Integrating velocity from time t_0 to t_3 is the job of the second integrator. It gives B units of displacement on the displacement axis at time t_3. The displacement readout device changes continuously as long as the second integrator produces an output. The second integrator ceases to produce an output when the first integrator (velocity) ceases to produce an output. The velocity integrator continues to produce until receiving an acceleration that balances out the initial acceleration. At this point, it produces a net acceleration of zero. The readout device stops at the point where the net acceleration is zero. Until reaching this condition, the readout device shows a continuous change in displacement.

The return trip is described as follows. The train is at point B during time interval t_3 to t_4; it begins traveling backwards to point A at time t_4. The acceleration detector senses an acceleration $-a_2$, which is negative and slightly less than the previous acceleration, $-a_1$. At time t_5 it reaches a steady velocity, and acceleration goes to zero at this point. Note that velocity is now negative since the direction of travel is reversed. Since the size of acceleration $-a_2$ is less than that of al, maximum velocity on the return trip is less. Therefore, the time required to return to point A is greater. Interval t_o to t_7, greater than time interval t_o to t_3 reflects this fact. The train begins to stop within a short distance of point A. This happens at time t_6, producing an acceleration of a_2 as sensed by the acceleration detector. The train comes to a full stop at time t_7. Here the detector senses zero acceleration. Since the net acceleration over the interval is again zero, the output of the first integrator (velocity) is zero. The second integrator (displacement) output stops with the displacement readout device showing the reference value. This value is the same originally noted at reference point A.

The simple single-axis INS just described will detect and compute all changes in displacement. However, the acceleration detector (accelerometer) must **retain** its straight-line orientation. Also, all

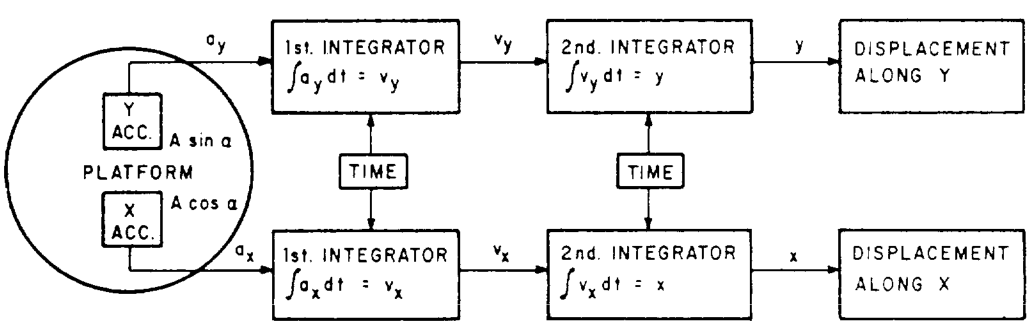


Figure 7-29.-Two-axis inertial navigation system, block diagram.

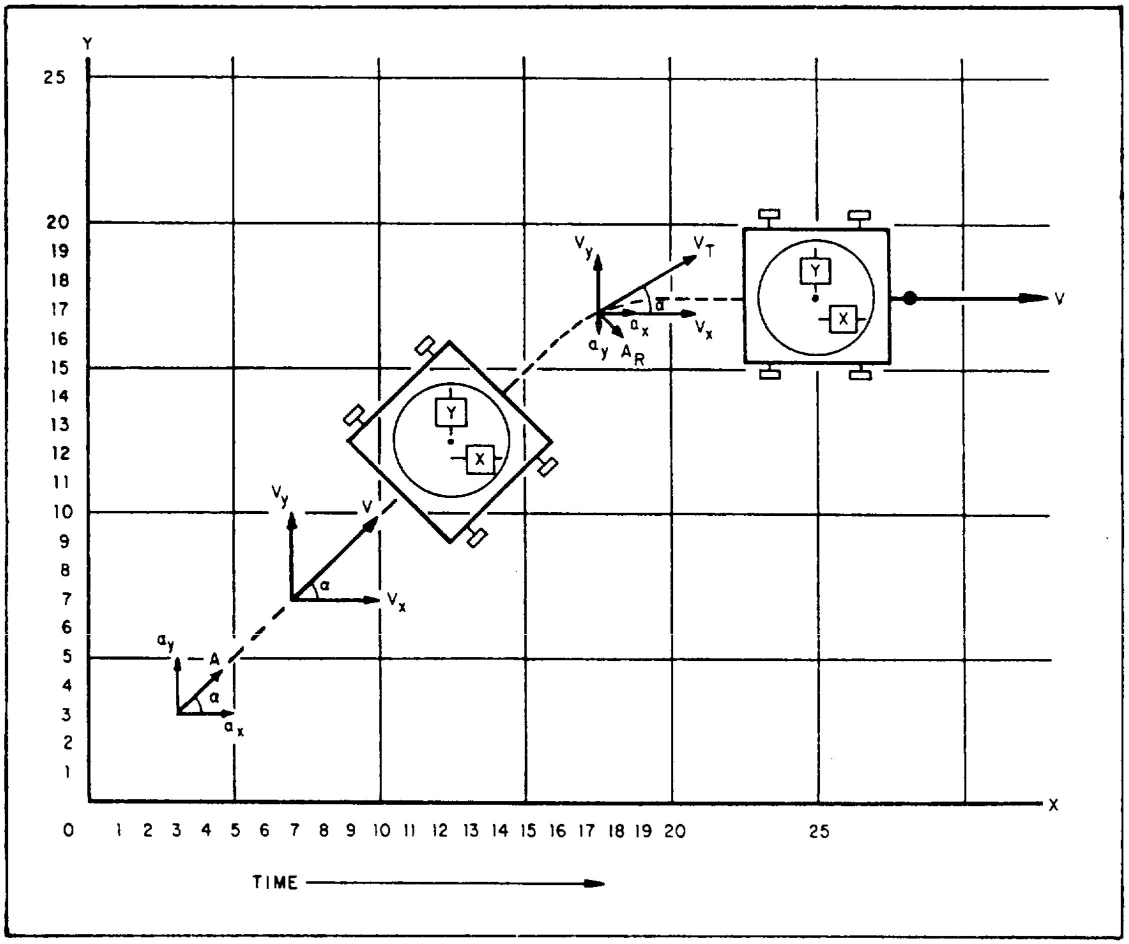


Figure 7-30.-Two-axis inertial platform in a plane coordinate system.

motion must be along a straight line passing through the reference or initial point. Obviously; using this simple INS, a person must navigate along a straight line.

Two-Axis Inertial Navigation System

Suppose, for example, that the earth is flat. If so, you can determine position by using a system of coordinate axes. This system of coordinates uses two sets of parallel lines (x and y). One set of lines is perpendicular to the other set of lines. These lines form a grid network over the earth's surface.

If you use two single-axis inertial navigation systems, you can determine position on the plane (flat surface). You simply maintain proper orientation of each accelerometer's sensitive axis relative to the coordinate system. One accelerometer mounts on a platform so that its sensitive axis lies along the x-axis. The other accelerometer mounts on the same platform so its sensitive axis lies along the y-axis. This will maintain their axes mutually perpendicular. The accelerometers will then sense any rate of change of velocity along the coordinate axes. Figure 7-29 is a block diagram of a simplified two-axis inertial navigation system.

Figure 7-30 is an illustration of the inertial platform mounted on a vehicle moving over a plane coordinate system. Note that the platform and accelerometers remain oriented with the coordinate axes regardless of vehicle heading. The vehicle's ground track represents the vehicle's displacement over the grid system. You can locate the vehicle at any given time by the x and y coordinates. You plot the x-displacement left to right, and the y-displacement is top to bottom on the page. You reference time to the x-axis.

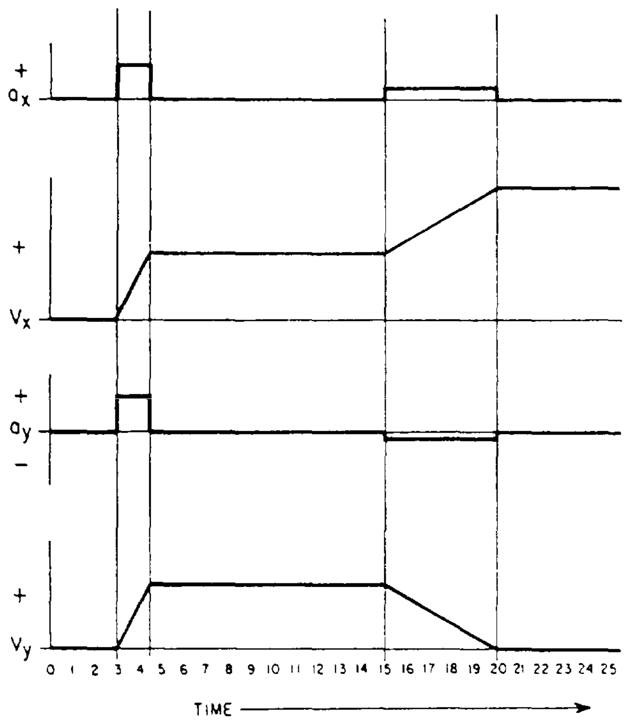


Figure 7-31.-Acceleration and velocity curves.

Figure 7-31 is an illustration of a typical set of acceleration and velocity curves from the INS shown in figure 7-30.

Referring to figures 7-30 and 7-31, the operation of the plane inertial navigation system is explained as follows: The vehicle aligns (initializes) on the coordinate system with a displacement of 3 on the x and y axes. That is, both x and y displacement indicators read 3. At time t_3, the vehicle experiences an acceleration, A, in a direction of 45° from the x-axis. The accelerometers detect only that portion of the acceleration that lies along its sensitive axis. This means the x-accelerometer detects the component of acceleration along the x-axis. This is A cos a. The y-accelerometer detects the component of A along the y-axis, which is A sin a. The vehicle continues in a direction of 45° until time t_{15}. At this time it begins a turn to the right. Since sine and cosine are equal at an angle of 450, the displacements along x and y are equal at time t_{15}. This says x = 15 and y = 15. Also, it means the acceleration and velocity along the x-axis is equal to the acceleration and velocity along the y-axis.

At time t_{15}, the vehicle begins a right turn, it completes the turn at time t_{20}. The new direction is parallel to the x-coordinate and perpendicular to the y-coordinate. By looking at figure 7-31, you see interval t_{15} to t_{20} shows the x-accelerometer detecting a positive acceleration. It also shows the y-accelerometer detecting a negative acceleration during this interval. If the vehicle maintains a constant speed throughout the turn, the detected acceleration results from a velocity change. This change is due to a change in direction rather than a change in speed. This acceleration is radial (centripetal) acceleration (A_R). The direction of the radial acceleration is toward the center of the turn and perpendicular to tangential velocity (V_T). Find coordinates (17.5, 17) in figure 7-30. If the speed hadn't been constant during the turn, a *tangential* acceleration (A_T) would have occurred. This acceleration would parallel the tangential velocity (V_T) vector and be normal (at a right angle) to the radial acceleration vector (A_R). The direction of the tangential acceleration would depend upon whether the speed was increasing or decreasing, positive or negative. If the turning vehicle's acceleration is due to changes in speed and direction, the accelerometers detect the x and y components of the resultant of the two accelerations.

Remember, when detecting acceleration of an accelerating body, accelerometers detect only the component of the resultant acceleration along their sensitive axis. Accelerometers can't tell if the detected velocity change is due to a speed change or a direction change or both, Nor does it matter what forces cause the velocity changes. The result is the same, provided the accelerometers maintain correspondence with the coordinate axes.

Refer to the acceleration and velocity curves in figure 7-31. Notice the integration of the x-component of acceleration for the interval t_{15} to t_{20}. It shows an increase in the x-component of velocity and, therefore, a corresponding increase in displacement along the x-axis. Integration of the y-component of acceleration over the same interval shows that the velocity goes to zero at time t_{20}. Therefore, the displacement along the y-axis ceases to change. Hence at time t_{15}, the displacement is (15, 15). At time t_{20}, the displacement is (20, 15) and at time t_{25}, the displacement is (25, 15), etc.

The INS just described navigates very well on a flat surface. However, navigation on the earth requires a highly complex inertial system. The earth, of course, is not flat, neither is it exactly round. Its radius at the poles is less than its radius at the equator. It also spins about its polar axis and orbits around the sun. You must take all of these factors into account and correct them (except the earth's motion in orbit around the sun). Once you accomplish these corrections, you may navigate on the earth by inertial means. The earth's motion about the sun does not affect an earth inertial navigation system. This motion is translational, and it is equal at all points on the earth.

BASIC SYSTEM COMPONENTS

The inertial navigation system continuously measures aircraft accelerations to compute aircraft velocity and change in present position. These measurements are made by precision inertial devices mounted on a three-axis stable element, which is part of a four-gimbal structure. The four-gimbal structure allows the stable element to move with 360 degrees of freedom about the three axes.

Two gyros provide gimbal stabilization signals to maintain the stable element level with the earth's surface and aligned to true north. Also, the system uses these signals to measure aircraft pitch-and-roll attitudes. The inertial characteristics of the gyroscopes used in the system define and maintain the reference axes for relatively long periods with great accuracy. With a gyrostabilized platform as a reference, it is possible to accurately detect components of motion in any direction. To do this, precision accelerometers and analog or digital computers are used in an INS.

Accelerometers

The primary data source for the inertial navigation system is the accelerometer. Three accelerometers are mounted on the stable element between the gyros. They provide output signals proportional to total accelerations experienced along the three axes of the stable element. The system uses these accelerations to produce aircraft velocities and changes in position.

An accelerometer consists of a pendulous mass that is free to rotate about a pivot axis in the instrument. Figure 7-32 shows one form of this device. It has an electrical pickoff that converts the rotation of the mass about the pivot axis to an output signal. An acceleration of the device to the right causes the pendulum to swing to the left. This provides an electrical pickoff signal,

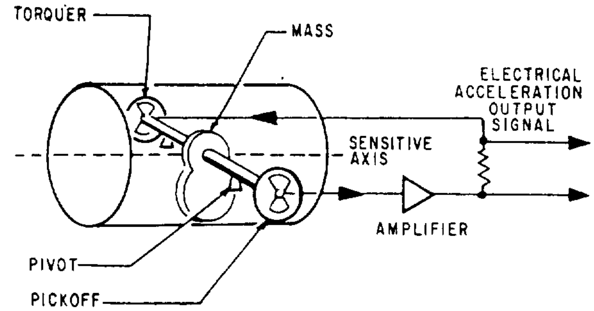


Figure 7-32.-Typical torque-balanced accelerometer.

which causes a torquer to restrain the pendulum. The pickoff signal goes to a high gain amplifier. The output of the amplifier connects to the torquer on the accelerometer. During an acceleration, this feedback loop sends a voltage to the torquer. This voltage holds the pickoff signal at a null under the influence of the measured acceleration. This voltage is proportional to the measured acceleration. It also provides the electrical output acceleration signal that goes to the computer.

The accelerometer (fig. 7-33, view A) cannot distinguish between the acceleration of the

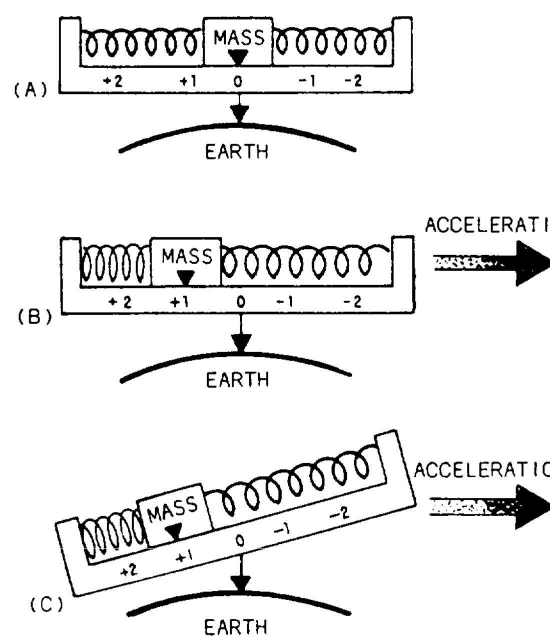


Figure 7-33.-Principle of an accelerometer: (A) accelerometer at null, (B) true acceleration, (C) spurious acceleration due to gravity.

vehicle and gravitational acceleration. Therefore, if the accelerometer tilts off level, its output includes a component of gravitational acceleration as well as vehicle acceleration. Look at figure 7-33, view C. To get the correct vehicle acceleration in the horizontal plane, hold the sensitive axis of the accelerometer normal to the gravitational field. Refer to figure 7-33, view B.

The accelerometer mounts on a platform (stable element) in a way that it is always level. In this position the accelerometer measures true aircraft acceleration in a horizontal direction along its sensitive axis. Mounting another level accelerometer perpendicular to the first one gives you the x and y axes. The system can now determine total true acceleration in a horizontal plane for any movement in any direction.

Integrators

To convert the measured acceleration to aircraft position information, the system processes the acceleration signals to produce velocity information. It must then process the velocity information to derive distance traveled. Figure 7-34 shows an analog type integrator. It is an electromechanical device that receives electrical input (acceleration or velocity) and produces a shaft speed proportional to the input. The shaft angle is the output of the integrator, and it is the mathematical integral of the input. If the input is acceleration, the output is velocity; if the input is velocity, the output is distance.

If one of the horizontal accelerometers points north, the other one will always point east. By connecting the accelerometer outputs to

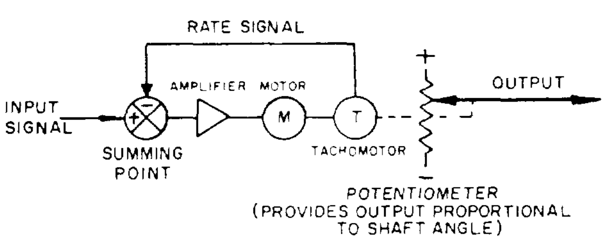


Figure 7-34.-Analog integrating device.

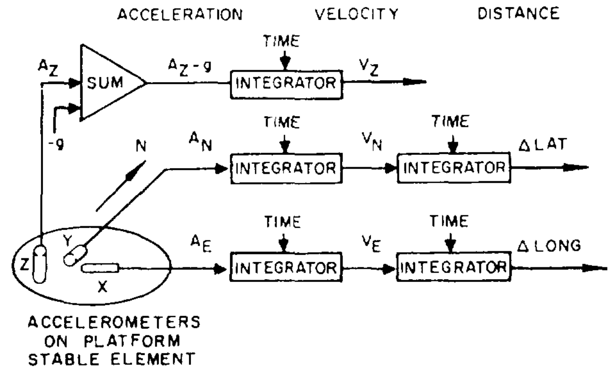


Figure 7-35.-Basic inertial navigation system.

integrators (fig. 7-35), the system can determine distance traveled in the north-south and east-west directions. It is important to maintain the proper accelerometer pointed north and maintain both accelerometers horizontal to the earth's surface. If the accelerometers tilt off level, it measures gravitational components, which results in navigation errors. A third accelerometer sometimes mounts on the stable element in the vertical plane to determine vertical acceleration. The computer subtracts the gravity component from the output of the accelerometer. The resulting signal represents actual aircraft vertical acceleration. A vertical acceleration signal goes to an integrator in the attitude computer. This computer computes vertical velocity.

Platform Stable Element

To maintain the proper orientation of the accelerometers, they mount on a stable element together with gyroscopes. The gyroscopes are the sensing elements for controlling the orientation of the stable element. The stable element (fig. 7-36) mounts on gimbals, which isolate it from angular motions of the aircraft.

GYROSCOPES. —The stable element contains two identical, floated, two-degree-of-freedom gyroscopes. They mount one on top of the other in a dumbbell configuration (fig. 7-36). The gyroscopes have their spin axes horizontal and at right angles to each other. The wheels in these gyroscopes, which spin at high speed, resist any effort to change the orientation of their spin axes.

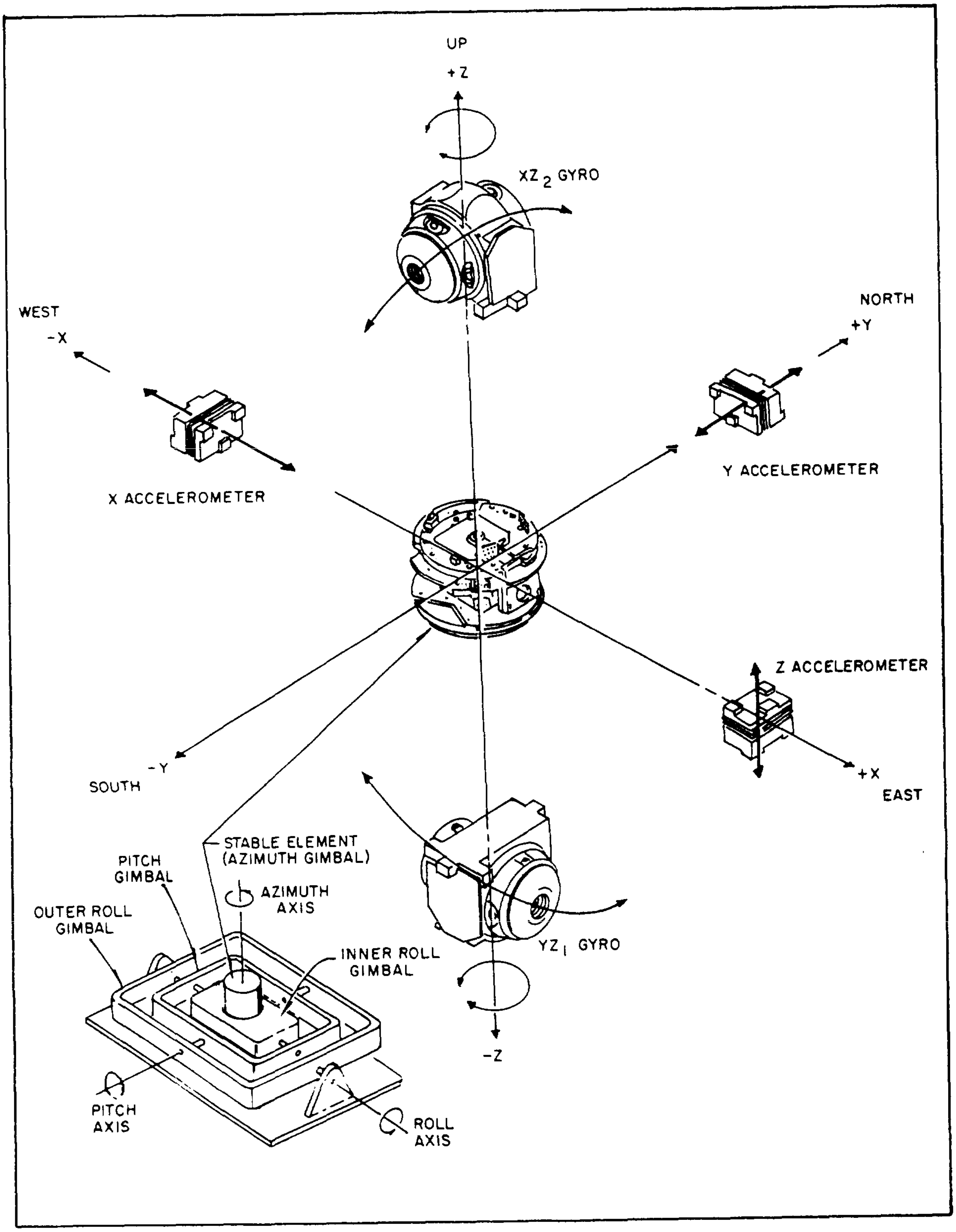


Figure 7-36.-Simplified platform stable element.

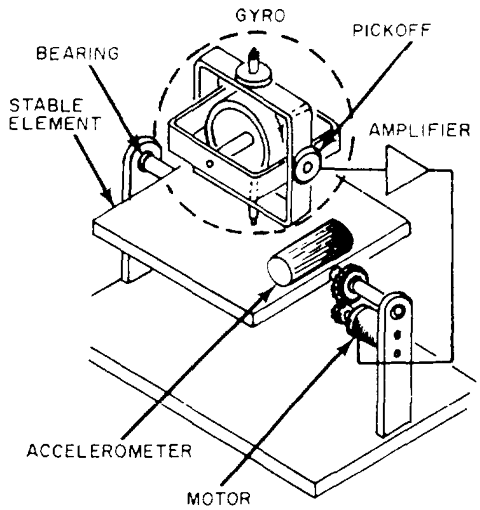


Figure 7-37.-Single-axis, gyrostablized platform.

Figure 7-37 shows a two-degree-of-freedom gyro and a single-axis stable platform. The pickoffs on the gimbals within the gyro produce electrical signals. These signals occur when the gyro case moves from its null position with respect to the gyro motor. The electrical pickoffs will sense any displacement of the stable element from the frame of reference. The signals thus created drive the platform gimbals to realign the stable element.

PLATFORM GIMBAL STRUCTURE. — Figure 7-36 shows the four-gimbal platform configuration actually used in an inertial navigation system. The stable element mounts in the gimbal structure so that, regardless of aircraft maneuvers, it retains the original orientation. The stable element serves as a level mount for the

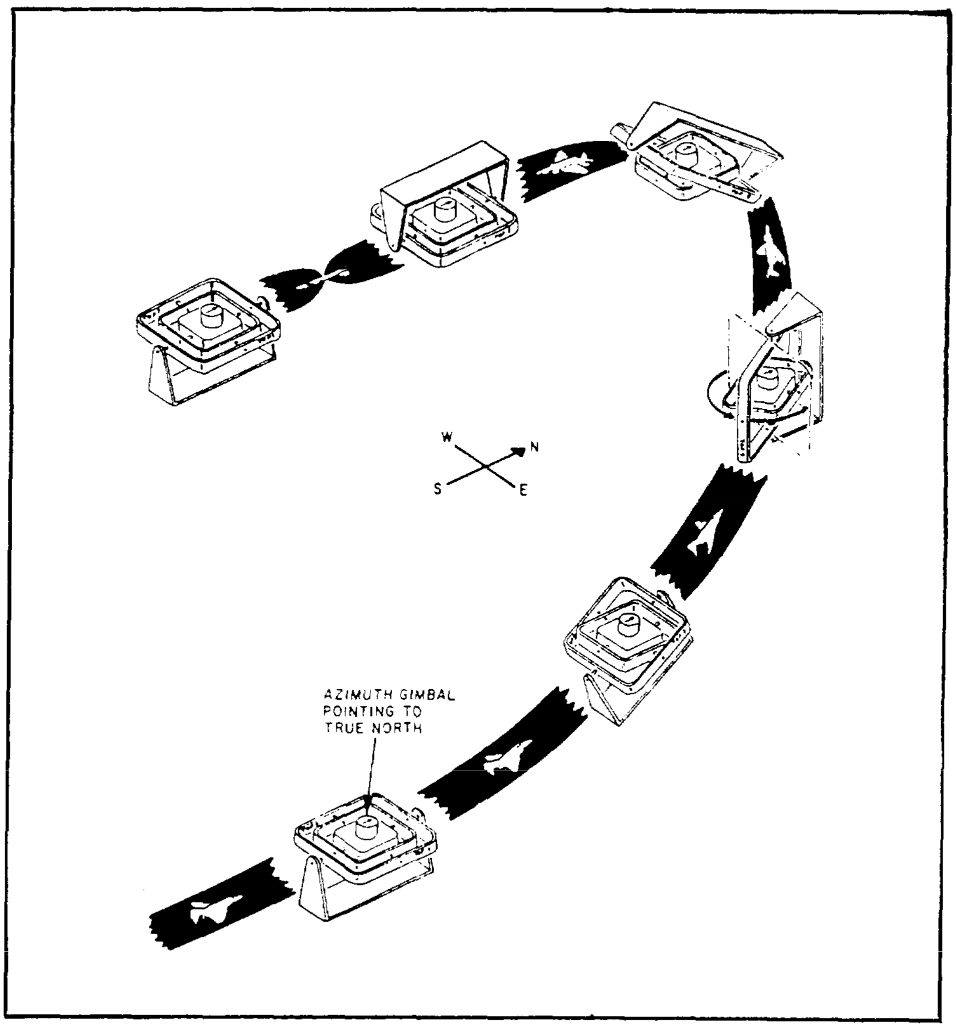


Figure 7-38.-Gimbal flipping action.

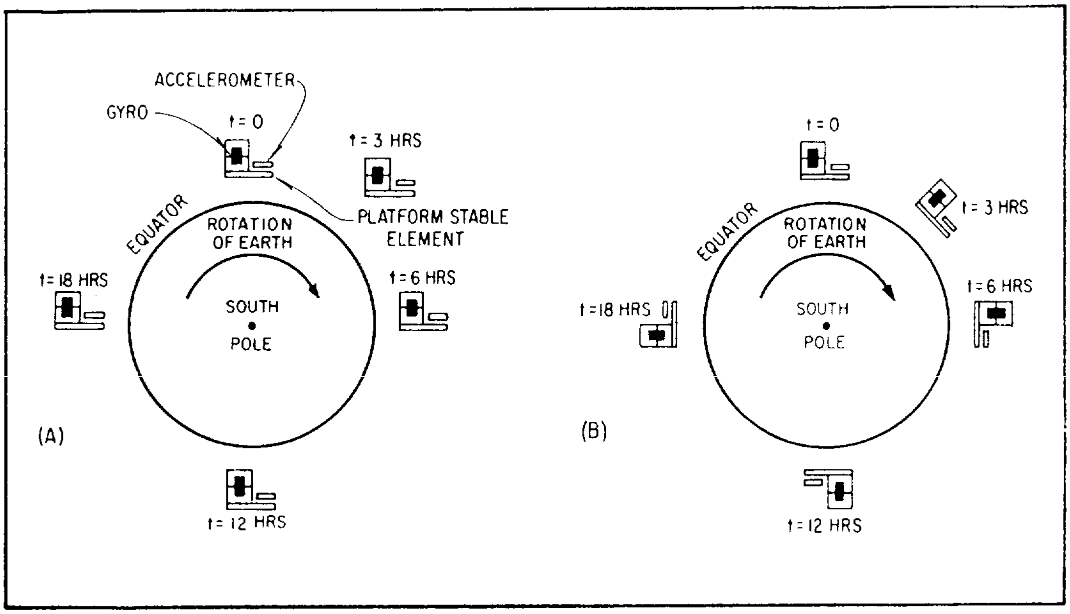


Figure 7-39.-Earth rate torquing: (A) without gyro torquing; (B) with gyro torquing.

accelerometers. An azimuth gimbal lets the aircraft change heading without affecting the orientation of the stable element. A pitch gimbal removes the effect of aircraft pitch, and a roll gimbal stops the effects of roll. An extra roll gimbal prevents the occurrence of gimbal lock during certain aircraft maneuvers and makes the system truly all-attitude. Look at figure 7-38. Note the inner roll gimbal that prevents gimbal lock, which would cause the stable element to tumble. Gimbal lock occurs when two of the gimbal axes become aligned parallel to each other. This causes the stable element to lose one of its degrees of freedom. When the aircraft exceeds 90° in pitch, the outer roll gimbal rotates through 180°. The gimbals are oriented so the system may sense aircraft attitude and heading by measuring angles between the gimbals. Synchros send this information to the attitude indicator and other systems in the aircraft.

PLATFORM ORIENTATION. —Figure 7-39, view A, shows the apparent rotation of a stabilized platform located at the equator. As shown, the platform will remain fixed with respect to inertial space. However, it appears to rotate about the surface of the earth as the earth spins about its polar axis. This is undesirable for navigation since the accelerometers will not remain horizontal to the earth's surface. Consequently, this produces gravitational components of acceleration in the outputs of the accelerometers.

Consider what happens to a stable element as the aircraft flies over the surface of the earth. As the aircraft flies straight north from the equator to the North Pole, the aircraft sees a continuing pitch maneuver. Look at figure 7-40, view A. At the pole, instead of the platform being level with the surface of the earth, it is now 90° off level.

GYRO TORQUING COMPUTATIONS. — To overcome the problems that arise from platform tilt, the system uses the gyroscopic principle of precession. By using this principle as the aircraft flies over the rotating earth, it is possible to apply a continuous torque to the proper gyro axis. This reorients the gyros to maintain the stable element horizontal to the earth's surface and pointed north. Figure 7-39,

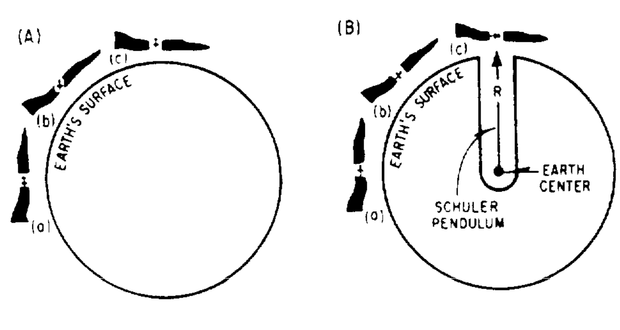


Figure 7-40.-Aircraft rate torquing: (A) without torquing; (B) with gyro torquing.

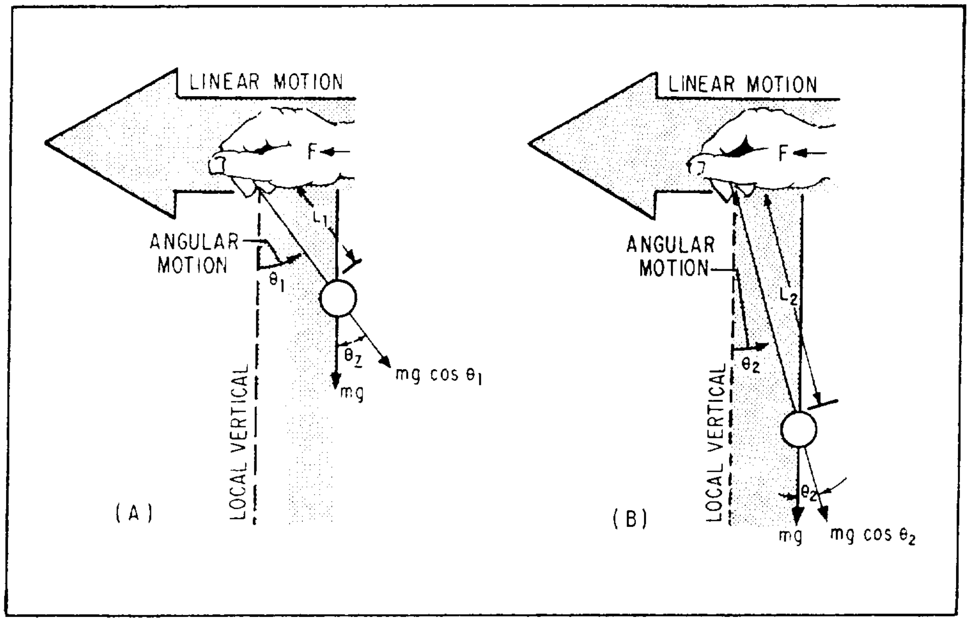


Figure 7-41.-Simple pendulum.

view B, and figure 7-40, view B, show platform operation with proper earth-rate and aircraft-rate torquing corrections.

An analog or a digital computer develops the signals necessary to properly torque the gyros. The corrections for earth rate depend on the aircraft's position on the earth's surface. The analog corrections come from highly accurate potentiometers that produce trigonometric functions of aircraft position. Position integrator shafts drive the potentiometers. To maintain the stable element oriented to the north reference, torquing corrections rotate the platform. The rotation is about the vertical axis compensating for vehicle velocity.

Schuler Pendulum

A pendulum is any suspended mass that is free to rotate about at least one axis. However, its center of gravity is NOT on the axis of rotation. Therefore, any pivoted mass that is not perfectly balanced is, by definition, a pendulum. The inertial platform is a pendulous device and, therefore, behaves as all pendulums behave. It aligns to the dynamic vertical when at rest. The pivot axis and the center of gravity align with the gravity vector. The center of gravity will be on the bottom. Also, it tends to break into its natural period of oscillation whenever the aircraft accelerates.

Pendulous oscillation is periodic angular motion with the gravity vector as its midpoint. Periodic motion around the local vertical produces obvious errors from an inertial platform. This happens because misalignment about the horizontal plane introduces gravity components on accelerometer inputs. The system will interpret gravity accelerations as horizontal acceleration of the aircraft. The Schuler pendulum is a specially constructed pendulum without the unwanted oscillatory motions of non-Schuler pendulums. It is a special case of both the simple and the compound pendulums, which are discussed in the following paragraphs.

SIMPLE PENDULUM. —The simple pendulum consists of a small body suspended by a weightless string. The motion of the simple pendulum is both periodic and oscillatory. The period of the simple pendulum is given by the mathematical formula

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where,

T = time of one oscillation in seconds,

L = length of the string, and

g = local gravity.

The formula shows that the period of a simple pendulum is proportional to the square root of the length of the suspending string. The longer the string, the longer the period.

One property of the simple pendulum that is very useful in the construction of an inertial stable element is shown in figure 7-41. Two pendulums are suspended by strings of different lengths. Equal forces horizontally accelerate the suspension point of each pendulum. The inertia of the bob resists the change in its state of motion. This action causes the bob to lag the point of suspension. It also produces an angular motion of the pendulum about the local gravity vector. Figure 7-41 shows that the length of pendulum (B) is longer than pendulum (A). It also shows angular motion of pendulum (B) is less than pendulum (A) for a corresponding linear motion of the suspension point. Therefore, the longer the suspending string, the less the angular motion of the pendulum for a given linear motion of the suspension point.

Consider what would happen in the following case. The suspending string is long enough to maintain the bob at the center of the earth. The suspension point is transported horizontally along the earth's surface (fig. 7-40, view B). The bob is hypothetically at the center of the earth, the seat of the earth's gravity field. Accelerating the suspension point along the earth's surface merely realigns the suspending string with the new local gravity vector. Therefore, the angular motion of the pendulum about the gravity vector for any horizontal acceleration of the suspension point is zero. This particular pendulum is the *Schuler pendulum,* shown in figure 7-40, view B. This pendulum gets its name from the German engineer, Maximilian Schuler.

Schuler solved the problem of oscillating shipboard gyrocompasses in the early 1900s. Of course, Schuler couldn't use the simple pendulum itself to solve this oscillating problem. He used the principle of the simple pendulum to construct a pendulum that reacted like a simple pendulum. The length of this pendulum equals the radius of the earth, which is about 3,440 nautical miles long. The period of oscillation for this pendulum is about 84.4 minutes. Remember the period of oscillation of a pendulum is proportional to the square root of its length. Therefore, any pendulum constructed to oscillate with a period of 84.4 minutes would have an equivalent length of about 3,440 nautical miles. Such a pendulum is the Schuler pendulum, a special case of the compound or physical pendulum. Figure 7-42 shows three examples of compound pendulums.

COMPOUND PENDULUM. —In figure 7-42, view A, the pivot point, P, is farthest away from the center of gravity, represented by distance d.

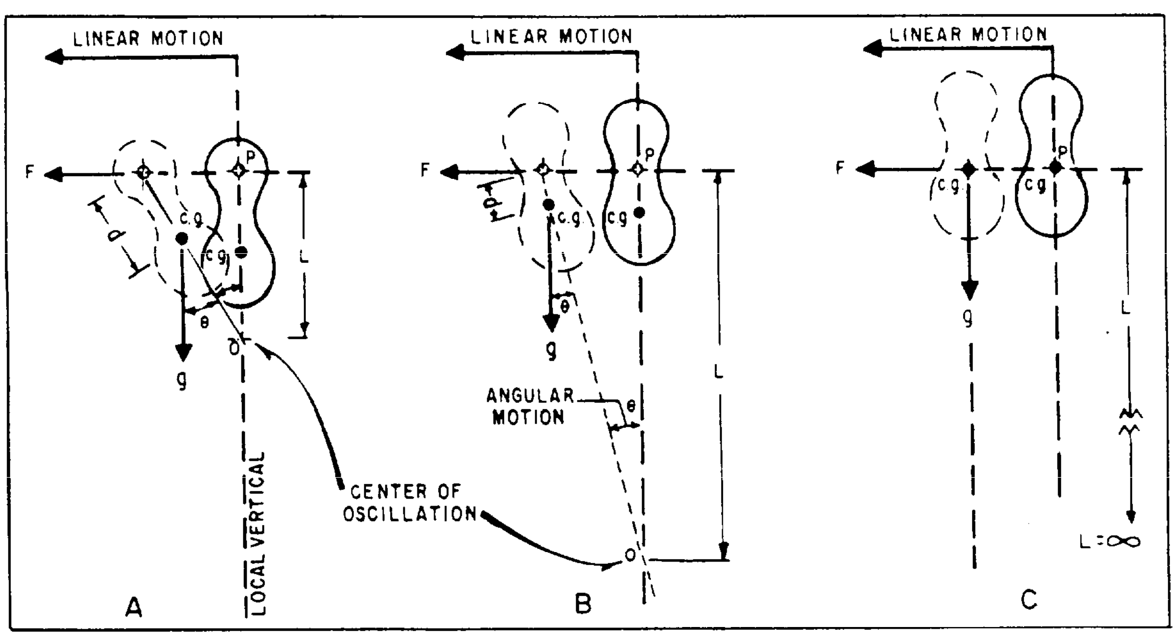


Figure 7-42.-Compound pendulum.

In view B, the pivot point is closer to the center of gravity than in view A. However, it is farther away than the one shown in view C, which pivots at the center of gravity.

The pivot point of each pendulum in figure 7-42 is given the same acceleration. Therefore, each pendulum has the same linear motion at its pivot point. Yet, each pendulum has a different angular motion. As distance d decreases, the angular motion of the pendulum about the local vertical (gravity vector) decreases and distance L increases. Distance L is the distance from pivot point P to the center of oscillation, point O. Also, the pivot point and the center of gravity come closer together, and equivalent length L of the pendulum becomes longer. Figure 7-42, view C, shows the pendulum pivoted at the center of gravity. In this case there is no angular motion of the pendulum and the equivalent length L is infinite. Therefore, it is not a pendulum; it is a perfectly balanced mass that has an infinite period of oscillation. Thus, it is possible to construct a pendulum of infinite equivalent length and period. It is also possible to construct one that has an equivalent length of 3,440 nautical miles. Such a pendulum would be pivoted at some distance d from the center of gravity. This distance would be greater than the one in figure 7-42, view C, but less than the one in 7-42, view B. When pivoted at a point where the period of oscillation is found to be 84.4 minutes, it becomes a Schuler pendulum.

The stable element is essentially a Schuler pendulum. However, it is not entirely mechanical because the earth's radius varies with latitude. The earth's radius is greater at the equator than it is at the poles. For this reason the stable element uses the process of *Schuler tuning*. Schuler tuning torques the platform to a position normal to the gravity vector by signals received from a computing loop.

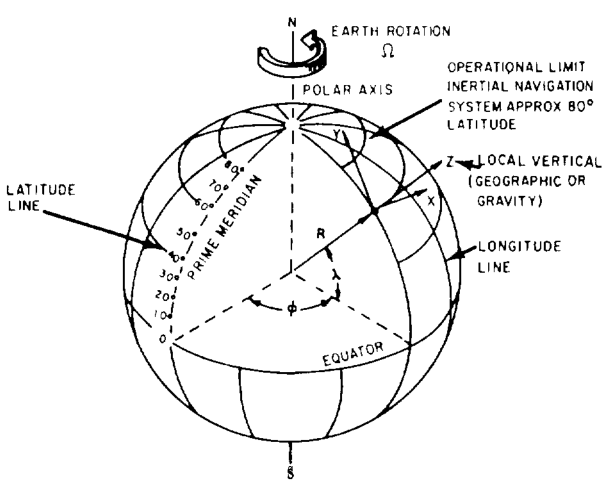


Figure 7-43.-Frame of reference.

Frame of Reference

The frame of reference about which the INS defines the instantaneous position of the aircraft is the conventional latitude-longitude coordinate system (fig. 7-43). The local vertical, established and maintained by the inertial navigation system, is the gravity vertical and is coincident with the geographic vertical. The inertial navigation system orients to the true north reference by sensing the motion of the earth rotating on the polar axis. The frame of reference defined is horizontally aligned in a plane parallel to the surface of the earth and oriented to true north.

ESTABLISHING THE REFERENCE. —Refer to figures 7-36 and 7-43. By establishing the frame of reference, three perpendicular axes of the stable element will align to the horizontal coordinates of the latitude-longitude navigational system. That is, the stable element z-axis aligns with the local vertical and the y-axis aligns north-south. Therefore, the z-axis is coincident with lines of longitude, and the x-axis aligns east-west coincident with lines of latitude. In all calculations, x-axis is positive east and y-axis is positive north. The z-axis is positive away from the center of the earth.

A pair of two-degree-of-freedom gyroscopes establishes and maintains the stable element to the frame of reference. Since a two-degree-of-freedom gyroscope has two sensitive axes, it is necessary to use two such gyroscopes (fig. 7-36). The upper gyroscope z-axis is not in use. They physically mount on the stable element so their spin axes are exactly perpendicular in the horizontal plane. With this arrangement, alignment of the upper gyroscope spin axis north-south will automatically align the lower gyroscope spin axis east-west.

The stable element containing the gyroscopes is supported by the platform gimbal system. Thus, the gyroscopes control the stable element. However, if a free gyroscope initially orients so the spin axis aligns east-west in a horizontal plane, the gyro will precess. The precession will be about the earth's surface because of the earth's rotation on its polar axis. To maintain an earth reference, the system must torque the gyro opposite and equal to the apparent precession. The earth's rotation affects the upper (XZ_2) and lower (YZ_1) gyros. Corrections for earth rotation go to the Y and Z_1 torquing coils (Z_1 and Z_2 are caged together and both respond accordingly). The system does not use the X torquing coil for earth rate corrections.

To establish an earth frame of reference, the gyroscopes are controlled by continuously computed signals. These signals introduce forces (torque) to cause the gyro spin axes to precess in the desired direction. This torque is in the form of direct current signals applied to torquing coils mounted on the gyro float assembly. It creates a magnetic field that aids or opposes the magnetic fields of the permanent magnets mounted on the end bells. This circuit effectively torques the gyro, causing the spin axis to precess to the desired orientation.

The first step in establishing a frame of reference is leveling the stable element. To level the stable element, you align it to the local vertical (gravity vector). This is done by torquing the XZ_2 and YZ_1 gyros. This moves the stable element until the x and y accelerometers cease to sense any acceleration caused by gravity. This says that the outputs from the accelerometers provide the torquing signals for the gyros. During this time, and while operating, computed earth rate torquing signals continuously go to the y and z axes torquing coils of the lower gyro. The size of these earth rate torquing signals is resolved by computing the vertical and horizontal components of earth rate as a function of latitude.

After establishing the stable element in a rough level position, the x-axis torquing signal drives the stable element in azimuth to null this signal (fine alignment). This signal consist of earth rate acceleration only, which is a measure of stable element unlevelness. At this time, the X gyro's spin axis is aligned to true north establishing the frame of reference. This alignment condition will remain until you manually sequence the inertial navigation system to the navigate position.

As previously shown, the earth's rotation does not affect the upper X-axis gyro. Therefore, no compensating earth rate torquing signal goes to this gyro.

MAINTAINING THE HORIZONTAL REFERENCE. —When the aircraft remains stationary or moves at a constant velocity, the accelerometer outputs are zero. If the aircraft attitude changes while maintaining a constant speed, the accelerometers on an unstabilized platform sense an acceleration due to gravity. Since the accelerometers cannot distinguish gravitational accelerations from horizontal accelerations, the integrators develop a fictitious velocity with a corresponding distance error. It is essential, therefore, that the system maintains the accelerometers in a truly horizontal reference plane. This plane must be independent of aircraft attitude at all times.

This is a basic requirement of the inertial navigation system. The accuracy with which the horizontal reference is maintained determines the overall performance capabilities of the system. A gyrostabilized platform in a gimbal structure serves as an inertial reference. Also, it accurately defines directional reference for the coordinate system.

With the platform installed in the aircraft and aligned along the y-axis, it will remain level regardless of aircraft attitude. The instant the aircraft begins to change pitch attitude (fig. 7-44), the platform gyro senses this angular movement. The gyros then begin to precess at a rate proportional to the pitching rate. A pickoff coil on the gyro axis senses this movement and changes it to a voltage. After amplification, the voltage goes to the pitch gimbal servo drive motor. The motor rotates the stable element exactly equal and opposite to the aircraft angular motion. As a result, it continuously precesses the gyro to its neutral or level position. This action maintains the gyro output signal at null.

Regardless of any new pitch attitude the aircraft assumes, the gyro will keep the stable element level. This is the only position that allows the gyro's output signal to be at null. In actual practice, the stable element is maintained level. It uses a similar method to maintain its azimuth

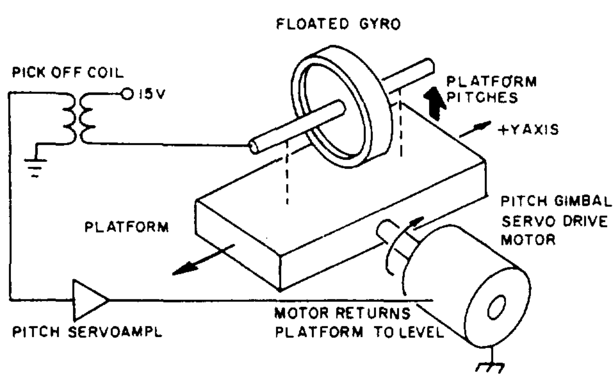


Figure 7-44.-Gyro maintaining inertial platform level.

alignment in yaw and roll. This is necessary so the sensitive axis of the north-south accelerometer aligns true north-south. It is also necessary for the east-west accelerometer to align true east-west. The stable element is then accurately aligned to the three coordinates—north (y-axis), east (x-axis), and up or true vertical (z-axis). This arrangement allows the accelerometers to accurately detect aircraft motion.

MAINTAINING THE VERTICAL REFERENCE. —The stable element must remain perfectly level or the accelerometers will sense a false acceleration due to the earth's gravity. The gyros try to maintain their inertial position in space and not with respect to the local vertical. This causes the stable element to drift off level as the aircraft moves over the curvature of the earth (fig. 7-40). If this situation were allowed to build up, very large errors in velocity and distance would occur. This condition develops whether or not the aircraft is moving over the earth's surface. The earth's rotation alone will develop the same type of errors.

The stable element must always be perpendicular to the local vertical. Therefore, the system must make the gyros precess in such a manner as to maintain the stable element level. With the stable element level, the sensitive axes of the accelerometers are maintained horizontal to the earth at all times. Now they respond only to the horizontal component of acceleration.

MAINTAINING THE FRAME OF REFERENCE. —Accuracy in maintaining the stable element to the frame of reference determines the overall performance capabilities of the system. Gyro torquing rate signals are continuously computed to maintain the frame of reference. After alignment, the inertial navigation system is manually sequenced to its operating condition (navigate). If the aircraft were to remain stationary, the gyro torquing rate signals would consist of earth rate only. However, as the aircraft moves over the curvature of the earth, the stable element earth reference would be lost. This happens because vehicle movement causes the gyros to precess. (Refer to figures 7-39 and 7-40.) Therefore, the system continuously computes additional gyro torquing signals to compensate for the vehicle's movement. These signals are aircraft rate torquing signals. They depend on the velocity of the aircraft wth respect to the frame of reference; that is, east-west velocity and north-south velocity. The angular rate is directly proportional to the velocity of the aircraft along the circumference of the earth. The system applies aircraft rate torquing to both gyros so they will precess about all three axes (x, y, and z). Thus, the system continuously maintains the frame of reference.

Deriving Velocity and Distance

The inertial navigation system can accurately detect aircraft acceleration, and using precision integrators, determine aircraft velocity and measure distance traveled. Accelerations are measured in units of ft/sec^2 by the accelerometers. However, for analog computation, the accelerations are developed in volts per g of accelerating force. The velocity integrator integrates the accelerating force to obtain velocity. The distance integrator integrates velocity to obtain the distance traveled.

There are two velocity integrators in the system to obtain V_X and V_Y along the two horizontal axes. There are two distance integrators to obtain distance traveled along the two horizontal axes. In addition, some inertial navigation systems employ one other velocity integrator to obtain V_Z along the vertical axis.

Accelerometer Output Corrections

The arrangement of the accelerometers is perfectly suited to navigation over a stationary plane or over flat terrain moving at uniform speed in a straight line. The earth, however, is a rotating sphere. As far as the inertial platform is concerned, only points along the equator can be considered to possess uniform linear motion. Here, and only here, the accelerometer signals can translate directly into position information. For this reason, it is necessary to provide an automatic device to alter the accelerometer signals, The automatic device allows the system to report meaningful information. The corrective device is purely electrical. All or part of the circuitry is active whenever a velocity signal voltage is present anywhere north or south of the equator. These circuits use the velocity signals, modified according to the latitude of the aircraft position, They insert artificial acceleration signals to those already in the accelerometer output circuits.

The circuits are divided logically—some are for centripetal effect, some for Coriolis. Note, however, that the corrections are complementary.

Although it is convenient to assign a separate purpose to the circuits, as in the following discussions, the functions overlap, and it is not accurate for you to consider them separately.

CENTRIPETAL CORRECTION. —Centripetal errors are false accelerations sensed when the platform is torqued to maintain its plane of reference. Centripetal correction differs from that of the Coriolis correction in that it has no relationship to earth dynamics. Even if the earth were stationary, it would still be necessary to insert centripetal correction voltages to the accelerometer signal. Correction voltages ensure an accurate plot of any course that does not coincide with one of the earth's coordinate great circle routes; that is, an exact polar or an exact equatorial orbit.On a great circle route, a route that circles the earth's center, every linear acceleration initiates motion. However, unless the route is due north-south or directly along the equator, the system can't plot the route accurately from raw accelerometer signals.

The orbit resulting from linear acceleration, and the logic of applying centripetal corrections to get an accurate plot of track, can be understood if you consider any simple circumstance involving a single acceleration and the inertial reaction. For example, assume a perfect bowling lane surrounds the earth at the equator. Theoretically, a bowler could stand behind the pins and roll the ball in the lane in the opposite direction (away from the pins). After a few years time, the bowler gets a perfect strike on the head pin. However, if the lane is on latitude 10°N, the ball would invariably veer south. After a few thousand yards, the ball would fall into the right-hand gutter if rolled east. It would fall into the left-hand gutter if rolled west. In both cases, the ball would roll into the south gutter. The reason for this phenomenon is clear if you consider a lane built on a latitude in the Arctic only a few yards from the pole. Here, the curve of the lane is obvious. It is apparent if the ball accelerates due east; it will follow, in inertial space, a straight course intersecting the outside gutter. For the ball to roll at a uniform speed and remain in the alley, a uniform north acceleration force must be exerted on the ball in transit. In this case, the north acceleration force is exerted on the ball during transit. Also, remember that north acceleration is a corrective force and does not produce north velocity with respect to the alley.

As shown in figure 7-45, a north-south accelerometer aboard an aircraft circling the pole finds the same phenomenon. In a steep-banked turn, the centrifugal force deflects the north-south accelerometer. It blindly reports a steady north acceleration. The system will show a growing north velocity when, in fact, only an east velocity exists.

The fault is not in the accelerometers but in the geographic coordinate system's nonlinear pattern to which the platform is slaved. The

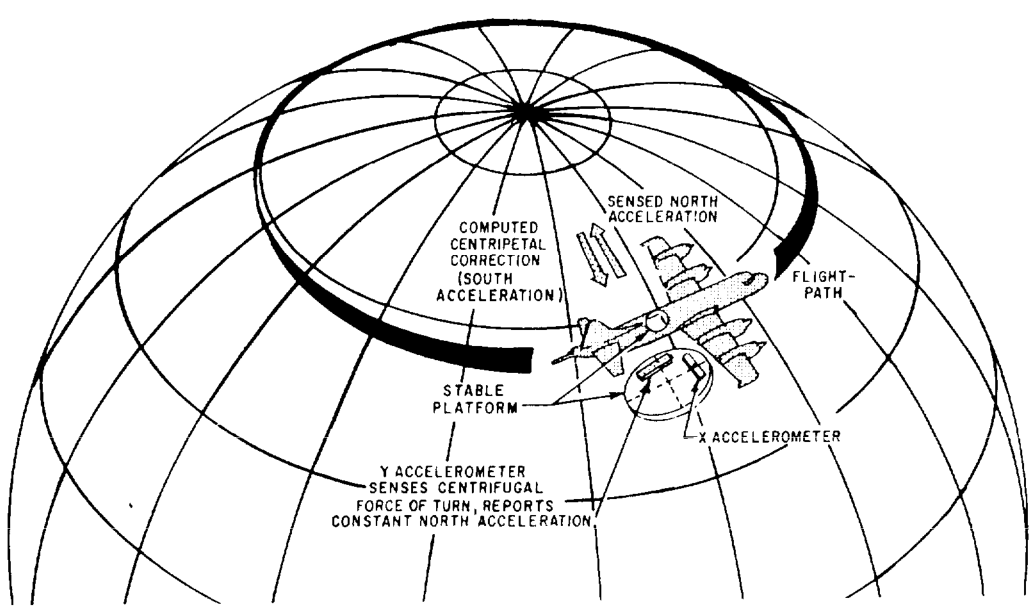


Figure 7-45.-Centripetal correction along latitude.

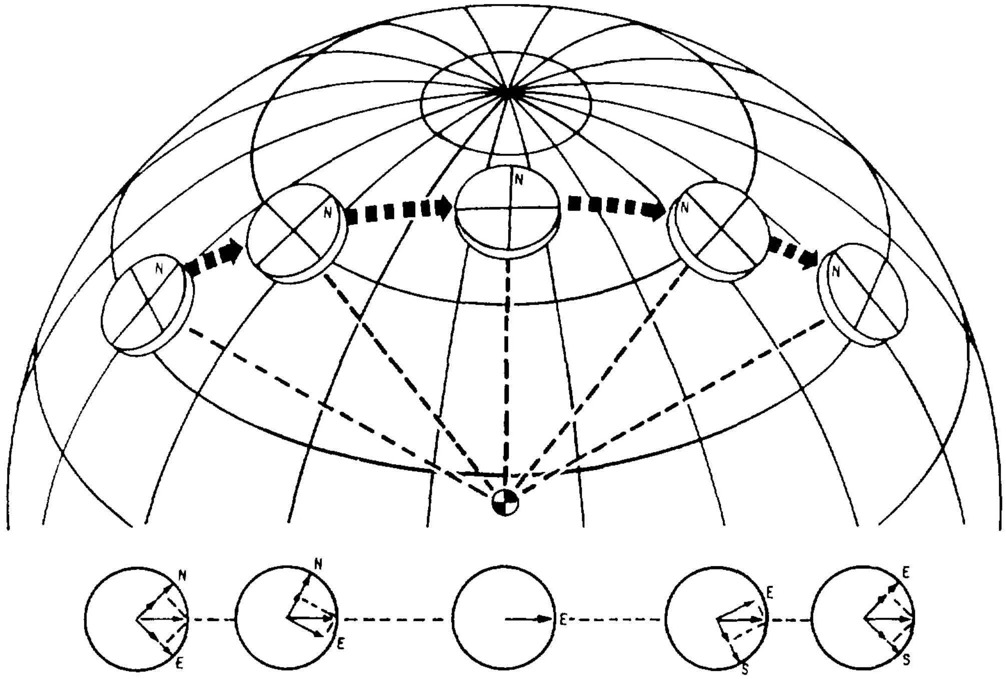


Figure 7-46.-Platform on great circle route.

coincidence of earth axis and pole implies earth dynamics in the phenomenon, but actually this is not a factor. Assume we shift the coordinate systems to place the pole at New York. Now use this city as the focal point of one accelerometer axis of an inertial navigator circling the city. The accelerometer sensitive to this axis will report acceleration toward the city.

In a spherical coordinate system, any linear vehicle acceleration initially affecting both accelerometers will result in the vehicle NEVER reaching the pole. The vehicle follows a great circle track that first approaches one of the poles. It will fly due east or west for a brief period, and then depart the pole, as shown in figure 7-46.

Although the velocity resulting from any given acceleration is initially computed correctly with respect to space, the direction of the speed must be constantly altered. This is necessary if the navigational system is to accurately report a great circle course that crosses both latitude and longitude. On such a course, the aircraft does not turn as it does following a line of latitude. Therefore, it does not generate uniformly false north acceleration signals. The centripetal correction circuit does, however, continue to *plant* signals of acceleration toward the equator. This has the effect of altering the reported speed (the result of velocity along both axes). No actual acceleration has taken place to cause a speed change. Thus, the centripetal correction circuit must simultaneously plant positive accelerations in one axis if it plants negative accelerations in the other. Therefore, when canceling some of the north or south velocity, the system must add a sufficient increment of east or west acceleration. This allows the reported total speed to remain unchanged, while the reported direction of flight *bends* toward the equator. As shown in figure 7-46, after a single north-east acceleration has occurred, the north vector becomes progressively shorter. Note that the resultant speed vector is always of the same size.

In summary, you can see that an east or west acceleration in either hemisphere contains a *hidden* element of acceleration toward the equator. Also, you can say centripetal correction simply acts to reveal this element. When aircraft velocity is not due north or due south, in the Northern Hemisphere the centripetal correction *manufactures* a south velocity component. In the Southern Hemisphere, it manufactures a north velocity component.

CORIOLIS CORRECTION. —As mentioned before, the scope of the centripetal correction makes no allowance for earth dynamics. Since the earth rotates toward the east, all points on the surface have a constant tangential velocity. This velocity is maximum along the equator and lessens at higher latitudes.

Tangential velocity is a linear quantity. It refers to the speed and direction an object would travel in a straight line if freed from the earth's gravity. An object near the equator travels about 1,000 miles per hour in a circular path. Assume the object is free from earth's gravity and atmosphere. Now it will travel at that speed in a straight line away from the earth (on a tangent to the earth). Its tangential velocity is 1,000 miles per hour. If the object moves toward the North Pole, its speed in circular travel will decrease as it approaches the pole. The speed will be zero when placed exactly over the pole.

Although the earth has a trajectory in space, this motion is not important to the inertial navigation system because every point on the sphere shares this trajectory. The only variable involved is the variation in the earth's tangential velocity at different latitudes. While the accelerometers don't automatically make allowance for this variation, the system must take it into account.

The need for such an allowance is illustrated in the following discussion. Put an aligned INS, devoid of any Coriolis corrective mechanism, aboard a train in the Northern Hemisphere, and transport it north. The earth's tangential velocity at the latitude where the INS aligned is 800 knots east. It is obvious the train's eastward velocity must be constantly reduced as it progresses north. This progressive reduction in velocity represents an acceleration.

Since the tracks constrain the train, a force from the east will be exerted on the wheel flanges. This force is sensed by the east-west accelerometer as acceleration to the west. The system begins computing west velocity that will grow. Refer to figure 7-47. An aircraft flying north directly along a moving longitude meridian subjects the east-west accelerometer to this same force. This happens as its course in space alters to the left,

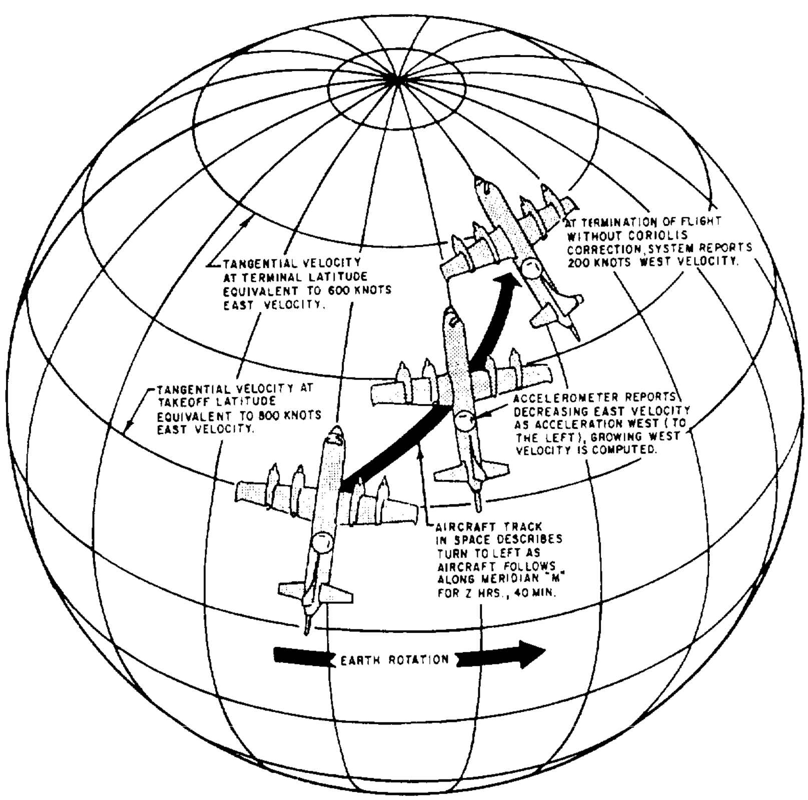


Figure 7-47.-Coriolis effects.

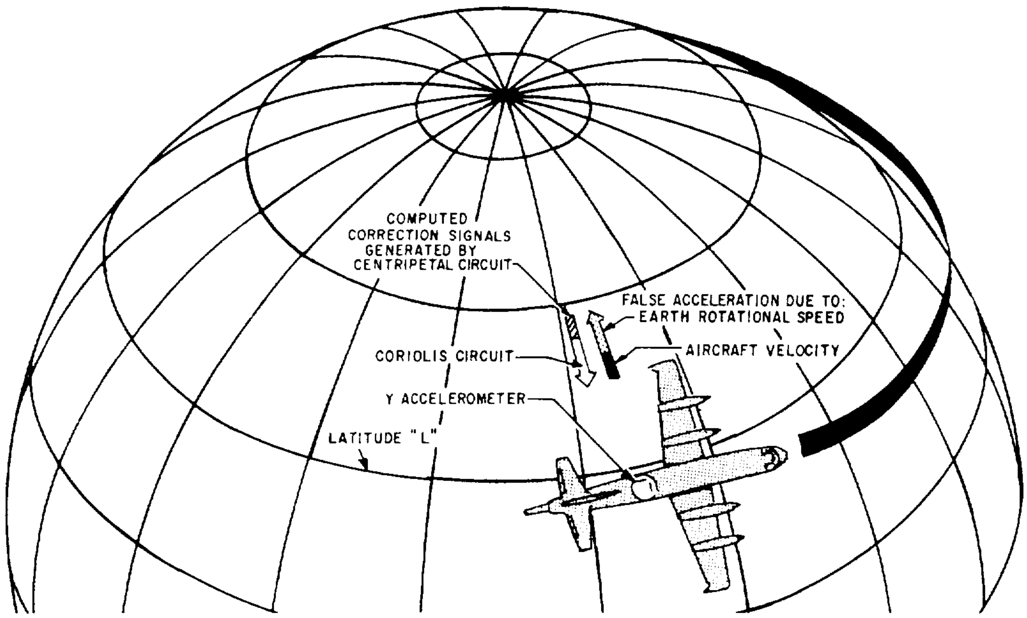


Figure 7-48.-Coriolis and centripetal corrections.

compensating for the decreasing eastward velocity of the earth's surface.

The train traveling north stops at a latitude where the earth's tangential velocity is 600 knots. This is 200 knots less than the tangential velocity at the point of its initial alignment. The velocity computer will continue to report that the vehicle is traveling west at 200 knots even though it is perfectly static. The Coriolis correction prevents this from happening. It creates enough east acceleration signal to offset the continual west acceleration generated by the east-west accelerometer as it travels north. The east and west accelerations cancel, thus, there is no change in longitude to report. Of course, on the return trip, the platform is under the delusion that 600 knots east is zero velocity. So as it travels south, the increasing earth tangential velocity causes it to constantly report east acceleration. In this case, the Coriolis correction also reverses. It now manufactures a west acceleration that exactly voids the east acceleration.

In both of the above cases, the Coriolis correction supplies an artificial signal of acceleration to the right side of the actual track. This is the nature of the Coriolis correction, regardless of the direction of travel in the Northern Hemisphere. Look at figure 7-48. When the track is east along a latitude line, centripetal correction offsets the increment of north acceleration generated by aircraft speed. The Coriolis correction accounts for the additional force generated by the earth's rotation. For example, if the earth's tangential velocity at latitude **L** is 700 knots and aircraft speed 350 knots, total speed is 1,050 knots. Centripetal correction offsets the acceleration caused by the centrifugal force of a 350-knot turn of this radius. Coriolis correction offsets the force of a 700-knot turn. In this case, the two corrections are summed.

If the course is reversed and the plane flies west, the correct ions become opposite in polarity. The centripetal signal is still south, but Coriolis is north (to the right of the track). Therefore, only a part of the larger correction is effective.

Schuler-Tuned Loop

The Schuler-tuned loop is a closed loop circuit between the accelerometer, velocity integrator, and stable element. It prevents large velocity and distance errors caused by misalignment of the stable element. Figure 7-49 shows a simplified Schuler-tuned loop with the platform aligned.

The output of the accelerometer is integrated to provide a velocity signal. The velocity signal is multiplied by 1/R where R equals the earth's radius. This operation derives an angular velocity about the earth's surface, V/R. The system uses this angular velocity to torque an integrating gyro.

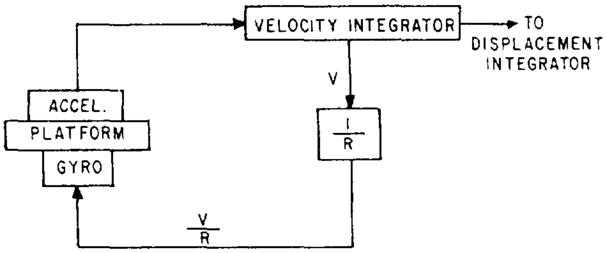


Figure 7-49.-Simplified Schuler-tuned loop, platform level.

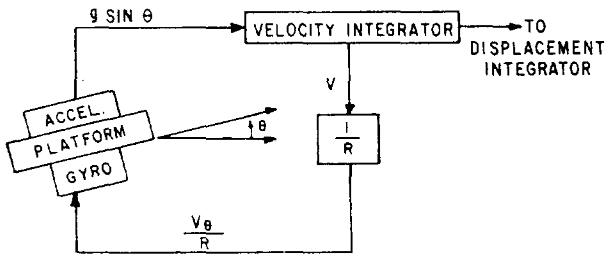


Figure 7-50.-Simplified Schuler-tuned loop, platform unlevel.

The torque causes the platform to precess about the earth's surface. This precession equals the rate the platform is being transported over the surface. This maintains the platform normal to the local vertical.

There are two such loops in an inertial navigation system, one for the north and the other for the east. The accelerometer in the north loop senses north-south accelerations, yet the gyro in the north loop senses east-west angular rates. That is, the vehicle's angular movements about the east-west axis.

By convention, we name accelerometers and gyros according to the direction of their sensitive or input axis. The inertial or Schuler loop takes the name of its accelerometer. The north loop contains the north accelerometer and the east gyro. The east loop contains the east accelerometer and the north gyro.

With the platform initially unlevel, as shown in figure 7-50, the accelerometer senses a component of gravity, g sin θ. This signal is integrated, resulting in the velocity signal Vθ. The velocity signal then causes the gyro to precess in a clockwise direction. When the accelerometer is positioned to sense zero gravity, the velocity output continues to torque the platform in a clockwise direction. This causes the accelerometer

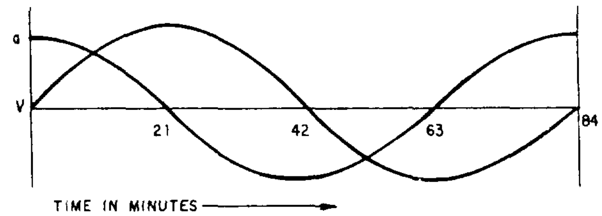


Figure 7-51.-Schuler tuning—acceleration errors versus velocity errors.

to now sense a gravity component of the opposite polarity. This signal causes the velocity signal to decrease to zero. The velocity signal now builds up in the opposite direction and precesses the platform in a counterclockwise direction. The oscillation set up by this mechanization has a period of 84 minutes, equal to that of the Schuler pendulum. Figure 7-51 shows the buildup and decay of acceleration and velocity errors as a result of such errors as just described.

ALIGNMENT

Inertial navigation depends on the integration of acceleration to obtain velocity and position. In any integration process, the system must first know the initial conditions. In this case the initial conditions are velocity and position. The accuracy in solving the navigation problem depends greatly upon the accuracy of the initial conditions. Therefore, system alignment is of paramount importance.

System alignment consists of creating a coincidence between the platform axes and the computer axes. This can be done by rotating either or both systems. There are two general methods of accomplishing this condition.

1. The system is slaved to an external reference source.
2. The system may have the built-in capability to sense misalignment and correct itself.

Of course, combinations of both these methods can be, and often are, used.

External references take three basic forms—terrestrial, celestial, and inertial. The terrestrial system uses surveyed lines, bench marks, plumb bobs, and bubble levels. These methods result in level accuracies of about 10 seconds of arc and heading accuracies to 3 minutes of arc. Celestial information from star trackers and radio sextants has accuracies to 10 seconds of arc. When using an inertial system as a source, the accuracies depend on its initial source and length of time since last aligned. Such a method is usually for mobile alignment where primary sources cannot be used.

The use of an external reference system requires transfer devices to transmit the reference information to the system. The transfer devices are either optical or electromechanical devices. Optical devices include theodolites and autocollimators; the electromechanical devices are synchro-resolver or digital type. Optical methods can produce accuracies of a few seconds of arc. The electromechanical methods are accurate to about 30 seconds of arc.

In self-alignment, the inertial sensing instruments mounted on the platform sense the deviation from the desired position. To determine the orientation of a three-axis orthogonal (perpendicular) coordinate system, you must have at least two noncollinear (not parallel) reference vectors. For self-alignment, the earth's spin vector and the mass attraction gravity vector serve this purpose. The self-alignment puts less requirements on the computer. In self-alignment, the accelerometer outputs don't have to be resolved into components of gravity and vehicle acceleration. When accelerometers and gyros mount on the same element, their relative position is fixed and does not have to be computed.

Self-alignment often divides into two modes—rough or course alignment (sometimes called caging) and fine alignment. Fine alignment itself divides into two modes—leveling and gyrocompassing.

Rough Alignment

Rough alignment provides a convenient starting point for the later phases of alignment. In most cases, the gimbals slave to their own synchro outputs or to some external source. This external source will have a particular orientation with respect to the vehicle. A timing network controls the duration of rough alignment, which is usually a short period.

Fine Alignment (Leveling)

To accomplish fine alignment or leveling, the system rotates the platform axes to the computer axes. For a locally level system, this is done by placing the X and Y accelerometer axes mutually perpendicular to the gravity vector. Since accelerometers mount at right angles, a motion about one axis causes the other to go through an angle with respect to the gravity vector. Therefore, you connect the accelerometer output in a way to allow it to torque about its perpendicular axis. The accelerometer can now slew itself to a null position, where it senses no component of gravity. As pointed out earlier, the device the system can torque about an axis is a gyro. In this case, the gyro being torqued is the one sensitive about the axis perpendicular to the accelerometer being leveled; that is, the Y gyro (north) torques the X accelerometer (east) to level, etc.

The accelerometer will provide a dc voltage that is proportional to the sine of the off level angle. In the leveling mode, after amplification this voltage goes to the gyro, whose sensitive axis is perpendicular to the sensitive axis of the accelerometer. (See fig. 7-52.) In other words, the output of the X accelerometer goes to the Y gyro. The output of the Y accelerometer goes to the X gyro.

Gyrocompassing

As mentioned, any gyro not having its spin axis parallel to the earth's spin axis will apparently precess about the earth. The rate at which it precesses is proportional to the angle between its spin axis and the earth's spin axis. This angle can be resolved into two components. Since the gyro spin axis lies in the level plane already established, one component can be found in the plane itself. Now, find the angle between the spin axis and a vector in the level plane that intersects the earth's spin vector. Once you find these two angles, you know the exact position of the platform axis.

You can see the rate at which the gyro in question appears to precess is equal to $\Omega \cos \lambda \sin a$ where

Ω = the earth's rate of rotation

λ = latitude

α = the angle the platform makes with true north.

The spin axis of this gyro can be torqued to a place where this term goes to zero ($\alpha = 0$). Also the computer can develop a torquing term equal to this and apply it to the gyro. In either case, the position of the platform is known. Figure 7-53 shows a typical heading alignment loop.

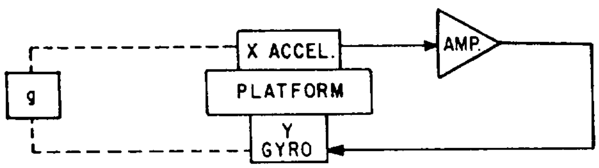


Figure 7-52.-Typical leveling loop.

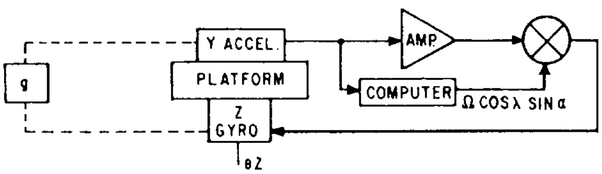


Figure 7-53.-Typical heading alignment loop.

In a north seeking platform, the system uses the earth's rotation to align the platform to true north. It accomplishes this by using the output of the y accelerometer. The system applies this output to the torquing coils of the z (azimuth) and the x (east) gyros. At the beginning of the gyrocompass phase (after the platform is leveled), the stable element is torqued in azimuth. This nulls out the residual east gyro torquing rate. If the stable element is not aligned to true north now, it begins to tilt due to precession of the gyros. The y accelerometer senses deviation of the stable element from level because of gravity. The output of the accelerometer then torques the x gyro until the stable element is level. At the same time, the output signal also torques the z gyro in azimuth. The process continues until the stable element aligns to true north.

Once the platform is aligned, the operator switches the system from the alignment phase to the navigation phase of operation. In the navigation phase, the stable element would maintain an orientation about free space if not for corrections supplied by the computer. The computer maintains the stable element level with respect to the earth and oriented to true north. If not, the accelerometers sense gravity in addition to movement of the aircraft. Coriolis, centripetal, and earth rate corrections are computed and used to hold the stable element level and aligned to true north. In the navigation phase of operation, the orientation to true north is dependent on the original aligned position and the computed corrections.

To this point, a north-pointing inertial system has been discussed. A disadvantage of the north-pointing system is that it cannot operate in the polar regions; it must always be physically pointed north. If the system flies directly over the pole, it must rotate 1800 to again be pointing north. This rotation would not be physically possible because of the extremely high torquing rates necessary. Most north-pointing inertial systems cannot operate within several hundred miles of the poles due to stress on the system components.

Wander Azimuth

The wander-azimuth inertial system solves the problems of operating an inertial system at the poles. The fundamentals of a wander-azimuth system are the same as a north-pointing system. During the gyrocompassing mode, the system allows the platform to take an arbitrary angle (wander angle) with respect to true north.

As previously mentioned, the platform is leveled; but, the accelerometer outputs are now supplying torquing signals to **both** gyros. This action compensates for the earth's rotation (this signal was sent to x gyro only in the north-pointing system). Eventually, the correct earth rate torquing signals maintain the platform level. The computer then uses the ratio of earth rate compensation to compute the wander angle (fig. 7-54).

As the wander-azimuth system navigates around the earth, the wander angle (with respect

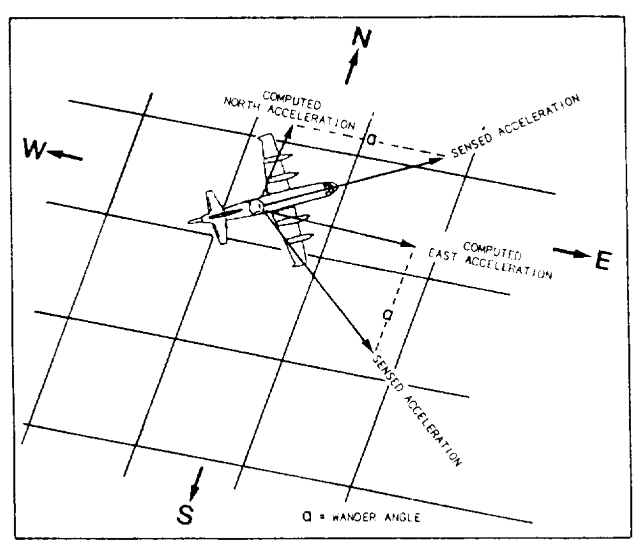


Figure 7-54.-Wander angle.

to true north) changes as a function of longitude. The system operation is the same as a north-pointing system. However, the wander angle is taken into account by the computer with the north and east sensored accelerations.

Alignment at Sea

Problems that arise in aligning an aircraft inertial navigation system on aircraft carriers at sea are, more complex than aligning the INS ashore. This situation exists even though our carrier-based inertial reference is another INS of very high accuracy. The inertial navigation reference system aboard an aircraft carrier is the ship's inertial navigation system (SINS) and the relative velocity computer (RVC). Outlets on the flight deck make it convenient to pipe the SINS reference information into the aircraft inertial navigation system. However, one major problem still remains that makes proper alignment difficult. The accelerations experienced by the ship's inertial navigation accelerometers located below deck. These accelerometers are remote from the aircraft accelerometers, and therefore do not sense the same accelerations.

COARSE SEA ALIGNMENT. —During coarse sea alignment, the best available true heading is from the SINS and the RVC. Aircraft carrier true heading goes to the RVC. Here a manually selected aircraft heading angle, with respect to the aircraft carrier, is inserted. The combined signals then go to the heading computer in the aircraft's inertial navigation system, thus concluding the coarse sea alignment.

FINE SEA ALIGNMENT. —During fine sea alignment, the accelerometers sense the aircraft carrier movement in addition to gravity. Only the gravity component is used in the leveling. This allows accelerometer output caused by aircraft carrier movement to be canceled. The SINS and RVC accomplish this task by supplying continuously computed corrections. The accelerometer error signals are integrated to supply a velocity. The reference velocity supplied by the RVC during sea alignment, actual aircraft velocity, is subtracted from the accelerometer derived velocity. The difference corresponds to the gravity component sensed by the accelerometer. After amplification it is applied to the torquing coils of the gyros. The processing of the gyro pickoff signals cause the gimbals to rotate and cancel the pickoff error signals. The stable element is torqued until the accelerometers show a null or level condition.

REVIEW SUBSET NUMBER 3

Q1. What is the operating principle of the inertial navigation system?

Q2. What must an object first experience before its state of rest or state of motion can change?

Q3. What is the result of acceleration being integrated over a specific period of time?

Q4. What is the purpose of an inertial navigation system?

Q5. Name the primary data source for the inertial navigation system.

Q6. Does the accelerometer distinguish between the acceleration of the vehicle and gravitational acceleration?

Q7. What allows the INS to determine total true accelerations in a horizontal plane for any movement in any direction?

Q8. What gimbal prevents gimbal lock making the INS a true all-attitude system?

Q9. How long is the period of oscillation for the Schuler pendulum?

Q10. False accelerations sensed when the platform is torqued to maintain its plane of reference are known as ______________.

Q11. Name the three basic external references that may be used to align an INS.

Q12. The rate at which a gyro precesses is proportional to the angle between its spin axis and the spin axis of the ___________.

TYPES OF INERTIAL NAVIGATION SYSTEMS

Learning Objective: *Recognize the two types of inertial navigation systems and discriminate between systems within those two types.*

You can classify inertial navigation systems under two broad types—pure and hybrid. The types of pure inertial navigation systems are analytic, semianalytic, geometric, and strapdown. The types of hybrid inertial navigation systems are radio inertial, Doppler inertial, and stellar inertial.

PURE INERTIAL NAVIGATION SYSTEMS

As the name implies, a pure inertial navigation system is not combined with other equipment to improve its operating performance.

Analytic Inertial Navigation System

The analytic INS uses a platform with a fixed angular reference to some point in inertial space. The system makes no attempt to force the accelerometer input axes into a preferred alignment with respect to the earth. This method does not require gyro torquing. As a result, this platform is subjected to errors of gyro drift only.

Because the platform remains rigid in space and rotates about the earth, the output accelerations become complex. They essentially consist of two major accelerations—the actual acceleration of the vehicle and the gravitational acceleration of the earth. For navigation purposes only aircraft accelerations are required and wanted; therefore, the gravitational accelerations must be canceled. Yet, this cancellation is difficult to obtain because the earth's gravitational acceleration is not uniform. Therefore, the computer must store an enormous amount of data to effect this cancellation.

The significant disadvantage of analytic inertial navigation is the result of maintaining the accelerometer referenced to a fixed point in inertial space. As the stable element navigates about the earth, the accelerometers must sense aircraft acceleration and the earth's gravitational field component. The accelerometers for this system must have a wide dynamic range as well as a high overall accuracy. The most serious problem, however, is the cancellation of the gravitational accelerations. Irregularities in the earth's shape and mass cause variations in the gravitational field. Therefore, the cancellation of these variations requires a complex computer with a very large storage capacity.

Semianalytic Inertial Navigation System

The semianalytic system is the inertial navigation system most commonly in use today. All naval aircraft that use inertial navigation systems have this type of system. It may either be a pure system or work with another navigation system as a hybrid system. This system's chief advantages are the simple platform gimbal structure and computer functions are easily attained by either analog or digital means.

The semianalytic system always maintains the stable element normal to the earth's gravitational vector just as in other systems already discussed in this chapter. In this system, the computer converts the output accelerations of the stable element to angular velocities. These angular velocity signals then torque the platform gyros to maintain the platform normal to the earth's gravity vector.

The computer also develops signals to prevent the platform from processing off level due to the earth's rotation about its polar axis. These signals are equal to the angular velocity of the earth

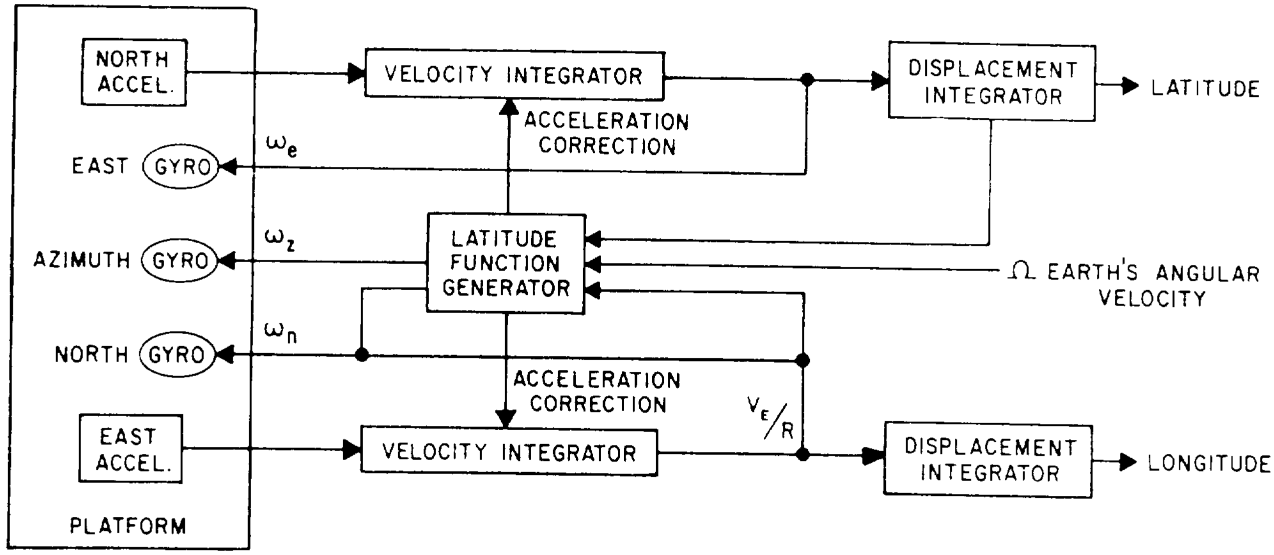


Figure 7-55.-Typical semianalytic inertial navagation system, block diagram.

resolved into the system axes. The system then applies these signals to the gyro torquers. A typical simplified block diagram of a semianalytic inertial navigation system is shown in figure 7-55.

In a semianalytic inertial system, the platform aligns normal to the gravity vector. It may or may not align to true north. The output of the north accelerometer goes to an integrator. Here, the output is summed with acceleration correction terms to derive a true vehicular acceleration over the earth's surface. This acceleration signal is then integrated with respect to time, deriving the north velocity component of the vehicle's track. Through scaling, the INS converts the velocity term to an angular velocity. It then integrates the angular velocity to provide a position readout in the form of latitude. In addition, the latitude function generator uses the north angular velocity signal to develop accelerometer correction terms. It also uses this signal to develop a gyro torquing signal for the east gyro.

The east accelerometer output is summed with accelerometer correction terms and integrated to provide an east component of the vehicle's track. Through scaling, the INS converts the velocity signal to an angular velocity. This angular velocity goes to the latitude function generator. The function generator uses it to develop accelerometer correction terms and torquing signals for the north gyro and the azimuth gyro. In addition, the INS integrates the angular velocity to develop a position readout in the form of longitude.

Geometric Inertial Navigation System

The geometric INS uses a gyro system that, like the analytic system, is referenced to inertial space in a nonrotating plane. The accelerometers, however, mount on the gimbal structure in a manner as to remain normal to the earth's gravitational field.

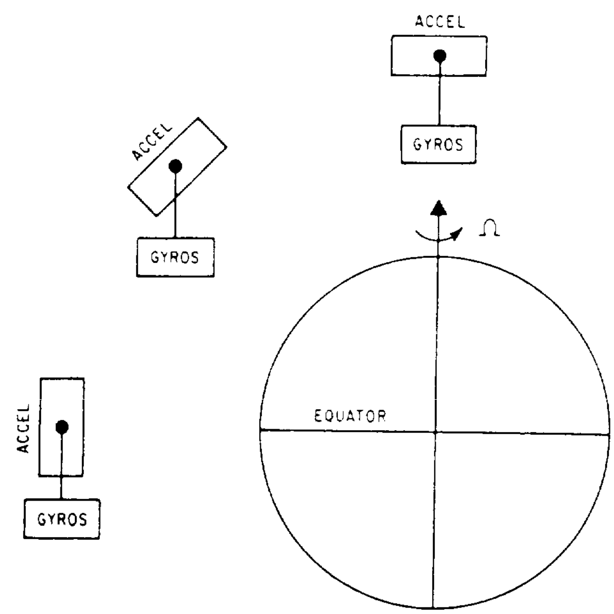


Figure 7-56.-Transport of the geometric system's stable element.

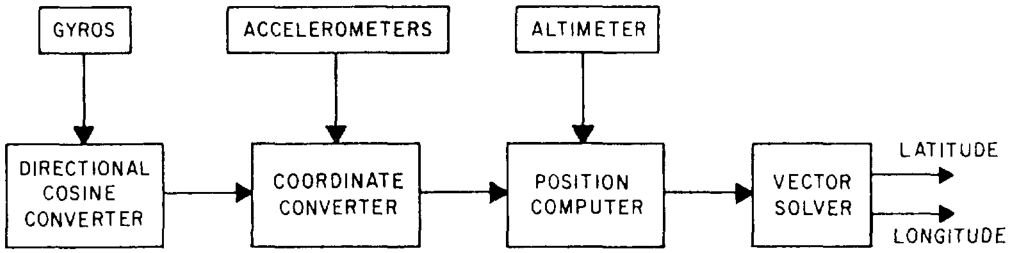


Figure 7-57.-Strap-down inertial navigation system, block diagram.

Figure 7-56 shows the relationship of the accelerometers and gyros as the platform moves over the surface of the earth. When the platform is aligned at the equator and then moves north, the gyros maintain their position in inertial space. The accelerometers remain in a plane tangent to the earth's surface at all times.

The main advantage of this system is that the gyros are not torqued. Therefore, scaling of the gyros is not critical.

The major disadvantage is economy. The system requires a high degree of accuracy to position the latitude and longitude gimbals. The semianalytic system requires much less precision to achieve similar accuracy; therefore, it costs less.

Strap-Down Inertial Navigation System

In the strap-down system, the gyros and accelerometers mount directly to the frame of the vehicle. Its principal use is in ballistic missiles and spacecraft. This type of system can be mechanized for use in aircraft. However, the present state of technology makes it more feasible to use one of the other type of systems for aircraft use.

The strap-down system requires complex digital computers; analog computers are not accurate enough for use in this system. The computer in the strap-down system replaces the gimbal structure as the gimbal structure replaced the physical length of the Schuler pendulum. Figure 7-57 shows a simplified block diagram of a strap-down inertial navigation system.

In the strap-down system, the gyros provide angular rates, which the system converts to directional cosines (for example, space vectors). The strap-down uses these signals to determine vehicle attitude about an inertial frame of reference. The coordinate converter, using inputs from the accelerometers and the directional cosine converter, determines accelerations along the inertial reference axes. The position converter accepts inertial acceleration and altitude information to develop Cartesian coordinates representing the vehicle's position in inertial space. These vectors then go to the vector solver, where they are summed to provide readouts of latitude and longitude.

To accomplish strap-down system alignment, you must supply the directional cosines of the vehicle frame to the computer. The vehicle requires no physical orientation.

HYBRID INERTIAL NAVIGATION SYSTEMS

The hybrid system is a combination of inertial navigation system and some other type of navigation system. The other navigation system is for updating or improving the accuracy of the inertial navigation system. In other words, the hybrid inertial system combines two navigation systems so that the good characteristics of both are maintained.

There are two types of updating processes used in hybrid systems. One type is the damping effect, which compares the inertial ground velocities with the ground velocities of some other system. The system uses the error, or difference between the two velocities, to damp out platform errors. The other type is the reset method. This method ignores the orientation of the platform and merely resets the position of the velocity shafts periodically.

CALIBRATION

As you learned earlier in this chapter, variation and deviation affect the accuracy of a magnetic compass. Variation is a natural phenomenon whose magnetic strength varies in intensity throughout the world. Variation is marked on navigation maps and is corrected for by the pilot. You can consider deviation as man-made. The magnetic fields of aircraft components cause deviation. These components are engines, electric equipment, landing gear struts, and flight control surfaces and their control cables. You can keep the effects of deviation to the very minimum by a process called *compass swinging.*

As an AE, you must be completely familiar with the two methods of compass swinging. These two methods are the MC-2 compass calibration set and the use of a compass rose. For a gyro-stabilized compass or inertial navigation system, the MC-2 is considered the primary means of swinging. Deviation in a wet or standby compass is corrected for on a compass rose. The following paragraphs describe the compass rose and the MC-2 calibration set.

Compass Rose

Aircraft magnetic compasses (wet or standby) have devices called *compensators,* which provide a means for correcting deviation errors. You cannot eliminate all errors, but you can reduce them to a minimum.

Swinging the compass, you first compensate the N-S and E-W headings. Then set the aircraft on every 15- or 30-degree heading on the compass rose. Here, you note the difference between the aircraft heading and the indicated heading. You then adjust the compensators to reduce this difference or deviation to a minimum.

There are two types of compensators. One type is the universal screw type. It consists of an assembly having a group of small compensating magnets permanently installed in it. To change the compensating effect of the assembly, you use two adjusting screws. One screw is for north-south compensation, the other for east-west. The other type of compensator has small, loose magnets that you place in special chambers on the compass as needed. The chamber positions allow one to make east-west corrections. The other (at right angles to the east-west chamber) corrects north-south deviation. Compensation is done only on the cardinal headings on standby compasses. However, on all other compass systems in naval aircraft, compensation is at 15-degree increments.

Before starting the swinging operation, you should make sure all magnetic equipment is in the posit ion it occupies in normal flight. Also, be sure that no one near the aircraft compasses during swinging operations has any magnetic materials on their person. Magnetic materials include tools, pocketknives, mechanical pencils, wristwatches, dog tags, bracelets, eyeglasses, jewelry, officer caps, badges, etc. Remember, too, that you use a nonmagnetic screwdriver in adjusting universal compensator screws.

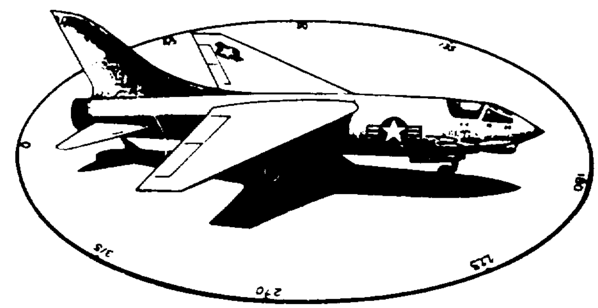


Figure 7-58.-Compass rose, with aircraft on south heading.

You actually swing a compass in one of several ways. However, as an AE, your chief interest is in ground swings. You usually accomplish a ground swing with the aircraft at rest on a compass rose. Look at figure 7-58.

Most air stations have a compass rose. The compass rose looks much like an oversized card from a navigation compass. The directions shown by it are magnetic directions, and the north arrow points toward the earth's north magnetic pole. A compass rose may also have a line showing true north.

Jacks, lifts, hoists, or any dolly needed to perform the ground swinging job should preferably be of nonmagnetic material. However, this is not always possible. Devices used in the swinging process must be tested for their effects on the compasses. You do this by moving them about the aircraft in a circle with normal separation distance between the device and the instruments. Do not use devices that cause more than one-quarter degree change in the compass reading.

Trucks, automobiles, railroad cars, and other aircraft containing magnetic metals should not be within the swinging area. These items could have a magnetic effect on the compasses of the aircraft being adjusted. You should be sure that the compass is in good condition. Examine the compass for clear liquid and proper level. Check to see that the card assembly is level. Also check that it turns freely when the aircraft's tail is in a level flying position.

Set the compensator so it has no effect on the main compass magnets. Using a loose-magnet compensator, remove all loose magnets from their chambers. Set universal screw-type compensators for zero effect by turning both adjusting screws until the dots on the screws match with the dots on the compensator case.

Then, place the aircraft on a south magnetic heading over the compass rose, with the tail in a level flying position. The aircraft engine(s) should be turning, and as many pieces of avionics equipment as possible turned on. This will create as many stray magnetic fields as possible and simulate the condition of the aircraft in flight. Note the compass reading and record it. From this reading, it is simply a matter of algebraic subtraction (or subtraction of numbers having plus and minus signs) to determine the deviation on the south heading. The deviation is the algebraic difference between the magnetic heading and the compass reading. Deviation is the error in a magnetic compass caused by electromagnetic disturbances in the aircraft.

After doing this, place the aircraft on a west heading. Again, note the compass reading and determine the deviation or difference between the magnetic heading and what the compass reads. Next, turn the aircraft heading to magnetic north. Take the compass reading on this heading and determine the deviation. Now subtract, algebraically, the south heading deviation from the north heading deviation and divide the remainder by two.

For example, if the compass reads 175 1/2° while on the south heading (180°0), record this as a deviation of +4 1/2°(180°– 175 1/2°). If the compass reading is too low, the deviation is plus; if the reading is too high, the deviation is minus.

Suppose that on the north (000°), heading, the compass reads 006 1/2°. Such a reading is 6 1/2° too high. You would record this as a deviation of –6 1/2° (000° – 006 1/2°).

The next job is to determine the coefficient of north-south deviation. You accomplish this by subtracting, algebraically, the deviation on the south heading from the deviation on the north heading. You then divide the remainder by two.

$$\frac{(-6\ 1/2^\circ) - (4\ 1/4^\circ)}{2} = \frac{-11^\circ}{2} = -5\ 1/2^\circ$$

The aircraft is still on the north heading and the compass reads 006 1/2°. Since the coefficient of the north-south deviation is – 5 1/2°, you must adjust the north-south compensator by this amount. The compass reading on the north heading will now be 001°. This adjustment also corrects the south deviation by the same amount (but in the opposite sense). The south heading on the compass will now read 181°. The coefficient of north-south deviation, which is – 5 1/2° in this case, is called coefficient **C.**

On the loose-magnet type compensator, you adjust north-south deviation by inserting the necessary number of magnets into the lateral (athwartship) chamber of the compensator. If the compass has a universal compensator, you make the adjustment by turning the north-south (N-S) compensator screw.

The next step is to determine the east-west deviation. Turn the aircraft heading to magnetic east, according to the compass rose. Record the compass reading on that heading. Now determine the coefficient of east-west deviation, otherwise known as coefficient **B.**

Assume, for example, that the compass reads 2760 when the aircraft was on the west (270°, heading. Also assume it reads exactly 90° on the east (90°) heading. You find coefficient **B** by algebraically subtracting the deviation on west (– 6°) from the deviation on east (O°) and dividing by two.

$$\frac{(0^\circ) - (-6^\circ)}{2} = \frac{+6}{2} = +3$$

While the aircraft is on the east heading, adjust the east-west (E-W) compensator to add 3° to the compass reading. This reading becomes 93° on the east heading, and the compass would read 273° on the west heading. Make this adjustment by turning the E-W screw on a universal compensator. On the loose magnet type compensator, add the necessary magnets in the longitudinal (fore-and-aft) chamber. Leaving the aircraft on an east magnetic heading, next compute an overall deviation correction based on coefficient **A.** This coefficient is equal to the algebraic sum of the compass deviations on all four cardinal headings (north, east, south, and west) divided by four.

$$\frac{(-6\ 1/2^\circ + (0^\circ) + (4\ 1/2^\circ) + (-6)}{4} = \frac{(-8)}{4} = -2^\circ$$

You must compensate instrument panel compasses for coefficient **A** if it amounts to 2° or more in either direction. When making this correction, leave the magnetic compensators alone. To compensate for coefficient **A,** move the instrument in its mounting.

Compensate panel-mounted compasses for coefficient **A** by slightly realigning the whole

	COMPENSATING SWING			RESIDUAL SWING	
	ACTUAL HEAD (M)	AIRCRAFT COMP.	DEV'N	ACTUAL HEAD (M)	AIRCRAFT COMP.
N 000	000	006½	−6½	000	001
				045	045
E 090	090	090	0	090	093
				135	135
S 180	180	175½	+4½	180	181
				225	225
W 270	270	276	−6	270	273
				315	315
	(1)	(2)	(1) − (2)	(3)	(4)

IF SWINGING COMPASS USED AHEAD OF AIRCRAFT ADD OR SUBTRACT 180 DEGREES

COEFF $C = \frac{N-S}{2} = \frac{(-6\frac{1}{2}°)-(4\frac{1}{2}°)}{2} = -\frac{11}{2}° = -5\frac{1}{2}°$

COEFF $B = \frac{E-W}{2} = \frac{(0°)-(-6°)}{2} = \frac{+6°}{2} = +3°$

COEFF $A = \frac{N+E+S+W}{4} = \frac{(-6\frac{1}{2}°)+(0°)+(4\frac{1}{2}°)+(-6°)}{4} = \frac{(-8°)}{4} = -2°$

BU# 151357
SER# 9548-553
SWUNG 7-23-74

AIRCRAFT COMPASS
BY [signature]

TO FLY	STEER	TO FLY	STEER
N	001	180	181
015	016	195	196
030	030½	210	210
045	045	225	225
060	061	240	240½
075	078	255	256½
090	093	270	273
105	107	285	286½
120	121	300	300½
135	135	315	315
150	150	330	330
165	165½	345	346

Figure 7-59.-Compass correction card.

instrument panel. You can also turn the compass a little with relation to the front of the panel and placing washers or spacers under its mounting screws.

After completing this swing, swing the aircraft again on at least eight equally spaced headings (for example, 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). Record the compass readings for each heading on a compass correction card. Figure 7-59 shows an illustration of a compass correction card.

Detach the small right-hand portion of the compass correction card and mount with the compass. It is thus available for ready reference, telling the pilot or navigator the comparative compass headings and magnetic headings. Turn the larger portion of the card into maintenance control for insertion into the aircraft logbook.

MC-2 Magnetic Compass Calibrator Set

The MC-2 (fig. 7-60) provides a controlled magnetic field (simulated earth's magnetic field) about the aircraft flux valve **to** accurately calibrate the compass system. Use of the MC-2 only requires the aircraft be accurately placed on a north-south line, thus eliminating the need for rotating the aircraft on a compass rose. The compass calibrator provides electrical heading inputs from 0° to 345° in 15-degree increments with an accuracy of 0.1°. The compass calibrator can survey an area for magnetic uniformity. It also provides the necessary data for layout and marking of a compass swing site.

The compass calibrator consists of four major components—the control console, magnetic field monitor, remote transmitter turntable, and field tester. The set also includes various cable assemblies, reels, racks, tripods, and some special alignment equipment.

The control console contains the controls, indicators, and electronic components that allow the compass calibrator set to operate. It uses 115 volts, 400 Hz at a maximum of 1 ampere. The MC-2 changes this electrical power into ac and dc voltages that it requires.

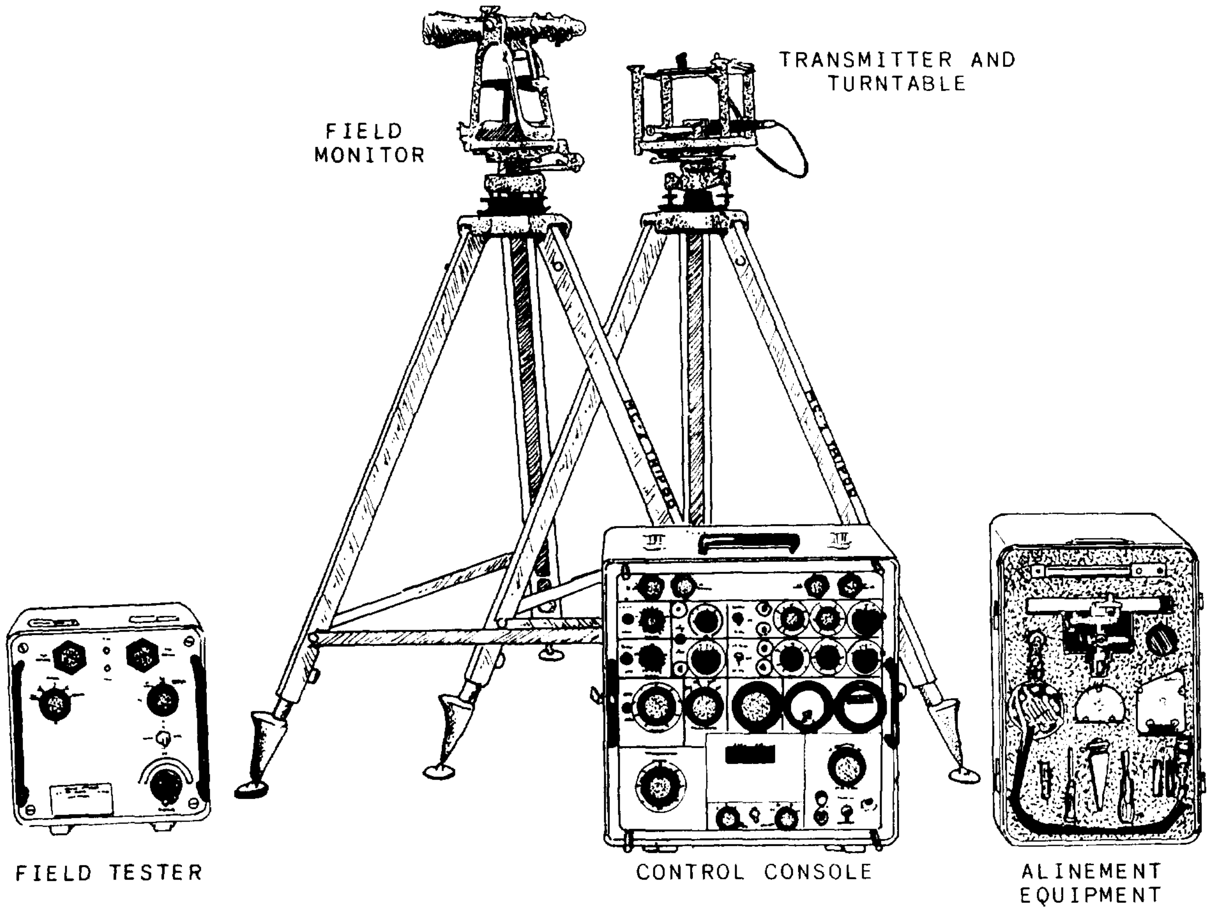


Figure 7-60.-MC-2 magnetic compass calibrator set.

The magnetic field monitor is an engineer's transit that has been modified to operate as a part of the compass calibrator set. The modification consists of installing a magnetic sensing element in place of the magnetic compass. The monitor is of nonferrous and nonmagnetic materials. It has a telescope, a horizontal circular scale with an adjustable vernier azimuth scale, levels, and leveling adjustment screws. The telescope is 22-power with an interior focusing optical system, and rotates 180 ° in a vertical plane.

The remote transmitter turntable is also an engineer-type transit with the compass, vertical circle, and telescope removed. Also included with the turntable is a transmitter mounting bracket and a rain hood.

The field tester is a portable metal-encased tester. It consists of a test panel, a shield can assembly, and a magnetic azimuth reference detector. All connectors, controls, switches, and electronic parts mount on the test panel. The shield can assembly contains a valve assembly within two magnetic shield cans. The magnetic azimuth reference detector consists of a 6-power telescope with azimuth adjustment and a flux valve assembly on a triangular support plate. The valve assembly has an attaching cable assembly.

The alignment equipment consists of a telescope, two plate assemblies, shaft coupling, quick connector, plumb bob and adapter, screw-drivers, magnifier, wrenches, and sunshade. The parts you use depend on the aircraft and transmitter under calibration. The telescope is a fixed-focus type, 8-power, with 360-degree azimuth rotation. A drum dial fine-adjusts azimuth, and an azimuth lock prevents unwanted rotation.

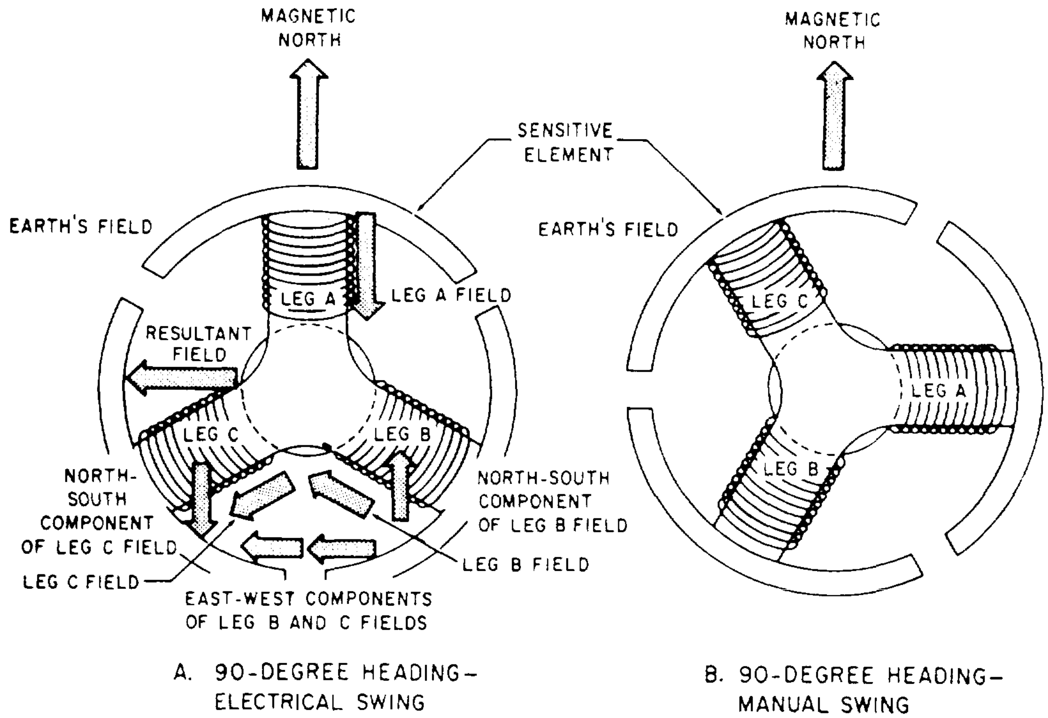


Figure 7-61.-Electrical swing and manual swing at a 90-degree heading.

The compass calibrator set is used to conduct an area magnetic survey. The survey determines the size and direction of the earth's magnetic field at a proposed aircraft swing site. You will also use the compass calibrator to conduct the actual compass swing. The control console provides controlled dc currents for the transmitter. The monitor detects the size and direction of the earth's magnetic field and supplies this information to the control console. You use the alignment equipment with the turntable to optically align the compass system transmitter (flux valve).

A review of the flux valve will be helpful in the following discussion.

In an electrical compass swing, a dc magnetic field is generated in the transmitter and varied in size and direction. This allows the MC-2, in combination with the horizontal component of the earth's field, to simulate an equivalent earth's field in the transmitter at a desired heading. Errors in the compass system are measured as the difference between the aircraft magnetic heading and the simulated earth's field magnetic heading. The aircraft heading shows on the aircraft compass indicator. The simulated earth's field heading shows by selecting the HEADING SELECTOR switch on the control console.

Controlled dc currents to the secondary coils of the transmitter generate an electromagnetic field (electrical swing). By applying a current to coil leg A of the transmitter (fig. 7-61), you generate a field that aligns to leg A. In the electrical swing, this field provides the north-south component of the simulated earth's field. A dc current also goes through coil legs B and C to generate two fields, each aligned to its respective coil. These fields are so oriented that north-south components of these two fields cancel, leaving one east-west component. By reversing the direction of the current flow, you can rotate the east-west component 180°.

The procedures for an electrical compass swing using the magnetic compass calibrator set are as listed below.

1. Set up the turntable over the spot where the remote compass transmitter will be when the aircraft is on the **north** line.
2. Remove the remote compass transmitter (flux valve) from the aircraft and mount it on the turntable.
3. Determine the alignment of the transmitter to magnetic north and its electrical calibration to the ambient magnetic field. Calibrate the N-S and E-W adjustments on the transmitter.

4. Mount the necessary optical alignment equipment to the remote compass transmitter. Align the telescope to a predetermined target one-half mile or more away.

5. Tow the aircraft into position exactly on the north line by using plumb bobs or some other accurate method.

6. Compute the optical alignment correction. Insert the correction into the optical alignment scope. Replace the compass transmitter in the aircraft (sighting on the same target used in step 4 above).

7. With the transmitter fastened down, reconnect the leads.

8. Using the appropriate adapter cables, connect the compass calibrator set into the compass system.

The aircraft magnetic headings are set in with the heading selector on the control console. Record the errors as the difference between the indicated heading and that set in with the heading selector. Calibrate the compass system components to within 0.10 of the heading selector position.

For more detailed information on compass swinging, refer to *Military Standards,* MIL-STD-765A. Consult this specification for additional information in connection with swinging, compensating, and calibrating compasses.

REVIEW SUBSET NUMBER 4

Q1. What INS solved the problem of operating an inertial system at the poles?

Q2. Having to maintain the accelerometer referenced to a fixed point in inertial space is a significant disadvantage of the ______________________.

Q3. What is the main advantage of the geometric inertial navigation system?

Q4. What two types of compensators are used on flux valves?

Q5. When must you compensate instrument panel compasses for coefficient A?

CHAPTER 8

AUTOMATIC FLIGHT CONTROL AND STABILIZATION SYSTEMS

Aircraft fly under many conditions. External conditions can alter the desired flight characteristics of the aircraft. To maintain the desired characteristics of the aircraft, the pilot moves the control surfaces either manually or automatically.

You have already learned about indicating systems and instruments that supply the pilot with information on the performance of the aircraft. The pilot must be able to see and interpret each of these indicators, and then react to get the desired performance. In high-performance aircraft, especially in single-piloted aircraft, other flight duties require much of the pilot's time. Navigation, communication, radar, and other special equipment is severely limited if the pilot has to work consistently on the physical manipulation of the controls.

In high-performance aircraft capable of supersonic flight, aircraft speed is so great that the pilot's normal response time is far too slow. By the time the pilot reacts to an indicator to position a control surface, the aircraft may already be out of control.

Automatic flight control and stabilization systems ease the pilot's workload and provide aircraft stability at all speeds. The information now flows directly to a flight control computer rather than to an indicator. This action lessens the time required to start a control movement to nearly zero (increased stability). The system also provides command controls by which the computer can control the aircraft in nearly any desired flight condition. Some automatic flight control systems are capable of flying the aircraft to radio navigation aids, correcting for wind, and making pilot-unaided landings.

The terms *automatic flight control system (AFCS)* or *automatic stabilization equipment (ASE)* are used instead of the older term *automatic pilot,* or the shortened version, *autopilot.* A reliable AFCS is necessary because pilots have duties other than moving the flight controls. However, regardless of how sophisticated the AFCS computer may be, the reasoning power of the pilot cannot be duplicated.

PRINCIPLES OF FLIGHT

Learning Objective: *Recognize principles of flight for both fixed- and rotary-wing aircraft.*

To understand automatic flight control and stabilization systems, you must study the effects that the various controls have on the aircraft. *Airman,* NAVEDTRA 14014, contains a basic introduction to the principles of flight and flight controls. You should review this text before proceeding with this chapter.

An airfoil is any part of an aircraft designed to produce lift. Obviously a wing is the primary airfoil on an aircraft; but, propeller blades, tail surfaces, and even the fuselage itself are important airfoils. The design of a specific airfoil is determined by the job it is to do. All airfoils have the basic elements shown in figure 8-1.

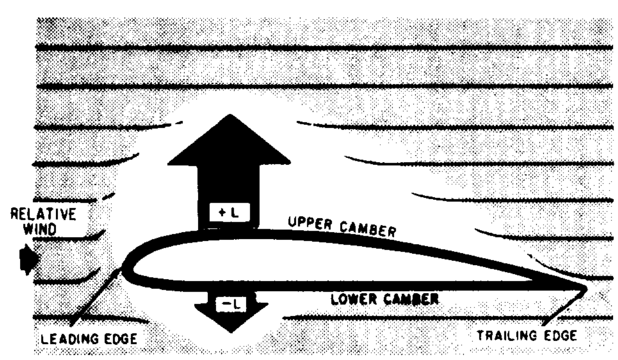


Figure 8-1.-An airfoil.

An airfoil consists of two nearly parallel surfaces, with one surface being more rounded than the other. As air passes over these two surfaces, the air passing over the rounded surface has farther to travel than the air passing over the flat surface. However, two particles of air leaving the airfoil's leading edge at the same instant, one going over the rounded surface and one over the flat, arrive at the trailing edge at the same time. Therefore, you can infer that air passing over the rounded surface travels at a higher velocity than air passing over the flat surface.

Bernoulli's theory concerning the behavior of fluids, E = V x P, explains how pressure is changed and lift is produced. Here, E is the total energy produced by the airfoil passing through the air, V is velocity energy, and P is pressure energy. An airfoil that passes through air at a velocity of 50 feet per second and exerts a pressure of 10 pounds per square inch on the flat surface produces a total energy of 500 foot-pounds per square inch per second.

$$E = V \times P = 50 \times 10 = 500 \text{ foot-pounds inch}^2\text{/sec}$$

If the airflow velocity over the rounded surface is increased to 60 feet per second, and the total energy is unchanged, it exerts a pressure of 8.33 foot-pounds per square inch per second on the rounded surface.

$$P = \frac{E}{V} = \frac{500}{60} = 8.33 \text{ foot-pounds}^2\text{/sec}$$

The difference in the pressure between the rounded surface and the flat surface of the airfoil is called *lift.*

In actual practice, the flat surface is not perfectly flat and causes some decreased pressure. The decreased pressure is negative lift. Negative lift is compensated for by the creation of a high pressure on the flat surface. Air packed beneath the airfoil (dynamic lift) causes the high pressure. The true measure of lift remains the difference in pressure between the rounded and flat portions of the airfoil.

Increased lift is the result of a larger pressure difference between the surfaces. The difference can be produced in two ways—by increasing the forward movement of the airfoil through the air (fig. 8-2), or by changing the angle of attack. Angle of attack is *the acute angle between the chord line of an airfoil and its direction of motion relative to the air.* The chord of an airfoil is an imaginary straight line drawn from the leading edge to the trailing edge of the airfoil (fig. 8-3). As the angle of attack increases, the air strikes the leading edge closer to the flat portion of the airfoil. The distance air must flow over the rounded portion becomes even greater in relation to that flowing over the flat portion. This action causes a larger pressure difference, and develops more lift.

If the angle of attack increases too much, airflow over the airfoil's rounded portion separates from the surface and becomes turbulent. Turbulence causes the pressure on both surfaces to become nearly equal, and the airfoil is said to *stall.*

When producing lift, a secondary effect called *drag* is also produced. Drag produced by a lifting surface or airfoil is called *induced drag.* Induced drag develops in direct proportion to lift—when lift increases, induced drag also increases. At a given speed and angle of attack, a thick airfoil produces more lift and drag than does a thin

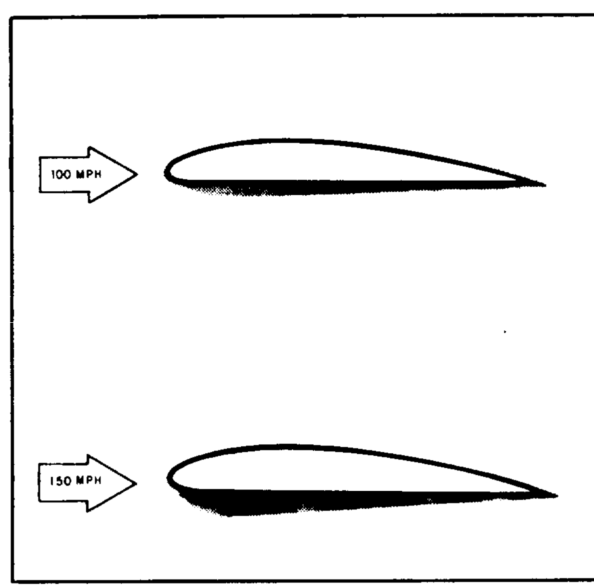


Figure 8-2.-Lift increases as velocity increases.

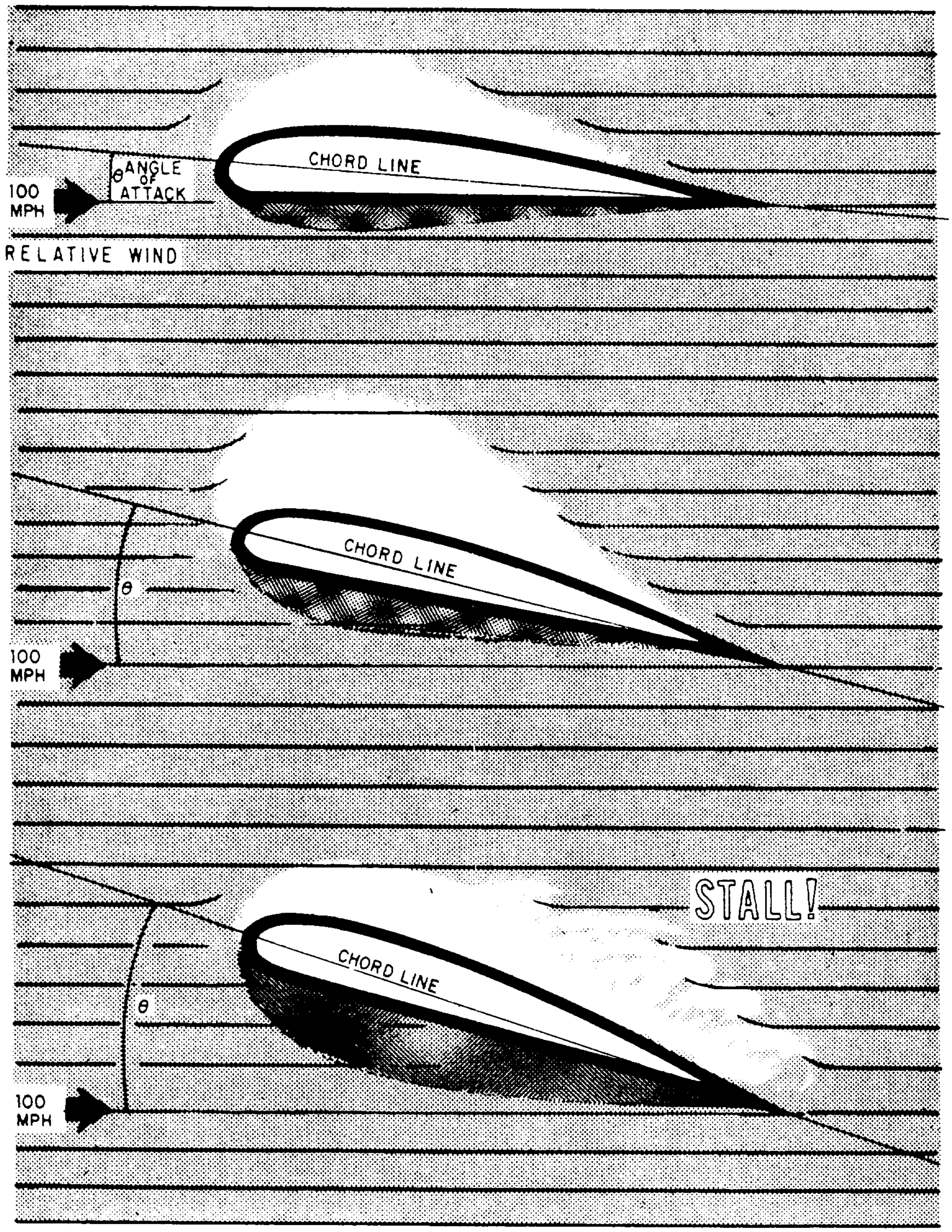


Figure 8-3.-Constant velocity verus increasing angle of attack.

airfoil (fig. 8-4). It follows that large, subsonic aircraft have thick wings to produce a great amount of lift at slow speeds. Supersonic aircraft must have very thin wings to decrease drag at high speeds.

Many airfoils have devices attached to them to increase or decrease lift in various flight conditions or attitudes. These devices may mount on the leading edge, trailing edge, rounded surface, or flat surface. If the trailing edge attaches by a hinge and has controls to move the trailing edge, you control lift by changing the angle of attack (fig. 8-5). When the trailing edge moves into the higher pressure air on the airfoil's flat side, the angle of attack is effectively increased. This causes more lift and drag. Conversely, if the trailing edge moves into the airfoil's low-pressure side, the angle of attack decreases. Lift and drag decrease accordingly.

In flight, each aircraft has certain forces acting upon it (fig. 8-6). To sustain flight at a constant altitude, the total lift of all airfoils must equal the aircraft weight. To change altitude you must change the total lift. If the aircraft weighs 10,000 pounds, 10,001 pounds of lift causes the aircraft to climb; 9,999 pounds of lift causes the aircraft to descend.

To fly at a constant airspeed, the forces of thrust and drag must be equal. When one force is greater than the other, the aircraft accelerates or decelerates.

To turn, place the aircraft in a bank angle (fig. 8-7). The lift developed by the airfoils can then be broken down into components of horizontal and vertical lift. The horizontal component of lift pulls the aircraft around in the turn. The vertical component of lift must be equal and opposite to gravity for the aircraft to remain at a constant altitude. (Note that total lift must be increased to prevent a loss in altitude.)

When centrifugal force equals horizontal lift, the aircraft is in a constant-rate turn. For a faster rate of turn, increase horizontal lift by increasing the bank angle. When all lift is vertical to gravity, any turning motion is called a *skid.*

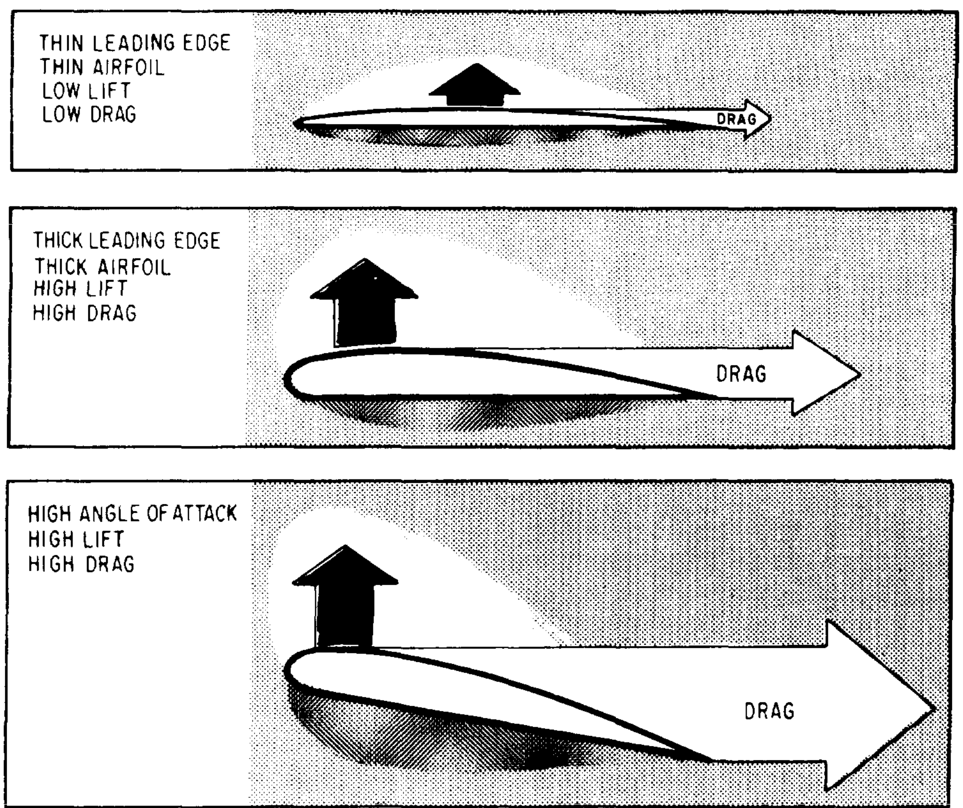


Figure 8-4.-Induced drag.

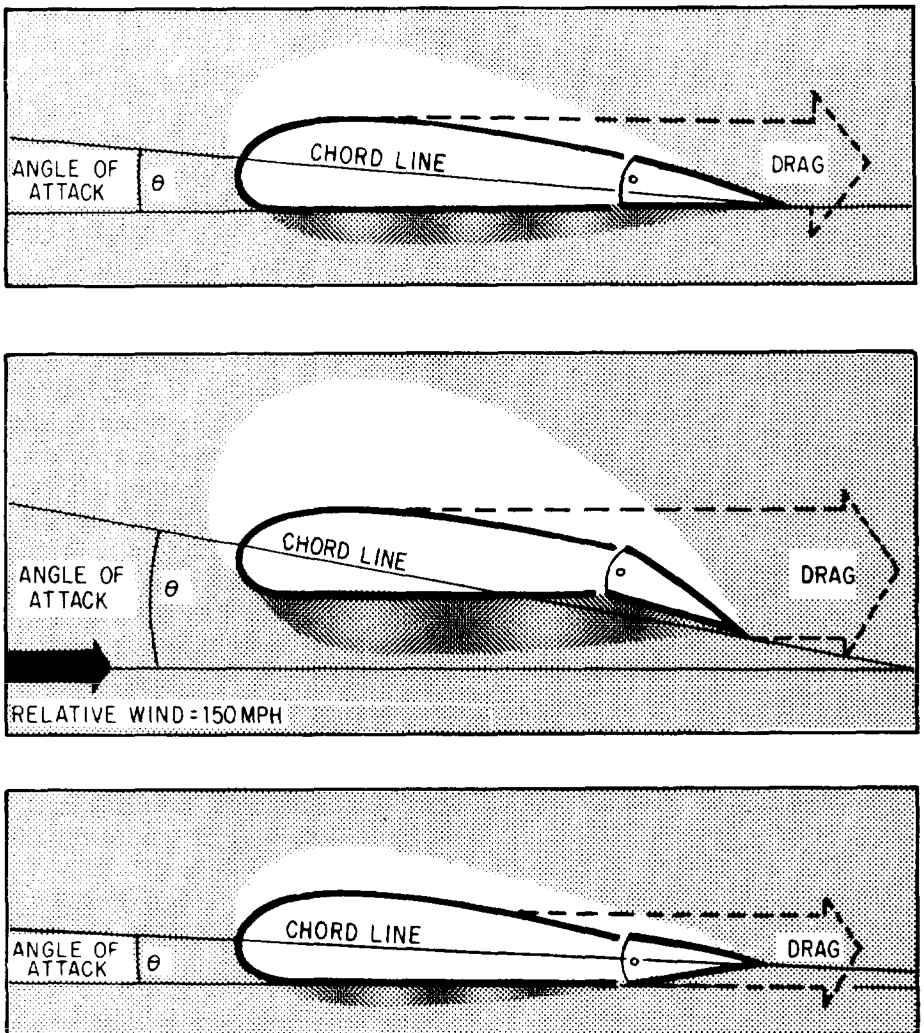


Figure 8-5.-Lift and drag change proportionately with the shape of the airfoil.

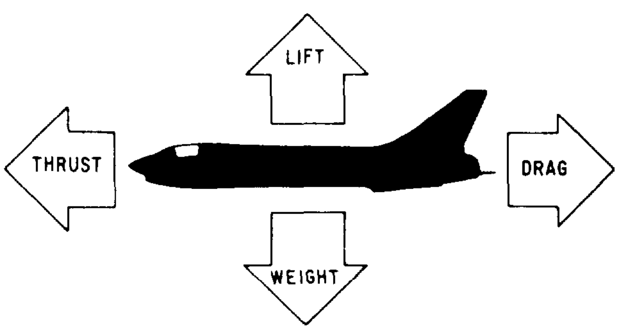


Figure 8-6.-Forces on an aircraft.

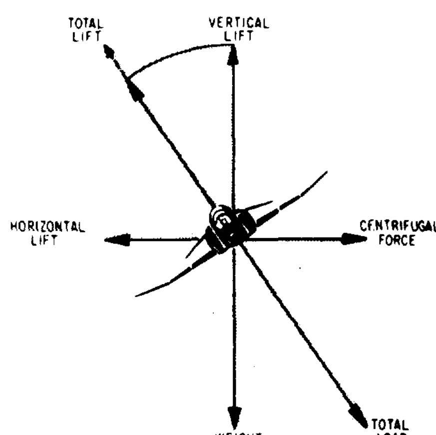


Figure 8-7.-Forces in a turn.

REVIEW SUBSET NUMBER 1

Q1. What are the two main purposes of the AFCS and ASE?

Q2. What is an airfoil?

Q3. When the pressure on both sides of the airfoil is nearly equal, what happens to the airfoil?

FIXED-WING AIRCRAFT

A fixed-wing aircraft is one in which the main lifting surface remains stationary with respect to the rest of the aircraft. This classification also includes such aircraft designs as the swing wing F-14. Fixed-wing aircraft have certain fixed surfaces or airfoils—wings and vertical and horizontal stabilizers—that provide stability (fig. 8-8). In addition, these aircraft have movable airfoils—ailerons, elevators, and a rudder. These permit the pilot to control the aircraft.

Movement about the lateral axis of the aircraft (the axis that extends from wing to wing through the center of gravity) is *pitch.* To control pitch you use the elevators. If you desire a nose-up attitude, apply an aft motion on the cockpit control (stick or yoke). This causes the elevator to move up, creating a downward force on the horizontal stabilizer. Rotation about the lateral axis then causes the nose to rise. Conversely, if you want to lower the aircraft nose, apply a forward motion on the cockpit control. This causes the elevator to lower, creating an upward force on the horizontal stabilizer. Rotation about the lateral axis then causes the nose to lower.

Movement of the aircraft about the longitudinal axis (from nose to tail) is known as *bank* or *roll.* You control this motion by using the ailerons. The ailerons mechanically connect to each other, but move in opposite directions. For the aircraft to enter a left bank, the angle of attack of a portion of the right wing must increase. You accomplish this by lowering that aileron to increase the lift on that wing. The aileron on the left wing is raised to decrease the lift on that wing. The aircraft then rotates about its longitudinal axis until the ailerons are neutralized in some angle of bank. The aircraft remains in that bank angle until you again move the ailerons.

Refer to figure 8-7. Whenever the aircraft is in a bank, lift developed by the wings is displaced

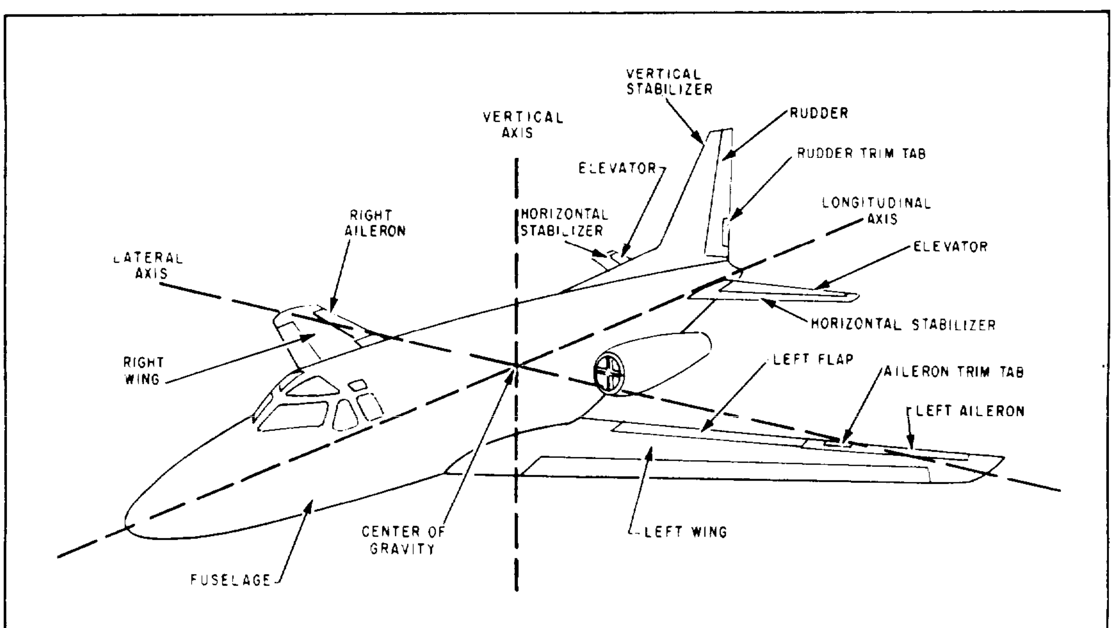


Figure 8-8.-Fixed-wing aircraft controls.

from the vertical position. If you do not increase lift, its vertical component is insufficient to maintain the aircraft at a constant altitude. A change in pitch attitude to increase the angle of attack of the wings is used to prevent a loss in altitude. A few degrees of bank angle requires an imperceptibly small pitch change. A 90-degree bank in level flight (no altitude change) is theoretically impossible because of the absence of vertical lift. As the bank angle changes, coordination between ailerons and elevators is necessary to prevent a loss in altitude.

To return to level flight, increase lift on the left wing by lowering its aileron into the higher pressure area beneath the airfoil. Reduce lift on the right wing by raising its aileron into the lower pressure area at the top of the airfoil. As the wings become level, neutralize the ailerons.

Movement about the vertical axis is *yaw*. Usually this movement is undesirable in an aircraft. Use the rudder to correct any tendency of the aircraft to yaw. The rudder is NOT used to turn the aircraft (change heading).

When placing the ailerons into the airstream, the aircraft has a tendency to yaw. In banking to the right, the aircraft produces more lift and drag on the left wing, and less lift and drag on the right wing. Even though the intention is to turn to the right by going into a right bank, the initial tendency is for the nose of the aircraft to go to the left. This happens because of the increased drag on the left wing and decreased drag on the right wing. This is adverse yaw; you compensate for it by displacing the rudder in the same direction as the intended turn.

If an aircraft in a turn tends to slip into the inside of the turn or skid to the outside of the turn, this is also yaw. You also compensate for it by using the rudder. Many other things may cause yaw, such as the engines on one wing of a multiengined aircraft producing more power than the engines on the other wing.

You can see, then, when you place a fixed-wing aircraft in a bank angle, coordination between all three controls—ailerons, elevators, and rudder—is necessary. The pilot accomplishes control of elevators, ailerons, and rudder through the use of a control stick and rudder pedals (fig. 8-9). To operate the ailerons, move the control stick right or left in the direction of the intended turn (fig. 8-9, view A). Aft force on the control stick raises the elevator and causes the nose to pitch up. Forward pressure on the control stick lowers the elevator and causes the nose to pitch down (fig. 8-9, view B). You use your feet

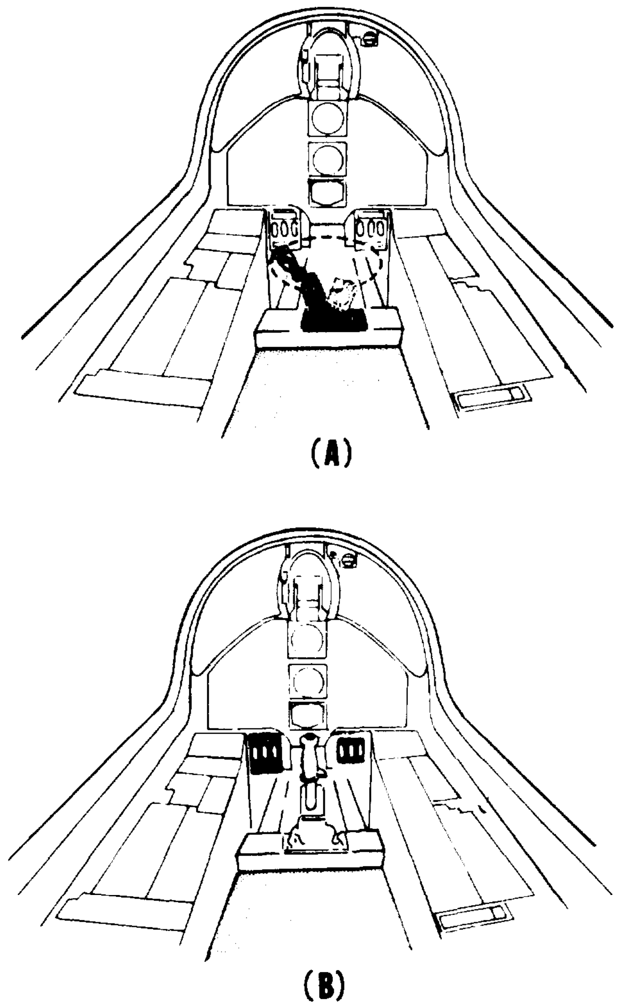


Figure 8-9.-Flight controls. (A) Elevator and aileron; (B) Rudder.

to operate the rudder pedals. Pressure on either rudder pedal causes rudder deflection in that direction.

Weight distribution in an aircraft varies for many reasons. For example, fuel may be used faster from one wing tank than from the other, allowing that wing to become lighter. In large aircraft where crew members or passengers walk around, the balance point, called the *center of gravity (CG),* shifts whenever someone changes position in the aircraft. As fuel is used, the aircraft gross weight reduces. The pilot must reduce the angle of attack of the wings to lessen lift and prevent a gain in altitude.

The pilot must use control pressures to compensate for these unbalanced flight conditions. Several methods are used to reduce these control pressures and to ease the pilot's workload. The most common method is the trim tab. Look at figure 8-8. The figure shows only rudder and aileron trim tabs. Trim tabs on the elevators on this particular aircraft are undesirable because they produce excessive drag. Another method of elevator trim involves linkage pressure.

When pilots must exert a force on the cockpit control, they can use the trim control to relieve that force. For instance, when they must hold left rudder pressure to prevent yaw movement to the right, they can move the rudder trim tab to the right. The airflow on the vertical stabilizer strikes the trim tab and moves the complete rudder a little to the left. Since the rudder trim tab now supplies the required rudder pressure, the pilot no longer has to hold pressure on the rudder pedals.

ROTARY-WING AIRCRAFT

An aircraft that derives its main lifting force from a horizontally driven propeller device (rotor) is a rotary-wing aircraft. The most common rotary-wing aircraft is the helicopter. There must be relative motion between an airfoil and an air mass. Therefore, the major advantage of a rotary-wing aircraft is its ability to maintain zero or very low airspeed while the wings (rotors) are still creating lift.

Forces acting on a rotary-wing aircraft are identical to those acting on a fixed-wing aircraft (fig. 8-6). You must also control the rotary-wing aircraft about the vertical, longitudinal, and lateral axes, as in figure 8-8.

In the conventional helicopter, the main and tail rotor are engine driven. Remember the earlier discussion on airfoils. You increase lift by either increasing the speed of the airfoil through the air or by increasing the angle of attack of the air foil. In helicopters, the air foil's angle-of-attack is known as *blade pitch.* When the rotor speed is constant, the pilot maintains complete control of the aircraft by varying the pitch of the rotor blades.

Figure 8-10 shows helicopter flight controls. The pilot operates collective control with the left hand, cyclic control with the right hand, and rudder control with the feet. The collective and cyclic controls command the main rotor. Operation of the rudder control changes the blade angle of the tail rotor.

In helicopter flight (except hovering flight), the main rotor provides altitude, bank, and directional control through use of the collective and cyclic controls. The tail rotor prevents the main body of the helicopter from spinning (yawing) with the torque of the main rotor. It prevents yaw in much the same way as the fixed-wing aircraft rudder.

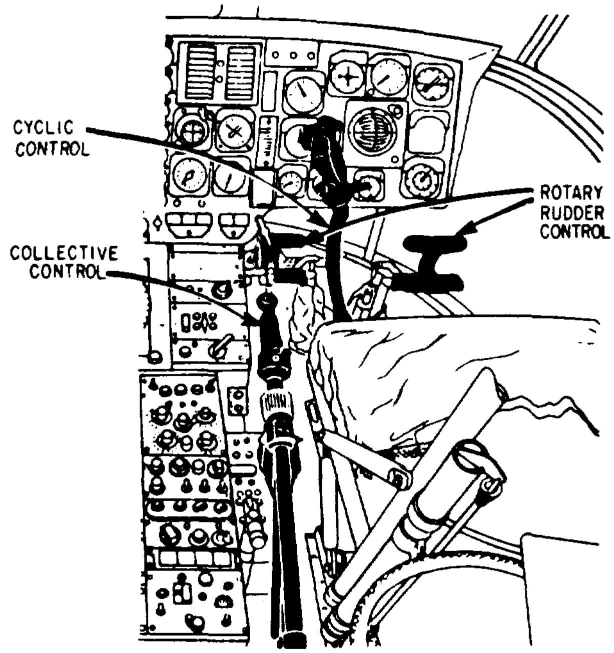


Figure 8-10.-Helicopter flight controls.

Collective control maintains or changes altitude. Moving the collective control causes an equal change in pitch (angle of attack) of all main rotor blades. Also, through a mechanical mixer, it automatically changes tail rotor pitch. The collective control changes tail rotor pitch to compensate for increases or decreases in main rotor torque. Since the rotor blades are somewhat flexible, the more collective control applied, the more an action called *coning* takes place. As the blades rotate, they take the shape of a cone (fig. 8-11). The speed and pitch of the blade tips determines the coning angle. With a constant

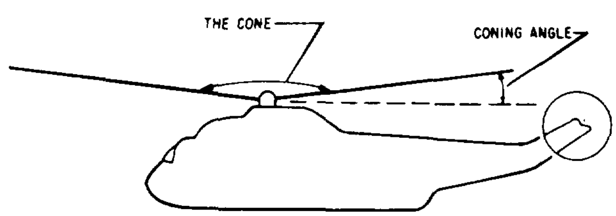


Figure 8-11.-Coning angle increases as load increases.

pitch, the faster the rotor blades turn, the more horizontal the blades become because of centrifugal force. As the blade pitch increases, lift also increases, and the coning angle increases because of the load on the blades.

In hovering flight, cyclic controls pitch and roll, which create forward and sideward motion, respectively. The collective controls altitude and the rudder pedals control heading.

The cyclic stick provides pitch and directional control of the helicopter. When the pilot applies pressure to the cyclic stick, each blade moves to a specific pitch angle as it passes a certain point in its rotation (fig. 8-12). To accomplish forward flight, the blade pitch is greatest as it passes the 90-degree position. The blade pitch will be least at the 270-degree position, and equal at the 0-degree and 180-degree positions. To turn the aircraft, lateral motion of the cyclic stick causes blade pitch to be greatest at 0 and 180 degrees, and least at 90 and 270 degrees. Since the blades form a spinning mass, the gyroscopic principle of precession occurs 90 degrees in the direction of rotation from where the lifting force is applied. The coning angle remains the same. However, the cone tilts (called *flapping angle)* in the direction

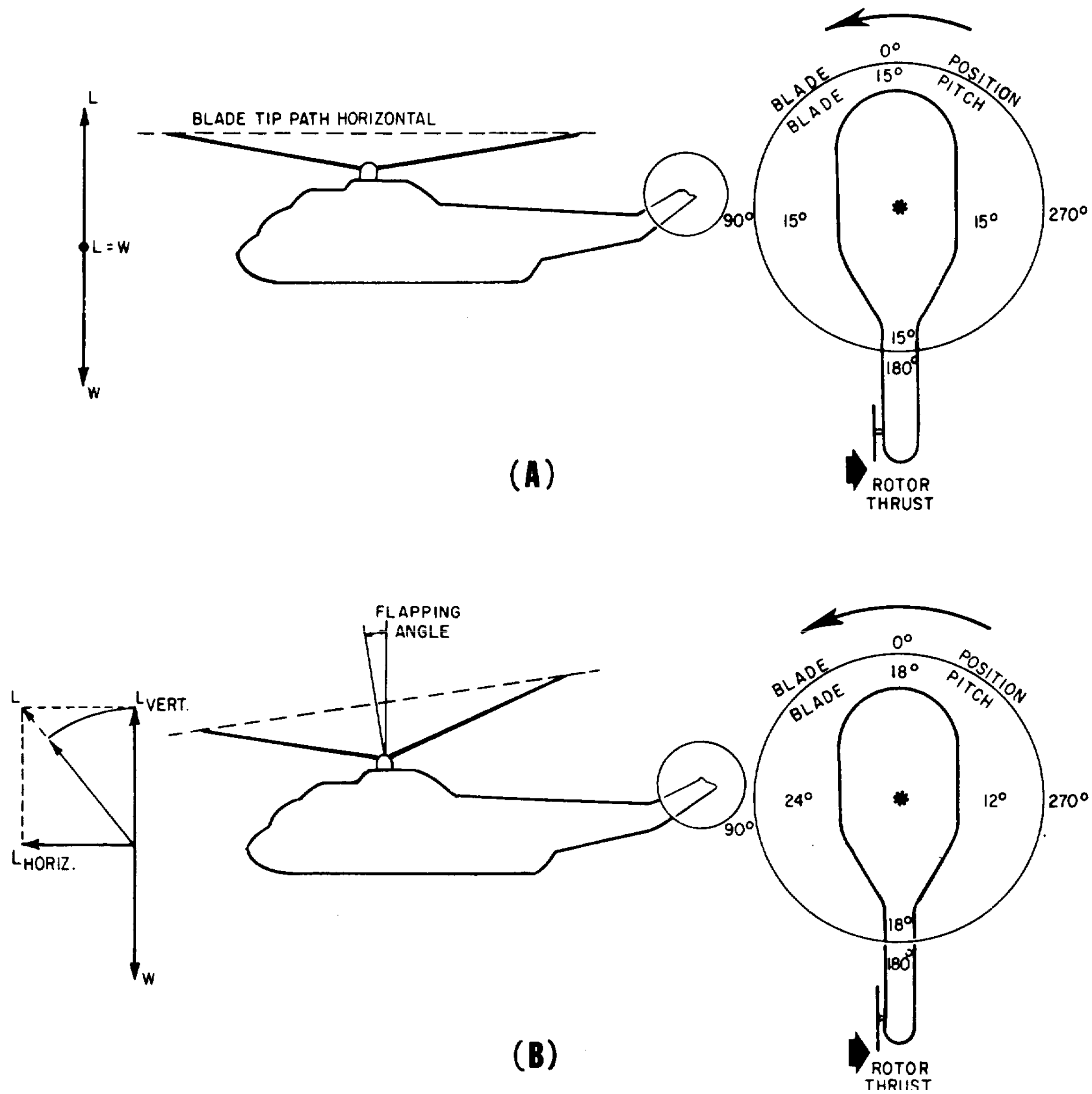


Figure 8-12.-Flapping angle creates horizontal lift. (A) Hovering flight; (B) Forward flight.

of the desired flight path. You can again break lift down into its vertical and horizontal components. Look at figure 8-12, view B. To maintain altitude, the vertical lift is increased until it is equal to gravity. With the cone at a flapping angle, the helicopter accelerates in the desired direction until drag is equal to horizontal lift.

To accelerate the helicopter in a forward direction, move the cyclic control stick forward. You also must make a corresponding increase in collective to maintain altitude. As the collective increases, torque on the main rotor blade increases. This makes the helicopter tend to rotate in the direction opposite to the rotor blade rotation (nose right). A mechanical mixer automatically changes the pitch of the tail rotor to overcome the right turning tendency (skid).

To turn the helicopter (change heading), place the cyclic control stick to the right or left. Flapping action of the main rotor blades causes the cone to tilt in the direction of the desired turn. As in the fixed-wing aircraft, the pilot must maintain coordination in a turn by using the rudder pedals to prevent skid or slip. Also, the pilot must adjust collective to prevent a loss in altitude. In hovering flight, the pilot uses the rudder pedals only to turn the helicopter, thus producing a skid.

REVIEW SUBSET NUMBER 2

Q1. On *a fixed-wing aircraft, what control surface corrects for yaw?*

Q2. As fuel is used, what must the pilot reduce to lessen lift and prevent a gain in altitude?

Q3. How does the pilot increase lift in a helicopter with a constant speed rotor?

Q4. When does the action called coning take place?

AUTOMATIC FLIGHT CONTROL SYSTEMS (AFCS)

Learning Objective: *Relative to the automatic flight control system, recognize functions and operating principles and modes, including air data and flap position information and coordination inputs, and identify AFCS components.*

In the human body, signals to move us from place to place start with our five senses as they reference outside conditions. The brain processes these signals and sends them through the nerves to the muscles. The body then does its required movement by muscle power. Similarly, most automatic flight control systems (AFCS) have their component parts divided into three major groups—sensors (information inputs), amplifier/computer, and output units.

The sensors originate the signals as they are acted upon by outside references. They only sense changes and do not have sufficient power to make corrections.

The amplifiers and computers are the *brains* for the AFCS. They receive the weak signals from the sensors, which in most cases are synchros, and determine how much and in which direction correction is necessary. The synchro signals are usually in millivolts, but the correct strength needed is in volts. Therefore, the amplifier increases the weak signal to a workable voltage. The value of the synchro signal depends on the amount of rotor displacement with respect to the stator from the null position. The direction of rotor displacement from the stator determines the direction of the correction. Most amplifiers have at least two stages of voltage amplification—one stage of phase discrimination, and an amplifier where power amplification takes place, Other types of amplifiers control the voltage to control valves in hydraulic servos.

The output unit is the *muscle* of the AFCS. It consists of an electro/hydraulic booster package. There is a booster package for each control surface—rudder, aileron, and elevator. The boosters also assist the pilot in manual control of the aircraft.

Summing up the major groups, the sensors send a small signal to the amplifier/computer when a displacement occurs. The amplifier/computer amplifies the weak signal to a workable voltage and sends it to the output unit. The output unit changes the electrical energy to mechanical displacement. It then moves the control surfaces by an amount commanded by the sensor signal.

AFCS COMPONENTS

The automatic flight control system (AFCS) consists of many controls, sensors, and electro-mechanical components. To understand the entire system, you need to know what each component of the system does. In this section, you will read about the components that make up the AFCS.

Electrical/Electronic Components

The electrical/electronic components make automatic flight control systems work. The control panel is used to program any pilot-desired maneuver that is within the capability of the system. Originally, AFCS systems were very limited. They supplied only one-channel operation to the ailerons to keep the wings level. Newer aircraft receive signals from other aircraft systems. Radar and barometric altimeter signals couple with the AFCS to maintain the aircraft at a constant altitude. Some aircraft use signals from data-link systems to fly the aircraft during approaches and landings. Some fighters have the fire control system tied in so the aircraft can fly automatically to an enemy aircraft. Fighter bombers with a weapons control system tie-in can fly automatically to the target and release their weapons at the proper time. Long-range patrol aircraft have their ASW systems tied into their AFCS. The AFCS operates the rudder, the elevator, and the ailerons by using various sensors and electrically controlled hydraulic servos. Before engagement, the AFCS is synchronized with the flight control surfaces to prevent sudden or violent maneuvers.

The system senses deviation from the reference flight condition and causes the aileron control to maintain either a reference bank angle or a heading. It also causes the elevator control to maintain either a reference pitch angle or an altitude. Also, it makes the rudder control coordinate turns and provides automatic yaw damping.

CONTROL PANEL. —The AFCS control panel contains all the switches and controls necessary for the pilot to select/control the autopilot modes. Control panels are designed for the particular type and mission of the aircraft. Some control panels are simple, while others are complex. Figure 8-13 is an example of a AFCS control panel. Here, the switches serve as manually operated interlocks in setting up the circuitry to engage the various AFCS modes of operation. This control panel has six switches. They are labeled as follows: ACL/OFF/PDC, ALT/OFF/MACH, HDG OFF/NORM/ROLL CMD, AUTO/STAB-AUG, ON/OFF, and ATTITUDE REF.

The ACL/OFF/PCD, ALT/OFF/MACH, and HDG OFF/NORM/ROLL CMD switches are solenoid-held toggle switches. Each has a lever-lock toggle feature that prevents accidental engagement in the operate position. The AUTO/STAB-AUG and ON/OFF switches are solenoid-held, spring-loaded switches. When not engaged or with no power applied, the switches return to the STAB-AUG and OFF positions, respectively. The ATTITUDE REF switch is a miniature, positive-break, aircraft-type toggle switch.

AIR NAVIGATION COMPUTER (ANC). — All operating functions of the automatic flight control systems channel through the air navigation computer. It is sometimes called the *amplifier computer,* and it is the heart of the entire system.

The ANC modifies the combined signals supplied by various sensors and command controls to develop output signals. The output signals control the aircraft's ailerons, rudder, and elevators. By use of these flight controls, the aircraft automatically maintains a reference attitude, heading, and altitude. Also, it can maneuver in a coordinated manner in response to turn and pitch control settings on the control panel.

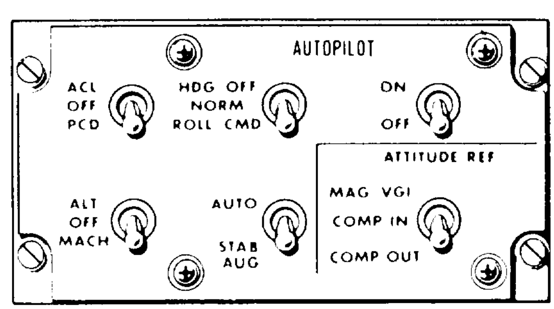


Figure 8-13.-AFCS control panel.

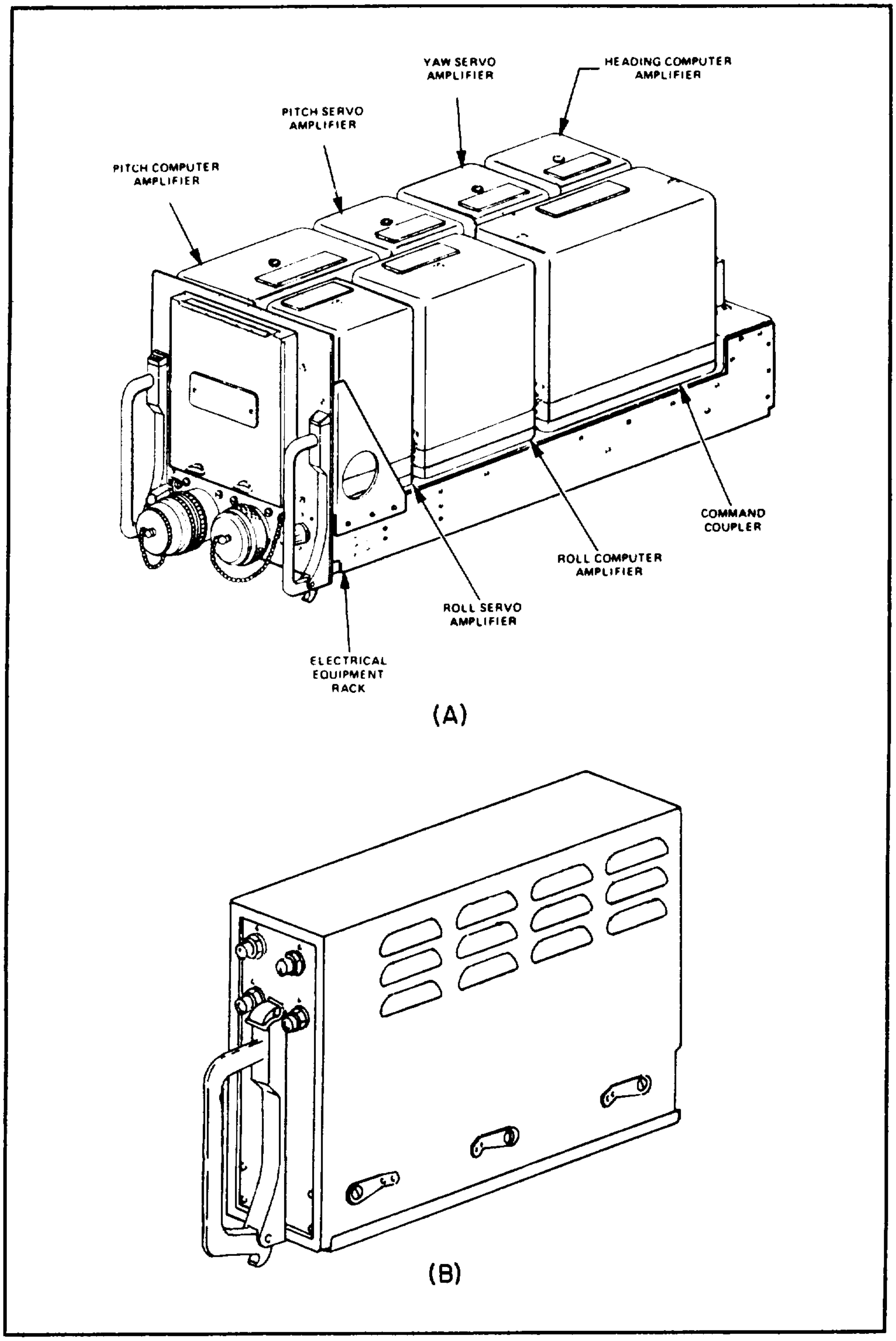


Figure 8-14.-(A) Air navigation computer; (B) One-channel amplifier/computer.

The physical appearance of the ANC depends on the type and mission of the aircraft. Figure 8-14 shows two different types of ANC. View A of figure 8-14 shows an ANC that consists of an equipment rack and seven amplifier modules, which are listed below.

1. Roll servo amplifier
2. Pitch servo amplifier
3. Yaw servo amplifier
4. Roll computer amplifier
5. Pitch computer amplifier
6. Heading computer amplifier
7. Command coupler

Each of the seven modules contains sub-assemblies and sub-subassemblies. Some of these are interchangeable between modules. The roll, pitch, and yaw servo amplifiers are identical. The other modules have individual differences. The computer, through an interlocking relay arrangement in conjunction with the control panel mode selection switches, controls signal switching operations. A calibration board on the front of the ANC provides gain adjustments of the major system parameters.

View B of figure 8-14 shows a one-channel amplifier/computer. Normally, this particular type of autopilot computer consists of three individual amplifier/computer modules—one for each control surface—aileron channel (roll), rudder channel (yaw), elevator channel (pitch).

This one-channel computer accomplishes analog computations by using servomechanisms. These servomechanisms consist of electro-mechanical computer cards and electronic amplifier cards mounted in the amplifier/computer. In addition, a transformer board and a resistor board provide summing networks. The networks combine the various signals supplied to and generated within the unit. An interlocking relay arrangement is included to perform most of the switching control in the automatic flight control system.

CONTROL STICK. —Control stick or control wheel steering is used on some aircraft to control the aircraft electronically through the AFCS, using the regular control stick or control wheel. On fighters, the signals are generated in a unit such as the one labeled "motional pickup transducer," in figure 8-15.

When the AFCS is on and the control stick is moved left or right, pressure on the roll force switch momentarily disengages the roll channel of the AFCS. The pilot then controls the roll

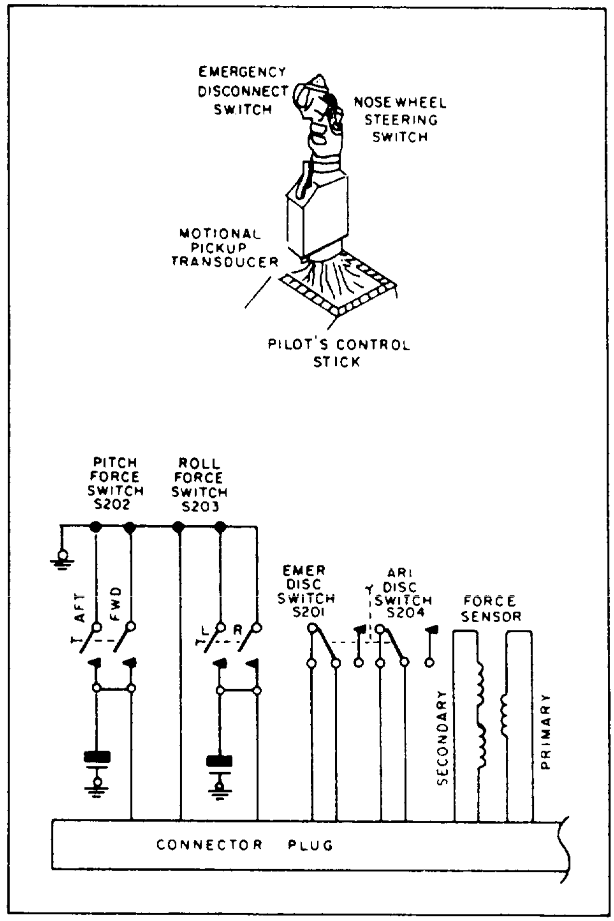


Figure 8-15.-Control stick steering components.

attitude of the aircraft through regular stick control. When the pilot releases stick pressure, the force switch opens, allowing the AFCS to reengage roll. If the bank angle is above a given angle (for example, 5 degrees), the AFCS will maintain the bank angle. If the bank angle is below the given angle, the AFCS automatically returns to wings level.

The pitch force switches close when a fore or aft pressure is on the control stick. This momentarily disengages the AFCS. The stick pressure also couples a signal through the E pickoff transformer that is labeled "force sensor," as shown in figure 8-15. The signal couples with the AFCS pitch channel. Depending on the direction of the stick pressure (fore or aft), the aircraft either climbs or dives.

Electrical/Electronic Sensors

Many electrical and electronic sensors provide input to the AFCS. This section of the TRAMAN includes a review of the sensors already discussed, and it introduces you to other sensors in the AFCS.

SIGNAL GENERATOR PICKOFF (SYNCHRO). —Figure 8-16 illustrates the principal of operation for a signal generator pickoff. The pickoff consists of a stator and rotor. The stator is ring-shaped and has four poles. Each pole has a primary and secondary winding. The rotor has no windings. It serves to change the reluctance of the magnetic flux path between the stator poles. The primary and secondary windings are connected so the voltages induced into the secondaries are of opposite polarity on adjacent poles. However, opposite poles have the same polarity.

The voltage output of the secondary is zero if the rotor is in its neutral position (fig. 8-16, view A). Repositioning the rotor (fig. 8-16, views B and C) makes a stronger magnetic field on a single pair of poles. This results in a voltage output on the secondary winding. The amplitude of the output voltage is proportional to the amount of rotor displacement—the greater the displacement, the greater the amplitude. The direction of rotor movement determines the polarity of the output voltage. The polarity will either be in phase with the input voltage or 180 degrees out of phase with it.

Synchro construction allows accurate voltage production versus angle signal, effective through 360 degrees of rotation. For more information

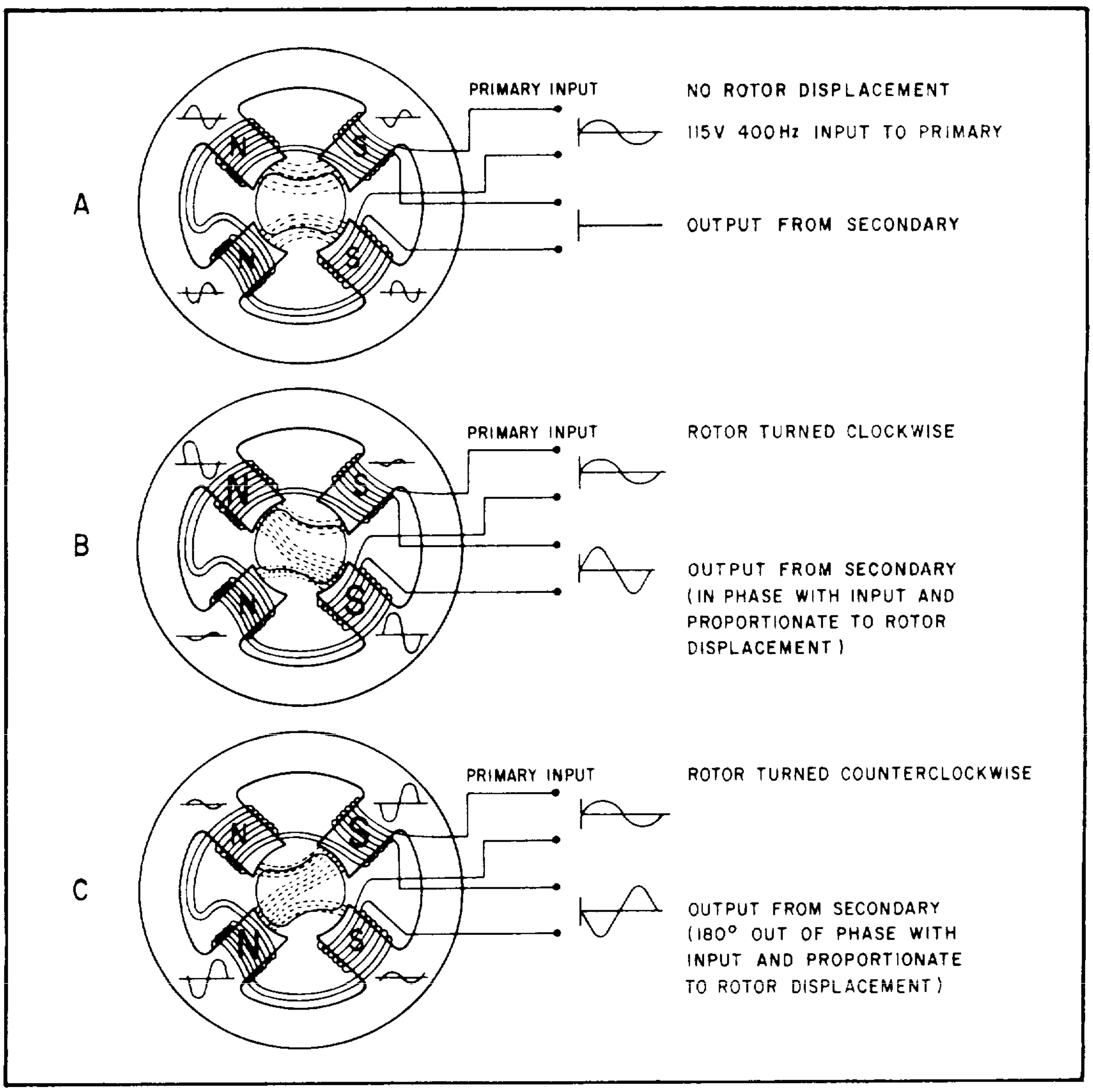


Figure 8-16.-Signal generator pickoff operation.

about synchros, servos, and gyros, you should refer to Navy Electricity and Electronics Training Series (NEETS), module 15, *Principles of Synchros, Servos, and Gyros.*

GYROS. —There are several different gyros used with the AFCS. You have already learned about most of them earlier in the TRAMAN. The following paragraphs provide a review of gyros and how they specifically affect the AFCS.

Vertical Gyro. —The vertical gyroscope (fig. 8-17) is an electrically driven gyro that provides pitch and bank attitude references for the AFCS. It can also provide pitch and bank attitude references for servo indicators and other systems of the aircraft. It has enough signal load capacity to sustain several systems at the same time.

The vertical gyro is a two-degree-of-freedom gyro. This gyro is termed the *vertical gyro* because it is continuously erect with its spin axis vertical to the surface of the earth. The spin axis provides a vertical reference for measurement of aircraft bank angle and pitch angle. Pitch and roll gimbals

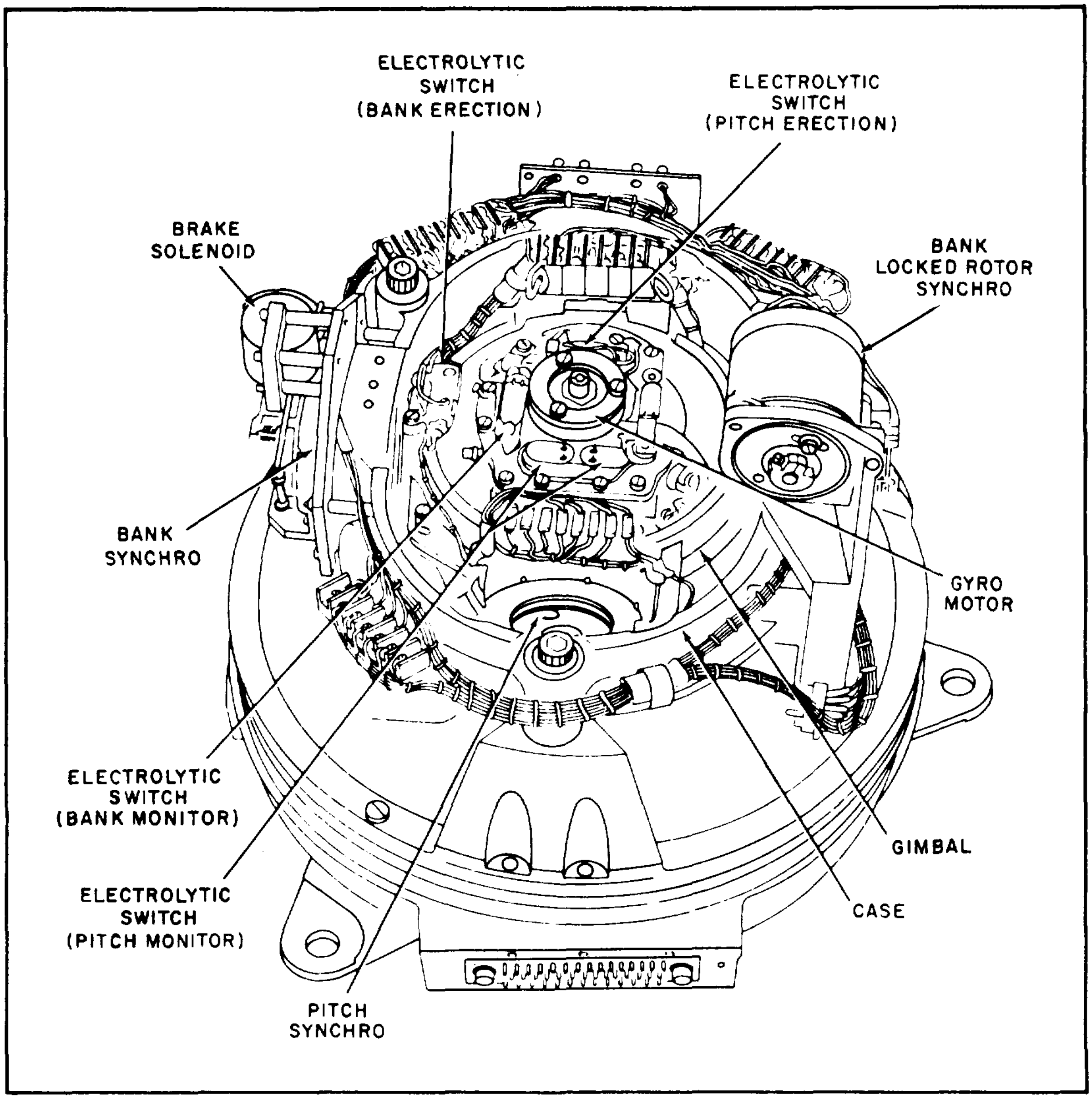


Figure 8-17.-Vertical gyro components.

isolate the gyro from its housing and the aircraft. Thus, the aircraft can bank or pitch while the gyro remains vertical because of gyroscopic action (fig. 8-18). A pitch synchro, mounted on the vertical gyro's pitch pivot, centinuously senses the relative pitch angle between gyro and aircraft. Similarly, a bank synchro, mounted on the vertical gyro's bank pivot, continuously senses the relative bank angle between gyro and aircraft.

The gyro motor rotates at a speed of about 20,000 RPM. A solenoid-operated friction brake prevents tilting and tumbling when the gyro motor is idle and during the initial starting torque.

Synchros mounted on the gyro detect motion between the gyro, the gyro gimbal, and the gyro case. A synchro generates a weak signal when its rotor is displaced from its stator. The pitch synchro mounts with its rotor on the gyro pivot and its stator on the gyro gimbal. Thus, the synchro measures the displacement angle between the gyro and the gimbal. This is the pitch displacement angle from the vertical reference. The bank synchro mounts with its rotor on the gyro gimbal pivot and its stator on the gyro case. Thus, the synchro measures the displacement angle between the gimbal and the case. This is the bank displacement angle from the vertical reference.

As the pitch attitude of the aircraft changes, the gyro case and gimbal turn about the gyro rotor. The pitch synchro rotor is held rigid in space by the gyro. This generates voltages in the pitch synchro proportional to the aircraft's pitch angle with respect to the surface of the earth. During changes in pitch attitude, the bank synchro remains at null since the gyro gimbal is not free to rotate with respect to the case in pitch. Therefore, it tilts with the case.

As the bank attitude of the aircraft changes, the bank synchro stator turns about the bank synchro rotor. The gimbal is held rigid in space by the gyro because it is not free to rotate with respect to the gyro in bank. Thus, the bank synchro generates voltages proportional to the

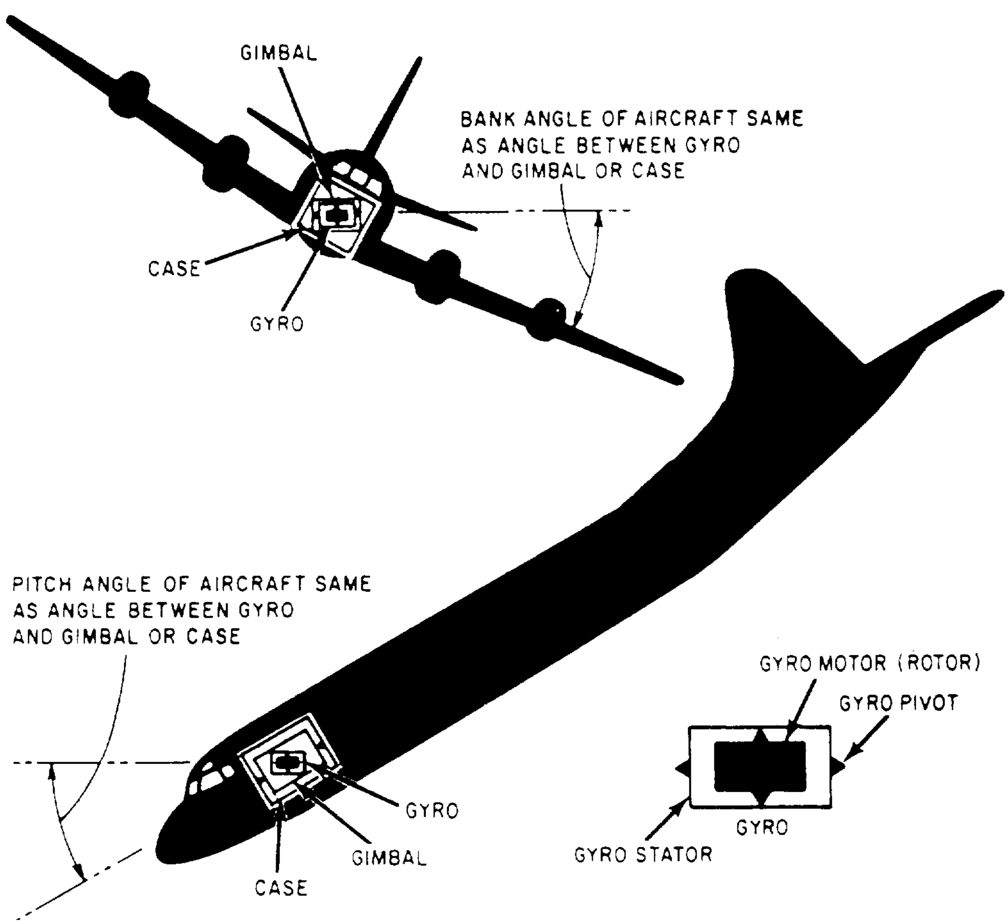


Figure 8-18.-Vertical pitch and roll reference.

bank angle between the aircraft and the surface of the earth.

When the aircraft yaws, the case, the gimbal, and the gyro stator turn about the rotating gyro motor. This has no significant effect upon the relative positions between the gyro and the case. As a result, there are no pitch and bank synchro output voltages in response to changes in yaw.

Three-Axis Rate Gyroscopes. —Rate gyros sense the rate of movement of an aircraft about its vertical, lateral, or longitudinal axis. They provide synchro signal outputs representing yaw rate, pitch rate, or roll rate to the air navigation computer. These units are sometimes very similar in appearance to the rate switching gyro, but they provide entirely different information to the system. Physically, rate gyroscopes are the same. They differ only in respect to calibration, alignment, range, sensitivity, and natural frequency. Each gyro measures angular rate. It uses the proportional precessional torque generated by the rate of movement about the gyro-sensitive axis (fig. 8-19) to make these measurements.

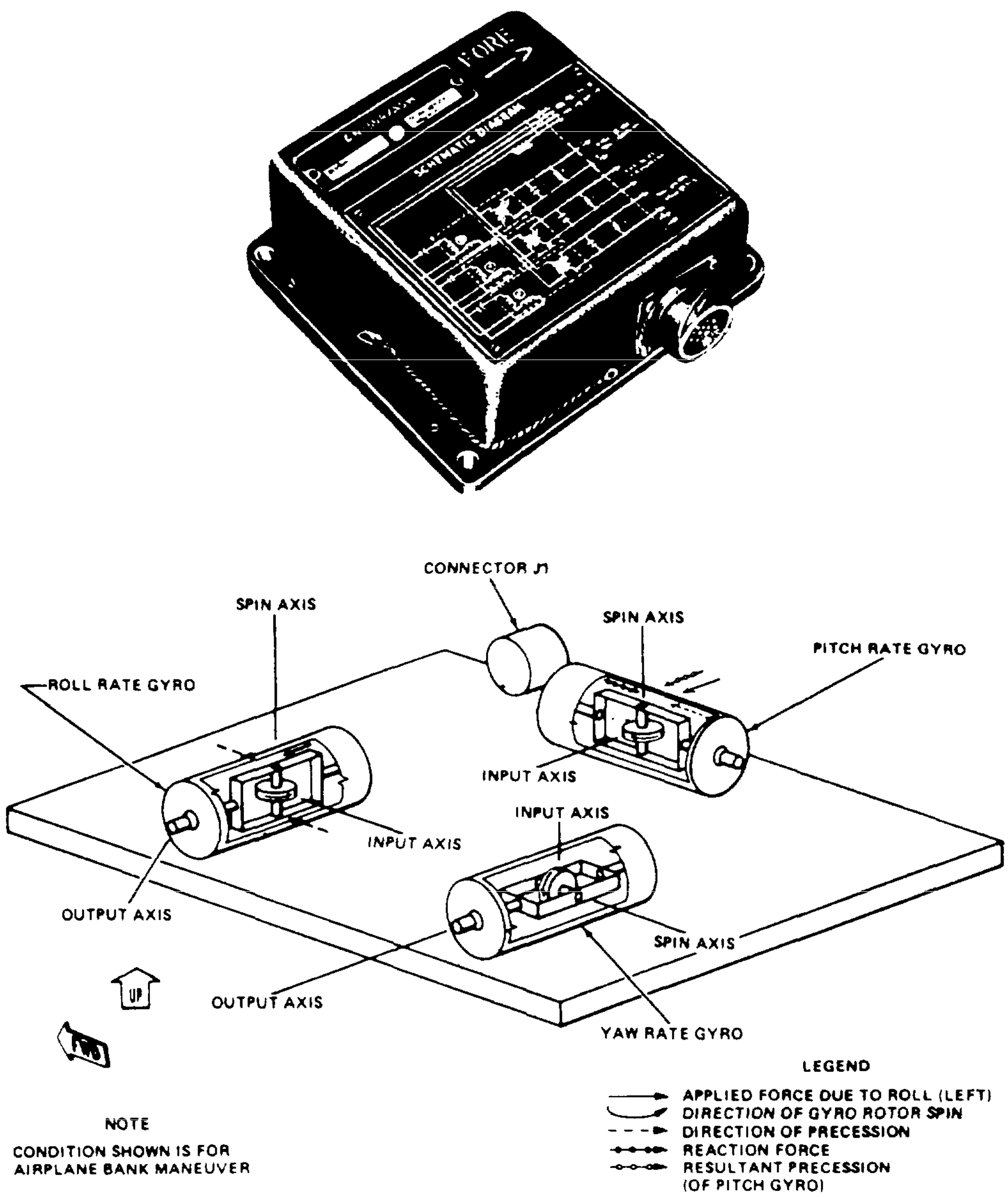


Figure 8-19.-Three-axis rate gyro orientation diagram.

Internally, each rate gyro consists of a small viscous-damped, single-degree-of-freedom gyro with a differential transformer pickoff (fig. 8-20). The gyroscopic element of each gyro is the rotor of a synchronous motor. The rotor mounts in a gimbal frame and spins at high speed about its spin axis. The gimbal is flexible and free to rotate about an output axis. This axis is perpendicular to both the spin axis and the input axis. A torsion-restoring spring that couples the gimbal to the case limits the rotational freedom about the output axis. The gyro gimbal carries the pickoff rotor on an extension along its output axis. The pickoff rotor senses the relative angular displacement of the gimbal and case.

With the pickoff rotor in its zero or neutral position, the mutual inductance is zero. The current flowing in the pickoff primary causes essentially no voltage in the secondary (output) winding. As the pickoff rotor is turned one way or the other about its output axis by gyro gimbal deflection, a proportional mutual inductance is introduced. The polarity of the inductance (positive or negative) depends upon the direction of deflection from the neutral position. Hence, the current flowing in the primary produces a voltage proportional to this mutual inductance in the pickoff secondary. The output voltage is proportional to the aircraft's angular velocity input to the gyro in the particular axis.

COMPASS INFORMATION. —Normally, compass information for the AFCS is supplied by the aircraft compass system or the inertial navigation system (INS). However, some compass information is developed for the AFCS.

The compass system/INS incorporates a gear train to drive several synchros. The gear train is driven by a motor generator unit that aligns to aircraft heading. Of the several synchros, one provides heading information to the pilot's compass indicator. One synchro attached to the gear train through a clutch provides a clutched heading. When the AFCS is not engaged, the clutch remains de-energized, wit h its rotor spring loaded to an electrical null condition. When the pilot engages the AFCS, the clutch engages the engaged heading to establish a reference heading for the system. If the aircraft drifts off heading, the gear train drives against the spring tension on the rotor generating an electrical signal. This signal goes to the aileron channel, much like the signal generator pickoff operation (fig. 8-16). Limiters in the AFCS prevent the bank angle from becoming excessive when large heading errors are detected.

Another type of compass information is derived from the heading indicator in the cockpit. The pilot selects a desired heading on the face of the indicator. The difference between the selected heading and the actual heading becomes an error signal to the AFCS. This error signal causes the aircraft to turn to the desired heading.

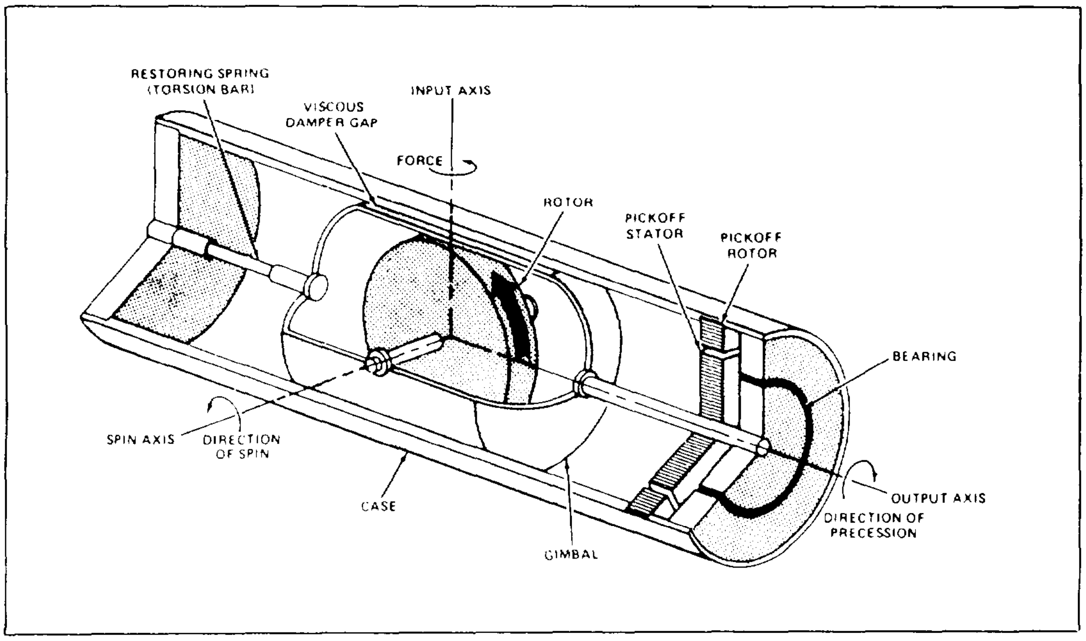


Figure 8-20.-Rate gyro axis orientation.

A radio navigation aid can also supply heading information to the AFCS. If the pilot desires to fly to a selected ground station, the radio reciever develops a signal to produce the desired ground track directly to the station.

AIR DATA INFORMATION. —Changes in the speed of an aircraft also affect the effectiveness of the control surfaces. At a given altitude, slow speeds require more control surface movement than high speeds to accomplish the same maneuver. The pilot maintains (or changes) the altitude by reference to the altimeter. The AFCS can also maintain a constant altitude. To accomplish this task the AFCS uses altitude data supplied by an air data sensor or air data computer (ADC) as the reference altitude.

Airspeed. —Control surface signals are modified by a gain control unit to compensate for changes in airspeed. This unit uses the difference between ram pressure and static pressure. A mechanical schematic of the gain control unit is shown in figure 8-21. Here, you can see that as airspeed increases (ram air pressure increases), the bellows causes the spring to become more compressed. This allows the armature to move each potentiometer's sliding arm to modify the control surface signals an amount representative of the change in airspeed of the aircraft. When airspeed decreases, the armature moves to the right, selecting a different amplifier gain. The opposite occurs for increases in airspeed.

Altitude. —The AFCS includes an altitude control feature to maintain the aircraft at a fixed altitude. The altitude controller consists of an aneroid, a mechanism for transmitting and magnifying the motion of the aneroid, and a solenoid-operated clutch. It also includes a synchro transmitter and a centering device for returning the synchro transmitter rotor to the null or no-signal position. Some aircraft do not use an altitude controller. In place of an altitude controller, the AFCS uses signals from the ADC.

Figure 8-22, view A, shows a three-quarter view of a barometric altitude control. The outside

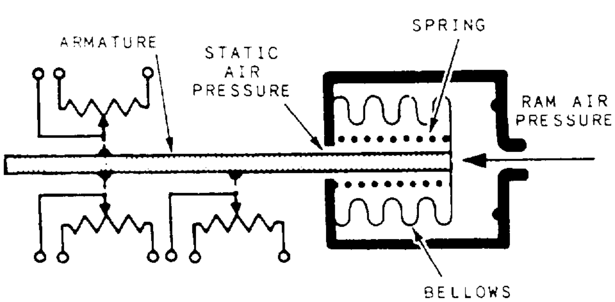


Figure 8-21.-Mechanical schematic of a gain control unit.

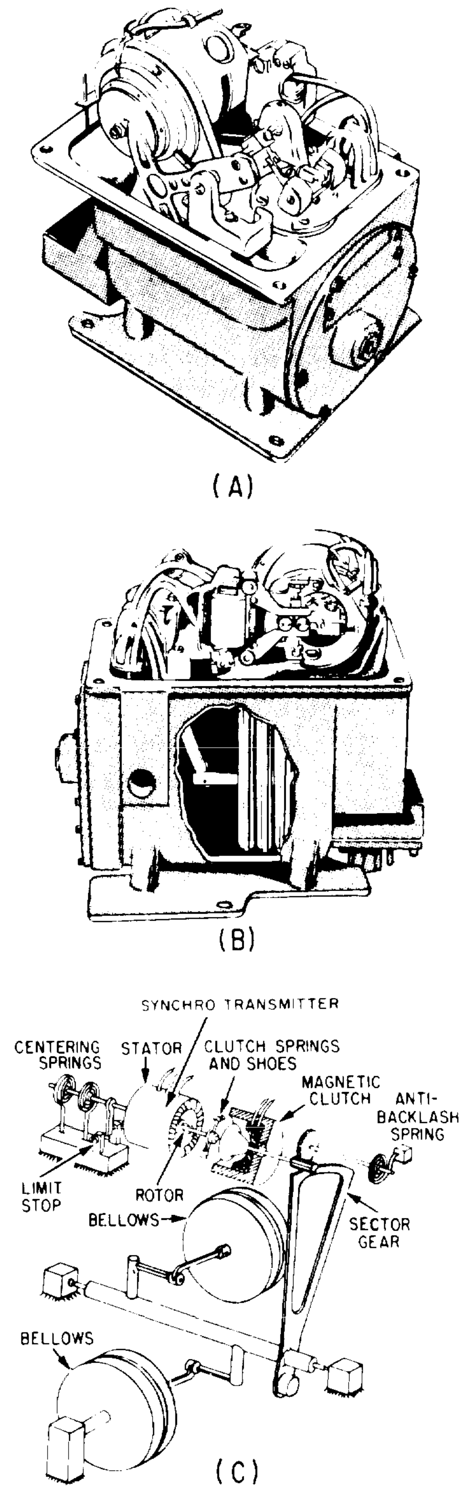


Figure 8-22.-(A) Barometric altitude control; (B) Internal parts; (C) Simplied schematic.

appearance of various controls of this type varies, depending upon the manufacturer; however, the working parts are similar. Figure 8-22, view B, shows the internal parts of a barometric altitude control, and view C shows a simplified mechanical schematic.

The aneroid consists of two diaphragms sealed internally at standard (sea level) barometric pressure. The two diaphragms connect in tandem to a single pushrod, and are mounted in an airtight case (fig. 8-22, view B). A tube connects the case to a source of static air pressure. The diaphragm pushrod mechanically links to one of the clutch plates. This linkage consisting of a lever, a pivoted shaft to which a sector gear is attached, and a pinion gear.

When the aircraft deviates from the barometric pressure altitude to which the altitude control switch is set, the aneroid diaphragms move. This motion is transmitted through the linkage to displace the rotor of the synchro transmitter. This displacement generates a signal in the synchro transmitter stator. The signal is applied to the elevator channel to return the aircraft to the pressure altitude indicated by the aneroid. When the aircraft reaches the correct altitude, the synchro transmitter signal becomes zero, and normal AFCS operation resumes.

When the altitude control switch is off, the magnetic clutch and the centering device actuating coil de-energizes. This opens the clutch to disengage the synchro transmitter rotor from the aneroid mechanism. The centering yoke, by spring action, closes on the synchro transmitter rotor shaft lever to return the rotor to the null or no-signal position. In this way, the synchro transmitter rotor is always at the no-signal position when altitude control is not selected. Since the clutch is disengaged, the aneroid is free to move. This allows the pilot to engage the altitude control at any time. Regardless of the aneroid position, the altitude that it senses is the one used as the reference altitude. It is not necessary to wait for synchronization or alignment.

FLAP POSITION INFORMATION. —When the flaps are lowered on some aircraft, the increased lift causes the aircraft to gain altitude (normally called ballooning). Ballooning is undesirable, and it is counteracted by using nosedown pressure on the flight control. When the AFCS is engaged and the flaps are lowered, automatic nosedown force is applied to the elevator. Flap position is detected by the use of a flap position transmitter.

The flap position transmitter consists of two synchro transmitters with a single input shaft (fig. 8-23). The synchro transmitters supply flap position information to the AFCS elevator channel and the external flap position indicator.

ACCELEROMETER TRANSMITTER.—The normal accelerometer (fig. 8-24, view A) generates a signal proportional to normal vertical acceleration. This signal is used for altitude or Mach hold vertical path damping and as the g-command reference. The unit consists of a cast housing assembly, a sensitive element assembly, bellows, and calibration resistors (R51, R52, and R53). The sensitive element assembly has an E pickoff, an armature and armature support, flexure springs, and a backplate.

When assembled, the sensitive element assembly and bellows are sealed inside the housing, which is filled with damping fluid. The metal bellows allow the volume of the damping fluid to change with temperature and pressure variations. The damping fluid provides viscous damping during motion of the armature.

The sensitive element is mechanically biased to produce zero output when mounted in the correct position and subjected to the normal gravity force of 1 g.

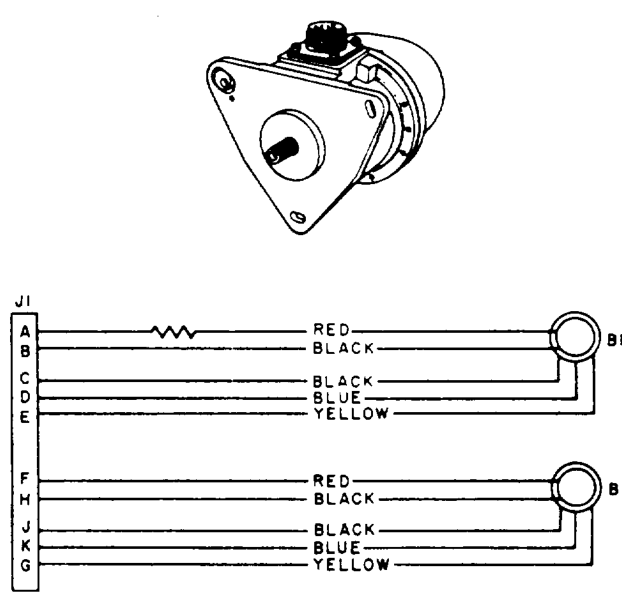


Figure 8-23.-Flap position transmitter and schematic.

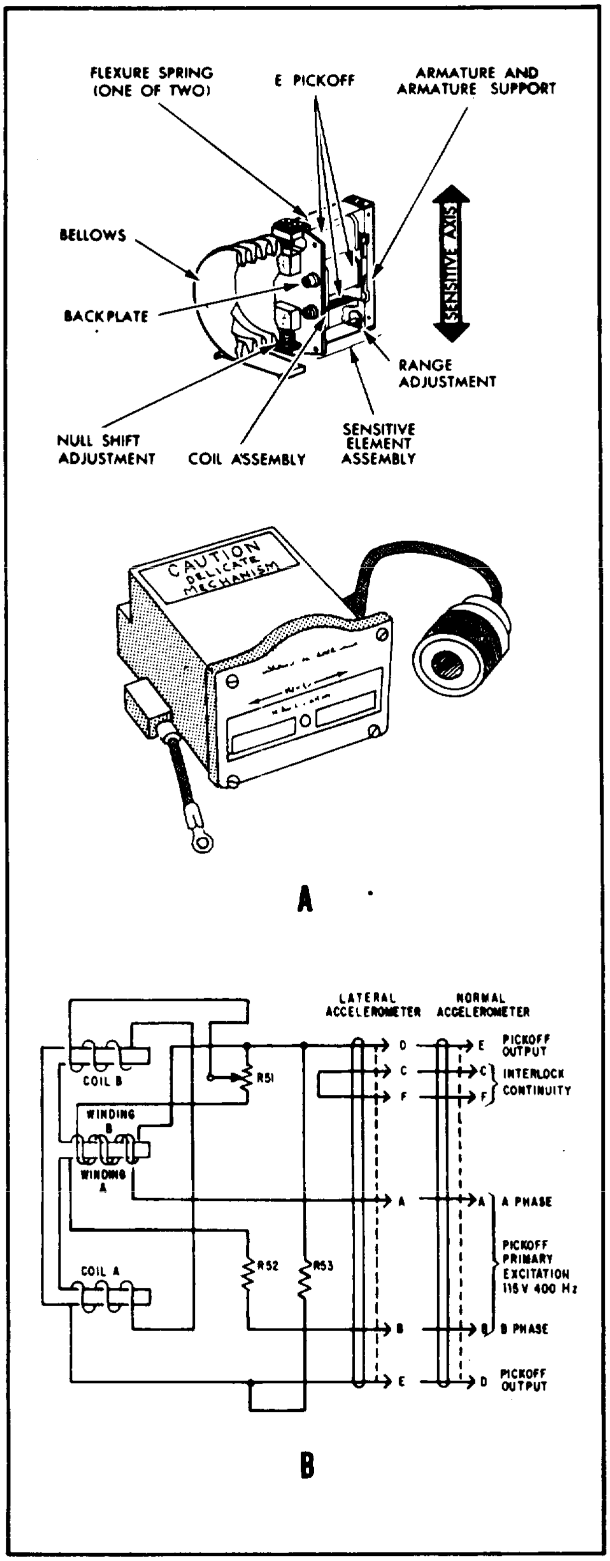


Figure 8-24.-Accelerometer transmitter.

While you read this section, refer to figure 8-24. As the aircraft accelerates in the sensitive vertical direction, the suspended armature tends to remain behind due to its inertia. This reaction varies the reluctance of the magnetic circuit set up by the E pickoff windings and armature (view B). The armature completes the magnetic circuit through a small air gap. The relative motion between the armature and E pickoff varies the reluctance through the signal output windings. This variation results in a signal that is proportional to acceleration. When operating, the output voltage is either in phase or 180 degrees out of phase with the excitation, depending on the direction of acceleration.

COORDINATION INPUT. —In some aircraft, a dynamic vertical sensor detects lateral accelerations (slip or skid) of the aircraft. The sensor supplies a signal to position the rudder to correct the slip or skid, coordinating the turn. The signal is proportional to the amount of the aircraft deviation from the vertical axis of the aircraft. In other aircraft, a horizontally mounted accelerometer aligned with the lateral axis of the aircraft provides the same information. Only the dynamic vertical sensor is covered in this TRAMAN.

The dynamic vertical sensor consists of a viscous-damped pendulum mechanically connected to the rotor shaft of a transmitter synchro. The cutaway view of the sensor (fig. 8-25) shows the mechanism assembly, which includes a synchro transmitter with a pendulum and vane assembly attached to the rotor. The vane moves in an oil-filled chamber. The damping effect of

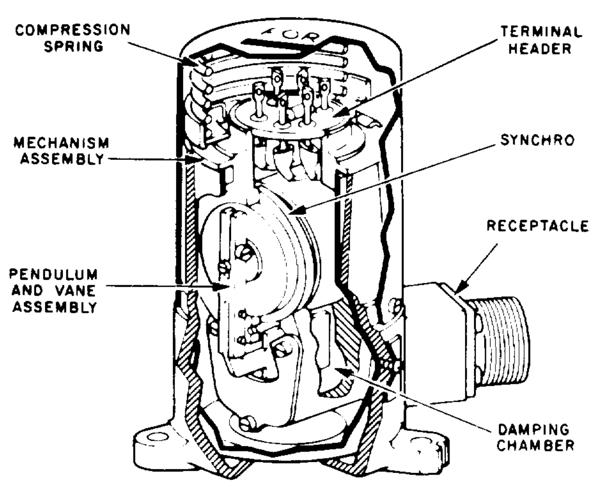


Figure 8-25.-Cutaway view of a dynamic vertical sensor.

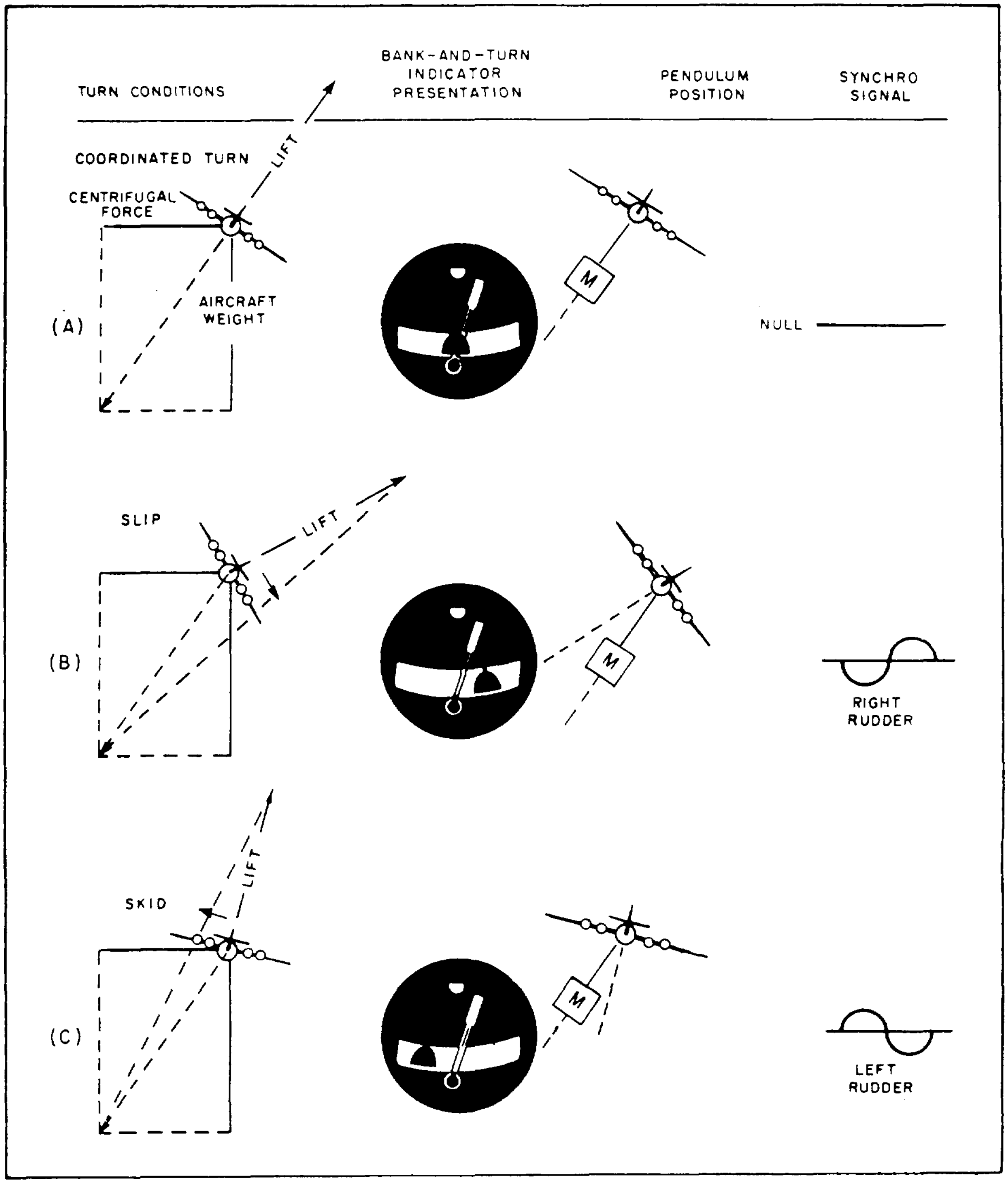


Figure 8-26.-Dynamic sensor pendulum positions: (A) Coordinated turn; (B) Slip; (C)Skid.

the fluid gives a long-term sensing characteristic that makes the unit relatively insensitive to transient oscillations. The damping chamber also limits displacement of the pendulum to 10 degrees either side of the center position.

A pin in the housing fits into a slot in the mechanism shell. This positions the mechanism to give proper alignment of the synchro rotor with the longitudinal axis of the aircraft when installed.

The sensor functions in the same manner as the ball in a turn-and-bank indicator. The ball gives a visual indication of slip or skid resulting from lateral acceleration. The sensor provides a signal output of this condition. Figure 8-26 shows a diagram of the forces acting on the aircraft in a turn. Refer to this figure as you read this section. In a coordinated turn, the vertical and lateral forces resolve into a vector perpendicular to the span of the aircraft. When the aircraft is turning with the two forces in balance, the ball is centered; the pendulum in the sensor gives a null output.

When the aircraft bank angle is too large for the turn rate, the balance is upset (fig. 8-26, view B). The ball moves away from the center toward the inside of the turn, and the pendulum moves the synchro rotor from the center null position. The rotor displacement produces a signal with magnitude proportional to the displacement angle and signal polarity corresponding to the direction of displacement. The unbalanced condition results from a sideways accelerating force, causing the aircraft to slip toward the inside of the turn.

When the aircraft is insufficiently banked for the turn, an acceleration acts toward the outside of the turn (fig. 8-26, view C). The ball in the turn-and-bank indicator moves from the center, and the pendulum in the dynamic vertical sensor is displaced from null in the direction corresponding to the ball. This gives a signal whose polarity is opposite to that of the signal when the aircraft was in a slip. The signal is fed to the rudder channel for right or left rudder to coordinate the turn. Since the pendulum is unaffected by transients, the rudder adjustment is on a comparatively long-term basis.

Hydraulic Components

Hydraulic systems provide the physical power to move the flight control surfaces. All electrohydraulic (AFCS) actuators work in the same manner. A brief discussion of electrohydraulics is presented in the following paragraphs.

ELECTROHYDRAULIC SERVO ACTUATORS. —Electrohydraulic servo actuators (hydraulic booster packages) are discussed in chapter 4 of this TRAMAN. Modern aircraft use several types of actuators, with each booster actuator having at least two modes of operation—manual mode and electrical signals.

The first mode is the manual mode. Its primary purpose is to aid the pilot in manually positioning the control surfaces. Control surfaces on large aircraft are much too large to move unaided. On smaller high-speed aircraft, the high air pressure makes it nearly impossible to move the controls unaided. In the manual mode of operation, the hydraulic booster package is connected between the pilot's control stick and the control surface. It provides hydraulic assistance to the pilot in much the same manner that power steering aids the driver of a car or truck.

Mode two of the hydraulic booster package uses electrical signals from the AFCS to move the flight control surfaces. In this mode, the booster package connects the AFCS to the control surface and provides the muscle to move the surface. Synchro devices on the boost package provide feedback signals to the AFCS (fig. 8-27).

The surface position transmitter sends the AFCS a signal representing the amount and direction of control surface displacement from the streamline position. This signal acts as a follow-up to prevent overshoot of the controls. Also, it serves to return the control surface to the trimmed condition as the original signal returns to zero.

The modulating piston is displaced only when the control surface is in motion. The position of the modulating piston is monitored to sense the control surface rate of movement. This action generates a signal to dampen control surface movement.

Hydraulic load sensors determine the amount of pressure the AFCS is applying to the control surface so the pilot can properly trim the aircraft before disengaging the AFCS. If the aircraft is not properly trimmed and the control pressure is suddenly relieved, the control surface moves rapidly, causing sudden aircraft movement.

Some aircraft use both manual and AFCS modes simultaneously. Aircraft stabilization is provided from the AFCS, while the pilot manually controls the aircraft. All flight control systems have a method of disconnecting the booster package. This method gives the pilot manual control of the flight control surfaces if the booster malfunctions or failure of the hydraulic system occurs.

AUTOMATIC TRIM. —Some AFCS systems incorporate automatic trimming. When a signal is present in the control channel, there is an unbalance in fluid pressure at the input to the hydraulic booster. The hydraulic load sensor (fig. 8-28) detects this unbalance. Its signal is amplified and drives the trim servomotor. The engagement clutch engages when the AFCS is operating and the automatic trim system is functioning properly. The slip clutch allows the pilot to override the automatic trim in case of a malfunction. Most AFCS use autotrim in the pitch channel; however, it can be used for yaw and roll as well.

THEORY OF OPERATION

The AFCS has three main control channels to control movement of the aircraft about its axis. These channels control the yaw (rudder), roll (aileron), and pitch (elevator). Each of the control channels has similar functional equipment groupings. The groupings include controls, sensors, signal coupling circuits, AFCS servo loops, and aircraft flight controls.

Each channel of the AFCS supplies control signals to the flight controls and receives error signals from the sensors. The error sensors and the signal coupling circuits in use in each control channel depend on the mode of operation. The AFCS servo loops

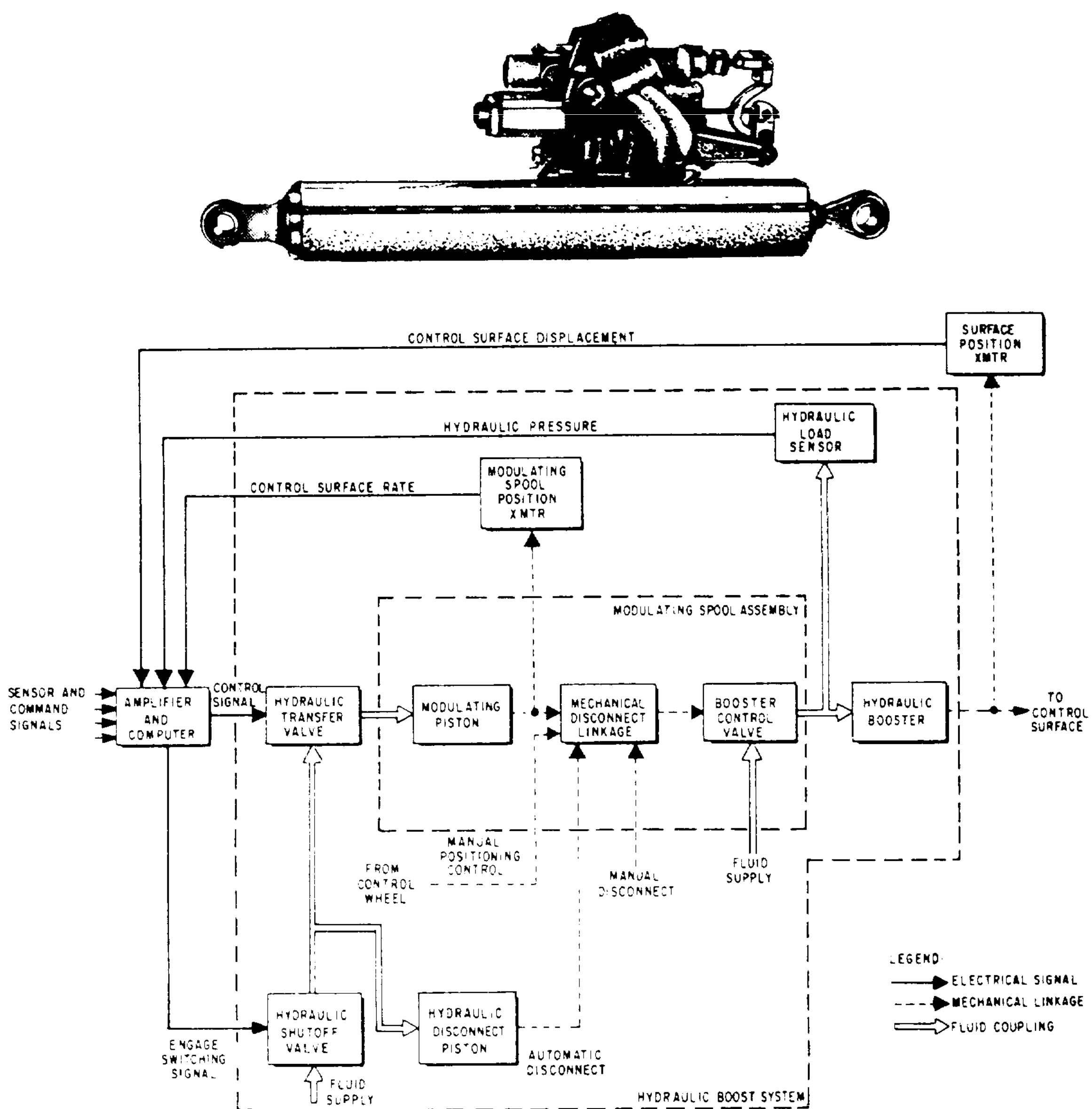


Figure 8-27.-Hydraulic booster block diagram.

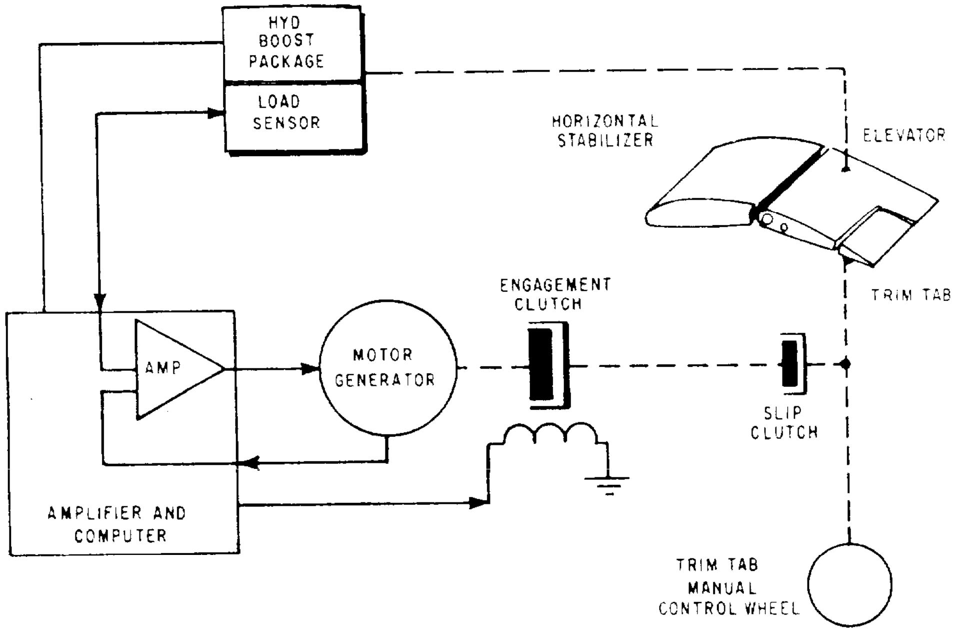


Figure 8-28.—Automatic pitch trim block diagram.

and the aircraft flight control system provide the final amplifying link to move the flight control surfaces.

Look at figure 8-29. Each AFCS control channel is basically the same; however, its design depends on the type and mission of the aircraft.

NOTE: The AFCS channel shown in figure 8-29 represents the basic design of the channel and is **for instructional use only.** For further study of the AFCS, you should refer to the MIM for your particular aircraft.

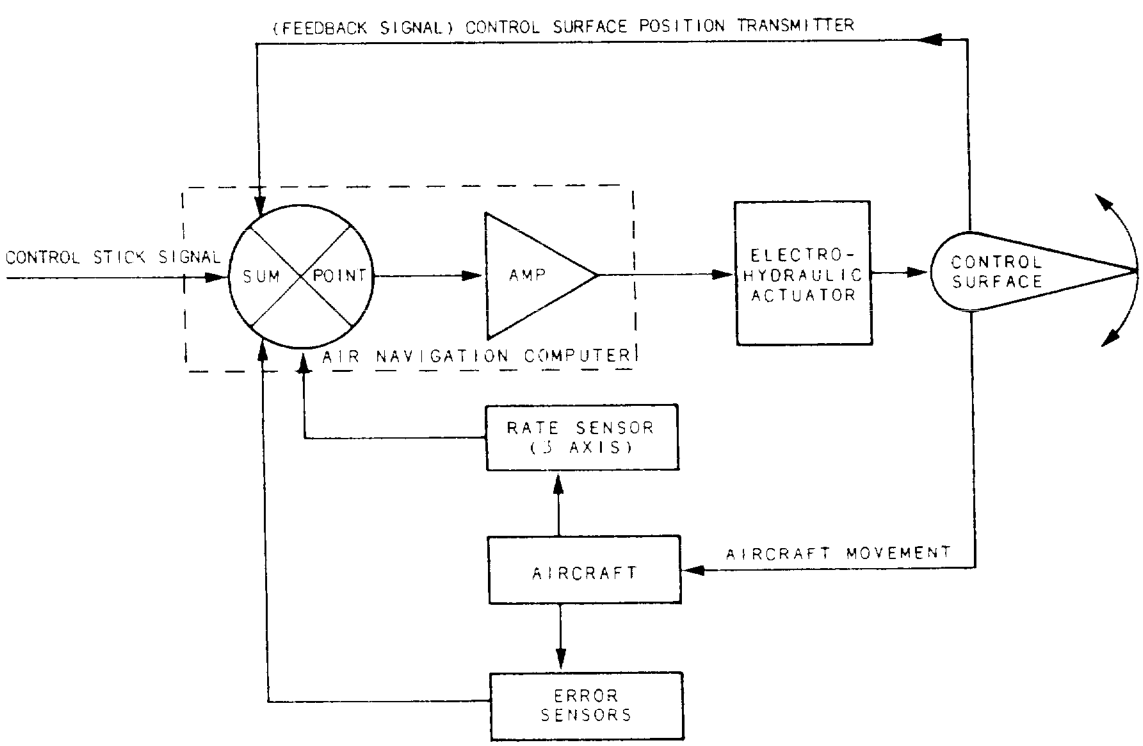


Figure 8-29.-Basic AFCS control channel.

The amplifier/computer (ANC) receivres various error and control signals. These weak signals are coupled (summed), modified, and amplified to develop the control surface command signal to drive the electrohydraulic actuators. The actuator moves a certain direction for a specific distance, depending on the command signal's polarity and magnitude.

The flight control surfaces (rudder, aileron, and elevator) are mechanically linked to the electrohydraulic actuator. As the control surface moves, a position transmitter synchro develops a feedback signal having the opposite polarity to the error signal. The magnitude of the feedback signal increases as the control surface displacement increases. When the error signal and feedback signal are equal and opposite in magnitude and polarity, the control surface will no longer move.

Movement of the control surface causes the aircraft to displace about its axis (or reference). This movement corrects the original error signal as sensed by the sensors. Without any error signal inputs to the control channel of the amplifier/computer, only the feedback signal is present. The feedback signal is opposite in polarity and magnitude to the original error signal. This drives the electrohydraulic actuator an equal distance in the opposite direction and brings the control surface back to the null or reference position.

AFCS MODES

This part of the chapter contains a brief description of the various modes available in a typical automatic flight control system. The pilot selects one of these modes on the AFCS control panel by moving the control stick or using knobs on some instruments. Because the circuitry is complex and varies among the different weapons systems, no specific mode will be diagramed.

Stability Augmentation Mode

The stability augmentation (STAB AUG) mode provides improved control of the aircraft by automatically damping oscillations about the pitch, roll, and yaw axes. Signals from rate gyroscopes command control surface movement through electrohydraulic actuators. In some high-speed aircraft, STAB AUG is considered critical to safe flight. For this reason, the STAB AUG engagement switch connects in series with all other modes of the AFCS. This arrangement ensures that STAB AUG is engaged before any other mode of the AFCS.

Attitude Hold

The attitude hold mode is the basic, hands-off mode of operation. With attitude hold mode engaged, the AFCS maintains aircraft attitude at the time of engagement in pitch and roll. This particular mode is governed by the actual degrees of bank or pitch of the aircraft. For example, a typical attitude hold mode will release when the aircraft exceeds ±60 degrees in pitch or ±70 degrees in roll.

Altitude Hold

With altitude hold engaged, the aircraft will maintain the altitude at the time of engagement. If the aircraft is climbing or diving at engagement, the aircraft returns to the altitude that existed at engagement. The AFCS receives control signals for this mode from the air data computer.

Heading Hold

With heading hold engaged, the AFCS maintains aircraft heading at the time of engagement. If the pilot is flying a heading of 180 degrees and engages the heading hold, the AFCS maintains the heading of 180 degrees.

Control Stick Steering/Control Wheel Steering

The control stick steering/control wheel steering mode lets the pilot manually (moving the stick/wheel) change the attitude of the aircraft with the AFCS engaged without disengaging it. After achieving the new attitude, the pilot releases the stick/wheel, and the AFCS resumes control of the aircraft.

Heading Select

In the heading select mode, the aircraft will automatically turn to a course selected by the pilot. Upon engagement, the aircraft will assume a fixed maximum roll and turn to the selected heading.

Mach Hold

The Mach hold function maintains the Mach number existing at the time of Mach hold engagement. In this mode, the air data computer commands a pitch-up or pitch-down when airspeed is above or below the selected math number.

Automatic Carrier Landing System (ACLS)

In the ACLS mode, the pilot can make a "hands-off" carrier landing. The aircraft follows command signals generated by the data link receiver.

Ground Control Bombing

Similar to ACLS, the aircraft follows command signals from personnel on the ground.

REVIEW SUBSET NUMBER 3

Q1. What two types of altitude signals can the AFCS use to maintain a constant altitude?

Q2. Why is the AFCS synchronized with the flight controls before engaging the AFCS?

Q3. What unit is considered the heart of the AFCS?

Q4. What AFCS component provides signal outputs representing yaw, pitch, and roll rates?

Q5. What type of heading signal does the AFCS receive from the compass/INS system?

Q6. What are the two modes of operation for electrohydraulic servo actuators?

Q7. What unit of the AFCS sends a signal that acts as a follow-up to flight control movement?

Q8. What AFCS mode automatically dampens oscillations in the yaw, pitch, and roll axes?

HELICOPTER AFCS

In many respects, the helicopter differs radically from conventional fixed-wing aircraft. However, rotary-wing aerodynamics are very similar to fixed-wing aerodynamics. A review of *Airman,* NAVEDTRA 14014, will help you understand the material in this discussion.

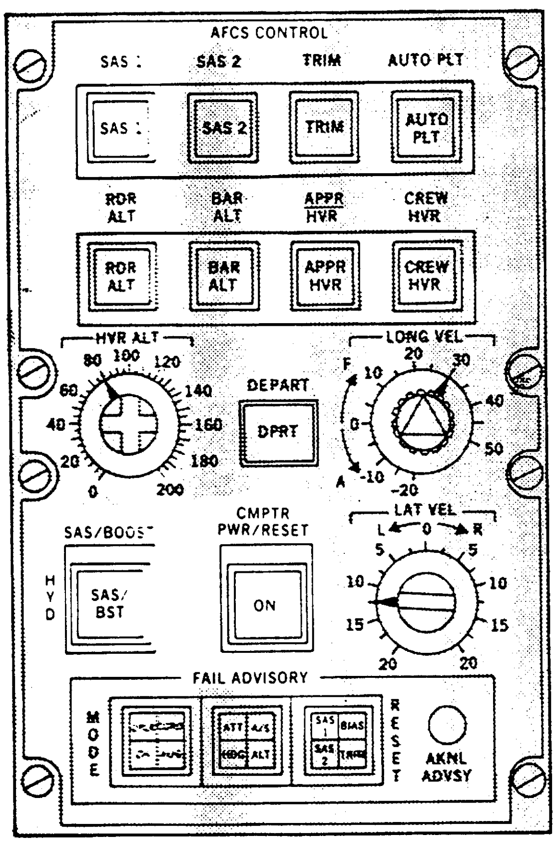
The AFCS is an electrohydromechanical system. It provides inputs to the flight control system to aid the pilot in maneuvering and handling the helicopter. The AFCS consist of three major subsystems—the stability augmentation system (SAS), the stabilator system, and the digital automatic flight control system (DAFCS). All engagement controls for the three subsystems are on the AFCS and stabilator control panels. Each subsystem operates independently of the other two subsystems, and they complement one another. The pilot engages autopilot functions by pushing the AUTO PLT push button on the AFCS CONTROL panel. The AFCS system provides the following features:

- Pitch, roll, and yaw stability augmentation
- Stabilator control
- Cyclic, collective, and pedal trim
- Pitch and roll attitude hold
- Airspeed hold
- Heading hold
- Barometric altitude hold
- Radar altitude hold
- Pitch and roll hover augmentation/gust alleviation
- Turn coordination
- Maneuvering stability
- Automatic approach to hover
- Hover coupler

- Automatic depart
- Crew hover
- Longitudinal stick gradient augmentation (pitch bias actuator)
- Blade-fold assist
- Automatic preflight check
- Diagnostics (mode failure display)

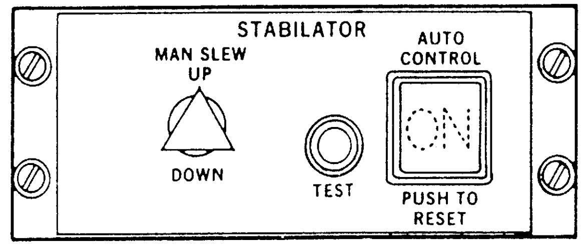
AFCS Control Panels

The pilot controls the AFCS from the AFCS CONTROL panel and the stabilator control panel (figs. 8-30 and 8-31). The stabilator control panel contains all the operating controls for the stabilator. All the other AFCS controls are on the AFCS CONTROL panel. All detectable AFCS mode failures, except the stabilator, illuminate the AFCS



AUTO FLIGHT CONTROL PANEL

Figure 8-30.-Helicopter automatic flight control system panel.



STABILATOR CONTROL PANEL

Figure 8-31.-Stabilator control panel.

DEGRADED light on the caution/advisory panel. They will also illuminate the appropriate mode failure capsule on the failure advisory section of the AFCS CONTROL panel. Stabilator failures illuminate the STABILATOR caution light on the caution/advisory panel and generate an aural warning tone in the pilot's and ATO's headsets.

The AFCS CONTROL panel has switches to electronically engage the SAS 1, SAS 2, and a SAWBOOST HYD switch. The SAS/BOOST HYD switch controls pressure application to SAS actuators and pitch boost servos.

Stability Augmentation System (SAS)

The SAS 1 system provides electrical control signals proportional to sensor inputs to the pitch, roll, and yaw servo valves. The servo valves convert electrical control signals into hydraulic commands for the SAS actuators. The SAS actuators respond to the hydraulic commands and produce mechanical movement of the flight control linkages without moving the cyclic sticks and pedals. The flight control linkages direct changes in main rotor and tail rotor pitch.

With both SAS 1 and SAS 2 engaged, the SAS actuators each have 10 percent authority of flight control movement. Each SAS system has 5 percent authority. With only SAS 1 engaged, the gain of the SAS amplifier is double, but the control authority remains at 5 percent. The AFCS control panel provides a signal to the SAS amplifier to indicate SAS 2 engagement.

The SAS 1 pitch channel provides dynamic stability for the helicopter's pitch axis. The No. 1 pitch rate gyro senses changes in pitch rate and applies this rate to the No. 1 stabilator amplifier. The No, 1 stabilator amplifier filters this pitch rate signal and applies it to the SAS amplifier. The SAS amplifier processes the pitch rate signal to remove long term rate signals and applies a correction signal to the pitch SAS servo valve. The servo valve controls hydraulic pressure to the SAS actuator. The SAS actuator provides mechanical movement of the flight controls, producing rotor head movement opposing the sensed pitch rate.

The SAS 1 roll channel provides dynamic stability and limited roll stability for the helicopter's roll axis. A roll attitude signal is provided to the SAS amplifier from the ATO's Attitude. Heading Reference system. The SAS amplifier limits this signal and uses it with a roll rate signal from an internal roll rate gyro. The amplifier applies the resultant correction signal to the roll SAS servo valve. This servo valve controls the actuator, which positions the flight controls to oppose the sensor inputs.

The SAS 1 yaw channel provides dynamic stability for the helicopter's yaw axis and turn coordination. At airspeeds of less than 50 knots, the No. 1 stabilator amplifier provides a +12 to +15 VDC airspeed switch discrete. The discrete inhibits No. 1 lateral acceleration and roll rate signals in the SAS amplifier. The discrete controls the internal yaw rate gyro in the SAS amplifier as the yaw channel sensor. When sensing a yaw rate, the SAS amplifier processes it to remove long term yaw rate signals. It then develops a short term correction signal and applies it to the yaw SAS servo valve. The servo valve controls the actuator, which moves the flight controls to oppose the yaw rate.

At speeds below 50 knots, the airspeed transducer is applied to stabilator amplifier No. 1 and sent to SAS 1 amplifier (discrete signal). This discrete signal allows the yaw SAS amplifier and flight controls to use the internal yaw rate gyro. Above 50 knots, the SAS amplifier recieves a –12 to –15 VDC airspeed switch discrete from the No. 1 stabilator amplifier. This enables filtered No. 1 lateral acceleration and roll rate to sum with the yaw rate signal. Airspeed discrete from No. 1 stabilator amplifier is inhibited for this situation (above 50 knots). Airspeed discrete is not removed from SAS amplifier.

The AFCS consists of many components. To understand the entire system, you need to know what each component does. The following discussion describes the components that make up the AFCS.

AFCS POWER SWITCHING ASSEMBLY.— The AFCS power switching assembly provides power switching for the digital automatic flight control system computer and the SAS and BOOST shutoff valves.

NO. 1 LATERAL ACCELEROMETER. — The accelerometer provides lateral acceleration to the SAS amplifier via the No. 1 stabilator amplifier for the turn coordination function of SAS 1.

NO. 1 PITCH RATE GYRO. —The gyro provides pitch rate to the SAS amplifier via the No. 1 stabilator amplifier for the pitch dynamic stability function. The pitch rate gyros are also part of the stabilator control system.

SAS ACTUATORS. —The SAS actuators, on the pilot-assist servos, convert electrical signals from the analog SAS 1 and digital SAS 2 to mechanical motion to move the flight controls. The actuators are electrohydraulic, operating from pressure supplied by the No. 2 transfer module, applied through the SAS shutoff valve. When the SAS/BOOST HYD switch is pressed, power is removed from the SAS shutoff valve, opening the valve. Opening the valve allows the actuators to move with signals applied from SAS 1, SAS 2, or both. With pressure removed from the actuators, a spring-loaded device locks the actuator piston in center position. Each actuator output piston connects to linkage. When the actuator piston becomes locked, it forms a fixed pivot point on one end of the linkage. This allows the linkage to move with stick, pedal, or trim inputs.

SAS AMPLIFIER. —The SAS amplifier contains the No. 1 roll and yaw rate gyro power supplies and processing circuitry for SAS 1. The outputs of the internal roll and yaw rate gyros are used by SAS 1 and the digital automatic flight control system computer. The amplifier processes rate and proportional signals. Amplifier outputs operate the SAS actuators on the pilot-assist servo assembly.

NO. 1 STABILATOR AMPLIFIER. —The No. 1 stabilator amplifier provides filtered lateral acceleration and pitch rate signals and an airspeed discrete to the SAS amplifier. The stabilator amplifier is part of the stabilator control system.

Stabilator System

The stabilator system optimizes trim attitudes for cruise, climb, and autorotation. Also, it provides pitch stability augmentation to complement the SAS system for additional redundancy. The stabilator system is completely independent of the other two AFCS subsystems except for common airspeed sensors, lateral accelerometers, and pitch rate gyros. The stabilator control system is a completely automatic fly-by-wire control system with a manual backup slew control. The primary purpose of the stabilator control system is to stop undesirable noseup attitudes. The noseup attitude is caused by rotor downwash impinging on the horizontal stabilator during low-speed flight and transition to a hover.

The stabilator panel contains an automatic control (AUTO CONTROL) switch, a TEST push button, and a manual slew (MAN SLEW) switch. The AUTO CONTROL switch is used to engage the automatic mode or to reset the stabilator if it should fail. The pilot can manually position the stabilator to any position within the stabilator limits by moving the MAN SLEW switch. The TEST push button is used to check the automatic mode fault detector.

Two electric jackscrews, working in series, position the stabilator. Each actuator provides one-half the input to position the stabilator and is controlled by a separate and redundant stabilator amplifier. The stabilator travels from 40 degrees trailing edge down for hover and low-speed flight below 30 knots to 8 degrees trailing edge up for cruise and maneuvering flight. Four inputs are required to position the stabilator—airspeed, collective stick position, lateral acceleration, and pitch rate.

Each stabilator amplifier receives these four inputs, but they receive the inputs from independent sensors. The DAFCS computer monitors each of these sensors for malfunctions, and the stabilator control system monitors and compares the position of the two actuators. Any system malfunction caused by a difference between the two stabilator actuator positions results in the stabilator remaining in the last position. A malfunction also causes an automatic power shutdown to both actuators, an aural tone to the pilot, and a STABILATOR caution light illuminating. The shutdown threshold between the two stabilator actuator positions is 10 degrees for airspeeds less than 50 KIAS and 4 degrees for airspeeds greater than 120 KIAS with a linear variation between 50 KIAS and 120 KIAS.

The airspeed input aligns the stabilator with the main rotor downwash during slow-speed flight. The collective stick position input decouples aircraft pitch attitude with collective position. Pitch rate and lateral acceleration inputs improve the dynamic response of the aircraft, especially in gusty air conditions. The pitch rate input supplements the dynamic stability provided by the SAS and DAFCS. The lateral accelerometer input decouples the aircraft pitch response with changes in tail rotor lift caused by changes in airflow on the canted tail induced with sideslip.

If a malfunction of the stabilator system occurs, the pilot can manually position the stabilator with the manual slew switch. The manual slew switch bypasses the stabilator amplifier automatic mode, applying power directly to the actuators through relays in the amplifiers. A stabilator position indicator aids the pilot in positioning the stabilator to any position between the stabilator travel limits. However, total travel is restricted if the malfunction is an actuator failure. Stabilator travel is restricted to 35 degrees if an actuator fails in the full-down position; 30 degrees if an actuator fails in the full-up position. The stabilator control rate is limited to ±6 degrees per second.

The following is a description of the components of the stabilator system. To understand the system, you will need to know what these components do.

AIRSPEED TRANSDUCER. —The stabilator position program is a function of four sensor inputs. Each function has dual sensors for fail-safe operation. Airspeed for the No. 1 stabilator system is sensed by the airspeed transducer. It connects into the ATO pitot static system and produces a dc output voltage that is proportional to airspeed.

AIR DATA TRANSDUCER. —An air data transducer accomplishes airspeed sensing in the No. 2 stabilator system. The air data transducer connects into the pilot's pitot static system. It produces dc output voltages proportional to airspeed, altitude, and altitude rate. Airspeed data is used by the stabilator system and AFCS computer. Altitude and altitude rate are applied to the DAFCS computer only for altitude hold and depart modes of operation.

LATERAL ACCELEROMETERS. —There are two lateral accelerometers—No. 1 and No 2. They each produce a dc output signal proportional to helicopter lateral acceleration. Each accelerometer dc signal goes to its related stabilator amplifier, where it is conditioned. The filtered lateral acceleration signal is used to position the stabilator to counteract tail rotor downwash on its upper wing surface. No. 1 and No. 2 filtered lateral acceleration is used by the DAFCS computer for signal quality comparison and software generation. No. 1 filtered lateral acceleration is also used in analog SAS for slip or skid correction above 50 knots.

STABILATOR POSITION INDICATOR. —Stabilator position is displayed by an indicator on the center of the cockpit instrument panel. This indicator is a synchro-type device driven by a synchro transmitter mounted in the stabilator position transmitter and limit switch assembly in the tail pylon.

STABILATOR CONTROL PANEL. —Control functions for the system are provided by the stabilator control panel. The panel consists of an AUTO CONTROL PUSH TO RESET push-button switch, a TEST push button, and a MAN SLEW UP/DOWN switch. Engagement of the system is automatic, upon application of helicopter ac and dc power, provided all interlocks are in their proper condition.

TEST Push Button. —A TEST push button, operational below 50 knots, provides a check of the system fault monitors by inserting an airspeed derived test signal into the No. 1 system. This signal drives only the No. 1 stabilator actuator, which produces a difference between the two actuators. The fault monitor circuit in either the No. 1 or No. 2 amplifier, or both, should disengage the automatic mode of operation when the programmed threadhold trips.

MAN SLEW UP/DOWN Switch. —If the automatic mode disengages, and cannot be reset due to a malfunction, the MAN SLEW switch is used to manually position the stabilator. Relays in the No. 1 and No. 2 stabilator amplifiers are operated by dc power from the switch, when it is placed to UP or DOWN. Using the switch, when the automatic mode is engaged, will disengage the automatic mode. As a result, the STABILATOR caution light will go on, and a beeping tone will be heard in the ICS.

COLLECTIVE STICK POSITION SENSORS. –Collective stick position also affects the stabilator position schedule. Stick position is sensed by two collective stick position sensors. No. 1 and No. 2 collective stick position sensors each produces a dc output signal proportional to the collective stick position. Both signals are used by the DAFCS computer for signal level comparison and for software generation of collective-to-yaw pedal coupling.

STABILATOR AMPLIFIER. —Processing of airspeed, lateral acceleration, collective stick position, and pitch rate is accomplished within each stabilator amplifier. The amplifiers contain a power supply, processing and feedback circuits, and a fault monitor circuit. Sensor inputs are processed, summed, and applied to a motor driver circuit. The motor driver circuit output is applied, through contacts of relays, to the respective stabilator actuators. Any difference of actuator position is sensed by the fault monitor circuit in either or both amplifiers, causing an automatic mode disengagement.

ACTUATORS. —Two actuators position the stabilator. Each actuator contains an electric motor (geared to a jackscrew), limit switches, and a feedback potentiometer. The potentiometer provides actuator position feedback to each amplifier. The actuators extend or retract, as necessary, to position the stabilator.

PITCH RATE GYROS. —There are two pitch rate gyros—No. 1 and No. 2. Each rate gyro produces a dc output signal relative to the pitch rate of the aircraft. Each rate gyro signal goes to its respective stabilator amplifier, where it is conditioned. The stabilator system uses the filtered pitch rate signal to enhance the AFCS systems ability to correct short-term pitch disturbances. The DAFCS computer uses No. 1 and No. 2 filtered pitch rate signals for signal quality comparison and software generation. The No. 1 filtered pitch rate signal is also used in analog SAS for short-term pitch correction of the rotor head.

Digital Automatic Flight Control System (DAFCS)

The central component of the DAFCS is the digital computer. The computer commands the pitch bias actuator (PBA), the inner-loop SAS actuators, and the outer-loop trim actuators in all four control channels. The computer also provides self-monitoring, fault isolation, and failure advisory.

The DAFCS uses two types of control–identified as inner loop and outer loop. The inner loop (SAS) uses rate damping to improve helicopter stability. This system is fast in response, limited in authority, and operates without causing movement of the flight controls. The outer loop (AUTO PILOT) provides long-term inputs by trimming the flight controls to the position required to maintain the selected flight regime. It can drive the flight controls throughout their full range of travel (100-percent authority). The outer-loop drive rate is limited to 10 percent per second. Both inner and outer loops allow for complete pilot override through the normal use of the flight controls.

The DAFCS computer processes incoming information from various sensors (fig. 8-32) aboard the aircraft and stores this information in its memory. The central processing unit (CPU) uses the sensor information to compute required correction signals. Inner-loop correction signals go to the SAS actuators, and outer-loop signals operate trim servos and actuators.

TRIM SYSTEM. —The parallel trim actuator assemblies provide the flight control force gradients and detent positions and the outer-loop autopilot control functions. The trim actuators command full control authority in all four control channels, but are rate-limited to 10 percent per second. Pressing the trim release switch (cyclic trim release, collective trim release, and pedal release) disengages the respective trim function and allows free control motion. Releasing the trim release switch re-engages trim. For yaw trim release above 50 knots, the pilot must press the pedal microswitches and the cyclic trim switch. Below 50 knots only the pedal microswitches have to be pressed. The pilot can override the trim control forces in all channels.

AUTOPILOT. —The autopilot maintains helicopter pitch and roll attitude, airspeed, and heading during cruise flight and provides a coordinated turn feature at airspeeds above 50 knots. To engage the autopilot function, the pilot presses the control panel SAS 1 or SAS 2 switches, TRIM switch, and then the AUTO PLT push button. The autopilot may be disengaged by pressing the AUTO PLT push button or pressing the AFCS release button. The computer also provides command signals to the trim actuators to reposition the flight controls using the trim system.

ATTITUDE AND AIRSPEED HOLD. — Attitude and airspeed hold are engaged with AUTO PLT. In the pitch channel, at airspeeds of less than 50 knots, attitude changes are commanded by changing the cyclic stick position. The pilot can use the TRIM REL switch or the four-direction (beeper) TRIM switch to change cyclic stick position. This causes the cyclic stick to move, and the helicopter attitude to change about 5 degrees per second. When cyclic movement stops, the autopilot stabilizes the helicopter around the new stick position and attitude. Above 50 knots and bank angles less than 30 degrees, the system becomes airspeed sensitive in pitch. Operating the four-direction TRIM switch causes the cyclic stick to move and the helicopter to change airspeed reference at 6 knots per second. Because of variations in the pitot-static system during gusty conditions, integrated longitudinal acceleration is used for short-term correction. The airspeed sensor is used for long-term updates through a 3-second filter.

The roll channel autopilot holds roll attitude of the helicopter. Attitude information is supplied to the computer from the pilot's and copilot's A/A24G vertical gyros. The command signal is applied to roll SAS 1 and SAS 2 and the roll trim system. When the pilot actuates the four-direction TRIM switch, the helicopter roll attitude will change at about 6 degrees per second. In addition to the attitude hold feature, the system includes an automatic wing-leveling capability. During transitions from hover to airspeeds above 50 knots, this feature automatically retrims the aircraft from a left roll attitude in a hover to a wings level attitude at 50 knots. After establishing a level attitude, the attitude hold feature maintains that attitude until a new roll attitude is commanded by the pilot.

HEADING HOLD. —The yaw channel of the autopilot provides the heading hold feature for hover and forward flight. It is engaged whenever the AUTO PLT PBS is illuminated. Heading hold is an outer-loop function, operating through the yaw trim actuator; therefore, it will only work when the yaw trim is engaged. Releasing all pedal switches at a given heading synchronizes the trim system to the established heading. A potentiometer in the yaw trim actuator applies a trim position feedback signal to the computer. This signal cancels the drive signal at the desired position, stopping the motor. The yaw autopilot also uses a collective stick position sensor to hold reference heading for yaw excursions caused by main rotor torque changes. The collective stick position sensor is controlled by an airspeed signal

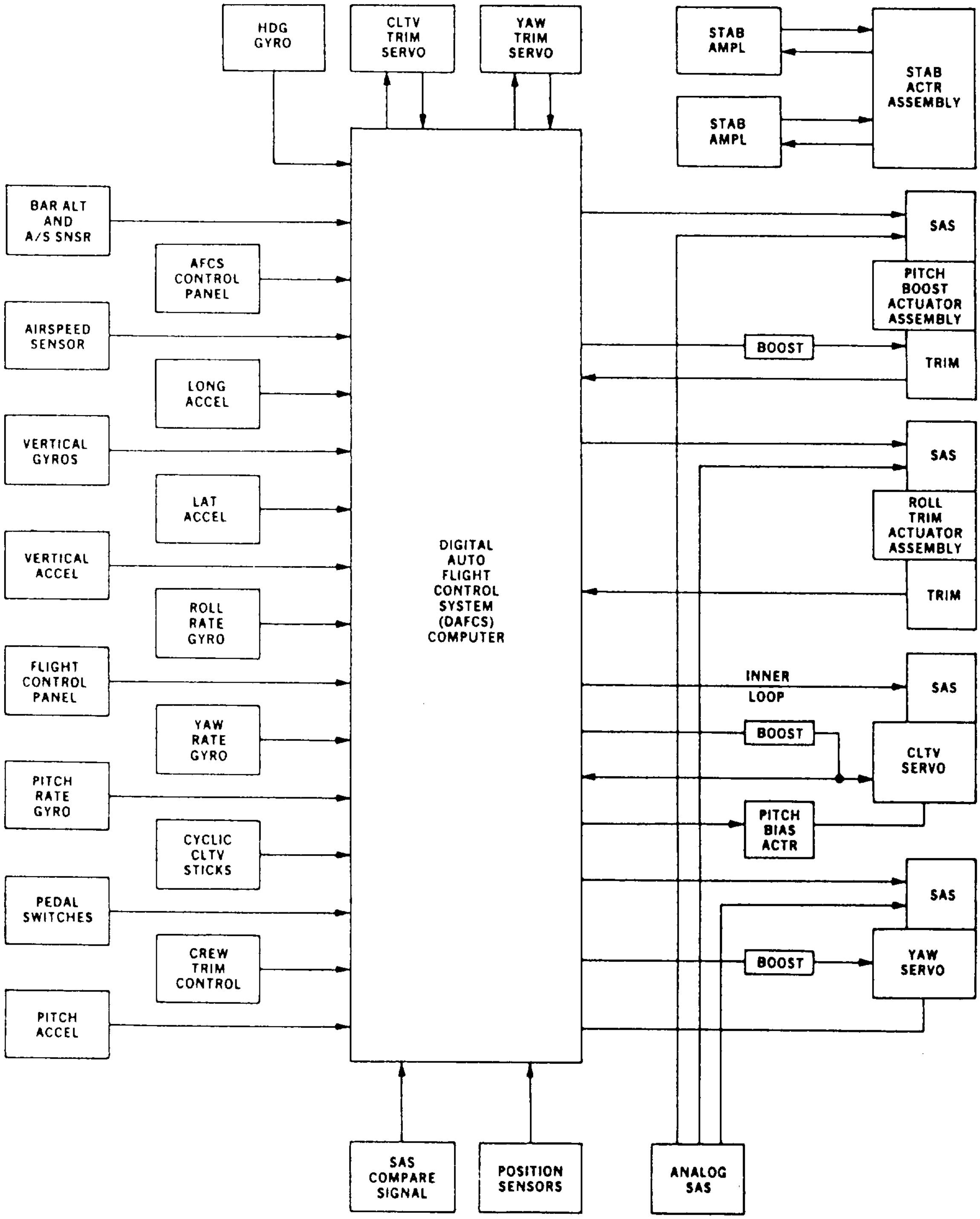


Figure 8-32.-DAFCS input/output block diagram.

that reduces its gain as airspeed increases. When the heading hold is engaged, the HDG TRIM (slew) switch on the collective lets the pilot make heading changes without retrimming. Below 50 KIAS, the aircraft slews at 3 degrees per second. Above 50 KIAS, actuation of the switch for less than 1 second provides a 1-degree heading change. Actuation for greater than one second provides a 1 degree per second coordinated turn. The heading hold is re-engaged following a turn when the following conditions are maintained for 2 seconds:

- Aircraft roll attitude is within 2 degrees of wings level.

- Yaw rate is less than 2 degrees per second.

The heading hold is disengaged by the weight-on-wheels switch when the aircraft is on the ground.

ALTITUDE HOLD. —Either barometric or radar altitude hold is selectable from the AFCS CONTROL panel. With the altitude hold mode on, the DAFCS computer uses a reference altitude. The reference altitude comes from either the air data transducer or the radar altimeter, depending on whether barometric altitude hold or radar altitude hold is selected. The DAFCS computer uses altitude and rate from the barometric or radar altitude systems (depending on which hold mode is selected) and vertical acceleration to command the collective SAS and trim actuators. The computer also monitors engine torque to prevent dual engine torque from exceeding 116 percent whenever the collective trim is positioning the collective. Barometric altitude hold is engaged at any altitude and airspeed by depressing the BAR ALT PBS with SAS 2 and autopilot engaged. Depressing the collective trim release button temporarily disengages the mode. Upon release of the trim switch, barometer altitude hold automatically re-engages and maintains the altitude at the time of re-engagement. Radar altitude hold is engaged at any altitude from 0 to 5,000 feet AGL and at any airspeed by depressing the RDR ALT PBS with SAS 2 and autopilot engaged.

When in the hover coupler mode, altitude hold is referenced to the altitude selected on the AFCS CONTROL panel HVR ALT potentiometer. Depressing collective trim release temporarily disengages the mode. Upon release of the trim switch, radar altitude hold automatically re-engages to the altitude selected on the AFCS CONTROL panel HVR ALT potentiometer. When in the hover coupler mode, transition from one altitude to another is made with the HVR ALT knob on the AFCS CONTROL panel. If the radar altitude mode should fail while engaged, the barometric altitude hold automatically engages. Integrated vertical acceleration provides short-term radar altitude corrections, and rate information from the radar altimeter altitude signal provides long-term updates.

HOVER AUGMENTATION/GUST ALLEVIATION. —An additional feature of the SAS, provided only through SAS 2, is hover augmentation/gust alleviation. It further improves aircraft stability at low airspeed using attitude retention and longitudinal and lateral acceleration to eliminate drift.

TURN COORDINATION. —Automatic turn coordination is provided at airspeeds greater than 50 knots. Turn coordination lets the pilot fly a coordinated turn with directional control provided by the AFCS. The AFCS uses lateral acceleration and roll rate to determine if the aircraft is out of balanced flight. It also provides the yaw SAS and yaw trim with the inputs necessary to maintain an automatic coordinated turn. Automatic turn coordination is engaged and heading hold disengaged when roll attitude is greater than 1 degree, and any of the following conditions exist:

- Lateral cyclic force is greater than 3.0 percent stick displacement.

- Cyclic trim release is pressed.

- Roll attitude is beeped beyond 2.5 degrees of bank angle.

Actuation of the collective-mounted heading slew for greater than 1 second provides a 1 percent per second coordinated trim.

MANEUVERING STABILITY. —Pitch control forces are increased to increase pilot effort required for a given pitch rate at bank angles greater than 30 degrees. The higher pitch control forces help alert the pilot to g loading during maneuvering flight, and are provided through the longitudinal trim actuator. A linear longitudinal stick force gradient is provided by trimming 1 percent forward stick for each 1.5 degrees angle of bank between 30 degrees and 75 degrees. At 75 degrees angle of bank, the longitudinal stick force is equivalent to 30 percent of stick displacement. The maneuvering stability feature is engaged whenever the AUTO PLT PBS is illuminated.

AUTOMATIC APPROACH TO HOVER. — The DAFCS provides the capability to perform an automatic approach to a zero longitudinal and any lateral ground speed selected on the LAT VEL control knob. Also, the DAFCS can perform an automatic approach to any radar altitude selected on the HVR ALT control knob between 40 feet and 200 feet. If the HVR ALT is set below 40 feet, the approach will be made to 40 feet and then continued to the HVR ALT setting when the mode is switched from APPR to HVR. The automatic approach can start at any airspeed and altitude. The automatic approach is an outer loop only function, and it commands the aircraft to decelerate or descend until meeting the approach profile conditions. If the approach mode is selected when aircraft conditions are below the approach profile, the DAFCS commands the aircraft to decelerate. The aircraft will decelerate at 1 knot) second while in the radar altitude hold mode until the approach conditions are met. If the approach mode is selected when the aircraft is above the approach profile, the DAFCS commands the aircraft to descend. The descent occurs at 360 feet/minute when the aircraft is more than 50 feet above the approach profile. It occurs at 120 feet/minute when the aircraft is less than 50 feet above the profile. During these conditions, the DAFCS uses the radar altimeter until the approach profile conditions are met. When the approach profile conditions are met, the aircraft simultaneously decelerates at 1 knot/second and descends at 120 feet/minute. This profile is maintained until the aircraft attains 1 knot of Doppler ground speed and comes to within 1 foot of the selected radar altitude. If the selected altitude is below 40 feet, the aircraft flies to 40 feet and zero longitudinal ground speed and then descends to the selected attitude. When ground speed equals 1 knot or less and the aircraft altitude is within 2 feet of the selected altitude, the hover coupler mode automatically engages. The aircraft then accelerates to the selected longitudinal ground speed.

HOVER COUPLER. —The hover coupler provides longitudinal and lateral ground speed control and stabilization about the selected ground speed and automatic altitude retention. The longitudinal and lateral ground speed and the altitude are selectable on the AFCS CONTROL panel. Longitudinal and lateral ground speed can also be beeped ± 10 knots with the cyclic trim switch about the ground speed selected on the AFCS CONTROL panel, The hover coupler mode can automatically engage at the termination of the automatic approach. Also, the pilot can manually engage it when the aircraft is hovering with less than 5 knots longitudinal groundspeed. To do this, the pilot presses the APPR/HVR button on the AFCS CONTROL panel with SAS 2, TRIM, and AUTO PLT engaged. The hover coupler engages when the longitudinal ground speed is less than 5 knots if engaged manually. After engagement, the aircraft accelerates to the longitudinal and lateral ground speeds selected on the AFCS CONTROL panel. Pressing and releasing the cyclic TRIM REL removes cyclic trim switch inputs. This action returns the aircraft to the LONG VEL and LAT VEL settings on the AFCS CONTROL panel. Because of Doppler noise, short-term longitudinal and lateral ground speed is obtained from integrated longitudinal and lateral inertial acceleration. Long-term correction is obtained from the Doppler sensor using a 7-second filter.

AUTOMATIC DEPART. —The automatic depart mode provides the capability to perform an automatic departure from a coupled hover or from an automatic approach. This mode can take the aircraft to a cruise airspeed of 100 KIAS and altitude of 500 feet. If the coupled hover or the automatic approach feature is engaged, engage the automatic depart mode by depressing the hover depart button on the cyclic grip. Depressing the DEPART PBS a second time disengages the automatic depart mode, but it doesn't automatically re-engage the RAD ALT hold. Depressing the hover depart button a second time disengages the automatic depart mode and returns aircraft control to the pilot. Upon engagement, the aircraft accelerates at 2 knot/second and climbs at 480 feet/minute. During the departure, the DAFCS computer monitors engine torque to ensure that it does not exceed 116 percent. At 100 KIAS, the airspeed hold automatically engages; at a radar altitude of 500 feet, the radar altitude hold automatically engages. Any alternate cruise airspeed or altitude condition of less than 100 KIAS and 500 feet is available to the pilot. The pilot attains an alternate condition by depressing the cyclic trim release and collective trim release at the desired airspeed and altitude, respectively. If either trim release button is depressed and released, the hold mode (airspeed or altitude) associated with that control axis is engaged. The aircraft continues to follow the depart profile for the other axis until the final cruise condition for that axis is met.

The automatic depart mode is an outer-loop function operating through the pitch, roll, and collective trim actuators. As in the automatic approach mode, above 60 KIAS, roll attitude is maintained, and below 60 KIAS, the DAFCS commands roll to eliminate lateral drift.

CREW HOVER. —The crew hover feature lets the crewman position the helicopter during hoist and rescue operations. The crewman controls the aircraft from the crew hover-trim panel. The crew hover controller has a control authority of ± 5 knots. This authority is laterally and longitudinally about the reference values selected on the AFCS CONTROL panel plus the speeds beeped from the cyclic trim beep switch, The crew hover feature is activated from the AFCS CONTROL panel by depressing the CREW HVR button. It can only be activated if the hover coupler mode is already engaged.

PITCH BIAS ACTUATOR (PBA). —The PBA provides longitudinal cyclic displacement proportional to airspeed. The DAFCS commands the PBA as a function of pitch attitude, pitch rate, and airspeed. The PBA is an electromechanical series actuator with ±15 percent control authority and ±3 percent per second rate limit. The PBA functions automatically upon application of power to the DAFCS computer, and it isn't selectable on the AFCS control panel. The DAFCS computer monitors the PBA position to confirm correct response to the input commands. If the PBA fails, the DAFCS lights the BIAS advisory light and flashes the AFCS DEGRADED light. Also, the DAFCS commands the PBA to a predetermined position, depending on the type of failure. The PBA is driven by the DAFCS computer as a function of airspeed, pitch rate, and pitch attitude. PBA failure modes are as follows:

- Attitude failure—bias actuator centered
- Pitch rate failure—faded out pitch rate component
- Airspeed failure—actuator goes to 120-knot position and attitude and rate continues to function.
- Actuator failure—power removed from actuator.

If the system malfunctions, the BIAS Fail Advisory light on the AFCS CONTROL panel will go on, and, in some cases, remove power from the actuator. If the malfunction that caused the shutdown was of an intermittent nature, the actuator operation can be reset by pressing the appropriate MODE RESET button.

REVIEW SUBSET NUMBER 4

Q1. Name the three major systems that make up the AFCS for helicopters.

Q2. How much flight control authority is there when only SAS 1 is engaged?

Q3. What is the primary purpose of the stabilator system?

Q4. When is the stabilator system TEST push button operational?

Q5. What is the purpose of the DAFCS inner-loop control system?

Q6. What is the rate limit of the DAFCS trim actuators?

Q7. What is the effective altitude range for the DAFCS radar altitude hold mode?

Q8. What is the rate of descent when the helicopter is less than 50 feet above the approach profile?

AUTOMATIC STABILIZATION EQUIPMENT

Learning Objective: *Recognize the operating principles and triodes of the automatic stabilization and coupler system, and identify control panel and channel monitor panel functions.*

Personnel in the AE rating maintain the automatic stabilization equipment (ASE) discussed in this chapter. The ASE is used in SH-3 aircraft, and is the system used to illustrate ASE equipment. For detailed information on ASE, you should refer to the appropriate maintenance instruction manual (MIM).

The ASE is to helicopters as the AFCS is to fixed-wing aircraft. ASE is designed to improve the handling characteristics of the helicopter. ASE lets the pilot fly the helicopter in automatic cruising flight and in hands-off flight. When energized, the ASE activates the attitude stabilization and heading retention systems in the helicopter. Also, ASE places the barometric altitude control in a synchronizing condition so it can be engaged when desired.

ASE provides selective attitude retention in all flight axes, and it also improves handling characteristics by introducing stability corrections. Barometric altitude (BAR ALT) maintains the aircraft at the desired altitude manually selected by the pilot. The coupler (CPLR) enables the helicopter to find and keep pilot-selected speeds, drifts, and altitudes during automatic cruise flight. During antisubmarine warfare (ASW) missions, the ASE enables the helicopter to make a transition from forward flight to hover. It also aids in maintaining a hover during sonar search. An attitude indicating system provides a visual display of the helicopter's attitude on the pilot's and copilot's attitude indicators.

ASE, with the coupler system, uses associated electronic and hydraulic systems to provide automatic hovering and automatic cruising. The coupler system consists of a Doppler radar system (ground speed measurement) and a vertical velocity system (used with a low-altitude radar altimeter). Since radar systems are not maintained by the AE, they are not discussed in detail. Radar systems are mentioned only because they serve as signal sources for ASE operation.

ASE COMPONENTS

ASE, like the AFCS, consists of many components, including electrical/electronic, hydraulic, and mechanical. You will be able to understand how the system functions if you can describe the components and understand how they work.

Electrical/Electronic Components

The following paragraphs describe the major electrical/electronic components that make up an ASE system. These electrical/electronic components make the ASE function.

ASE CONTROL PANEL. —The ASE control panel (fig. 8-33) is on the cockpit center console between the pilot and copilot. The panel contains five push-button switches and five control knobs. These switches and knobs control the ASE modes of operation. The control also contains two toggle switches used with the other controls. When the pilot presses the ASE button, the pitch, roll, and yaw control circuits start operating.

When the pilot presses the BAR ALT button, the barometric altitude controller in the collective channel engages. The collective channel barometric altitude controller disengages when the pilot depresses the BAR OFF button. If the barometric altitude controller is engaged, the pilot can momentarily release it by pressing the BAR

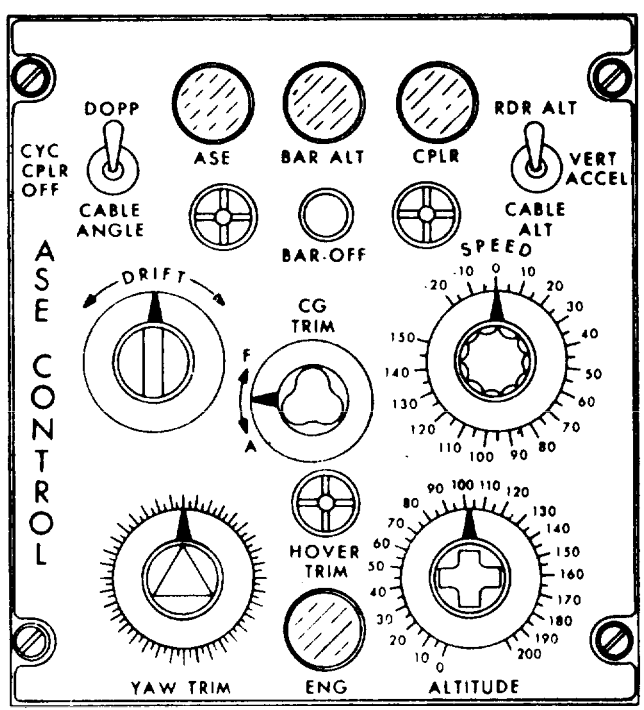


Figure 8-33.-ASE control panel.

REL button on the collective pitch stick grip. This action makes possible a change in altitude.

By pressing the CPLR button, the pilot engages the coupler and the ASE collective channel. The ASE must be on before engaging the coupler. The push button marked HOVER TRIM ENG can only be engaged when the CYC CPLR switch is in DOPP position. When HOVER TRIM is engaged, hover trim control transfers from the pilot to the crew member at the hoist position. Hover trim allows the hoist operator to maneuver the helicopter fore and aft and port and starboard during hoisting or similar operations. Hover trim control authority is limited to 11 ±4.5 knots of the speed established by the ASE speed control. The coupler release button, marked CPLR REL, on each collective pitch lever disengages the coupler portion of ASE. It also disengages the hover trim control. If the operator desires to remain in a Doppler hover, the hover trim may also be disengaged by cycling the cyclic coupler switch to OFF and then to DOPP.

Control knobs on the ASE panel have definitive characteristic shapes that permit the pilot to identify them without looking at them. Specific control knobs and their identifying shapes are described in the following paragraphs.

Altitude Set Knob.—This knob is cross shaped. With basic ASE and the radar altitude (RDR ALT) coupler engaged, the helicopter can accurately maintain any selected altitude from 0 to 200 feet. This mode of operation is advantageous during hover operations, as the pilot can vary altitude by rotating a single control.

Various models of ASE have different scales on the attitude set knob at different increments. (In one model, the scale runs from 0 to 1,000 feet with varying increments. In another model, the scale runs from 0 to 500 feet.) In the ASE discussed in this chapter, the ALTITUDE control scale is from 0 to 200 feet in 5-foot increments. The 0 to 200 foot configuration offers accuracy throughout the full range of travel of the control knob.

Yaw Trim Knob. —This knob is triangular shaped. The pilot turns the yaw control knob to trim the heading of the helicopter during flight. One rotation of the knob will turn the helicopter 72 degrees. Each increment on the knob equals 1 degree of movement.

Ground Speed Set Knob. —This knob is an indented circle. The pilot turns the ground speed set knob to preselect the forward or aft ground speed to be maintained by the coupler. Friction reduction built into the speed control permits the pilot to make small changes in speed.

Drift Knob. —This knob is bar shaped. The pilot turns the drift set knob to preselect the compensation for the helicopter's lateral drift about its ground track. The roll coupler mode will maintain this compensation. Full-scale sensitivity y is low enough to allow the pilot to make small changes in drift.

CC Trim Knob. —This knob is clover shaped. The pilot turns the CG (center of gravity) trim knob to adjust the pitch in small increments both fore and aft. The CG trim signal is summed with that of the position sensor to maintain a preselected pitch.

Cyclic Coupler Switch. —The cyclic coupler switch selects the coupler mode of operation. The switch has three-positions with the center position being OFF. When the switch is in the DOPP position, information comes from the Doppler radar. It also activates the Doppler mode of pitch and roll coupler operation.

With selection of the CABLE ANGLE position, the sonar operator controls the pitch and roll trim angle using the cable angle control panel. This control allows for compensation of helicopter drift over the sonar transducer.

Altitude Coupler Switch. —The altitude coupler switch is used with the coupler button for altitude reference. It is also a three-position switch. The RDR ALT position engages the radar altitude mode for absolute altitude reference. The CABLE ALT position engages the transducer cable altitude for absolute altitude reference. When the CPLR button is depressed with either RDR ALT or CABLE ALT selected, the BAR ALT mode automatically engages. The VERT ACCEL position of the altitude coupler switch engages the vertical accelerometer mode to eliminate collective pumping.

CHANNEL MONITOR PANEL. —The channel monitor panel (fig. 8-34) is to the right of the pilot's seat. This panel contains four ON-OFF toggle switches across the top row and four guarded switches marked HARDOVER across the middle of the panel. It also includes a meter select switch, and a vertical gyro switch.

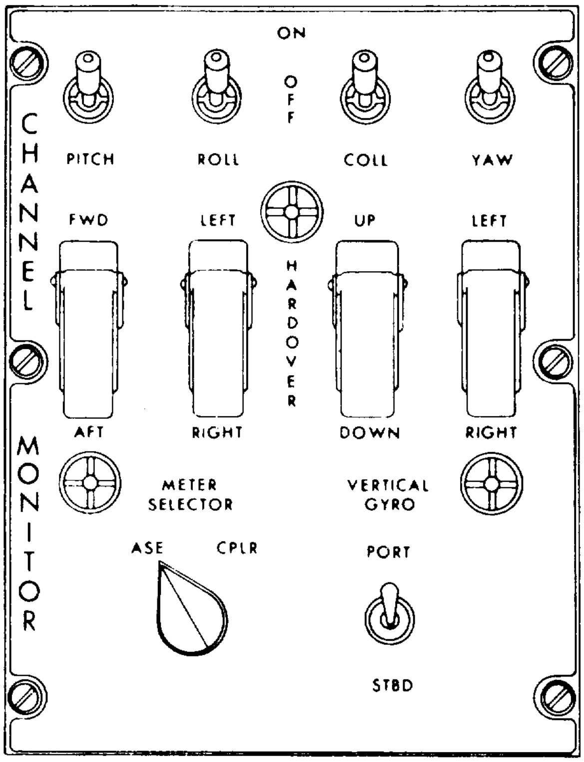


Figure 8-34.-Channel monitor panel.

The four ON-OFF toggle switches are PITCH, ROLL, COLL, and YAW. These switches let the pilot disengage any of the four channels of the ASE. Normally, the switches are left in the ON position. They are positioned to OFF to disengage a malfunctioning channel. The four guarded switches are for maintenance personnel to introduce HARDOVER signals to the individual channels when they test or troubleshoot the ASE.

NOTE: The channel monitor test switch on the pilot's compartment dome light panel MUST be in the test position before using the HARD-OVER switches.

The METER SELECTOR switch lets either ASE or CPLR inputs be monitored with the hover indicator (covered later in the chapter) in the **A** mode.

The VERTICAL GYRO SELECTOR switch is marked PORT and STBD. This switch lets the pilot select the port or starboard vertical gyro for ASE pitch and roll reference sources.

CABLE ANGLE CONTROL PANEL. —The cable angle control panel (fig. 8-35) is located at the sonar operator's console. This panel contains

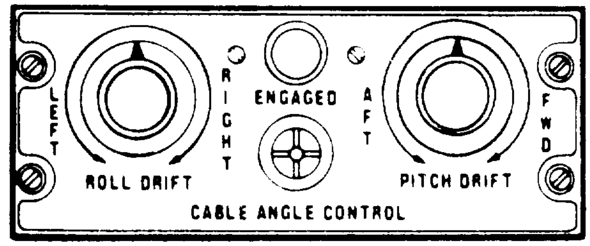


Figure 8-35.-Cable angle control panel.

an engagement switch (push-button type) and two potentiometers labeled ROLL DRIFT and PITCH DRIFT. The sonar operator has control of the ASE when the CPLR mode is on, and the cyclic coupler switch is in the CABLE ANGLE position. The sonar operator may engage and control the transducer cable angle by trimming the helicopter's pitch and roll attitude. This lets the operator maintain the cable angle perpendicular, relative to the horizon.

HOVER TRIM CONTROL PANEL. —This panel (fig. 8-36) features two rotary knobs and

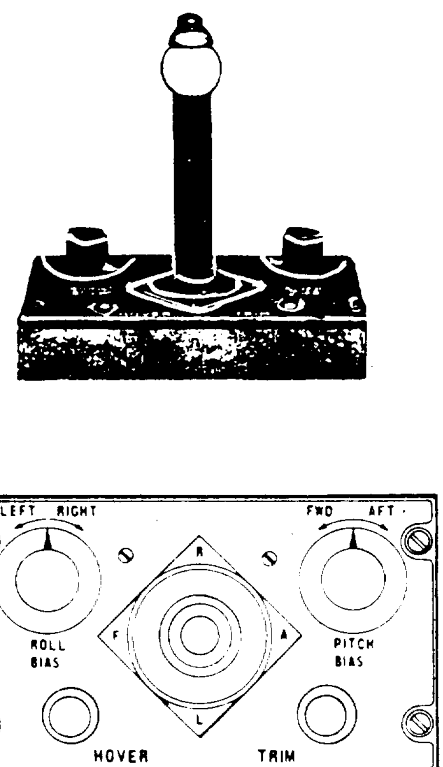


Figure 8-36.-Hover trim control panel.

a spring-centered hover trim stick. One of the two rotary knobs is marked ROLL BIAS, with directional arrows for left and right. The other rotary knob is marked PITCH BIAS, with marked arrows for forward and aft. The hover trim switch is outlined in its corners with the letters *R* (for right), *L* (for left), *F* (for forward), and *A* (for aft).

The hoist operator uses the knobs on the hover trim panel to control helicopter drift. With the hover stick centered, the hoist operator adjusts the roll and pitch bias knobs to trim the aircraft for hover. Signals introduced into the amplifier by the hoist operator correct any slight drifting of the helicopter while the aircraft is hovering. To energize the hover trim circuits, the pilot must depress the HOVER TRIM ENG button on the ASE control panel with the cyclic coupler switch in the DOPP position.

DUAL-CHANNEL LAG AMPLIFIER. — The function of the dual-channel lag amplifier (fig. 8-37) is to delay (lag) applied signals to ensure proper response in helicopter movement. The vertical velocity, roll stick position sensor, and the pitch and roll cable angle sensor signals are lagged by this amplifier.

ASE AMPLIFIER. —The ASE amplifier (fig. 8-38) compares pilot-selected attitude, altitude, and heading with the helicopter's actual attitude, altitude, and heading. The amplifier also provides error signals that maintain helicopter stability, within limited authority, regardless of combined aerodynamic disturbances.

The ASE amplifier integrates the input signals from the sensors and directs control operation. It also provides an output to the hydraulic sections of the control system activating servo units. The

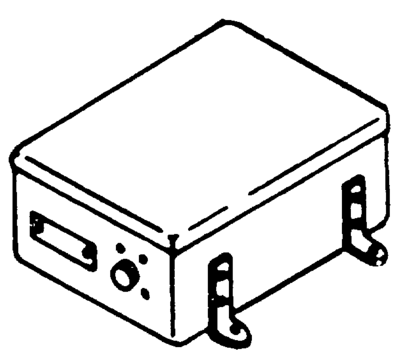


Figure 8-37.-Dual-channel LAG amplifier.

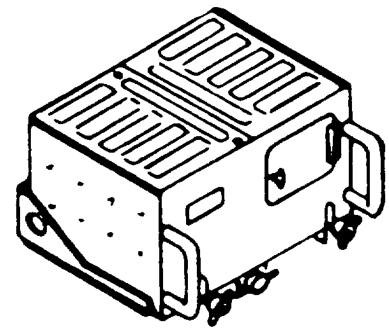


Figure 8-38.-ASE amplifier.

ASE amplifier contains eleven amplifiers. The amplifiers include four basic ASE modules, two coupler integrator modules, two coupler amplifier modules, one yaw synchronizer module, one collective coupler module, and one vertical accelerometer amplifier module. The ASE amplifier also contains nine gain capsules and a yaw rate gyro. The ASE amplifier modules and capsules are discussed below.

Modules. —The four basic ASE modules are pitch, roll, collective, and yaw. They serve to amplify, shape, and derive the rate signals used during ASE operation. These modules are interchangeable.

The pitch and roll coupler amplifier modules are used during pitch and roll coupler operation. These modules are also interchangeable.

The pitch and roll coupler integrator modules are also interchangeable. They provide steady-state error signals during pitch and roll coupler operation.

The collective coupler module amplifies signals during collective coupler operation.

The vertical accelerometer amplifier operates with selection of the CABLE ALT mode of collective coupler operation. The vertical accelerometer amplifier filters, amplifies, and lags the vertical accelerometer signal in the CABLE ALT mode.

The yaw synchronizer modules keep the yaw channel input nulled, except when ASE is operating and the pilot's feet are not on the control pedals.

Each ASE amplifier module and each of the yaw synchronizer modules contain a regulated power supply. Individual ac and dc fuses prevent failure in one channel from affecting another channel.

Gain Capsules. —Each module, except the yaw synchronizer module and the vertical accelerometer amplifier module, contains a plug-in gain capsule. A gain capsule consists of resistors and jumpers that determine module gain and signal path. Since each module has a particular function, you must be sure the proper gain capsule is inserted in the amplifier.

ATTITUDE DEMODULATOR. —When the ASE is operating in the **C** mode, the pitch and roll vertical gyro signals are demodulated by the attitude amplifier demodulator (fig. 8-39). The dc output of the demodulator is compared with the cable angle drift sensor dc voltage. The sum of the two dc voltages goes to the hover indicators.

HOVER INDICATOR. —There are two hover indicators on the instrument panel (fig. 8-40). The indicators show Doppler information during automatic cruise flight. During an automatic transition from forward flight to a hover, the indicator displays speed drift and rate of descent.

The hover indicator contains scale increment marks across the center vertical and horizontal axes and along the vertical (left side) and bottom of the dial face. Two movable bars coincide with the center vertical and horizontal axes scale marks on the dial. When the aircraft is hovering, these bars intersect at a small circle on the face. There are two arrowhead pointers. One pointer is on the left side of the indicator, which moves vertically up or down, coinciding with the vertical scale, The other pointer is located at the bottom of the

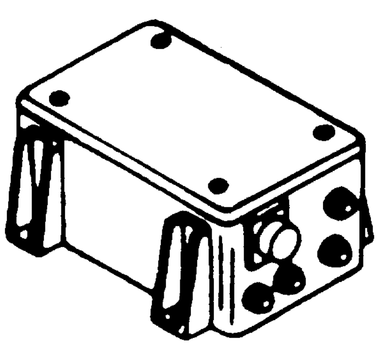


Figure 8-39. -Attitude demodulator.

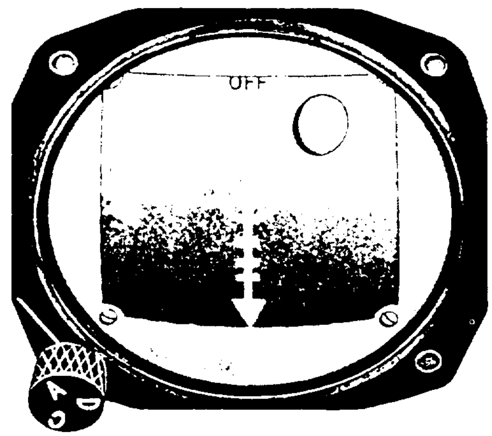


Figure 8-40.-Hover indicator.

indicator, which moves horizontally left or right, coinciding with the horizontal scale.

There is a mode selector switch on he lower left edge of the hover indicator case marked with positions *A, C,* and *D.* The hover indicator also contains a mode selector window on the dial face that operates with the mode selector switch. One of the letters *(A, C,* or *D)* is displayed here to show the mode of operation.

Operation in the *A* mode connects the hover indicator to ASE. With the meter selector on the channel monitor panel in ASE position, the hover indicator operates as a null indicator. The hover indicator horizontal bar monitors the pitch channel. The vertical bar monitors the roll channel; the vertical pointer, the altitude channel. The horizontal pointer monitors the yaw channel.

Operation in the *D* mode connects the hover indicator to the Doppler radar. The horizontal bar shows forward or aft velocities, and the vertical bar indicates left or right drift. Each increment on the hover indicator horizontal and vertical scales equals 10 knots ground speed, with a maximum indication of 40 knots. The vertical pointer shows vertical velocity, with each increment equal to 250 feet per minute. Full-scale deflection is equal to 1,000 feet per minute up or down. To show forward flight, the horizontal bar moves downward, To indicate drift, the vertical bar moves in a direction opposite to the direction of drift; therefore, the pilot flies into the bar for correction.

Operation in the *C* mode connects the hover indicator to the cable pickoff potentiometers mounted on the sonar hoist assembly. The horizontal and vertical bars of the indicator then represent cable angle, with each increment equal to about 2.5 degrees of cable angle. The vertical pointer shows sonar depth as an error signal. The null position represents the selected sonar search altitude. Each increment above and below the null point represents 10 feet of error.

In both *C* and *D)* modes, the yaw pointer is inoperative and should not move. An OFF flag on the upper dial face of the hover indicator can appear in all three modes of operation. In the *A* mode, the flag disappears when the ASE is engaged. In the *D* mode, the flag disappears when the Doppler signal is reliable. In the *C* mode, the flag disappears when the sonar equipment is turned on.

INERTIAL VELOCITY SYSTEM COMPUTER. —The inertial velocity system computer (fig. 8-41) derives separate inertial velocity signals for pitch and roll ASE channels during the cable angle mode of operation. The computer contains two separate channels for pitch and roll signals. It receives inputs from the pitch and roll accelerometers, the vertical gyro, and the Doppler system.

ASE operation is controlled by the sonar system when the transducer is submerged. The Doppler velocity signals are routed past the inertial velocity signals and then delayed for 40 seconds. The Doppler velocity signals then integrate with the accelerometer and vertical gyro signals, resulting in an inertial velocity signal. This signal represents both short-term velocity sensed by the accelerometer and long-term velocity produced by the delayed Doppler signal.

ALTITUDE CONTROLLER. —The altitude controller (fig. 8-42) senses changes in barometric

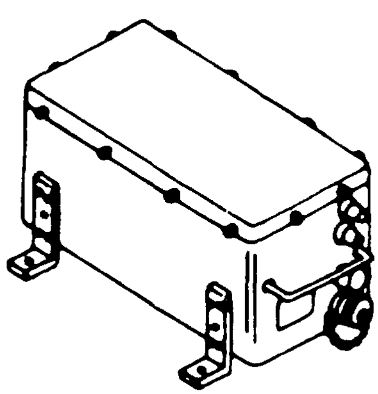


Figure 8-41.-Inertial velocity system computer.

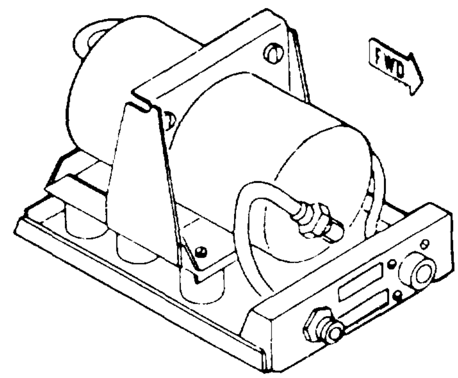


Figure 8-42.-Altitude controller.

altitude from a reference altitude and generates a voltage proportional to the altitude difference. The excitation voltage and the output voltage will be 180 degrees out of phase at altitudes below the established reference. They will be in phase at altitudes above the established reference.

A purifier chamber lessens the moisture content in the altitude controller by routing the airflow through a desiccant cartridge in this chamber.

CYCLIC STICK. —The pilot uses the cyclic stick (fig. 8-43) to control the direction in which

Figure 8-43.-Cyclic stick grip.

the helicopter moves. By moving the cyclic stick in any direction, the pilot causes the tip-path plane of rotation of the rotary wing blades to tilt in that direction. As a result, the helicopter moves in the same direction.

COLLECTIVE PITCH LEVER. —The pilot uses the collective pitch lever (fig. 8-44) to change the pitch of all the rotary-wing blades simultaneously. This angular change is equal on all the main rotor blades. Changing the pitch will increase or decrease the lift accordingly.

RUDDER PEDALS. —The pilot uses the rotary rudder pedals to change the pitch and thrust of the rotary rudder, thus changing the heading of the helicopter. By pressing the left pedal, the pilot causes the rotary rudder blade pitch to increase. This increases blade thrust and turns the helicopter to the left. By pressing the right pedal, the pilot causes the rotary rudder blade pitch to decrease. This decreases thrust and lets the rotor torque reaction turn the helicopter to the right.

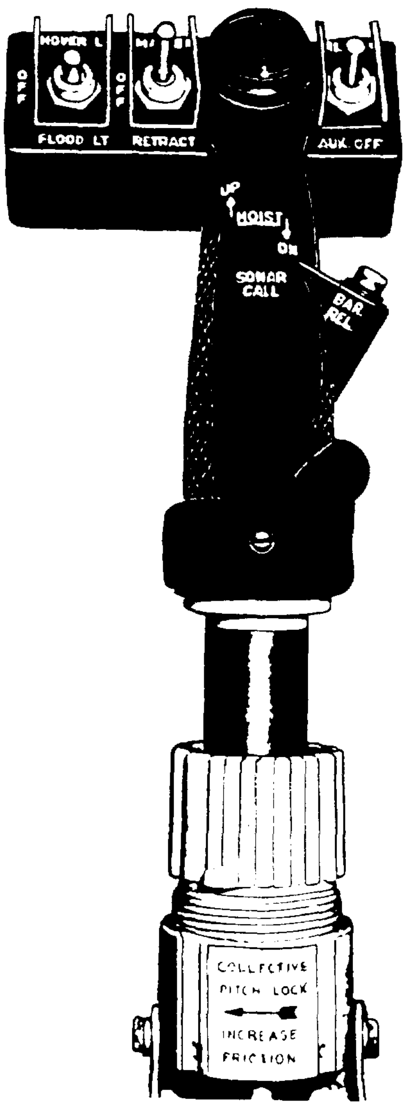


Figure 8-44.-Collective pitch lever grip.

ASE Sensors

ASE signal voltages for controlling helicopter movement come from the following sensors and associated components:

- Collective position sensor and clutch
- Pitch-and-roll position sensors
- Accelerometers
- Gyros
- Tilt table

COLLECTIVE POSITION SENSOR AND CLUTCH. —The electromechanical collective clutch nulls the collective position sensor (fig. 8-45, view A)

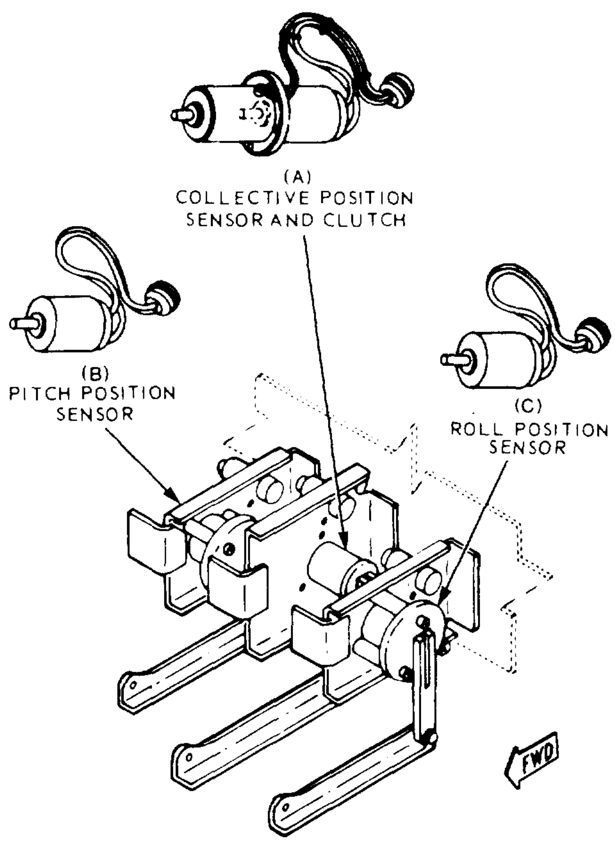
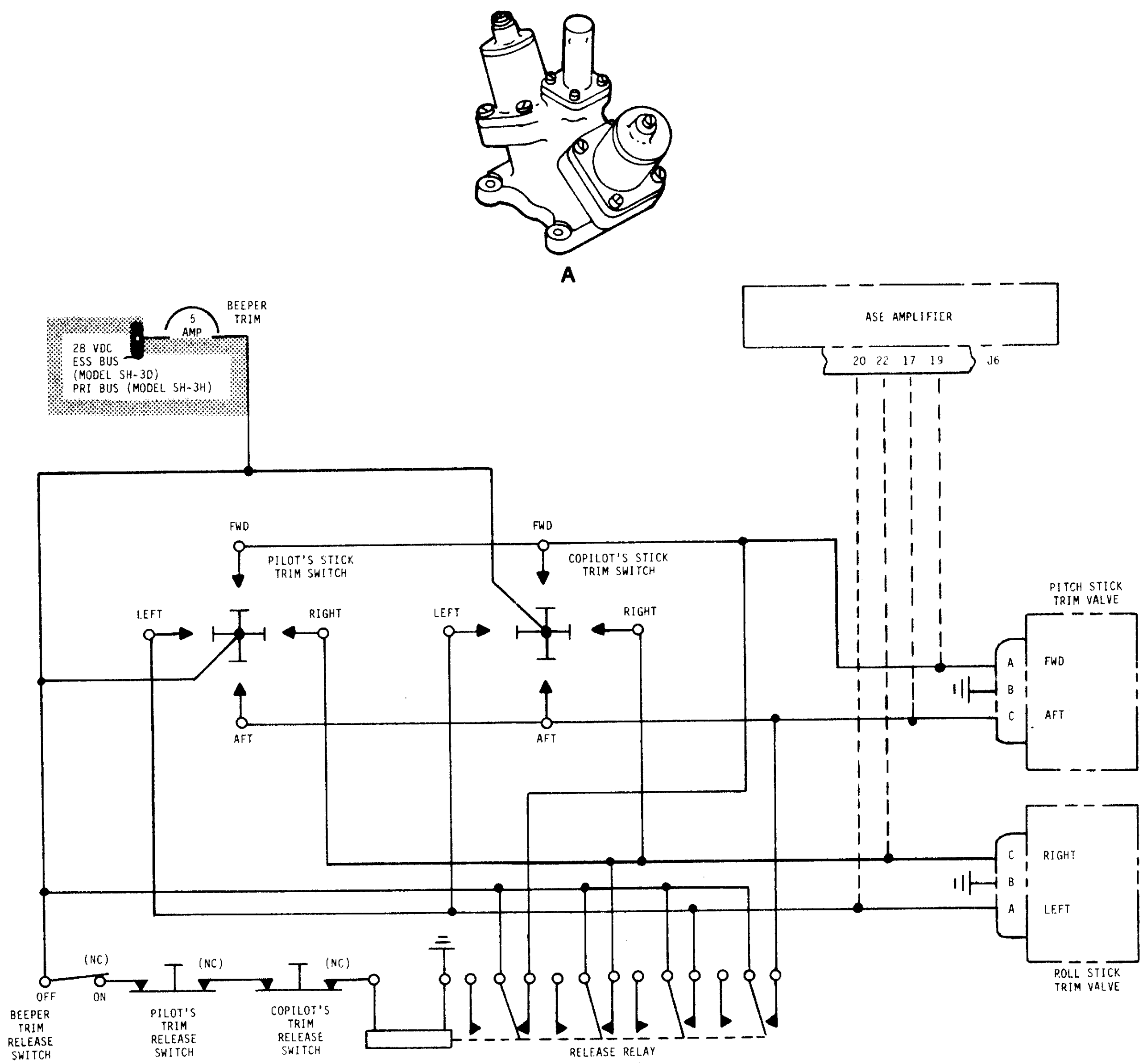


Figure 8-45.-Position sensors.

output when barometric altitude is disengaged. The clutch consists of a stationary coil and self-centering springs. The input male shaft can rotate continuously when disengaged. The output female shaft is spring-centered and follows, without slip, any input shaft rotation through a minimum of 45 degrees of rotation. The rotation can be in either direction from the 0-degree de-energized position. The clutch has no common ground between the coil and case and has an output zero rest position repeatability of one-quarter degree.

PITCH-AND-ROLL POSITION SENSORS. — The pitch-and-roll position sensors (fig. 8-45, views B and C) are identical single-phase, salient-pole, variable-induct ion transformers. The sensor rotor acts as the primary and the stator acts as the secondary. The stator is nonsinusoidally wound. The stator windings are isolated for practically unlimited sensor resolution.

As the flight controls mechanically rotate the rotor, a signal is produced. This signal is the sensor output required to cancel the vertical gyro signals in the pitch and roll channels. The signal



B

Figure 8-46.-Stick trim valve and schematic diagram.

dampens and repositions the collective stick during open-loop operation in the altitude channel. The pitch-and-roll sensors mechanically link to the cyclic sticks. The collective sensor mechanically links to the collective stick through the collective clutch.

ACCELEROMETERS. —Pitch, roll, and vertical accelerometers provide signal voltages proportional to linear input acceleration. The signals are phased to show the direction of acceleration.

RATE GYRO. —The rate gyro senses the turning rate of the helicopter and produces an ac output signal proportional to the rate of turn. The ac output signal goes to the yaw channel and also to the attitude indicating system.

TILT TABLE. —The tilt table consists of the starboard vertical gyro; the pitch, roll, and vertical accelerometers; the dc rate gyro; and the starboard rate switching gyro. These components provide signals to ASE and associated equipment proportional to direction and magnitude. During maintenance procedures, the tilt table components, along with the mobility of the table, also provide simulated flight conditions in pitch and roll. Changes in pitch and roll provide accurate displacement rate and acceleration signals to the ASE amplifier and associated equipment. These signals can then be measured as a known calibrated output.

Hydraulic Components

The hydraulic components actuated and controlled by ASE signals include stick trim valves and servo valves.

STICK TRIM VALVE. —There are two stick trim valves (fig. 8-46), one for pitch and one for roll. These valves are continuous-duty, dual-input type solenoid valves. The valves reposition the cyclic stick when the pilot actuates the trim switch. When the release relay de-energizes, all four solenoids on the trim valves energize. When the release relay energizes, each solenoid is independently controlled when the operator uses the cyclic stick trim switch.

ASE SERVO VALVES. —Error signals caused by changes in pitch and roll are sensed at the servo valves. The servo valve (fig. 8-47) converts the error signal into a mechanical output, making the auxiliary power piston move. This action affects the primary servo valve and changes the pitch or roll attitude of the rotary-wing blades.

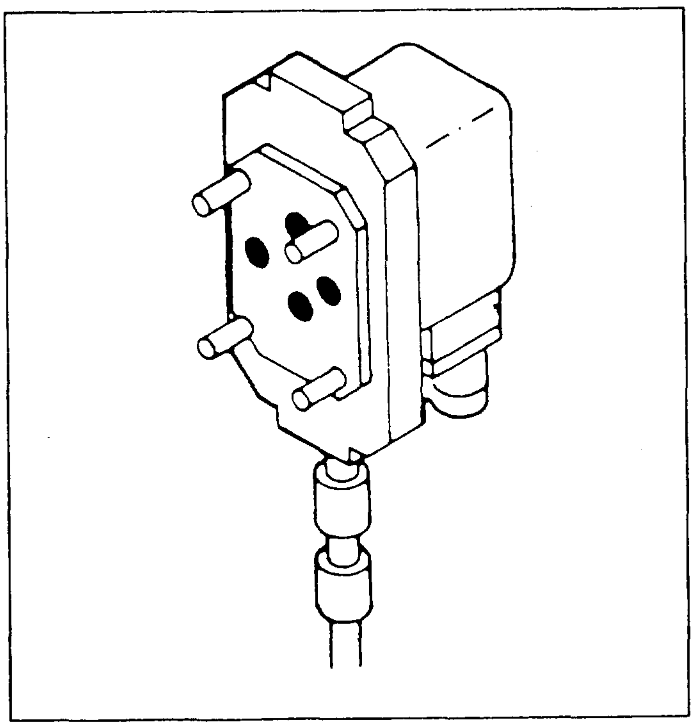


Figure 8-47.-Servo valve.

PRINCIPLES OF OPERATION OF ASE CONTROL CHANNELS

ASE stabilizes the helicopter at reference attitudes (pitch and roll), altitude (collective), and heading (yaw) selected by the pilot. ASE may be engaged before takeoff and remain engaged during an entire mission. Stability corrections are introduced into the flight control system so the pilot always has complete control of the helicopter through normal use of the primary flight controls. The flight control system consists of basic ASE and coupler systems. Basic ASE has pitch, roll, collective, and yaw stabilization channels; and the coupler has related pitch, roll, and collective stabilization channels. To stabilize the helicopter during basic ASE and coupler operation, signals representing actual attitudes, altitude, and heading are continuously fed into the ASE amplifier. These signals are compared with corresponding signals representing reference attitudes, altitude, and heading. The amplifier ties together all sensor and control panel input signals to produce stability correction output signals.

ASE compensates for any combination of temporary or continuous aerodynamic disturbances met by the helicopter. The attitude indicating system uses signals from the ASE rate gyro, the vertical gyros, and a dc rate gyro. These signals provide the pilot and copilot with pitch and roll attitude and rate-of-turn information.

ASE has time delay, system interface, and system interlock circuits. These circuits ensure the compatibility of modes and associated equipment when these modes and equipment are selected for use with ASE.

ASE has four basic channels of operation—pitch, roll, collective, and yaw. These channels are discussed in the following paragraphs.

Pitch Channel

Automatic pitch attitude stabilization is maintained continuously after ASE engagement. The vertical gyro produces a signal proportionate to displacement of the helicopter fuselage from the horizon (fig. 8-48). This signal also goes through a rate network to produce a signal equivalent to the rate of change of pitch attitude. The direction of the displacement and rate signals cause the rotor blades to produce lift, returning the fuselage to the desired attitude.

A combination of CG trim and cyclic stick position serves to provide the reference attitude. In a balanced state, the following occurs: The vertical gyro displacement and rate signals are equal and opposite to the CG trim/position sensor signal at the summing point. Therefore, there is no command for flight control movement. If the pitch attitude changes without the cyclic stick being moved, the vertical gyro senses the movement. Signals from the vertical gyro then cause the aircraft to return to its original pitch attitude. If the pilot desires to change the pitch attitude, the cyclic stick is moved forward or aft. This action produces an error signal at the summing point. As the helicopter changes attitude to correspond with the cyclic stick position, the vertical gyro pitch displacement signal increases until the two signals are equal and opposite again. This becomes the new pitch reference attitude.

During CPLR operation in the DOPP mode, the system compares Doppler ground speed with the speed selected on the ASE control panel. Any difference between the actual ground speed and the selected ground speed produces an error signal. The error signal causes the helicopter to change speed until the two voltages balance. An accelerometer monitoring the change in speed produces a rate signal to oppose any change in speed. This signal prevents large rapid changes in pitch attitude. The hover trim control panel allows the hoist operator to provide small attitude changes in hovering flight.

The integrator circuits monitor any steady-state error signal that may exist because of the difference between Doppler speed and selected speed (could be caused by head or tail winds). The larger the output of the integrator, the more correction is made until the Doppler speed equals selected speed.

In the cable angle mode, pitch attitude from the vertical gyro is compared with the cable angle (in respect to the deck of the helicopter). This allows the ASE to maintain the sonar cable vertical to the earth's surface regardless of aircraft attitude. The cable angle error signal is processed in a similar manner as the Doppler error signal.

An inertial velocity system (IVS) circuit becomes operational in the cable angle mode when the IVS control relay energizes. The voltage to energize the relay develops when the sonar transducer submerges to a depth below 11 feet. When the IVS circuit is operational, outputs from the accelerometer and the vertical gyro combine with the Doppler velocity signal. This combination produces a very accurate inertially derived signal.

The output of the coupler also goes to a stick trim actuator circuit. When the coupler output reaches a certain level, a solenoid of the pitch

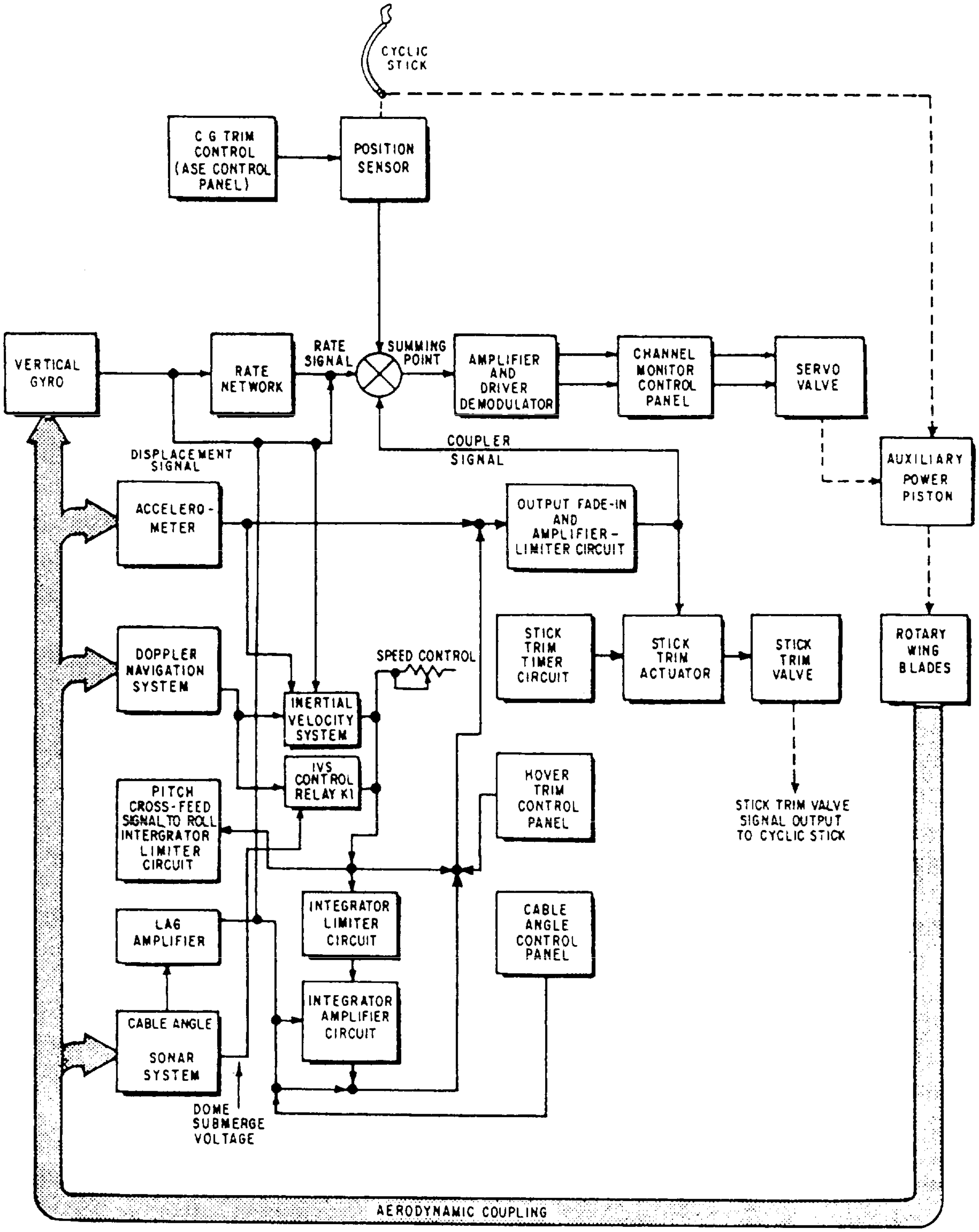


Figure 8-48.-ASE/coupler pitch channel.

stick trim valve is excited. The solenoid causes automatic repositioning of the cyclic stick, thereby extending pitch channel authority.

Roll Channel

Roll channel operation is similar to the pitch channel. (See fig. 8-49.) In basic ASE, the position sensor is lagged by an amplifier before being added to or subtracted from the rate-plus-displacement signal. In the Doppler mode, the pilot input is the DRIFT control on the ASE control panel. Roll signals are otherwise processed in the same manner as the pitch signals.

Collective Channel

After ASE is engaged, the pilot engages the collective channel by the BAR ALT engage button to stabilize helicopter altitude. Part of the altitude error signal goes to the collective coupler integrator during BAR ALT operation. (See figure 8-50.) If the altitude control error signal is steady-state (due to variables such as fuel, load, weather, etc.), a signal is developed to compensate for this steady-state error and to improve engaged altitude retention. When the pilot presses the BAR ALT REL button, the integrator cancels any remaining compensating signal.

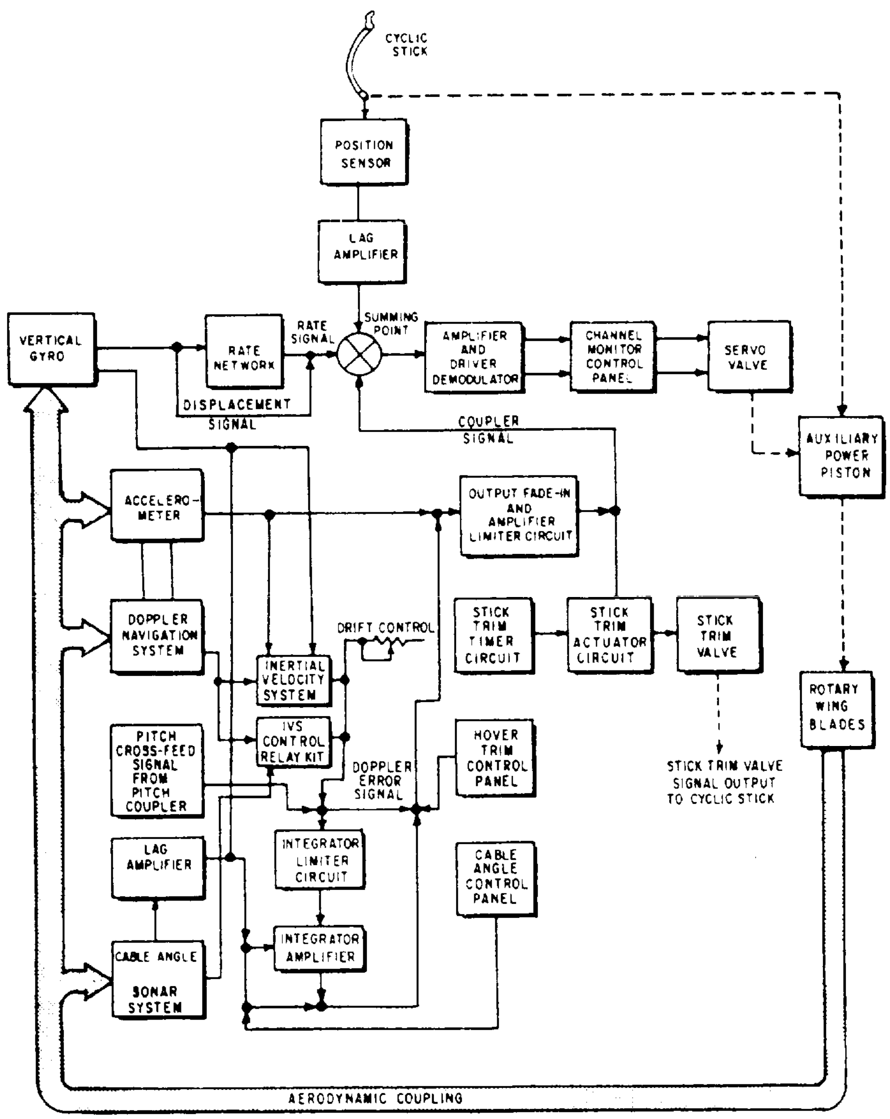


Figure 8-49.-ASE/coupler run channel.

As the servo valve corrects the altitude error signal through the auxiliary power piston and rotary wing blades, the altitude error signal diminishes. When the helicopter returns to the engaged altitude, the altitude control output error signal returns to null. However, as the servo valve corrects the altitude error signal, it places the collective servo system in an open-loop condition.

The open-loop spring and a balance spring support the collective stick and linkage weight so the stick retains the desired position. The stick should remain in this position with little or no external force applied to hold the stick. The open-loop spring also allows the barometric altitude control to make a larger than 10 percent correction over a period of time. The pilot may override open-loop operation by applying an opposing force on the collective stick. As the altitude error signal diminishes, the position sensor signal returns the collective pitch control stick to the engaged altitude position. While BAR ALT is on, the pilot applies collective and depresses the BAR REL button on the collective stick grip momentarily to change altitude. The collective clutch nulls the output of the position sensor and the barometric altitude input while the BAR REL button is depressed.

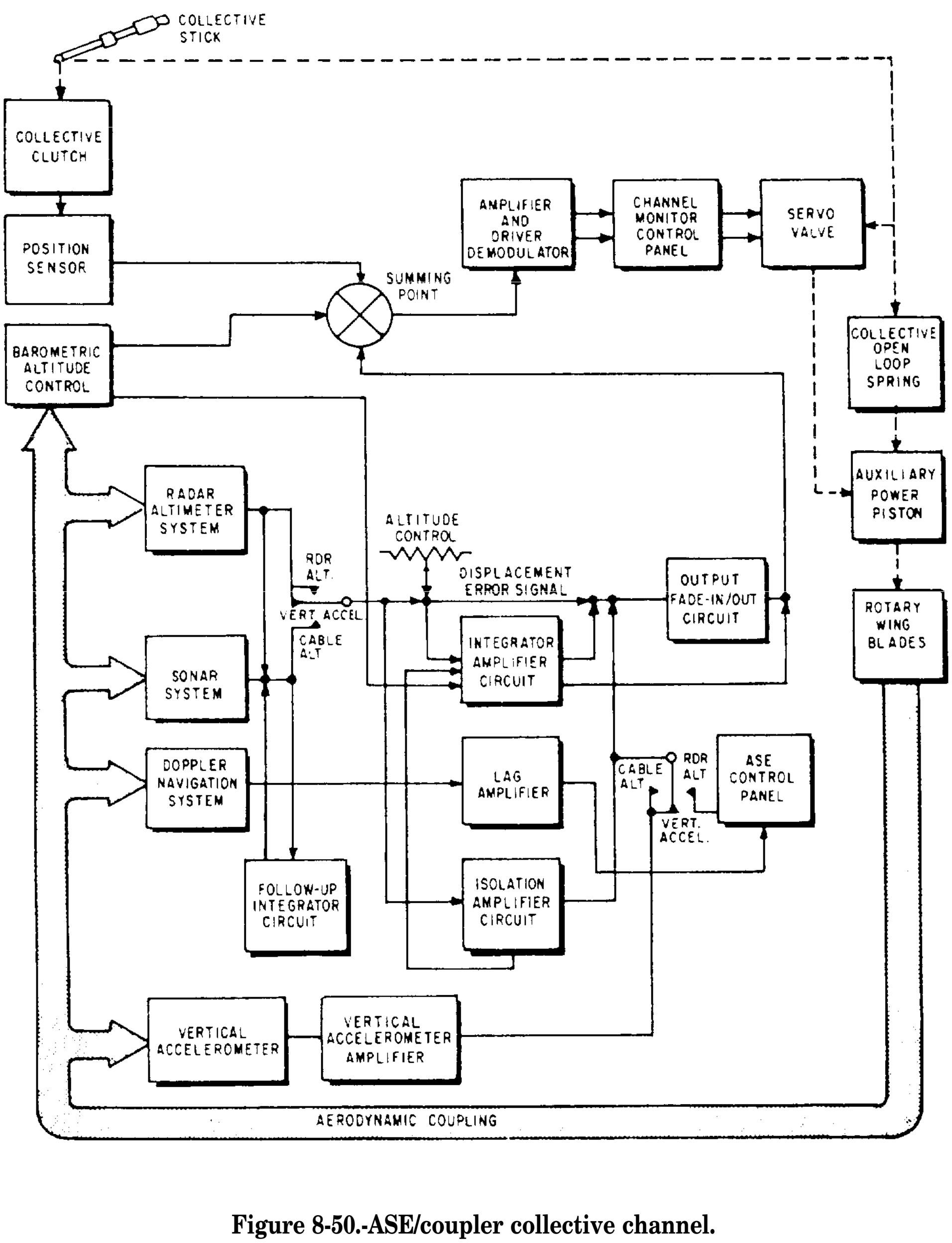


Figure 8-50.-ASE/coupler collective channel.

During collective coupler operation with radar altitude mode engaged, the coupler seeks and retains the altitude selected on the control panel. Any difference between radar altitude and the selected altitude produces an error voltage. This voltage causes the total lift developed by the rotor blades to change and seek the selected altitude. The radar altitude error signal is also fed to the integrator amplifier circuit. This circuit provides a signal to compensate for a steady-state error signal input. The compensating signal is added to the other portion of the radar altitude error signal. The combined signal then couples to an output fade-in circuit.

The radar navigation set produces a signal (vertical velocity) proportional to the rate of change in altitude. This rate signal is lagged approximately 1 second in the lag amplifier. The rate signal then goes through the ASE control panel, and couples to the output fade-in circuit. The coupler altitude error signal is coupled to the collective ASE amplifier and processed in a similar manner as the basic ASE altitude error signal.

In the cable attitude mode, the cable altitude output signal is compared to the radar altitude output signal. Any difference between signals goes to the follow-up integrator circuit. The follow-up output signal is fed back to the cable altitude input to correct the cable altitude signal. The corrected cable altitude input signal is summed with the ALTITUDE control. The resultant signal is coupled through the isolation amplifier to the fade-in circuit. The isolation amplifier output is summed with the vertical accelerometer signal, and the resultant is combined with the integrator amplifier output.

When operating in the collective coupler vertical accelerometer mode, the cable signal is disconnected. In this mode only the vertical accelerometer and radar altitude signals are applied to the output fade-in or fade-out circuit. During collective coupler operation, accidental momentary disengagement of the altitude control is prevented by a diode in the ASE control panel. This diode makes the momentary BAR REL button inoperative.

Yaw Channel

When the ASE is on, the yaw channel stabilizes the heading of the helicopter. The compass system sends a heading signal to a differential synchro in the ASE control panel. (See figure 8-51.) The physical position of the differential synchro is controlled by the ASE control panel YAW TRIM control. The output of the differential synchro is coupled to the yaw synchronizer module. Depending on the mode of the yaw channel, the signal becomes a synchronizing signal or a heading error signal. During the synchronizing mode (manual turns using cyclic stick and rudder pedals), heading signals are nulled out and no error signal is coupled to the yaw ASE amplifier. When the yaw

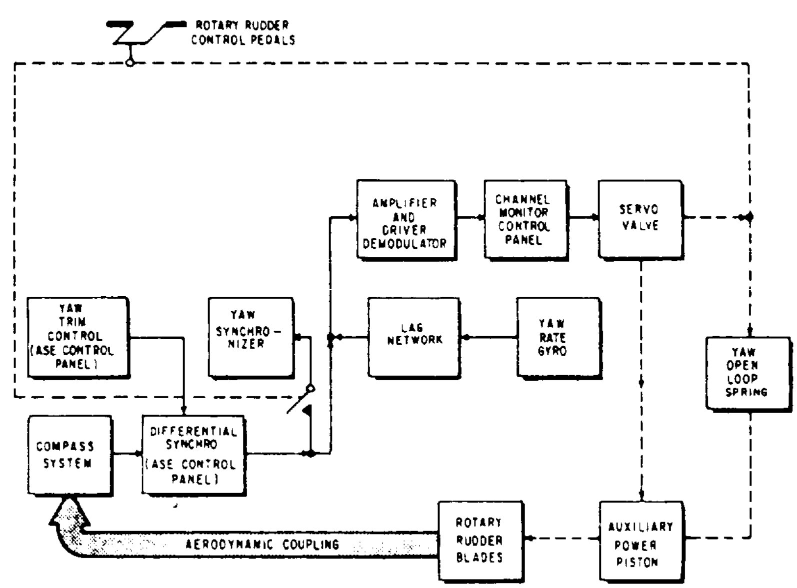


Figure 8-51.-ASE yaw channel.

channel is operating, heading error signals are added to a rate signal developed by the yaw rate gyro. The resultant signal goes through the channel monitor control panel as differential current flow. The differential current flow provides outputs to excite the yaw servo valve. This signal also couples to the hover indicators.

As the servo valve corrects the heading error signal through the auxiliary power piston and rotary rudder blades, the heading error signal diminishes. When the helicopter returns to its reference heading, the compass system output signals return to their original value. As the servo valve corrects large heading error signals, it places the yaw servo system in an open-loop condition. The open-loop condition enables the yaw channel to make larger heading corrections if necessary. The pilot may override the open-loop operation by applying an opposing force on the pedals.

If the pilot uses the pedals to turn manually while ASE is engaged, an artificial force is felt, which reduces the tendency to overcontrol. The yaw rate gyro produces a signal proportional to the turning rate of the helicopter. This rate signal is eventually coupled to the servo valve and places the yaw servo system in an open-loop condition, opposite to the turn direction.

REVIEW SUBSET NUMBER 5

Q1. What subsystems make up the ASE couple system?

Q2. When the ASE HOVER TRIM is engaged, hover trim control is transferred from the pilot to the ______________________

______________________________________.

Q3. How many degrees will one rotation of the ASE YAW TRIM knob turn the helicopter?

Q4. What ASE component allows the sonar operator to maintain the cable angle perpendicular, relative to the horizon?

Q5. What does the ASE hover indicator show during an automatic transition from forward flight to a hover?

Q6. How many stick trim valves does the ASE have?

Q7. What are the four basic channels of operation for the ASE?

APPENDIX I

GLOSSARY

ACCELEROMETER —A device that measures the acceleration to which it is subjected and develops a signal proportional to it.

AGONIC —An imaginary line of the earth's surface passing through points where the magnetic declination is 0O degrees; that is, points where the compass points to true north.

AMBIENT CONDITIONS —Physical conditions of the immediate environment, which may pertain to temperature, humidity, pressure, etc.

AMPERE —The basic unit of electrical current.

AMPERE-TURN —The magnetizing force produced by a current of 1 ampere flowing through a coil of 1 turn.

AMPLIDYNE —A rotary magnetic or dynamoelectric amplifier used in servomechanism and control applications.

AMPLIFICATION—The process of increasing the strength (current, power, or voltage) of a signal.

AMPLIFIER —A device used to increase the signal voltage, current, or power, generally composed of solid-state circuitry called a stage. It may contain several stages in order to obtain a desired gain.

AMPLITUDE —The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

ANALOG COMPUTER —A type of computer that provides a continuous solution to a mathematical problem with continuously changing inputs. Inputs and outputs are represented by physical quantities that may be easily generated or controlled.

APPARENT DRIFT —The effect of the earth's rotation on a gyro that causes the spinning axis to appear to make one complete rotation in 1 day. Also called APPARENT PRECESSION or APPARENT ROTATION.

APPARENT PRECESSION —*See* APPARENT DRIFT.

APPARENT ROTATION —*See* APPARENT DRIFT.

ARC —A flash caused by an electric current ionizing a gas or vapor.

ARMATURE —The rotating part of an electric motor or generator. The moving part of a relay or vibrator.

ATTENUATOR —A network of resistors used to reduce voltage, current, or power delivered to a load.

ATTRACTION —The force that tends to make two objects approach each other. Attraction exists between two unlike magnetic poles (north and south) or between two unlike static charges.

AUTOTRANSFORMER —A transformer in which the primary and secondary are connected together in one winding.

AVB —Avionic bulletin.

AVC —Avionic change.

AXIS —A straight line, either real or imaginary, passing through a body around which the body revolves.

AZIMUTH —Angular measurement in the horizontal plane in a clockwise direction.

BATTERY —Two or more primary or secondary cells connected together electrically. The term does not apply to a single cell. A device for converting chemical energy into electrical energy.

BATTERY CAPACITY —The amount of energy available from a battery. Battery capacity is expressed in ampere-hours.

BIAS —In vacuum tubes, the difference of potential between the control grid and the cathode; in transistors, the difference of potential between the base and emitter and between the base and collector; in magnetic amplifiers, the level of flux density in the core under no-signal conditions.

BLOCK DIAGRAM —A diagram in which the major components of an equipment or a system are represented by squares, rectangles, or other geometric figures, and the normal order of progression of a signal or current flow is represented by lines.

BRIDGE CIRCUIT —The *electrical bridge circuit* is a term referring to any one of a variety of electric circuit networks, one branch of which (the *bridge* proper) connects two points of equal potential; therefore, it carries no current when the circuit is properly adjusted or balanced.

BRUSH —The conducting material, usually a block of carbon, bearing against the commutator or slip rings through which the current flows in or out.

BUS BAR —A primary power distribution point connected to the main power source.

CABLE HARNESS —A group of wires or ribbons of wiring used to interconnect electronic systems and subsystems.

CAGING (GYRO) —The act of holding a gyro so that it cannot precess or change its attitude with respect to the body containing it.

CAPACITOR —Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the *dielectric.*

CAPACITOR-START MOTOR —A type of single-phase, ac induction motor in which a starting winding and a capacitor are placed in series to start the motor. The values of X_C and R are such that the main-winding and starting-winding currents are nearly 90 degrees apart, and the starting torque is produced as in a two-phase motor.

CARDIOPULMONARY RESUSCITATION–Procedure designed to restore breathing after cardiac arrest. Includes clearing air passages to lungs and heart massage.

CELL —A single unit that transforms chemical energy into electrical energy. Batteries are made up of cells.

CHOKE COIL —A coil of low ohmic resistance and high impedance to alternating current.

CIRCUIT —The complete path of an electric current.

CIRCUIT BREAKER —An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULAR MIL —An area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross section of wires.

COAXIAL CABLE —A transmission line consisting of two conductors concentric with and insulated from each other.

COMMUTATION —The act of a commutator in converting generator output from an ac voltage to a dc voltage.

COMMUTATOR —The copper segments on the armature of a motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes. A mechanical device that reverses armature connections in motors and generators at the proper instant so that current continues to flow in only one direction. In effect, the commutator changes ac to dc.

COMPARATOR —A circuit that compares two signals or values, and indicates agreement or variance between them.

COMPENSATING WINDINGS —Windings embedded in slots in pole pieces, connected in series with the armature, whose magnetic field opposes the armature field and cancels armature reaction.

COMPOUND-WOUND MOTORS AND GENERATORS —Machines that have a series field in addition to a shunt field. Such machines have characteristics of both series- and shunt-wound machines.

CONDUCTANCE —The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in mhos.

CONDUCTIVITY —The ease with which a substance transmits electricity.

CONDUCTOR —Any material suitable for carrying electric current.

CORE —A magnetic material that affords an easy path for magnetic flux lines in a coil.

COUNTER EMF —Counter electromotive force; an EMF induced in a coil or armature that opposes the applied voltage.

COUNTING CIRCUIT —A circuit that receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

COVALENT BOND —A type of linkage between atoms in which the atoms share valence electrons.

CPR —*See* **CARDIOPULMONARY RESUSCITATION.**

CURRENT —The movement of electrons past a reference point. The passage of electrons through a conductor. Measured in amperes.

CURRENT LIMITER —A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE —One complete positive and one complete negative alternation of a current or voltage.

D'ARSONVAL METER MOVEMENT —The permanent-magnet moving-coil movement used in most meters.

DEGREES OF FREEDOM (GYRO) —A term applied to gyros to describe the number of variable angles required to specify the position of the rotor spin axis relative to the case.

DELTA —A three-phase connection in which windings are connected end to end, forming a closed loop that resembles the Greek letter delta. A separate phase wire is then connected to each of the three junctions.

DEMODULATOR —A circuit used in servo systems to convert an ac signal to a dc signal, The magnitude of the dc output is determined by the magnitude of the ac input signal, and its polarity is determined by whether the ac input signal is in or out of phase with the ac reference voltage.

DIELECTRIC —An insulator; a term that refers to the insulating material between the plates of a capacitor.

DIFFERENTIAL —A mechanical computing device used to add or subtract two quantities.

DIGITAL COMPUTER —A type of computer in which quantities are represented in numerical form. It is generally made to solve complex mathematical problems by use of the fundamental processes of addition, subtraction, multiplication, and division. Its accuracy is limited only by the number of significant figures provided.

DIODE —A material of either germanium or silicon that is manufactured to allow current to flow in only one direction. Diodes are used as rectifiers and detectors.

DIRECT CURRENT —An electric current that flows in one direction only.

DISCRIMINATOR —A dual-input circuit in which the output is dependent on the variation of one input from the other input or from an applied standard.

DOPPLER EFFECT —An apparent change in the frequency of a sound wave or electromagnetic wave reaching a receiver when there is relative motion between the source and the receiver.

EDDY CURRENT —Induced circulating currents in a conducting material that are caused by a varying magnetic field.

EFFICIENCY —The ratio of output power to input power, generally expressed as a percentage.

ELECTROLYSIS —A type of corrosion (chemical, decomposition) caused by current flow resulting from contact of dissimilar metals.

ELECTROLYTE —A solution of a substance that is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET —A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMOTIVE FORCE (EMF) —The force that produces an electric current in a circuit.

ELECTRON —A negatively charged particle of matter.

ELECTRON SHELL —A group of electrons that have a common energy level that forms part of the outer structure (shell) of an atom.

ENERGY —The ability or capacity to do work.

EQUIVALENT CIRCUIT —A diagrammatic arrangement of component parts representing, in simplified form, the effects of a more complicated circuit to permit easier analysis.

ERECTING (A GYRO) —The positioning of a gyro into a desired position and the maintaining of that position.

ERROR SIGNAL —(1) In servo systems, the signal whose amplitude and polarity or phase are used to correct the alignment between the controlling and the controlled elements. (2) The name given to the electrical output of a control transformer.

E-TRANSFORMER —A magnetic device with an E configuration, used as an error detector.

FARAD —The unit of capacitance.

FEEDBACK —A transfer of energy from the output circuit of a device back to its input.

FIELD —The space containing electric or magnetic lines of force.

FIELD WINDING —The coil used to provide the magnetizing force in motors and generators.

FLUX —(1) In electrical or electromagnetic devices, a general term used to designate collectively all the electric or magnetic lines of force in a region, (2) A solution that removes surface oxides from metals being soldered.

FLUX DENSITY —The number of magnetic lines of force passing through a given area.

FLUX FIELD —All electric or magnetic lines of force in a given region.

FREE ELECTRONS —Electrons that are loosely held; consequently, they tend to move at random among the atoms of the material.

FREE GYRO —A gyro so gimbaled that it assumes and maintains any attitude in space. The free gyro has two degrees of freedom; torque cannot be applied to the rotor of a truly free gyro.

FREQUENCY —The number of complete cycles per second existing in any form of wave motion, such as the number of cycles per second of an alternating current.

FULL-WAVE RECTIFIER CIRCUIT —A circuit that uses both the positive and the negative alternations of an alternating current to produce a direct current.

FUSE —A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAIN —The ratio of the output power, voltage, or current to the input power, voltage, or current, respectively.

GALVANOMETER —An instrument used to measure small dc currents.

GENERATOR —A machine that converts mechanical energy into electrical energy.

GIMBAL —A frame in which the gyro wheel spins, and that allows the gyro wheel to have certain freedom of movement. It permits the gyro motor to incline freely and retain that position when the support is tipped or repositioned.

GROUND —A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential.

GROUND POTENTIAL —Zero potential with respect to the ground or earth.

GYROSCOPE —A wheel or disk so mounted as to spin rapidly about one axis and be free to move about one or both of the two axes mutually perpendicular to the axis of spin.

HALF-WAVE RECTIFIER —A rectifier using only one-half of each cycle to change ac to pulsating dc.

HEAT SHUNT —A device (preferably a clip-on type) used to absorb heat and protect heat-sensitive components during soldering.

HERO —Hazardous electromagnetic radiation to ordnance.

HERTZ —A unit of frequency equal to one cycle per second.

HMI —Handbook Maintenance Instructions.

HORSEPOWER —The English unit of power, equal to work done at the rate of 550 foot-pounds per second. Equal to 746 watts of electrical power.

HYSTERESIS —A lagging of the magnetic flux in a magnetic material behind the magnetizing force that is producing it.

Hz —*See* **HERTZ.**

IMPEDANCE —The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

INDUCED CURRENT —Current caused by the relative motion between a conductor and a magnetic field.

INDUCTANCE —The property of a circuit that tends to oppose a change in the existing current.

INDUCTION —The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

INDUCTION MOTOR —A simple, rugged, ac motor with desirable characteristics. The rotor is energized by transformer action (induction) from the stator. Induction motors are used more than any other type.

INDUCTIVE REACTANCE —The opposition to the flow of alternating or pulsating current caused by the inductance of a circuit. It is measured in ohms.

INERTIA —The physical tendency of a body in motion to remain in motion and a body at rest to remain at rest unless acted upon by an outside force (Newton's first law of motion).

lNFINITE —(1) Extending indefinitely, endless. (2) Boundless, having no limits, (3) An incalculable number.

IN PHASE —This term is applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

lNSULATION —A material used to prevent the leakage of electricity from a conductor and to provide mechanical spacing or support as protection against accidental contact with the conductor.

INTEGRATING CIRCUIT —A circuit whose output voltage is proportional to the product of the instantaneous applied input voltages and their durations.

INTEGRATOR —A computing device used for summing up an infinite number of minute quantities.

INVERSELY —Inverted or reversed in position or relationship.

ISOGONIC LINE —An imaginary line drawn through points on the earth's surface where the magnetic variation is equal.

JOULE. —A unit of energy or work. A joule of energy is liberated by 1 ampere flowing for 1 second through a resistance of 1 ohm.

JUNCTION —(1) The connection between two or more conductors, (2) The contact between two dissimilar metals or materials, as in a thermocouple.

JUNCTION BOX —A box with a cover that serves the purpose of joining different runs of wire or cable and provides space for the connection and branching of the enclosed conductors.

KINETIC ENERGY —Energy that a mass possesses by virtue of its motion.

KNEE (OF A CURVE) —An abrupt change in direction between two fairly straight segments of a curve.

LAG —The amount one wave is behind another in time; expressed in electrical degrees.

LAMINATED CORE —A core built up from thin sheets of metal and used in transformers and relays.

LEAD —The opposite of LAG. Also, a wire or connection.

LEAD-ACID CELL —A cell in an ordinary storage battery in which electrodes are grids of lead containing an active material consisting of certain lead oxides that change in composition during charging and discharging. The electrodes or plates are immersed in an electrolyte of diluted sulfuric acid.

LINE OF FORCE —A line in an electric or magnetic field that shows the direction of the force.

LOAD —The power that is being delivered by any power-producing device. The equipment that uses the power from the power-producing device.

LOGIC CIRCUITS —Digital computer circuits used to store information signals and/or to perform logical operations on those signals.

MAGNETIC AMPLIFIER —A saturable reactor-type device that is used in a circuit to amplify or control.

MAGNETIC CIRCUIT —The complete path of magnetic lines of force.

MAGNETIC FIELD —The space in which a magnetic force exists.

MAGNETIC FLUX —The total number of lines of force issuing from a pole of a magnet.

MAGNETIZE —To convert a material into a magnet by causing the molecules to rearrange.

MAGNETO —A generator that produces alternating current and has a permanent magnet as its field.

MATTER —Any physical entity that possesses mass.

METEOROLOGY AUTOMATED SYSTEM FOR UNIFORM RECALL AND REPORTING (MEASURE) —The Navy data processing system designed to provide a standardized system for the recall, scheduling, and documenting of test equipment into calibration facilities.

MEGGER. —A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operated dc generator used as an ohmmeter.

MEGOHM —A million ohms.

METER —A device used to measure a specific quantity, such as current, voltage, or frequency.

METER MOVEMENT —The part of the meter that moves to indicate some value.

METER SHUNT —A resistor placed in parallel with the meter terminals; used to provide increased range capability.

MICRO —A prefix meaning one-millionth.

MICROFICHE —A film negative card (fiche) developed for many purposes throughout the Navy where microfilming is used to reduce amounts of paper documents.

MICROMETER —A unit of length equal to 10^{-6} meter. Formerly a micron.

MICRON —*See* MICROMETER.

MIL —The diameter of a conductor equal to 1/1000 (.001) inch.

MIL-FOOT —A unit of measurement for conductors (diameter of 1 mil, 1 foot in length).

MILITARY SPECIFICATIONS (MILSPEC) — Technical requirements and standards adopted by the Department of Defense (DoD) that must be met by vendors selling materials to DoD.

MILITARY STANDARDS (MILSTD) — Standards of performance for components or equipment that must be met to be acceptable for military systems.

MILLI —A prefix meaning one-thousandth.

MILLIAMMETER —An ammeter that measures current in thousandths of an ampere.

MOTOR —A machine that converts electrical energy to mechanical energy. It is activated by ac or dc voltage, depending on the design.

MOTOR-GENERATOR —A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

MULTICONDUCTOR —More than one conductor, as in a cable.

MULTIMETER —A single meter combining the functions of an ammeter, a voltmeter, and an ohmmeter.

MULTIPHASE —*See* **POLYPHASE.**

MUTUAL INDUCTANCE —A circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of the other.

NAMP —The Naval Aviation Maintenance Program.

NANOMETER —A unit of length equal to 10^{-9} meter. Formerly millimicron.

NEGATIVE CHARGE —The electrical charge carried by a body that has an excess of electrons.

NEGATIVE FEEDBACK —Feedback in which the feedback signal is out of phase with the input signal.

NEGATIVE TEMPERATURE COEFFICIENT —A characteristic of a semiconductor material, such as silver sulfide, in which resistance to electrical current flow decreases as temperature increases.

NEUTRON —A particle having the weight of a proton but carrying no electric charge. It is located in the nucleus of an atom.

NOISE —Any undesired disturbance within the useful frequency band; also, that part of the modulation of a received signal (or an electrical or electronic signal within a circuit) representing an undesirable effect of transient conditions.

NUCLEUS —The central part of an atom that is mainly made up of protons and neutrons. It is the part of the atom that has the most mass.

NULL —A point or position where a variable-strength signal is at its minimum value (or zero).

OHM —The unit of electrical resistance. That value of electrical resistance through which a constant potential difference of 1 volt across the resistance will maintain a current flow of 1 ampere through the resistance.

OHM'S LAW —The current in an electrical circuit is directly proportional to the electromotive force in the circuit. The most common form of the law is $E = IR$, where E is the electromotive force or voltage across the circuit, I is the current flowing in the circuit, and R is the resistance of the circuit.

OVERLOAD —A load greater than the rated load of an electrical device.

PARAMETERS —In electronics, the design or operating characteristics of a circuit or device.

PERMALLOY —An alloy of nickel and iron having an abnormally high magnetic permeability.

PERMEABILITY —A measure of the ease with which magnetic lines of force can flow through a material as compared to air.

PHASE —The angular relationship between two alternating currents or voltages when the voltage or current is plotted as a function of time. When the two are in phase, the angle is zero; both reach their peak simultaneously. When out of phase, one will lead or lag the other; that is, at the instant when one is at its peak. The other phase will not be at peak value and (depending on the phase angle) may differ in polarity as well as magnitude.

PHASE DIFFERENCE —The time in electrical degree by which one wave leads or lags another.

PHOTON (hv) —An elementary quantity of radiant energy (quantium) whose value is equal to the product of Plank's constant and the frequency of the electromagnetic radiation.

PICKOFF —In gyros, a sensing device that measures the angle of the spin axis with respect to its reference and provides an error signal that indicates the direction and (in most cases) the magnitude of the displacement,

POLARITY —The character of having magnetic poles, or electric charges.

POLYPHASE —A circuit that uses more than one phase of alternating current.

POSITIVE CHARGE —The electrical charge carried by a body that has become deficient in electrons.

POSITIVE FEEDBACK —Feedback in which the feedback signal is in phase with the input signal.

POSITIVE TEMPERATURE COEFFICIENT —The characteristic of a conductor in which the resistance increases as temperature increases.

POTENTIAL —The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIOMETER —A variable voltage divider; a resistor that has a variable contact arm so that any portion of the potential applied between its ends may be selected.

POWER —The rate of doing work or the rate of expending energy. The unit of electrical power is the watt.

POWER FACTOR —The ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

POWER SUPPLY —A unit that supplies electrical power to another unit. It changes ac to dc and maintains a constant voltage output within limits.

PRECESSION —The reaction of a gyro to an applied torque, which causes the gyro to tilt itself at right angles to the direction of the applied torque in such a manner that the direction of spin of the gyro rotor will be in the same direction as the applied torque.

PRIMARY WINDING —The winding of a transformer connected to the electrical source.

PRIME MOVER —The source of the turning force applied to the rotor of a generator, This may be an electric motor, a gasoline engine, a steam turbine, and so forth.

PROTON —A positively charged particle in the nucleus of an atom.

RADAR —An acronym for radio detecting and ranging.

RADAR ALTIMETER —Airborne radar that measures the distance of the aircraft above the ground.

RADIAN —In a circle, the angle included within an arc equal to the radius of the circle. A complete circle contains 2 radians. One radian equals 57.3 degrees, and 1 degree equals 0.01745 radian.

RATE GYRO —A gyro with one degree of freedom that has an elastic restraint, with or without a damper, and whose output will be proportional to the rate of the applied torque.

RATIO —The value obtained by dividing one number by another, indicating their relative proportions.

REACTANCE —The opposition offered to the flow of an alternating current by the inductance, capacitance, or both, in any circuit.

RECTIFIERS —Devices used to change alternating current to unidirectional current. These may be vacuum tubes, semiconductors, such as germanium and silicon, and dry-disk rectifiers, such as selenium and copper oxide.

RELUCTANCE —A measure of the opposition that a material offers to magnetic lines of force.

RESISTANCE —The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RETENTIVITY —The measure of the ability of a material to hold its magnetism.

RHEOSTAT —A variable resistor.

RIGIDITY —In gyros, the characteristics of a spinning body that causes it to oppose all attempts to tilt it away from the axis in which it is spinning.

ROTATING FIELD —The magnetic field in a multiphase ac motor that is the result of field windings being energized by out-of-phase currents. In effect, the magnetic field is made to rotate electrically rather than mechanically.

ROTOR —(1) The revolving part of a rotating electrical machine. The rotor may be either the field or the armature, depending on the design of the machine. (2) The rotating member of a synchro that consists of one or more coils of wire wound on a laminated core. Depending on the type of synchro, the rotor functions similarly to the primary or secondary winding of a transformer.

SATURABLE REACTOR —A control device that uses a small dc current to control a large ac current by controlling core flux density.

SATURATION —The condition existing in any circuit when an increase in the driving signal produces no further change in the resultant effect.

SCHEMATIC —A diagram that shows, by means of graphic symbols, the electrical connections and functions of a specific circuit arrangement.

SECONDARY —The output coil of a transformer.

SELF-INDUCTION —The process by which a circuit induces an EMF into itself by its own magnetic field.

SERIES CIRCUIT —An arrangement where electrical devices are connected so that the total current must flow through all the devices; electrons have one path to travel from the negative terminal to the positive terminal.

SERIES-WOUND —A motor or generator in which the armature is wired in series with the field winding.

SERVO —A device used to convert a small movement into one of greater movement or force.

SERVOMECHANISM —A closed-loop system that produces a force to position an object according to the information that originates at the input.

SERVOMOTOR —An ac or dc motor used in servo systems to move a load to a desired position or at a desired speed. The ac motor is usually used to drive light loads at a constant speed, while the dc motor is used to drive heavy loads at varying speeds.

SERVO SYSTEM —An automatic feedback control system that compares a required condition (desired value, position, etc.) with an actual condition and uses the difference to drive a control device to achieve the required condition,

SHIELDING —(1) A metallic covering used to prevent magnetic or electromagnetic fields from affecting an object. (2) Technique designed to minimize internal and external interference.

SHUNT —A resistive device placed in parallel with another component. Appreciable current may flow through it, and an appreciable voltage may exist across it.

SLIP RINGS —Contacts that are mounted on the shaft of a motor or generator to which the rotor windings are connected and against which the brushes ride. Devices for making electric connections between stationary and rotating contacts.

SOLENOID —An electromagnetic coil that contains a movable plunger.

SOLID-STATE DEVICE —An electronic device that operates by the movement of electrons within a solid piece of semiconductor material.

SOURCE —(1) The object that produces the waves or disturbance. (2) The name given to the end of a two-wire transmission line that is connected to a source. (3) The device that furnishes the electrical energy used by a load.

SPECIFIC GRAVITY —The ratio between the density of a substance and that of pure water at a given temperature.

STATOR —(l) The stationary part of a rotating electrical machine. The stator may be either the field or the armature, depending on the design of the machine. (2) The stationary member of a synchro that consists of a cylindrical structure of slotted laminations on which three Y-connected coils are wound with their axes 120 degrees apart. Depending on the type of synchro, the stator's functions are similar to the primary or secondary windings of a transformer.

STRANDED CONDUCTOR —A conductor composed of a group of wires, The wires in a stranded conductor are usually twisted together and not insulated from each other.

STRANDS —Fine metallic filaments twisted together to form a single wire.

SUBASSEMBLY —Consists of two or more parts that form a portion of an assembly or a unit.

SUPPORT EQUIPMENT (SE) —All the equipment on the ground or ship needed to support aircraft in a state of readiness for flight.

SYNCHRO —A small motor-like analog device that operates like a variable transformer and is used primarily for the rapid and accurate transmission of data among equipments and stations.

SYNCHRO SYSTEM —An electrical system that gives remote indications or control by means of self-synchronizing motors.

TACHOMETER —An instrument for indicating revolutions per minute.

TEMPERATURE COEFFICIENT —The amount of change of resistance in a material per unit change in temperature.

TERTIARY WINDING —A third winding on a transformer or magnetic amplifier that is used as a second control winding.

THERMISTOR —A resistor that is used to compensate for temperature variations in a circuit. *See also* BOLOMETER.

THERMOCOUPLE —A junction of two dissimilar metals that produces a voltage when heated.

TINNING —The process of applying a thin coat of solder to materials prior to their being soldered; for example, application of a light coat of solder to the filaments of a conductor to hold the filaments in place prior to soldering of the conductor.

TORQUE —The turning effort or twist that a shaft sustains when transmitting power. A force tending to cause rotational motion; the product of the force applied times the distance from the force to the axis of rotation.

TOTAL RESISTANCE (RT)—The equivalent resistance of an entire circuit, For a series circuit: $R_T = R_1 + R_2 + R_3 + \ldots R_N$. For parallel circuits:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \frac{1}{R_n}$$

TRANSFORMER —A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

TRANSFORMER EFFICIENCY —The ratio of output power to input powver, generally expressed as a percentage.

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100.$$

TRANSFORMER, STEP-DOWN —A transformer constructed so that the number of turns in the secondary winding is less than the number of turns in the primary winding. This construction will provide less voltage in the secondary circuit than in the primary circuit.

TRANSFORMER, STEP-UP —A transformer constructed so that the number of turns in the secondary winding is more than the number of turns in the primary winding. This construction will provide more voltage in the secondary circuit than in the primary circuit.

TRUE BEARING —Angle between a target and true north measured clockwise in the horizontal plane.

TRUE NORTH —Geographic north.

TUMBLE (GYRO) —To subject a gyro to a torque so that it presents a precession violent enough to cause the gyro rotor to spin end over end.

TURNS RATIO -The ratio of the number of turns in the primary winding to the number of turns in the secondary winding of a transformer.

VALE NCE —The measure of the extent to which an atom is able to combine directly with other atoms. It generally depends on the number and arrangement of the electrons in the outermost shell of the atom.

VALENCE SHELL —The electrons that form the outermost shell of an atom.

VECTOR —A line used to represent both direction and magnitude.

VOLT —The unit of electromotive force or electrical pressure. One volt is the pressure required to send 1 ampere of current through a resistance of 1 ohm.

VOLTAGE —(1) The term used to signify electrical pressure. Voltage is a force that causes current to flow through an electrical conductor. (2) The voltage of a circuit is the greatest effective difference of potential between any two conductors of the circuit.

VOLTAGE DIVIDER —A series network in which desired portions of the source voltage may be tapped off for use in the circuit.

WATT —The unit of electrical power.

WHEATSTONE BRIDGE —An ac bridge circuit used to measure unknown values of resistance, inductance, or capacitance.

WIRING DIAGRAM —A diagram that shows the connections of an equipment or its component devices or parts. It may cover internal or external connections, or both, and contains such detail as is needed to make or trace connections that are involved.

WORK —The product of force and motion.

WYE (Y) —A three-phase connection in which one end of each phase winding is connected to a common ground.

X-AXIS —In a gyro, the spin axis of the gyro.

Y-AXIS —In a gyro, an axis through the center of gravity and perpendicular to the spin axis.

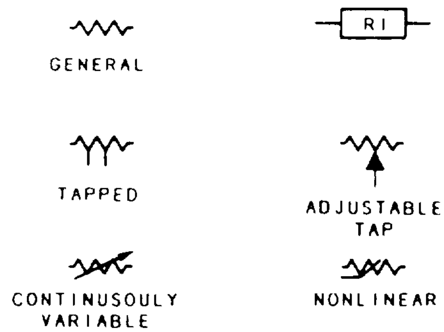
Z-AXIS -In a gyro, an axis through the center of gravity and mutually perpendicular to both the X (spin) and Y axes.

ZENER DIODE —A PN-junction, diode designed to operate in the reverse-bias breakdown region.

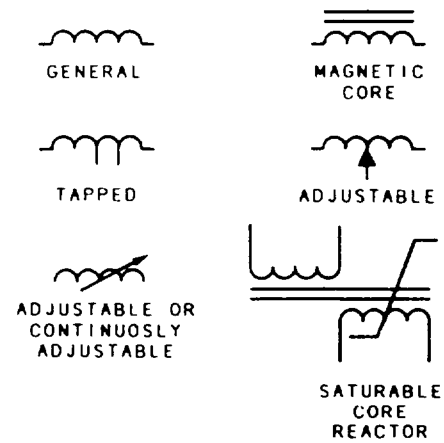
APPENDIX II

SYMBOLS

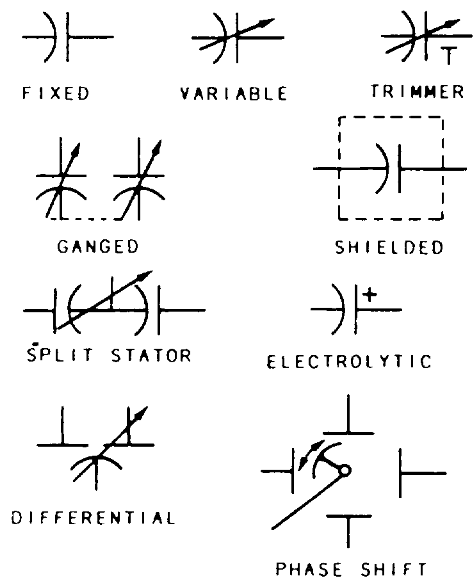
RESISTORS



INDUCTIVE COMPONENTS

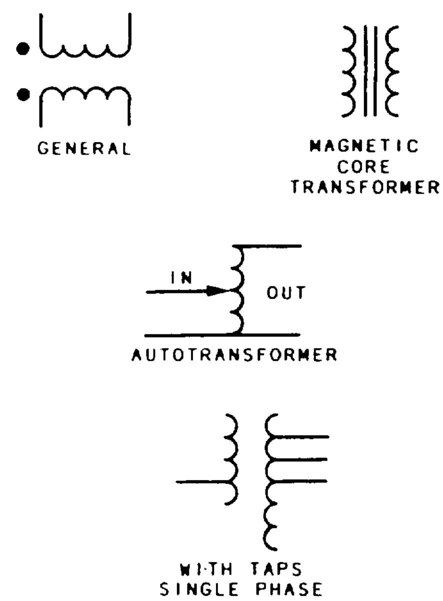


CAPACITORS



NOTE: WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT REPRESENTS THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.

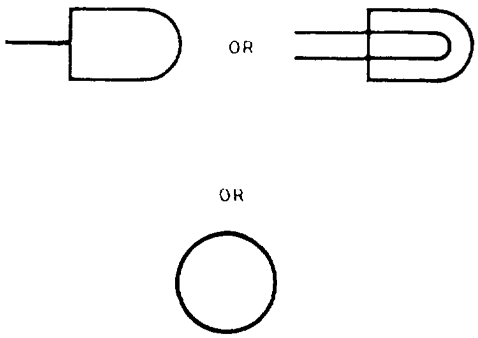
TRANSFORMERS



NOTE: A DOT, REPRESENTING INSTANTANEOUS POLARITY, MAY BE PLACED NEAR ONE END OF EACH COIL OR WINDING SYMBOL.

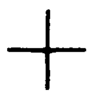
NOTE: FOR FURTHER INFORMATION CONCERNING SYMBOLS, REFER TO IEEE STANDARDS AND AMERICAN NATIONAL STANDARD GRAPHIC SYMBOLS FOR ELECTRICAL AND ELECTRONICS DIAGRAMS, ANSI & 32.2/IEEE NO. 315, WHICH HAS BEEN ADOPTED FOR MANDATORY USE BY THE DEPARTMENT OF DEFENSE.

INDICATOR LAMPS

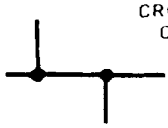


MAY HAVE APPLICABLE IDENTIFICATION FOR CIRCUIT USAGE OR COLOR.

PATH, TRANSMISSION

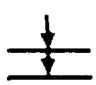


CROSSING NOT CONNECTED

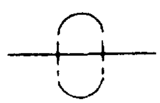


JUNCTION CONNECTED

SPLICE



TWISTER PAIR

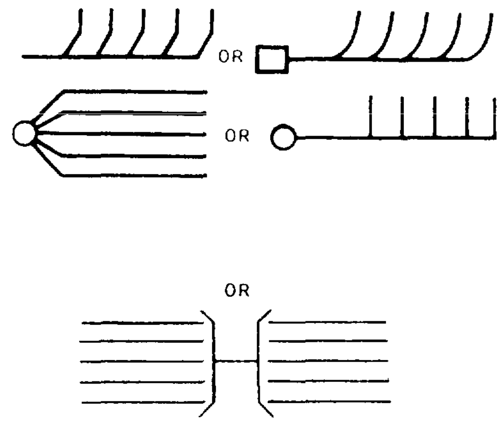


SHIELDED

AIR OR SPACE PATH

COAXIAL

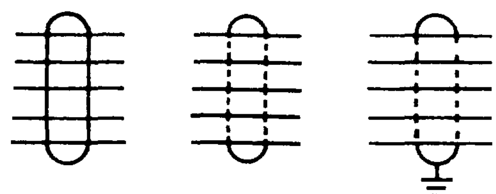
GROUPING OF WIRES IN BUNDLES



GROUPING LEADS.--(BEND IN LINE INDICATES WHERE OTHER END OF LEAD CAN BE FOUND.)

GROUPING OF WIRES IN CABLES

CABLES

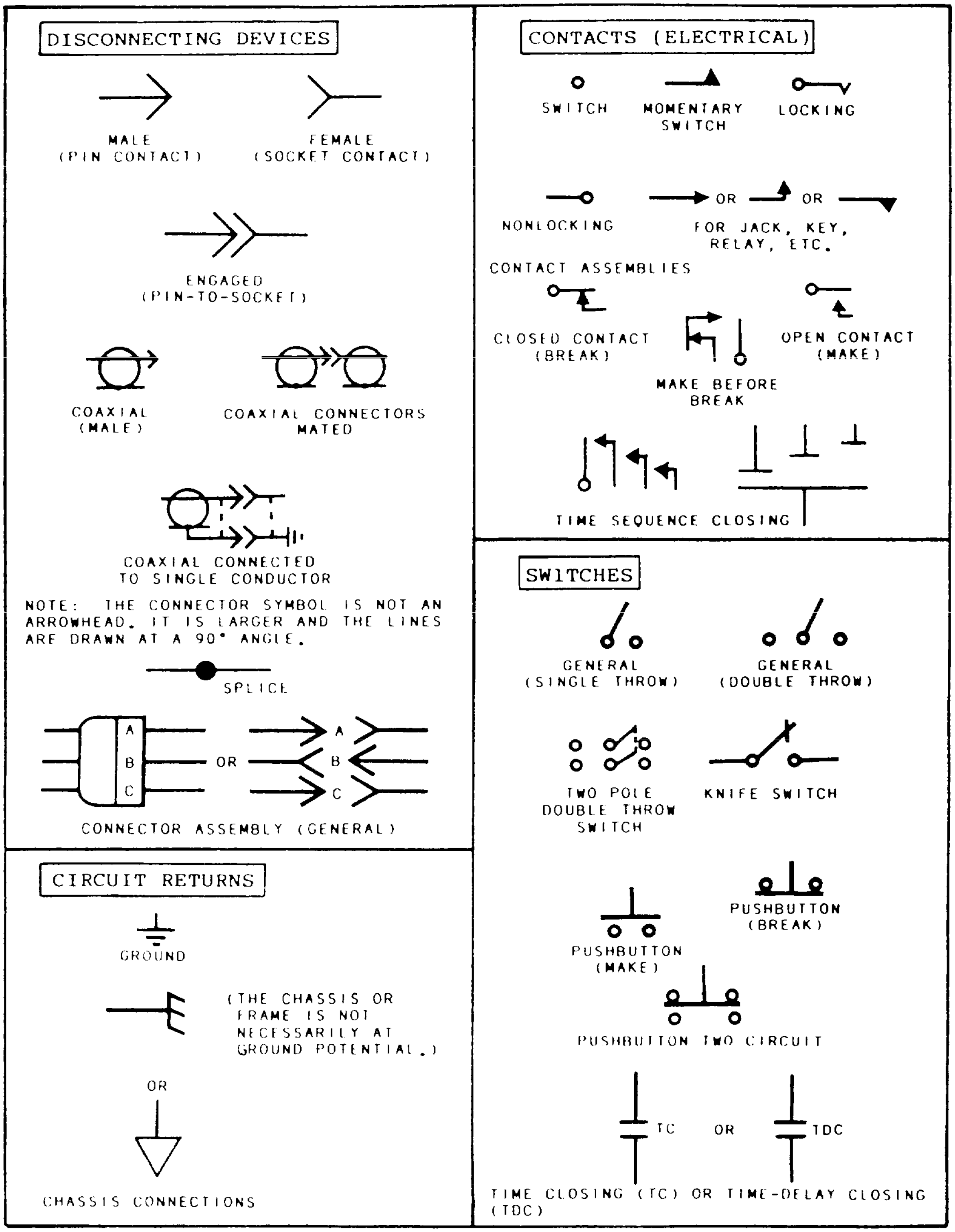


FIVE-CONDUCTOR CABLE

SHIELDED FIVE-CONDUCTOR CABLE

GROUNDED SHIELD

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY


DISCONNECTING DEVICES
MALE
(PIN CONTACT)
FEMALE
(SOCKET CONTACT)
ENGAGED
(PIN-TO-SOCKET)
COAXIAL
(MALE)
COAXIAL CONNECTORS
MATED
COAXIAL CONNECTED
TO SINGLE CONDUCTOR
NOTE: THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.
SPLICE
A
B
C
OR
A
B
C
CONNECTOR ASSEMBLY (GENERAL)
CIRCUIT RETURNS
GROUND
(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)
OR
CHASSIS CONNECTIONS
CONTACTS (ELECTRICAL)
SWITCH
MOMENTARY
SWITCH
LOCKING
NONLOCKING
OR
OR
FOR JACK, KEY,
RELAY, ETC.
CONTACT ASSEMBLIES
CLOSED CONTACT
(BREAK)
OPEN CONTACT
(MAKE)
MAKE BEFORE
BREAK
TIME SEQUENCE CLOSING
SWITCHES
GENERAL
(SINGLE THROW)
GENERAL
(DOUBLE THROW)
TWO POLE
DOUBLE THROW
SWITCH
KNIFE SWITCH
PUSHBUTTON
(BREAK)
PUSHBUTTON
(MAKE)
PUSHBUTTON TWO CIRCUIT
TC
OR
TDC
TIME CLOSING (TC) OR TIME-DELAY CLOSING (TDC)

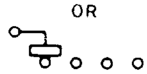
SELECTOR OR MULTIPOSITION SWITCHES

OR

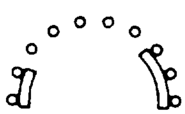
BREAK-BEFORE-MAKE, NONSHORTING (NONBRIDGING), DURING CONTACT TRANSFER

NOTE: THE POSITION IN WHICH THE SWITCH IS SHOWN MAY BE INDICATED BY A NOTE OR DESIGNATION OF SWITCH POSITION.

OR

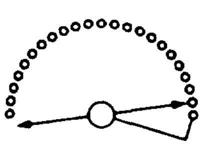


MAKE-BEFORE-BREAK, SHORTING (BRIDGING) DURING CONTACT TRANSFER

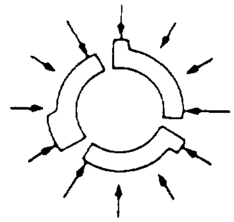


OR

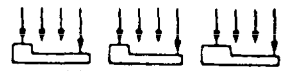
SEGMENTAL CONTACT



22-POINT SELECTOR SWITCH



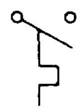
OR



ROTARY (SECTION-, DECK-, OR WAFER-TYPE) SWITCH.

VIEWED FROM END OPPOSITE CONTROL KNOB OR ACTUATOR UNLESS OTHERWISE INDICATED. FOR MORE THAN ONE SECTION, THE FIRST SECTION IS THE ONE NEAREST CONTROL KNOB OR ACTUATOR. WHEN CONTACTS ARE ON BOTH SIDES, FRONT CONTACTS ARE NEAREST CONTROL KNOB.

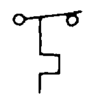
TEMPERATURE-ACTUATED SWITCHES



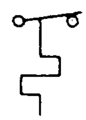
OR

THERMOSTAT

CLOSES ON RISING TEMPERATURE

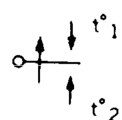


OR



THERMOSTAT

OPENS ON RISING TEMPERATURE



TRANSFER, WITH INTENDED CENTRAL-OFF (NEUTRAL) POSITION

NOTE: THE T° SYMBOL WILL BE SHOWN OR BE REPLACED BY DATA GIVING THE NOMINAL OR SPECIFIC OPERATING TEMPERATURE OF THE DEVICE.

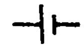
NOTE: IF CLARIFICATION OF DIRECTION OF CONTACT OPERATION IS NEEDED, A DIRECTIONAL ARROW MAY BE ADDED. THE ARROWHEAD WILL POINT IN THE DIRECTION OF RAISING TEMPERATURE OPERATION. A DIRECTIONAL ARROW WILL ALWAYS BE SHOWN FOR CENTRAL-OFF (NEUTRAL) POSITION DEVICES.

TEMPERATURE-ACTUATED SWITCHES CONT.

OR

FLASHER
SELF-INTERRUPTING
SWITCH

BATTERIES



ONE CELL

MULTICELL

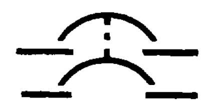
TAPPED
MULTICELL

(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

FUSE

PUSH PULL OR PUSH



GANGED

CIRCUIT BREAKERS

LIMIT SWITCHES, DIRECTLY ACTUATED, SPRING RETURN

NORMALLY OPEN

NORMALLY OPEN-HELD CLOSED

NORMALLY CLOSED

NORMALLY CLOSED-HELD OPEN

THERMAL ELEMENTS

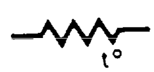
OR

THERMAL RELAY WITH
NORMALLY CLOSED
CONTACT.

OR

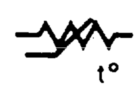
OR

FLASHER; THERMAL CUTOUT

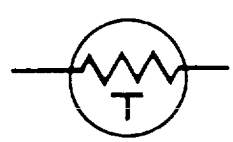


GENERAL

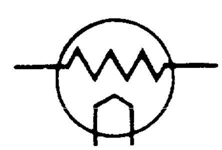
LINEAIR



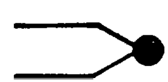
NONLINEAR



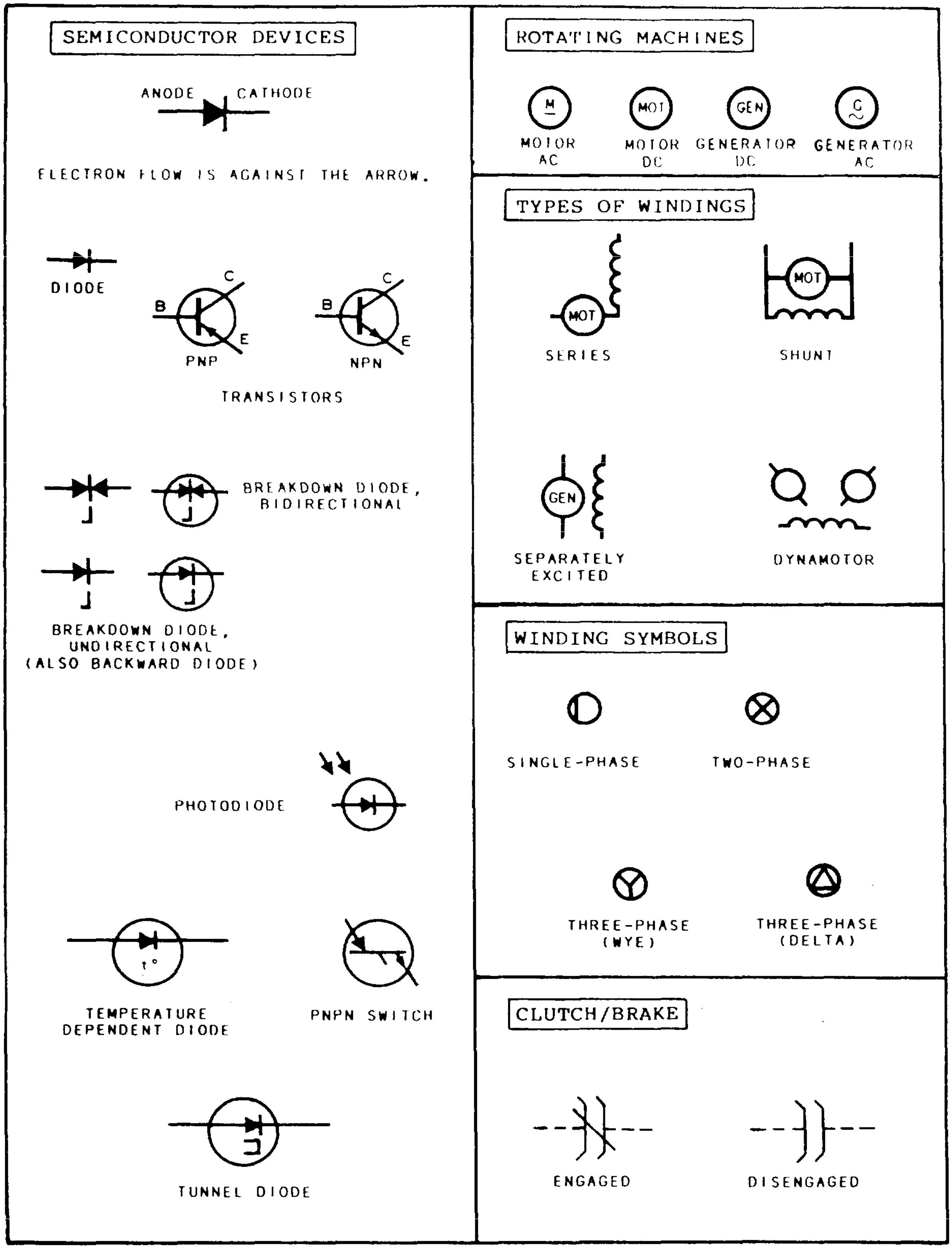
THERMISTOR



WITH INTEGRAL
HEATING ELEMENT



TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)

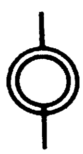

SEMICONDUCTOR DEVICES
ANODE
CATHODE
ELECTRON FLOW IS AGAINST THE ARROW.
DIODE
C
B
E
PNP
NPN
TRANSISTORS
BREAKDOWN DIODE, BIDIRECTIONAL
BREAKDOWN DIODE, UNDIRECTIONAL (ALSO BACKWARD DIODE)
PHOTODIODE
t°
TEMPERATURE DEPENDENT DIODE
PNPN SWITCH
TUNNEL DIODE
ROTATING MACHINES
M
MOT
GEN
G
MOTOR AC
MOTOR DC
GENERATOR DC
GENERATOR AC
TYPES OF WINDINGS
SERIES
SHUNT
SEPARATELY EXCITED
DYNAMOTOR
WINDING SYMBOLS
SINGLE-PHASE
TWO-PHASE
THREE-PHASE (WYE)
THREE-PHASE (DELTA)
CLUTCH/BRAKE
ENGAGED
DISENGAGED

METERS

A	AMMETER
AH	AMPERE-HOUR METER
CRO	OSCILLOSCOPE
DB	DB (DECIBEL) METER AUDIO LEVEL/METER
DBM	DBM (DECIBELS REFERRED TO 1 MILLIWATT) METER
F	FREQUENCY METER
μA OR UA	MICROAMMETER
MA	MILLIAMMETER
OHM	OHMMETER
PF	POWER FACTOR METER
PH	PHASEMETER
PI	POSITION INDICATOR
REC	RECORDING METER
SY	SYNCHROSCOPE
t°	TEMPERATURE METER
TT	TORAL TIME METER ELAPSED TIME METER
C	VOLTMETER
VA	VOLT-AMMETER
VAR	VARMETER
W	WATTMETER
WH	WATTHOUR METER

SYNCHROS

GENERAL

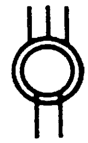


CDX	CONTROL-DIFFERENTIAL TRANSMITTER
CT	CONTROL TRANSFORMER
CX	CONTROL TRANSMITTER
TDR	TORQUE-DIFFERENTIAL RECEIVER
TDX	TORQUE-DIFFERENTIAL TRANSMITTER
TR	TORQUE RECEIVER
TX	TORQUE TRANSMITTER
RS	RESOLVER

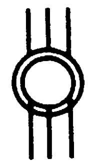
(IF THE OUTER WINDING ID ROTATABLE IN BEARINGS, THE SUFFIX B SHALL BE ADDED TO THE ABOVE LETTER COMBINATIONS.)

(COMPLETE SYMBOLS MAY ALSO BE FORMED BY USING A WINDING SYMBOL.)

SYNCHROS CONT.

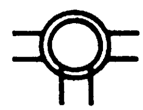


TRANSMITTER RECEIVER, OR CONTROL TRANSFORMER

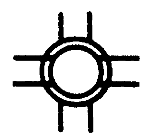


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

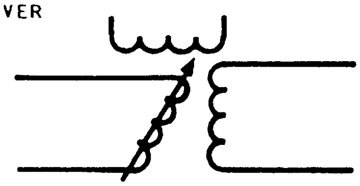


SINGLY-WOUND ROTOR

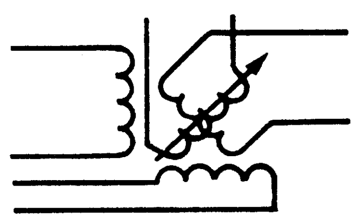


DOUBLY-WOUND ROTOR

RESOLVER

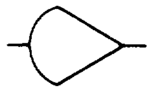


SINGLY-WOUND ROTOR

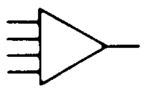


DOUBLY-WOUND ROTOR

AMPLIFIERS

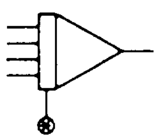


OPERATIONAL



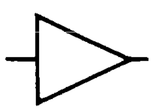
SUMMING AMPLIFIER

(4 INPUTS AND 1 OUTPUT SHOWN)

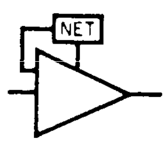


INTERGRATOR (AMPLIFIER)

(4 INPUTS AND 1 OUTPUT SHOWN)

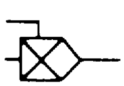


TRIANGLE POINTS IN DIRECTION OF TRANSMISSION (SIGNAL FLOW)

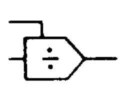


AMPLIFIER WITH EXTERNAL FEEDBACK PATH

BASIC SYMBOL INDICATES ANY MOTHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.



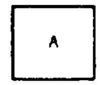
ELECTRONIC MULTIPLIER



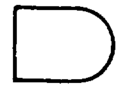
ELECTONIC DIVIDER

LOGIC FUNCTIONS

AND FUNCTION

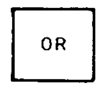


INPUT SIDE

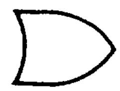


OUTPUT SIDE

INCLUSIVE OR FUNCTION

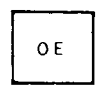


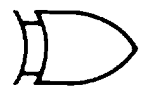
INPUT SIDE



OUTPUT SIDE

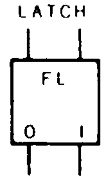
EXCLUSIVE OR FUNCTION



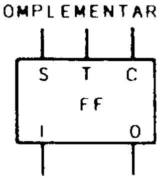


FLIP-FLOPS

LATCH

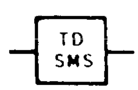


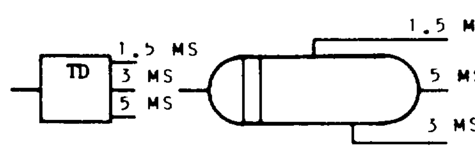
COMPLEMENTARY



S-SET T-TRIGGER C-CLEAR

TIME DELAY





APPENDIX III

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APPENDIX IV

REVIEW SUBSET ANSWERS

CHAPTER 2

REVIEW SUBSET NUMBER 1

A1. *Safety first.*

A2. *Open and tag the circuit breakers and main switches.*

A3. *Maintenance Instruction Manuals.*

A4. *Anticollision light.*

A5. *Energized.*

A6. *Shorting the terminals together.*

A7. *Endanger yourself.*

A8. *A, B, and C.*

A9. *Carbon dioxide* (CO_2).

A10. *Use the proper tool for its intended function in the proper manner. Maintain all tools in proper working order and a safe condition.*

REVIEW SUBSET NUMBER 2

A1. *(1) Analyze the symptom, (2) detect and isolate the trouble, and (3) correct the trouble and test your work.*

A2. *The ohmmeter.*

A3. *Replacement of parts.*

A4. *FOD.*

A5. *MIMs, schematics, and equipment records.*

A6. *Visual inspection.*

A7. *Broken wiring, loose terminals or plug connections, faulty relays and switches.*

A8. *Installation Practices, Electrical and Electronic Wiring, NAVAIR 01-1A-505.*

A9. *MIM.*

A10. *Make sure it works properly.*

REVIEW SUBSET NUMBER 3

A1. In parallel.

A2. The highest range.

A3. Open circuit.

A4. A continuity test.

A5. Circuit shorting to ground.

A6. (1) The VOM can load the circuit, and (2) the meter movement is easy to damage.

A7. A megger.

A8. An oscilloscope.

A9. An abnormal resistance or impedance that interferes with normal signal flow.

A10. Differential voltmeter.

REVIEW SUBSET NUMBER 4

A1. MIL-W-22759.

A2. Aluminum.

A3. 15 inches maximum.

A4. Ground.

A5. Selecting the right soldering iron.

REVIEW SUBSET NUMBER 5

A1. Aircraft Structural Hardware for Aircraft Repair, NAVAIR 01-1A-8.

A2. Corrosion, strength, size, length, magnetic properties, special features, and lubrication or coating of the substitution part.

A3. To separate the wire bundle from the plumbing line.

A4. (1) Lock wire, (2) shear wire, (3) seal wire.

A5. To ensure that all metal parts of the aircraft have the same electrical charge.

REVIEW SUBSET NUMBER 6

A1. Aircraft Weapons Systems Cleaning and Corrosion Control, NAVAIR 01-1A-509, and Avionic Cleaning and Corrosion Prevention/Control, NAVAIR 16-1-540.

A2. The capability to perform microminiature circuit repair.

REVIEW SUBSET NUMBER 7

A1. Common and peculiar.

A2. The MA-2 aircraft electrical power test set.

REVIEW SUBSET NUMBER 8

A1. A power-off condition.

A2. SND mode.

A3. Open circuit signature.

A4. The test leads are only conductive at the tips.

A5. 270 ohms.

REVIEW SUBSET NUMBER 9

A1. Jet ignition system tester.

A2. Make the ground connection for the power lead.

A3. 95 to 135 Vac.

REVIEW SUBSET NUMBER 10

A1. TTU-205C/E.

A2. Tank unit probe capacitance and tank unit insulation resistance.

A3. The angle-of-attack.

REVIEW SUBSET NUMBER 11

A1. Self-check.

A2. Debugging new programs.

REVIEW SUBSET NUMBER 12

A1. 20 volts.

A2. Ground.

A3. 250,000 ohms.

CHAPTER 4

REVIEW SUBSET NUMBER 1

A1. To provide specialized exterior lighting and illuminating the interior.

A2. To prevent filament fatigue failure.

A3. Single and double contact bayonet.

A4. Navigation lights.

A5. Right wing tip.

A6. Tanker aircraft.

A7. Amber.

REVIEW SUBSET NUMBER 2

A1. Hydraulics.

A2. Control the flow of the fluid.

A3. The pump.

A4. Useful work by linear/reciprocating-mechanical motion.

A5. To ensure the hook is up and locked before removing hydraulic pressure.

A6. Nose wheel steering.

A7. The airstream pressure.

A8. 2,750 PSI.

REVIEW SUBSET NUMBER 3

A1. Ram air temperature.

A2. Crew safety and comfort.

A3. On the inner surface of the outer pane of glass.

A4. Hot air from combustion heaters or engine compressors.

A5. Electrical heating elements.

CHAPTER 5

REVIEW SUBSET NUMBER 1

A1. Start, constant speed drive, and air turbine motor generator.

A2. Overspeed switch mechanism.

A3. Converts energy from compressed air to shaft power.

A4. Removing the positive potential.

REVIEW SUBSET NUMBER 2

A1. Jet engines run on a continuous burning fire.

A2. The ignition exciter.

A3. Between 45 percent and 65 percent of the engine rated speed.

A4. 34 pulses.

A5. A flameout or during aircraft weapons fire.

REVIEW SUBSET NUMBER 3

A1. Feather, ground stop, run, and airstart.

A2. When the power lever is above 66°F coordinator and the temp datum switch is in AUTO.

A3. Below 94 percent RPM.

A4. Chromel and Alumel.

A5. A variable potentiometer, discriminating device, and a cam-operated switch.

REVIEW SUBSET NUMBER 4

A1. 65 percent RPM.

A2. 16, 65, and 94 percent switches.

A3. 10 percent.

A4. To accommodate the temperature datum valve.

A5. Drain valves.

REVIEW SUBSET NUMBER 5

A1. Friction of the air over the aircraft creates enough heat to prevent icing.

A2. Hot bleed air and electrical.

A3. Air at the inlet guide vanes.

A4. Deicing removes ice already built up whereas anti-icing prevents ice buildup.

REVIEW SUBSET NUMBER 6

A1. Short discriminator circuit.

A2. As the temperature increases, the resistance of the sensing element decreases.

A3. The fire warning will not come on. The system senses a short.

A4. Bromotrifluoromethane (CF_3Br).

REVIEW SUBSET NUMBER 7

A1. Fuel tanks 2 and 3.

A2. When the fuel level drops below the high pilot valves in tanks 1 and/or 4.

A3. When fuel tank 1 transfers at a faster rate than fuel tank 4.

REVIEW SUBSET NUMBER 8

A1. Closed.

A2. The electrical control assembly (ECA).

REVIEW SUBSET NUMBER 9

A1. Flight and ground operation ranges.

A2. Synchrophasing governing mode.

A3. Phase and trim control unit.

A4. Engine RPM.

A5. The limiting circuit (two precent).

REVIEW SUBSET NUMBER 10

A1. Thrust.

A2. Low pitch stop.

A3. Variable hydraulic low pitch stop.

A4. Pitch lock reset.

A5. Feather valve.

A6. Automatic feathering system.

A7. Energize the pressure cutout override button.

REVIEW SUBSET NUMBER 11

A1. Engine power.

A2. The throttles override the system.

A3. A three-position temperature switch.

REVIEW SUBSET NUMBER 12

A1. Transmission pressure switch.

A2. Counterclockwise.

A3. Yes.

A4. To relieve stress built up on the segment gear.

A5. About 50 open.

REVIEW SUBSET NUMBER 13

A1. Mach number.

A2. Two flight control computers.

CHAPTER 6

REVIEW SUBSET NUMBER 1

A1. By operating principles and the job they perform.

A2. The weight of the air above that altitude.

A3. 12.23 pounds per square inch.

A4. Airspeed, altimeter, and vertical speed indicator.

A5. Airspeed indicator.

A6. Mach 2.

A7. AGL—Altitude above ground level, and MSL —altitude above mean sea level.

A8. The distance between the aircraft and the terrain it is flying over.

A9. Bimetal yoke.

A10. Total pressure (pitot), indicated static pressure, indicated angle of attack, and total temperature.

A11. The force of air against the aircraft.

A12. 80,000 feet of altitude and Mach 2.5.

A13. Angle of attack.

A14. The number of gimbals the gyro has.

A15. Rigidity in space and precession.

A16. Turn-and-bank indicator.

REVIEW SUBSET NUMBER 2

A1. Frequency.

A2. Zero.

A3. How the permanent magnet aligns to the flux of the two coils.

A4. A junction of two unlike metals used to sense temperature.

A5. Magnets (ring magnet and bar magnet).

A6. The Bourdon tube and the synchro system.

A7. The outer shaft.

REVIEW SUBSET NUMBER 3

A1. Non characterized and characterized.

A2. Temperature.

A3. The compensator probe.

A4. Integrated position indicator.

REVIEW SUBSET NUMBER 4

A1. White paint.

A2. One.

A3. Brown and orange.

A4. Flammable material, toxic and poisonous materials, anesthetics and harmful materials, and physically dangerous materials.

CHAPTER 7

REVIEW SUBSET NUMBER 1

A1. Position.

A2. Course.

A3. True north and the direction in which you are pointing.

A4. Longitude.

A5. The prime meridian.

A6. Variation.

A7. East or west, respectively, of true north.

A8. Deviation.

A9. Compass error.

A10. Add.

A11. Dead reckoning.

A12. Inertial navigation systems.

REVIEW SUBSET NUMBER 2

A1. It allows the platform to retain the original orientation regardless of aircraft.

A2. When the displacement gyroscope is malfunctioning.

REVIEW SUBSET NUMBER 3

A1. Newton's first law of motion.

A2. Acceleration.

A3. Velocity.

A4. To keep track opposition.

A5. The accelerometer.

A6. No.

A7. Mounting another accelerometer perpendicular to the first one.

A8. The inner roll gimbal.

A9. 84.4 minutes.

A10. Centripetal errors.

A11. Terrestrial, celestial, and inertial.

A 12. Earth.

REVIEW SUBSET NUMBER 4

A1. The wander-azimuth system.

A2. Analytic inertial navigation system.

A3. The gyros are not torqued.

A4. Universal screw and the loose magnet type.

A5. When coefficient A amounts to 2° or more in either direction.

CHAPTER 8

REVIEW SUBSET NUMBER 1

A1. Ease pilot workload and provide aircraft stability at all speeds.

A2. Any part of an aircraft designed to produce lift.

A3. The airfoil stalls.

REVIEW SUBSET NUMBER 2

A1. Rudder.

A2. Angle of attack on the wing.

A3. By increasing the airfoil's angle of attack (blade pitch).

A4. When the pilot applies collective to the main rotor.

REVIEW SUBSET NUMBER 3

A1. Radar and barometric altimeter signals.

A2. To prevent sudden and violent maneuvers upon engagement.

A3. The air navigation computer.

A4. Three axis rate gyro.

A5. A clutched heading signal.

A6. Manual and AFCS engaged.

A7. Surface position transmitter.

A8. Stability augmentation mode.

REVIEW SUBSET NUMBER 4

A1. Stability augmentation system, stabilator system, and digital automatic flight control system.

A2. 5-percent control authority.

A3. To stop undesirable noseup attitudes.

A4. When airspeed is below 50 knots.

A5. To improve helicopter stability.

A6. 10 percent per second.

A7. 0 to 5,000 feet.

A8. 120 feet/minute.

REVIEW SUBSET NUMBER 5

A1. The Doppler radar system and the vertical velocity system.

A2. The crew member at the hoist position.

A3. 72 degrees.

A4. The cable angle control panel.

A5. Speed drift and rate of descent.

A6. Two, one for pitch and one for roll.

A7. Pitch, roll, collective, and yaw.

Assignment Questions

<u>Information</u>: The text pages that you are to study are provided at the beginning of the assignment questions.

A S S I G N M E N T   1

Textbook Assignment: "Basic Physics." Pages 1-1 through 1-15.

*Assignment 1 has been deleted.

A S S I G N M E N T   2

Textbook Assignment: "Basic Physics" and "Electrical Maintenance and Troubleshooting." Pages 1-20 through 2-17.

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*Questions 2-1 through 2-39 have been deleted. This Assignment begins with Question 2-40. On the answer sheet, leave questions 2-1 through 2-39 blank.

Learning Objective: Identify safety precautions regarding aircraft, personnel, material, and tools.

2-40. Under what category(ies) can all maintenance performed on naval aircraft be grouped?

1. Preventive only
2. Unscheduled only
3. Scheduled and unscheduled
4. Scheduled and preventive

2-41. An accident-free naval career can best be achieved by following which of the following courses of action?

1. Constantly reading technical manuals
2. Reading all naval rules and regulations
3. Making a list of all potential work hazards
4. Taking a common-sense approach towards safety

2-42. If electrical equipment is to be repaired, what action should you take before beginning the actual work?

1. Remove the fuses for the associated circuits
2. Short out the main supply switches
3. Secure the main power switches in the open position and properly tag them
4. Station an individual with a fire extinguisher near the work area

2-43. When an aircraft anticollision light is operating on the flight line, it warns personnel of what potential hazards?

1. Aircraft refueling in progress
2. Ordnance loading in progress
3. Liquid oxygen converters being filled
4. Aircraft engines are operating

2-44. If you are working on high-voltage circuits or around wires having exposed surfaces, you should keep tools and equipment that have metal parts what minimum number of feet from the work area?

1. 5 feet
2. 2 feet
3. 5 feet
4. 4 feet

2-45. To prevent low-voltage shock, you should be careful handling equipment having what minimum circuit voltage?

1. 13 volts
2. 12 volts
3. 10 volts
4. 6 volts

2-46. The intensity of electrical shock is determined by which of the following properties?

1. Current
2. Voltage
3. Impedance
4. Electromagnetic force

2-47. Which of the following is the primary reason why a person should not move about after receiving an electrical shock?

1. The heart is temporarily weakened
2. Muscles have been damaged
3. Nerves have been damaged
4. The brain is impaired

2-48. When fighting an electrical fire, you should use which of the following fire-extinguishing agents?

1. Foam
2. Water (H_2O)
3. Soda and water
4. Carbon dioxide (CO_2)

2-49. If you swallow gasoline, which of the following actions should you take?

1. Swallow three glasses of salt water to induce vomiting
2. Drink large amounts of milk or water and take 4 tablespoons of vegetable oil, if available
3. Take two aspirins and two glasses of water
4. Swallow a solution of bicarbonate of soda and water

2-50. Which of the following statements describes the hazards of compressed air?

1. It can inject minute foreign bodies into the skin
2. It can rupture cell tissue and cause severe wounds
3. It can pass through clothing and may cause fatal injury
4. Each of the above

2-51. When using compressed air to clean out fixtures and jigs, you should observe the proper safety precautions. Also, you should maintain the air pressure below what maximum value?

1. 10 PSI
2. 20 PSI
3. 30 PSI
4. 40 PSI

2-52. When using tools, you should observe which of the following rules?

1. Use tools for their intended purpose
2. Maintain tools in good repair
3. Replace tools that are damaged or not working properly
4. Each of the above

2-53. Which of the following is the cause of most accidents in electrical and electronic work centers?

1. Moving machinery
2. Carelessness
3. Improper grounding
4. Exposed electrical fixtures

2-54. If one of your tools becomes worn, damaged, or broken, you should report this fact to what person?

1. Crew leader
2. Division officer
3. Work center supervisor
4. Material control officer

2-55. What alley is used to make most nonmagnetic tools?

1. Cadmium
2. Nickel-iron
3. Beryllium-copper
4. Copper-Constantine

2-56. At the local level, you may insulate tools for use on what type of circuit?

1. High-voltage
2. Low-voltage
3. Low-resistance
4. High-resistance

2-57. When you find a damaged power tool electrical cord, what action should you take?

1. Cover it with rudder tape
2. Shorten the cord to remove the damaged part
3. Repair the damage with insulating tape
4. Replace the cord

2-58. Which of the following is NOT a safety practice to follow when using a soldering iron?

1. Provide ventilation for the iron while it is on its rest rack
2. Hold small soldering jobs with pliers or clamps
3. Disconnect the iron during temporary absences from the work area
4. Shake the iron to get rid of excess solder

2-59. While using an electric drill, you experience an electrical shock. Which of the following conditions is the most likely cause?

1. The voltage source is too high
2. The voltage source is too low
3. An incorrectly grounded drill
4. An overloaded drill

2-60. What color is the safety ground wire for electrical tools?

1. Black
2. White
3. Green
4. Red

2-61. You need to apply voltage to a power tool having a three-wire system. The receptacle is a two-wire type. To connect the tool to this voltage source, you should use an adapter with an external ground wire and connect it in which of the following configurations?

1. Tape the exposed ground wire terminal
2. Connect the safety ground to a good ground before plugging in the tool
3. Connect the safety ground wire of the adapter to the tool case
4. Connect the safety ground wire to the center screw of the receptacle before plugging in the tool

2-62. Discrepancies found before, during, or after a flight require what type of maintenance?

1. Preventive
2. Unscheduled
3. Scheduled
4. Field

2-63. You are troubleshooting an electrical device that is not receiving any power. What check should you make first?

1. Check fuse or circuit breaker
2. Check the power source
3. Check for loose connector pins
4. Check for visible indications of trouble

2-64. Which of the following meters should you use when troubleshooting an open circuit?

1. Voltmeter
2. Wattmeter
3. Ohmmeter
4. Ammeter

After planning the job of correcting an electrical power failure on an aircraft, the AE assembled the necessary tools and equipment. Then the AE performed the following steps:

A. DISCONNECTED THE AIRCRAFT BATTERY

B. REMOVED A SECTION OF OXYGEN LINE TO GAIN ACCESS TO AN ELECTRICAL POWER CONNECTOR

C. DISCONNECTED THE CONNECTOR

D. REPLACED A CORRODED PIN IN THE CONNECTOR

E. REASSEMBLED THE CONNECTOR AND THE OXYGEN LINE AND RECONNECTED THE BATTERY

Figure 2A

IN ANSWERING QUESTION 2-65, REFER TO FIGURE 2A.

2-65. What error did the AE commit, and why was his/her action incorrect?

1. The battery was disconnected; the main circuit protector should have been disconnected
2. The connector was repaired in the aircraft; it should have been repaired in the shop
3. The oxygen line was removed and replaced; this action should have been done by an AME
4. One pin in the connector was replaced? the complete connector should have been replaced

2-66. Before replacing a major component in an aircraft, the AE should make which of the following determinations?

1. Whether the component is defective
2. Whether the intended replacement is a suitable substitute
3. Whether the repair will require a test flight
4. Whether the appropriate work center has been assigned the replacement task

2-67. Before making an adjustment to any system, you should consult which of the following publications?

1. MIM
2. IPB
3. NAVSUP 2002
4. NATOPS

Learning Objective: Recognize the various types of general-purpose test equipment used in aircraft electrical maintenance, and identify tests the AE makes using these equipments. (This objective is continued in assignment 3.)

2-68. An ammeter is connected into a circuit in which of the following ways?

1. In parallel with the circuit
2. In series-parallel with the circuit
3. Both 1 and 2 above
4. In series with the circuit

2-69. When a multimeter is not being used, the selector switch should be in which of the following positions?

1. High resistance
2. High dc volts
3. High ac volts
4. Low resistance

2-70. Which of the following conditions is the most probable cause for a grounded circuit?

1. A blown fuse
2. A tripped circuit breaker
3. Frayed insulation on wiring
4. Loose terminal lugs

2-71. For precise resistance measurements, you should use which of the following instruments?

1. Wheatstone bridge
2. Multimeter
3. Ohmmeter
4. Megger

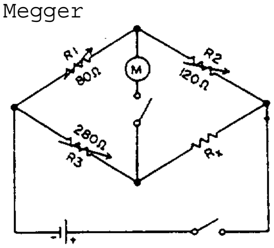

Figure 2B

IN ANSWERING QUESTION 2-72, REFER TO FIGURE 2B.

2-72. What is the value of R_x in the dc resistance bridge?

1. 42 ohms
2. 400 ohms
3. 420 ohms
4. 4,200 ohms

2-73. Which of the following types of meters are contained in the multimeter?

1. Voltmeter, frequency meter, and ohmmeter
2. Frequency meter, ammeter, and voltmeter
3. Frequency meter, ohmmeter, and ammeter
4. Ammeter, voltmeter, and ohmmeter

2-74. A permanent-magnet, moving-coil meter mechanism can be adapted to measure alternating current and voltage if it is used with which of the following devices?

1. A transformer
2. A transponder
3. A rectifier
4. A reactor

2-75. Which of the following is a standard feature of the Fluke Model 8100A digital multimeter?

1. A selectable input filter
2. A full four-digit readout
3. A power source of 115 volts or 230 volts can be used
4. Each of the above

A S S I G N M E N T 3

Textbook Assignment: "Electrical Maintenance and Troubleshooting."
Pages 2-17 through 2-74.

Learning Objective (continued): Recognize the various types of general-purpose test equipment used in aircraft electrical maintenance, and identify tests the AE will make using these equipments.

3-1. To test insulation for high resistance, grounds, and leakage, what meter should you use?

1. VTVM
2. Megger
3. Ohmmeter
4. Multimeter

3-2. A megger is prevented from exceeding its rated output voltage by the action of a

1. friction clutch
2. voltage regulator
3. diode limiter
4. variable resistor

3-3. Which of the following values can be measured by using an oscilloscope?

1. Frequency
2. Voltage amplitude
3. Phase differences
4. Each of the above

3-4. What term is used to define abnormal resistance or impedance that interferes with the normal signal flow?

1. Discontinuity
2. Distortion
3. Reflectometry
4. Reduction

3-5. What instrument should you use to troubleshoot fuel quantity coaxial cables?

1. Time-domain reflectometer
2. Whetstone bridge
3. Ammeter
4. Phase-angle voltmeter

3-6. The output of the phase detector in a phase-angle voltmeter is proportional to the signal amplitude multiplied by which of the following angles of phase difference?

1. Sine
2. Cosine
3. Tangent
4. Cotangent

3-7. Maximum deflection of the phase-angle voltmeter occurs when what phase relationships exists between the two signals?

1. 0° or 90°
2. 0° or 180°
3. 90° or 120°
4. 90° or 180°

3-8. What type of voltmeter is a precision voltmeter that compares an unknown voltage with an internal reference voltage?

1. Phase-angle voltmeter
2. Time-domain reflectometer
3. Differential voltmeter
4. Fluke Model 8100A

Learning Objective: Recognize aircraft wire and cable characteristics and various means of identifying and splicing wire and cables.

3-9. To be classified as a cable, a single conductor must have which of the following characteristics?

1. Be insulated and designed to carry RF energy
2. Be insulated and have a metallic braided shield
3. Be covered by a metal shield and designed to carry RF energy
4. Be covered by a metal shield and have at least a 00 wire size

3-10. To replace an aircraft electrical wire, you must determine the correct size and type of wire to use. To make this determination, what publication should you consult first?

1. The aircraft MIM
2. The aircraft IPB
3. Military Specifications, MIL-W-5088 (latest edition)
4. *Installation Practices for Aircraft Electric and Electronic Hiring,* NA 01-1A-505

3-11. Aluminum has the tendency to flow away from a point where pressure is applied. This tendency is known as

1. flowing
2. crystallization
3. creep
4. feed through

3-12. When stamping wires or cables, the distance between markings should not exceed what maximum distance?

1. *24* inches
2. 15 inches
3. 3 inches
4. 6 inches

3-13. You are reading a wire identification code. Which of the following types of information can you gain?

1. Circuit function
2. Wire size
3. Wire segment
4. Each of the above

3-14. Which of the following letters is NOT used to identify a wire segment?

1. E
2. O
3. X
4. Z

3-15. What letter suffix in the wire identification identifies the wire as being a ground?

1. A
2. B
3. C
4. N

3-16. Heat-shrinkable tubing has which of the following advantages?

1. It insulates wire terminals
2. It waterproofs wire splices
3. Both 1 and 2 above
4. It replaces wire terminal covers

3-17. When used on aircraft electrical wiring, the recommended power rating range for general-use soldering irons is within which of the following ranges?

1. 13 to 60 watts
2. 20 to 500 watts
3. 55 to 600 watts
4. 60 to 200 watts

Learning Objective: Recognize the uses for and characteristics of aircraft electrical and mechanical hardware.

3-18. Before reusing items of mounting hardware, what determination should you first make?

1. Whether they exceed the specifications for their intended use
2. That they are the same size and shape of the specified items
3. If their reuse is prohibited by existing directives
4. That they are not damaged and exceed the specification for the items required by the IPB

3-19. You have temporarily installed suitable substitute mounting parts. When should these parts be replaced?

1. During the next periodic inspection
2. During the time the aircraft is at NADEP
3. When the substitute parts become defective
4. When the required parts become available

3-20. Which of the following considerations should you observe when substituting mounting parts?

1. Color
2. Availability
3. Magnetic properties
4. Accessibility

3-21. Refer to figure 2-15 in your text. Which of the following statements is correct concerning the replacement of shock mounts?

1. Those shown in both view A and view B can be replaced, but all four must be replaced simultaneously
2. Those shown in view B can be individually replaced, and those in view A cannot be replaced
3. Those shown in view A can be individually replaced, and those in view B cannot be replaced
4. Each of the above

3-22. Refer to figure 2-15, view B, in your text. One vibration insulator is cracked. What corrective action should you take?

1. Replace the complete shock mount assembly
2. Replace the cracked insulator
3. Replace all the vibration insulators

3-23. What is the reason for moisture-proofing solder-type electrical connectors?

1. To reinforce the connector
2. To reduce the possibility of the connector cracking
3. To improve the connector's dielectric characteristics
4. To protect the connector for future use

3-24. The preferred method for attaching cable terminals to terminal blocks requires the use of what items of hardware?

1. An anchor nut and lock washer
2. An anchor nut and flat washer
3. A standard nut and lock washer
4. A standard nut and washer

3-25. Shielded conduit should be supported by the use of what type of clamp?

1. AN 742
2. Strap
3. Bonded
4. Nonbonded

3-26. When long runs of cable between panels need to be supported, which of the following types of clamps is preferred?

1. Strap
2. Plastic
3. Bonded
4. AN 742

3-27. When installing a cable through a lightening hole, you should use a grommet (rubber cushion) if the cables's distance from the edge of the hole is less than what minimum distance?

1. 1/4 inch
2. 3/8 inch
3. 1/2 inch
4. 5/8 inch

3-28. In addition to supporting and protecting electrical wires, what other advantage does conduit offer?

1. It protects against heat radiation
2. It provides radio shielding
3. It provides bullet deflection
4. It supports adjacent cables

3-29. What type of safety wire should you use to secure an oxygen regulator?

1. Lockwire
2. Seal wire
3. Shear wire
4. Soft steel wire

3-30. If an aircraft were improperly bonded, which of the following conditions would exist?

1. An increased likelihood of fire and a noisy radio receiver
2. An increased likelihood of lightening strikes
3. A decreased chance of lightening strikes
4. The likelihood of electrical failures increases

3-31. A primary objective of bonding is to provide an electrical path of

1. high dc resistance and high RF impedance
2. low dc resistance and high RF impedance
3. high dc resistance and low RF impedance
4. low dc resistance and low RF impedance

Learning Objective: Recognize electrical motor and generator maintenance procedures.

3-32. When using methyl chloroform to clean electrical equipment, you should remove the equipment from the solution within what maximum length of time?

1. 5 minutes
2. 5 to 15 minutes
3. 15 to 30 minutes
4. 30 to 60 minutes

3-33. A generator is not delivering its rated voltage or current. Before you remove this generator, you should check which of the following circuits?

1. Control
2. Feeder
3. Regulator
4. Each of the above

Learning Objective: Identify the characteristics of printed circuits, including modules and potted components, and recognize circuit construction features.

3-34. When a printed circuit is manufactured by the photoetching process, what portions of the plastic or phenolic sheet are actually photographically exposed?

1. All areas covered by light-sensitive enamel not covered by the circuit template
2. Only areas covered by the circuit template
3. Only areas where circuit components, such as resistors, are attached
4. Only areas that act as wires

3-35. Exposed copper is removed during the etching process, and the unexposed copper surfaces are protected by

1. enamel
2. solder
3. the printed circuitry overlay
4. the exposed copper smear

Learning Objective: Identify functions, capabilities, and operating characteristics of various types of aircraft test equipment.

3-36. What color paint is normally used for line test equipment?

1. Yellow
2. Orange
3. White
4. Red

3-37. Which of the following statements describes actions you should take when troubleshooting aircraft electrical equipment?

1. Use line test equipment in conjunction with shop test equipment
2. Follow the instructions in the applicable MIM
3. Use test equipment to isolate malfunctions to a specific component
4. Each of the above

3-38. The MA-2 Aircraft Electrical Power Test Set (stand) is NOT used to perform a complete test and check of which of the following components?

1. Generator outputs
2. Voltage regulator circuits
3. Reverse current relay operation
4. Generator spline wear

3-39. The load bank of the MA-2 is capable of supplying dc loads from 0 to what maximum value?

1. 500 amperes
2. 750 amperes
3. 1,000 amperes
4. 1,500 amperes

3-40. When using the Huntron Tracker 1000, which of the following statements is a test requirement?

1. All circuit power must be off
2. The signal fuse must be installed
3. The test leads attached to the device under test
4. Each of the above

3-41. The Huntron Tracker 2000 quadrant 3 shows which of the following displays?

1. Positive voltage and negative current
2. Negative current and negative voltage
3. Positive current and negative voltage
4. Positive current and positive voltage

3-42. When using the Huntron Tracker 1000 or 2000, you should begin testing in which of the following ranges?

1. Low
2. High
3. Medium

3-43. When testing analog circuits or devices with a Huntron Tracker, you should use the low range of the tester for which of the following reasons?

1. Defects will show easier, and the internal impedance makes it more likely the device under test will load the tester
2. Defects are easier to find in the medium range
3. The internal impedance will cause the device under test to load the tester
4. Defects will show easier, and the internal 54 ohm impedance makes it less likely that parts in parallel with the device under test will load the tester

3-44. In the SND mode of the Automatic Transistor Analyzer Model 900, a good device is indicated by the Sonalert when it beeps in what way?

1. Out of phase with the amber light
2. In phase with the amber light
3. In phase with the green light
4. Out of phase with the red light

3-45. When using the Automatic Transistor Analyzer Model 900 to test a transistor, you can connect the transistor to the tester in (a) what total number of ways of which (b) what total number are correct?

1. (a) Six (b) one
2. (a) Four (b) two
3. (a) Four (b) one
4. (a) Six (b) two

3-46. You should use the jet ignition system tester to check the input/output of which of the following components?

1. Spark plug
2. Power output of the ignition unit
3. Power input to the ignition unit
4. Each of the above

ITEMS 3-47 AND 3-48 PERTAIN TO THE TTU-27E TACHOMETER INDICATOR TEST SET.

3-47. The test set can be used to test which of the following components?

1. Two-pole and four-pole tachometer generators for speed and output voltage under load
2. Tachometer indicator calibration accuracy
3. Tachometer indicator voltage
4. Each of the above

3-48. After the tachometer generator to be tested is. mounted on the tester, what component will control the speed at which it will be driven?

1. The master tachometer generator
2. A variable dc drive motor in the test set
3. The two-speed test pad
4. The gearbox drive

ITEMS 3-49 AND 3-50 PERTAIN TO THE JET CALIBRATION (JETCAL) ANALYZER.

3-49. When performing a functional ground test of the EGT system, heat for the thermocouples is provided by

1. heater probes
2. exhaust gas
3. the JETCAL potentiometer
4. the aircraft heating and air-conditioning system

3-50. An external ac power supply is required to supply electrical power to a JETCAL analyzer that is being used to make which of the following checks?

1. Engine speed
2. The EGT circuit for shorts and grounds
3. EGT indicators
4. The resistance of the EGT circuit

3-51. Which of the following pulses *is/are* generated by the synchrophaser test set?

1. Slave pulse only
2. Master pulse only
3. Slave and master pulses
4. Tachometer pulse

3-52. The gain test readout from the synchrophaser test set is provided by what front panel component?

1. The null meter
2. The galvanometers
3. The calibrated potentiometer
4. The feedback potentiometer

3-53. Which of the following test sets provides regulated pitot and static pressure for evaluating the performance characteristics of air data systems, aircraft pneumatic instruments, and other auxiliary equipment?

1. TF-20
2. TTU-205C/E
3. TTU-27E
4. AN/PSM-17A

3-54. Of the following lists, which one gives the power requirements for the TTU-205C/E test set?

1. 28 Vdc, three-phase, 360 hertz
2. 28 Vdc, 115 Vat, single phase, 400 hertz
3. 115 Vac, single phase, 400 hertz
4. 115 Vac, three-phase, 400 hertz

3-55. The TF-20 liquid quantity test set can be used to perform which of the following functions'?

1. Measure tank unit probe capacitance and insulation resistance
2. Simulate the total capacitance of a probe for checking the aircraft fuel quantity indicator
3. Calibrate the test set's megohmmeter scales and capacitance indicator dial
4. Each of the above

3-56. When using the AN/FSM-17A to dynamically test the transmitter of the angle-of-attack system, what type of energy is fed to the transmitter probe?

1. Hydraulic or pneumatic
2. Vacuum or air pressure
3. Mechanical
4. Electrical

3-57. The AN/PSM-21A air-conditioning test set is used to troubleshoot and check which of the following systems?

1. Cabin pressure
2. Pressure suit
3. Equipment air conditioning
4. Each of the above

3-58. The basic configuration of a typical VAST station consists of which of the following components?

1. A computer subsystem, a DTU, and a stimulus and measurement section
2. A computer processing unit, a DTU, and a stimulus and measurement section
3. A computer subsystem, a CPU, and a stimulus and measurement section
4. A CPU, a DTU, and an output monitor

3-59. What component of the VAST system serves to synchronize instructions between the computer and the VAST system's functional building blocks?

1. Stimulus and measurement section
2. MTTU
3. CPU
4. DTU

3-60. What are the three levels of fault detection used in the VAST?

1. Primary, secondary, and building blocks
2. Basic block, core block, and peripheral block
3. Self-test, auto-check, and self-check
4. Manual, semiautomatic, and automatic

3-61. What test should you run on a VAST station before you apply power to a UUT?

1. Self-test
2. Auto-test
3. Continuity test
4. Dynamic functional test

3-62. Programmed halts are used during VAST testing to permit the operator to manually intervene in order to perform which of the following procedures?

1. Self-tests
2. Observations only
3. Adjustments only
4. Observations and adjustments

Learning Objective: Recognize the hazards to ESD-sensitive devices, to include proper handling and packaging techniques.

3-63. What is the lowest voltage that will destroy or damage an ESD-sensitive device?

1. 10 volts
2. 20 volts
3. 30 volts
4. 25 volts

3-64. The generation of static electricity on an object by rubbing is known as the

1. electrostatic charge
2. dielectric effect
3. triboelectric effect
4. prime charge

3-65. Under which of the following conditions is generated static electricity decreased?

1. Dry air
2. Humid air
3. Cold air
4. Hot air

3-66. Which of the following is NOT an ESD prime generator?

1. Synthetic mats
2. Vinyl
3. Common solder suckers
4. Carbon impregnated polyethylene

3-67. What is the minimum resistance for personnel ground straps?

1. 25,000 ohms
2. 150,000 ohms
3. 250,000 ohms
4. 500,000 ohms

3-68. Which of the following procedures should NOT be performed when working on ESD-sensitive devices?

1. Ground the work area, wrist straps, and equipment
2. After testing, replace shorting devices and protective packaging
3. Perform dielectric strength tests
4. Use of a Simpson 260 meter or equivalent to test components

A S S I G N M E N T   4

Textbook Assignment: "Power Generation and Control Systems" and "Aircraft Electrical Systems." Pages 3-1 through 4-2.

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*Assignment 4 has been deleted.

A S S I G N M E N T 5

Textbook Assignment: "Aircraft Electrical Systems" and "Aircraft Power Plant Systems." Pages 4-4 through 5-6.

Learning Objective: Identify the types, purposes, and uses of aircraft external lighting.

5-1. The minimum requirements for navigation lights on all military heavier-than-air aircraft are established by what agency?

1. Department of Defense
2. Department of Transportation
3. Federal Transportation Administration
4. Federal Aviation Administration

5-2. Flight safety is the primary purpose of which of the following lights?

1. Position lights
2. Formation lights
3. Fuselage lights
4. Anticollision lights

5-3. Refer to figure 4-6 in your text. The actuation of what device releases the magnetic brake allowing the landing light to extend or retract?

1. Mechanical linkage actuation only
2. Retract-extend switch actuation only
3. Mechanical linkage and retract-extend switch actuation
4. Gear train actuation

5-4. What type of light provides the landing safety officer with a visual indication of a carrier aircraft's safe or unsafe landing configuration?

1. Index lights
2. Position lights
3. Formation lights
4. Approach lights

IN ANSWERING (QUESTIONS 5-5 THROUGH 5-7, MATCH THE ANGLE-OF-ATTACK INDICATION IN COLUMN A WITH THE CORRECT COLOR APPROACH LIGHT IN COLUMN B. ALL ANSWERS ARE NOT USED.

	A. ANGLE-OF-ATTACK INDICATION	B. APPROACH LIGHT
5-5.	Angle of attack is too low	1. Amber
		2. Green
5-6.	Angle of attack is too high	3. Red
5-7.	Angle of attack is optimum	4. White

5-8. What lights provide the pilot with angle-of-attack information?

1. Approach lights
2. Indexer lights
3. Instrument lights
4. Position lights

5-9. With reference to the indexer lights, an inverted V indicates to the pilot that the angle of attack is in which of the following positions?

1. Slightly low
2. Slightly high
3. Very high
4. Very low

5-10. What is the landing configuration of an aircraft if the landing signal officer (LSO) observes flashing approach lights?

1. The landing gear is up only
2. The landing and arresting gears are up
3. The arresting gear is not fully extended
4. Normal operation

5-11. What is the function of the arresting gear override switch?

1. It activates a light showing the LSO that the arresting hook is extended for landing
2. It allows the approach lights to signal that the aircraft is unprepared to land
3. It allows the approach lights to function properly while the arresting hook is up
4. It shows the pilot the position of the arresting hook

5-12. The fuselage formation lights are connected in parallel with and controlled by the same switches as what other lights?

1. The fuselage signal lights only
2. The wingtip formation lights only
3. The fuselage signal and wingtip formation lights only
4. The fuselage signal, wingtip formation, and navigation lights

5-13. What is the purpose of the in-flight refueling probe light?

1. To illuminate the drogue of the refueling aircraft only
2. To illuminate the probe of the aircraft being refueled only
3. To illuminate the probe of the receiver aircraft and the drogue of the refueling aircraft
4. To indicate fuel flow and stoppage of fuel flow into the aircraft being refueled

5-14. When a controllable light is mounted in the nose of a helicopter, it has what total number of degrees of azimuth travel?

1. 90°
2. 180°
3. 270°
4. 360°

Learning Objective: Identify the types, purposes, and uses of aircraft internal lighting.

5-15. When replacing aircraft interior lamps or light covers, you should make sure that replacements meet the same specifications as the originally installed units for which of the following reasons?

1. Fire hazards can be easily created in lighting fixture alterations
2. The aircraft's power circuitry will be unbalanced if substitute lighting is used
3. Original specifications were based on scientific consider-ations of necessity and crew comfort
4. Each of the above

5-16. What are the advantages of the grain-of-wheat instrument lamps over other types of lamps used in instrument systems?

1. Longer life only
2. More rugged *only*
3. Better illumination only
4. Longer life, more rugged, and better illumination

5-17. What lighting feature is provided to aid a crew member who is reading a chart?

1. Red floodlights
2. White floodlights
3. Extension lights
4. Momentary contact switches to bypass the rheostats on floodlights

5-18. Which of the following statements describes the push-to-test feature on warning lights?

1. It provides a means for checking the condition of the warning light bulb only
2. It provides a means for checking the system's circuits only
3. It provides a means for checking the system's circuits and the condition of the warning light bulb
4. It provides a means for momentarily activating all equipments and circuits in the respective systems

IN ANSWERING QUESTIONS 3-19 THROUGH 5-22, REFER TO FIGURE 4-11 IN YOUR TEXT, AND MATCH THE COLOR OF THE LEGEND-TYPE LIGHT IN COLUMN B TO THE FUNCTION IT REPRESENTS IN COLUMN A. EACH ANSWER IS USED AT LEAST ONCE.

	A. FUNCTION	B. COLOR
5-19.	It indicates there is a requirement for immediate action	1. Yellow
		2. Red
5-20.	A malfunction is indicated	3. Green
5-21.	A safe or normal configuration is indicated	
5-22.	The condition or performance of equipment is indicated	

Learning Objective: Recognize the operating principles and characteristics of aircraft electrohydraulic and pneumatic systems.

5-23. In aircraft hydraulic systems, the AE maintains circuits that control the fluid

1. viscosity
2. flow
3. shape
4. pressure

5-24. All hydraulic systems contain a minimum of which of the following basic components?

1. Pump, selector valve, actuator, and reservoir
2. Pump, pressure regulator, switch, and reservoir
3. Selector valve, filter, pump, and actuator
4. Selector valve, actuator, pressure lines, and return lines

5-25. Which of the following components directs the fluid flow in a hydraulic system?

1. Reservoir
2. Pump
3. Selector valve
4. Actuating unit

IN ANSWERING QUESTIONS 5-26 THROUGH 5-29, REFER TO FIGURES 4-13 AND 4-14 IN YOUR TEXT.

5-26. Hydraulic pressure is supplied to AFCS components by which of the following components of the hydraulic surface control booster system?

1. Modulator piston transducer
2. Main control valve
3. Engagement valve
4. Transfer valve

5-27. When the hydraulic transfer valve is in the static state and the AFCS is engaged, which of the following forces hold(s) the plunger mechanism in the center position?

1. Equal hydraulic pressure on both sides of the modulator piston
2. Equal current flow in the transfer valve coils
3. Equal tension on both center springs
4. Both 2 and 3 above

5-28. The hydraulic surface control booster system operates in which of the following modes?

1. One--hydraulic
2. Two--manual and AFCS
3. Three--hydraulic, manual, and pneumatic
4. Each of the above

5-29. In the AFCS, what is the purpose of the modulator piston linear transducer?

1. To send rate signals to the AFCS computer
2. To send position signals to the AFCS computer
3. To reposition the modulator piston
4. To detect hydraulic failures

5-30. Which of the following functions is common to both the left and right main gear torque-link switches?

1. Preventing the throttles from being placed in the reverse propeller range while airborne
2. Furnishing power for the landing gear control lever locking solenoid
3. Disabling wing station external stores circuits
4. Energizing the bomb bay door control circuit

5-31. Refer to figure 4-15 in your text. What component prevents the landing gear control lever from being placed in the wheel-up position when the weight of the aircraft is on the landing gear?

1. A manually operated solenoid
2. An electrically operated but de-energized solenoid
3. The safety switch in the right main gear torque-link switch housing
4. An electrically operated solenoid that energizes when the aircraft lands.

IN ANSWERING QUESTIONS 5-32 AND 5-33, REFER TO FIGURE 4-16 IN YOUR TEXT.

5-32. Retraction of the arresting hook is electrically controlled and hydraulically actuated; however, extension of the hook is accomplished by the use of what means?

1. Hydraulic power only
2. Electrical power only
3. Electrical or hydraulic power
4. Mechanical

5-33. What is the purpose of the time-delay relay in the relay panel?

1. To dampen hydraulic pressure surges when the system is first engaged
2. To ensure that the arresting hook is fully up and locked before hydraulic pressure is removed
3. To prevent the arresting hook from dropping if the handle is inadvertently moved to the down position
4. To ensure that the arresting hook is completely down before hydraulic pressure is applied

IN ANSWERING QUESTIONS 5-34 THROUGH 5-37, SELECT FROM COLUMN B THE COMPONENT THAT PERFORMS EACH FUNCTION OF THE STEER-DAMPER UNIT LISTED IN COLUMN A. EACH ANSWER IS USED ONCE.

	A. FUNCTION	B. COMPONENT
5-34.	Controls hydraulic pressure to the steer-damper unit	1. Steering shutoff valve
		2. Servo valve
5-35.	Permits restricted hydraulic fluid flow to the bypass valve to dampen nosewheel shimmy	3. Unidirectional restrictors
		4. Fluid compensator
5-36.	Controls the flow of fluid to the actuator	
5-37.	Prevents system pressure from becoming excessive in the steer-damper unit	

IN ANSWERING QUESTIONS 5-38 THROUGH 5-41, SELECT THE COMPONENT FROM COLUMN B THAT PERFORMS THE FUNCTION LISTED IN COLUMN A. (THESE QUESTIONS CONCERN THE ELECTRICAL UNITS IN THE STEERING SYSTEM.) EACH ANSWER IS USED AT LEAST ONCE.

A. FUNCTION	B. COMPONENT
5-38. Contains a swivel disconnect switch to prevent reverse steering	1. Command potentiometer
5-39. Feeds a signal to the steering amplifier as the nosewheel is moved	2. Steering amplifier
5-40. Provides a nonlinear steering response as it is varied mechanically by the rudder pedals	3. Steering feedback potentiometer
5-41. Receives the turn signal ordered by the rudder pedals from the command potentiometer	

5-42. The catapulting system's launch bar warning light illuminates when which of the following conditions exist?

1. The launch bar is up and locked with weight off the landing gear
2. The launch bar is up and locked with weight on the landing gear
3. Solenoid B is energized
4. Solenoid A is energized

5-43. The launch bar control switch is placed to retract, and the warning light remains on. What component failure is indicated?

1. Valve position switch
2. Weight on gear switch
3. Selector valve
4. Control switch

5-44. Which of the following is a description of a speed brake control switch?

1. Speed brake extension will stop when the switch is released from the OUT position
2. Speed brake retraction will stop when the switch is momentarily held in the IN position
3. The speed brake moves fully to the indicated position when the switch is momentarily held in either the IN or OUT position
4. The degree of extension or retraction is controlled by the degree of movement of the switch lever to or from the STOP position

5-45. Refer to figure 4-19 in your text. To retract the speed brakes, the speed brake control switch is moved to the IN position, causing solenoid A and solenoid B to be in which of the following states?

1. Energized
2. De-energized
3. Energized and de-energized, respectively
4. De-energized and energized, respectively

QUESTIONS 5-46 THROUGH 5-48 PERTAIN TO THE CANOPY SYSTEMS OF AN A-6 AIRCRAFT.

5-46. Which of the following statements best describes the operational principle of the canopy selector valve?

1. It is hydraulically or electrically actuated and manually operated
2. It is manually or hydraulically actuated and manually operated
3. It is hydraulically or manually actuated and electrically operated
4. It is manually or electrically actuated and hydraulically operated

5-47. To close the canopy, which of the following conditions must exist?

1. The control circuit breaker closed, canopy switch closed, and solenoid 1 energized
2. The control circuit breaker closed, canopy switch open, and solenoid 2 de-energized
3. The control circuit breaker closed, the canopy switch closed, and solenoid 2 energized
4. The control circuit breaker open, the canopy switch closed, and solenoid 1 energized

5-48. To open the canopy, which of the following conditions must exist?

1. The control circuit breaker closed, the canopy switch open, and solenoid 1 energized
2. The control circuit breaker open, the canopy switch open, and solenoid 1 energized
3. The control circuit breaker closed, the canopy switch closed, and solenoid 2 energized
4. The control circuit breaker open, the canopy switch open, and solenoid 1 de-energized

IN ANSWERING QUESTIONS 5-49 THROUGH 5-52, SELECT FROM COLUMN B THE PNEUMATIC POWER SYSTEM COMPONENT THAT PERFORMS EACH FUNCTION LISTED IN COLUMN A. EACH ANSWER IS USED ONCE.

	A. FUNCTION	B. COMPONENT
5-49.	Ensures the fluid in the hydraulic motor is not surging	1. Pressure sensing switch
5-50.	Simultaneously passes voltage to the hydraulic selector valve and dump valve	2. Flow regulator
5-51.	Protects the motor against reverse fluid pressure	3. Dump valve
5-52.	Enables accumulated moisture to escape from the air system	4. Check valve

Learning Objective: Recognize terms, definitions, components, and operating principles and features of aircraft environmental systems, including those used to control temperature, pressure, and icing.

5-53. All of the following conditions create a demand for cabin air conditioning in aircraft flying at extreme airspeeds. Which one is the principal cause of cabin temperatures rising above the level at which the crew can maintain top physical and mental efficiency?

1. Engine heat
2. Solar heat
3. Body temperature
4. Ram-air friction

5-54. Temperature that is measured from a point at which there is no molecular motion is known as the

1. standard temperature
2. absolute temperature
3. critical temperature
4. ambient temperature

5-55. Which of the following is a correct temperature equivalent?

1. 100°C = 212°F
2. 32°C = 212°F
3. 32°F = 100°C
4. 0°F = 32°C

5-56. The cabin air-conditioning and pressurization system maintains the cabin air temperature and pressure at a comfortable and safe level by forcing which of the following kinds of air through cockpit diffusers?

1. Dehumidified refrigerated air
2. Hot engine bleed air
3. Both 1 and 2 above
4. Ambient refrigerated air and humidified hot engine bleed air

5-57. In an aircraft, cabin air pressure is controlled by the operation of which of the following components?

1. A safety valve and a manual dump control
2. A pressure regulator and a safety valve
3. A manual dump control and a pressure regulator
4. All of the above

5-58. With the cockpit switch in the ON position, the desired cabin temperature is maintained by which of the following means?

1. Variation in the opening of the ram-air valve
2. Proportional amounts of engine bleed air and refrigerated air being mixed by the dual temperature control valve
3. Proportional amounts of ram air and hot engine bleed air being mixed by the ram-air valve
4. Proportional amounts of ram air and refrigerated air being mixed by the ram-air valve

5-59. When the cockpit switch is in the RAM AIR position, what are the conditions of the various valves?

1. The dual temperature control valve is in the full hot position, the cabin bleed-air valve is closed, and the cabin ram-air valve is selected by the MAN/RAM AIR switch
2. The dual temperature control valve is selected by the MAN/RAM AIR switch, and the cabin ram-air valve is closed
3. Both the dual temperature control valves are closed, and the cabin ram-air valve is as selected by the MAN/RAM AIR switch
4. Both the dual temperature control valves are open, and the cabin ram-air valve is selected by the MAN/RAM AIR switch

5-60. Cabin temperature changes are anticipated by what component(s)?

1. Cabin temperature sensor only
2. Cabin temperature and duct sensors
3. Cabin duct dual temperature sensor
4. Temperature control wheel

5-61. At what altitude is cabin pressurization automatically initiated?

1. 6,000 feet
2. 8,000 feet
3. 10,000 feet
4. 12,000 feet

A. CABIN PRESSURE IS MAINTAINED AT SEA-LEVEL PRESSURE AT ALL ALTITUDES.

B. UP TO 8,000 FEET, CABIN PRESSURE IS HELD AT THE 8,000-FOOT ALTITUDE, AND ABOVE 8,000 FEET, A 5-PSI DIFFERENTIAL IS MAINTAINED BETWEEN CABIN AND AMBIENT PRESSURES.

C. UP TO 8,000 FEET, THE CABIN PRESSURE IS MAINTAINED AT SEA-LEVEL PRESSURE, AND ABOVE 8,000 FEET, CABIN PRESSURE IS HELD AT THE 9,000-FOOT PRESSURE LEVEL.

D. UP TO 8,000 FEET, THE CABIN PRESSURE IS THE SAME AS AMBIENT. ABOVE 8,000 FEET, THE CABIN PRESSURE REMAINS AT THE 8,000-FOOT PRESSURE LEVEL UNTIL A DIFFERENTIAL OF 5-PSI EXISTS BETWEEN CABIN AND AMBIENT PRESSURES. BEYOND THIS ALTITUDE THE PRESSURE DIFFERENTIAL REMAINS AT 5-PSI.

Figure 5A

IN ANSWERING QUESTION 5-62, REFER TO FIGURE 5A.

5-62. Which of the following is the pressure schedule maintained by the cabin pressure regulator?

1. A
2. B
3. C
4. D

5-63. Under what set of conditions will the right forward and aft equipment compartments receive moist, cooled bleed air?

1. When the equipment cooling valve iS open, the ram-air valves are open, and the temperature is below 46°C
2. When the equipment cooling valve is open, the ram-air valves are closed, and the temperature iS above 46°C
3. When the equipment cooling valve is open, the ram-air valves are open, and the temperature is above 46°C
4. When the equipment coolIng valve is closed, the ram-air valves are open, and the temperature is above 46°C

5-64. What is the function of the cabin duct limit bridge?

1. To limit the temperature of the cabin inlet air
2. To anticipate sudden cabin temperature changes
3. To select the desired cabin temperature
4. To override the cabin duct anticipator bridge

5-65. What is the purpose of the voltage from the feedback potentiometer in the cabin dual temperature control valve?

1. To reduce the starting voltage once the valve actuator motor has started rotating
2. To ensure the error feedback signal to the modulator circuit is the correct phase
3. To prevent oscillations of the valve actuator motor
4. To cause the valve actuator motor speed to increase, giving more positive control to the temperature regulation

5-66. Windshield overheating is prevented by the combined actions of a shutoff valve and what other component?

1. A thermostat
2. A dump valve
3. A thermistor
4. An electronic temperature controller

5-67. What is the location of the heating element for windshield anti-icing and defogging?

1. On the outer surfaces of both glasses
2. On the outer surface of the outer glass
3. Between the outer glass and the vinyl plastic core
4. Between the inner glass and the vinyl plastic core

5-68. What method is used to deice the empennage of P-3 aircraft?

1. A de-powered, at-controlled system providing constant heat to the empennage
2. Hot engine bleed air is circulated under the surfaces
3. The leading edges of the vertical and horizontal stabilizers are electrically heated
4. Heat from the cabin routed through control valves heats the empennage

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Learning Objective: Recognize the operating principles and characteristics of aircraft starting and ignition systems.

5-69. Jet engine starters must have which of the following capabilities?

1. Low starting torque and low speed
2. High starting torque and high speed
3. Low starting torque and high speed
4. High starting torque and low speed

5-70. What two sections make up the constant-speed drive/starter (CSD/S) unit?

1. A turbine motor and a planetary differential transmission
2. A turbine motor and a generator
3. A generator and a planetary differential transmission
4. A generator/turbine motor and a planetary differential transmission

5-71. The CSD/S is maintaining an output of 8,000 RPM from the engine input drive shaft. In what mode is the CSD/S operating?

1. The air turbine motor generator drive mode
2. The shaft mode only
3. The start and air turbine motor generator drive modes
4. The constant-speed drive mode

5-72. Refer to figure 5-3 in your text. The holding relay receives its positive potential after the start switch is momentarily pressed through the

1. multiengined starting system selector switch
2. normally closed stop switch
3. pressure cutout switch
4. starter overspeed switch

5-73. For a fire to occur, what elements must be present?

1. Oxygen and heat only
2. Heat and a combustible material only
3. Oxygen and a combustible material only
4. Heat, oxygen, and a combustible material

5-74. In an electronic ignition system, what component develops the voltage that produces a spark?

1. The exciter
2. The dynamotor
3. The transformer
4. The booster coil

5-75. In an electronic ignition system, ignition is discontinued when what percentage of the rated engine speed is reached?

1. Between 15 and 20 percent
2. Between 25 and 45 percent
3. Between 45 and 65 percent
4. Between 65 and 75 percent

ASSIGNMENT 6

Textbook Assignment: "Aircraft Power Plant Systems." Pages 5-9 through 5-50.

Learning Objective: Recognize operating principles and characteristics of aircraft engine temperature control and engine start control systems.

6-1. In turbine-powered aircraft, what relationship, if any, exists between engine power and turbine temperature?

1. They are directly proportional
2. They are inversely proportional
3. They tend to cancel each other
4. None

6-2. By what means does an engine temperature control system on turboprop engines control engine torque?

1. A converging and diverging panel circuit
2. Electronic fuel trimming
3. A restrictive airflow fan circuit
4. Variable airflow

6-3. The fuel shutoff valve is electrically closed on engine shutdown by placing the condition lever in what position?

1. Feather
2. Run
3. Ground stop
4. Air start

6-4. The engine coordinators function to coordinate the power and condition levers along with what other component(s)?

1. The fuel control only
2. The propeller and fuel control only
3. The electronic fuel trimming circuit only
4. The fuel control, the propeller, and the electronic fuel trimming circuit

6-5. The discriminating device will complete the feather cycle when the condition lever is placed in feather and the power lever is placed in what position?

1. In any position below the flight idle position only
2. In any position above the flight idle position only
3. In any taxi range position only
4. In any position

6-6. The reference temperature and turbine inlet temperature signals sent to the temperature datum control indicate a difference greater than 1.9°C, and a control signal is sent to the temperature datum valve. With the power lever in the temperature controlling range and the TEMP DATUM switch in the AUTO position, the control signal causes the temperature datum valve to

1. adjust the power lever assembly, regulating fuel flow to the engine being controlled
2. control a fuel-flow stabilizing pump on the engine being controlled
3. regulate the fuel flow to the engine being controlled
4. readjust the engine coordinator and trimming circuit on the engine being controlled

6-7. Engine speed is less than 94% and the engine coordinator is set above 66°. fit what temperature is the normal limiting temperature automatically set?

1. 730°C
2. 830°C
3. 978°C
4. 1,077°C

6-8. Dual unit thermocouples are radially mounted in what part of the engine?

1. Turbine inlet case
2. Compressor section
3. Inlet guide vanes
4. Turbine section

6-9. By which of the following methods are thermocouples electrically connected to provide an average temperature?

1. In series
2. In parallel
3. Either 1 or 2 above, as both will provide an average temperature
4. In series-parallel

6-10. An air turbine starter can be operated by compressed air from a GTC, an APU, or what other device?

1. An operating engine
2. The starter
3. An outside air vent
4. An emergency air tank

6-11. What is the function of the engine start system's speed-sensitive control?

1. To synchronize all engine speeds
2. To control engine RPM during start cycles
3. To prevent the engine from exceeding maximum RPM
4. To activate internal switches at predetermined intervals relative to the engine's normal speed

6-12. The ignition exciter provides which of the following voltages?

1. A stepped-up voltage for firing the ignition plugs
2. A 28-volt excitation voltage for closing the ignition relay
3. A 28-volt excitation voltage for activating the speed-sensitive control
4. A sine-wave voltage for application to the ignition relay solenoid

6-13. What behavior of the paralleling lamp indicates that the secondary element of a fuel pump has failed?

1. It illuminates continuously
2. It never illuminates
3. It illuminates above 65% RPM
4. It illuminates between 16% and 65% RPM

6-14. Along with the temperature datum valve, the fuel control functions to provide a starting fuel flow schedule and to

1. reduce nominal fuel requirements
2. prevent engine overtemperature and compressor surge
3. operate hydraulically actuated fuel cutoff valves
4. close the fuel shutoff valve during compressor surges

6-15. At what percentage, if any, of the rated engine RPM does the fuel control shutoff valve open to permit fuel flow to the engine?

1. 16% RPM
2. 65% RPM
3. 94% RPM
4. None

6-16. The temperature datum valve is located in which of the following positions?

1. Between the fuel tank and the fuel control
2. Between the fuel control and the engine fuel nozzles
3. Between the primary fuel pump and the secondary fuel pump
4. Between the fuel tank and the primary fuel pump

6-17. What is the function of compressor bleed-air valves?

1. To sequentially close the eight parts on the compressor housing
2. To bleed air from the compressor's fifth stage into its tenth stage
3. To reduce the compressor load during starts
4. To minimize the starter load on the compressor

IN ANSWERING QUESTIONS 6-18 THROUGH 6-21, REFER TO FIGURE 5-8 AND TABLE 5-1 IN YOUR TEXT.

6-18. The engine selector switch is placed in the engine No. 1 position, and the fuel and ignition switch for engine No. 1 is ON. What will happen to (a) the fuel control relay and (b) the temperature datum relay?

1. (a) Energize (b) de-energize
2. (a) De-energize (b) energize
3. (a) Energize (b) energize
4. (a) De-energize (b) de-energize

6-19. Which of the following conditions exists when the start control valve is energized?

1. The engine start switch is depressed
2. The selector switch is in position 1
3. The speed-sensitive control switch (65%) is closed
4. Each of the above

6-20. The yellow starter valve lights illuminate when which of the following conditions exists?

1. The primer switch is depressed
2. The primer valve solenoid is energized
3. The start control valve is open
4. The speed-sensitive control is inoperative

6-21. Which of the following events occurs when approximately 65% RPM is reached?

1. Switches in the speed-sensitive control will close
2. The ignition relay will energize
3. The fuel pumps will operate in series
4. A series light will illuminate

Learning Objective: Recognize the operating principles and characteristics of aircraft power plant, anti-icing and deicing, fire warning and extinguishing, fuel transfer, and oil temperature control systems.

6-22. Refer to figure 5-9 in your text. Anti-icing air is fed to the engine when the solenoid is energized. Energizing the solenoid causes the pressure in the anti-icing valve to

1. decrease in the poppet valve body
2. increase in the poppet valve body
3. increase on the face of the main poppet
4. decrease on the face of the main poppet

6-23. For any slow-cycle operation, the timing cycle for propeller deicers is such that current is supplied to the heating elements for approximately what time period?

1. 17 to 22 seconds
2. 25 to 35 seconds
3. 40 to 75 seconds
4. 80 to 120 seconds

6-24. The propeller deice timer motor is changed from fast speed to slow speed by which of the following actions?

1. Switching a filter in the motor circuit
2. Bypassing the variable resistor with two fixed resistors
3. Adjusting the variable resistor to provide maximum resistance
4. Switching an additional fixed resistor in series with the variable resistor

6-25. Under what condition will a fire warning light illuminate?

1. When the control unit does not monitor resistance changes
2. When the resistance of the sensing element does not change with a change in engine compartment temperature
3. When the resistance of the sensing element decreases to a predetermined level due to an increase in temperature
4. When the resistance of the sensing element increases to a predetermined level due to an increase in temperature

6-26. What is the purpose of the short discriminator circuit in the fire warning system?

1. To illuminate the fire warning lights during a test
2. To activate the fire warning system if an short occurs in the system
3. To prevent the fire warning system from actuating when an open occurs in the circuit
4. To prevent the fire warning system from actuating when a short occurs in the circuit

6-27. Which of the following statements describes the means by which CF_3Br extinguishes an aircraft engine fire?

1. It forms a blanket around the engine's air passages, smothering the fire
2. It cools the burning area to an extremely low temperature, extinguishing the fire
3. It uses the oxygen in the compartment at a rapid rate, making the air incapable of supporting a fire
4. It displaces the air in the nacelle, making the air incapable of supporting a fire

6-28. What component controls the oil cooler door position when the oil cooler switch is in the automatic mode?

1. A thermostat
2. A thermistor
3. A magnetic brake
4. A solenoid valve

Learning Objective: Recognize the operating principles and characteristics of the aircraft variable exhaust nozzle control system.

6-29. On an aircraft, what control system serves to vary the exhaust escape area to obtain the desired thrust and to maintain safe operating conditions?

1. Afterburner control system
2. Variable exhaust nozzle system
3. Main fuel control system
4. MIL control system

6-30. What VEN system components serve to schedule, compute, and control engine operation?

1. VEN power unit
2. ECA
3. VEN actuator
4. MFC

6-31. When the throttle is moved to the idle position, the VEN area rapidly moves to almost full open. The full open VEN area has which of the following effects on engine performance?

1. It reduces running temperature and exhaust temperature
2. It allows higher idle speed; reduces acceleration time
3. Aids starting; lowers thrust
4. Both 2 and 3 above

6-32. Decreasing the VEN area has what effect, if any, on EGT?

1. Increases EGT
2. Decreases EGT
3. Increases EGT up to 9,000 feet; decreases EGT above 9,000 feet of altitude
4. None

6-33. What component provides feedback to the ECA to ensure the VEN is positioned correctly?

1. The VEN synchronizing shaft
2. The VEN position transmitter LVDT
3. The VEN torque motor feedback circuit
4. The metering valve position transmitter LVDT

6-34. What is the function of the VEN power unit?

1. To provide electromechanical feedback to position the VEN
2. To provide hydraulic pressure to the actuator to position the VEN
3. To provide power for the electrical control assembly
4. To provide hydraulic pressure to drive the servomotor when signaled by the ECA

Learning Objective: Recognize the operating principles and characteristics of the propeller synchrophasing systems.

6-35. What is the function of the propeller governor?

1. To control engine speed by varying the pitch of the propeller
2. To control engine speed by varying the rate of fuel flow to the fuel nozzles
3. To control propeller pitch by varying hydraulic pressure
4. To control the propeller by varying engine speed

6-36. The pitch of the propeller blade is varied by porting hydraulic fluid directly to which of the following parts of the propeller piston?

1. Inboard side
2. Outboard side
3. Both 1 and 2 above
4. Geared cam

6-37. The synchrophaser will function in which of the following modes?

1. Normal
2. Synchrophasing
3. Both 1 and 2 above
4. Mechanical

6-38. What is the function of the pulse generator in the synchrophaser system?

1. To provide pulses for phase and speed control of the propellers
2. To establish the phase relationship between propellers
3. To translate synchrophaser electrical signals into mechanical bias
4. To provide pulses directly to the corresponding servomotor

6-39. What is the purpose of the phase and trim control tn the synchrophaser system?

1. To control the servomotor train
2. To provide pulses for speed control
3. To set the phase relationship between master and slave propellers
4. To convert electrical signals into mechanical motion

6-40. What is the function of the speed bias servo assembly?

1. To set the phase relationship between the master and slave propellers
2. To translate synchrophaser electrical signals into mechanical bias
3. To establish the reference pulse for the propellers
4. To provide pulses for speed and phase control

6-41. The synchrophaser provides which of the following servomotor control voltages?

1. An ac voltage 90° or 270° out of phase with the excitation voltage
2. An ac voltage in phase or 180° out of phase with the voltage applied to the reference
3. An ac voltage in phase or 180° out of phase with the excitation voltage
4. A negative or positive dc signal voltage

6-42. In the input windings of the magnetic modulator, what parameters of the current control the amplitude and phase of the modulator's output?

1. Amplitude controls magnitude, and phase controls direction
2. Magnitude controls amplitude, and phase controls direction
3. Amplitude controls magnitude, and direction controls phase
4. Magnitude controls amplitude, and direction controls phase

6-43. In a synchrophaser, what governoring mode is used to provide improved engine response to transient RPM changes?

1. Throttle lever anticipation mode
2. Master governoring mode
3. Synchrophasing mode
4. Normal mode

6-44. As the power lever is moved to decrease power, a more positive voltage is applied to the speed derivative circuit. What is the result of this action?

1. A leading voltage surge appears on the servomotor control winding of the mechanical governor
2. A change in the speed or phase of the master engine with respect to the slave engine
3. Resetting of the mechanical governor towards a decrease in propeller pitch
4. Resetting of the mechanical governor towards an increase in propeller pitch

6-45. In the synchrophaser, the speed derivative circuit senses changes in engine RPM and generates signals having what function?

1. To change the propeller pitch to align the slave propellers to the master propeller
2. To dampen engine RPM changes
3. To change the propeller pitch to correspond to engine RPM
4. To dampen propeller pitch transients

6-46. Refer to figure 5-36 in your text. The magnitudes of the signal input to the No. 1 winding of the magnetic modulator vary as a result of the

1. synchrophaser output signal changes
2. reflected impedance changes from the No. 2 winding and the dummy load
3. voltage changes in the input to the magnetic modulator
4. frequency changes in the engine's tachometer generator

6-47. When the synchrophasing mode of operation is used, all engines except the master engine operate with synchrophasing. With what does the master engine operate?

1. Normal governing only
2. Mechanical qoverning only
3. Normal and mechanical governing
4. Hydraulic governing

PROPELLER SYNCHRONIZING

A. SLAVE PULSES ARE COMPARED WITH MASTER PULSES, AND ERROR VOLTAGES ARE DELIVERED TO THE AMPLIFIER AND SPEED BIAS SERVOMOTOR SIMULTANEOUSLY.

B. PULSES FROM THE PROPELLER ARE FED TO THE SYNCHROPHASER, SLAVE PULSES ARE COMPARED WITH THE MASTER PULSES, ERROR VOLTAGES ARE DELIVERED TO THE AMPLIFIER, AND THE AMPLIFIER OUTPUT IS DELIVERED TO THE PILOT VALVE.

C. PULSES FROM THE PROPELLERS ARE FED TO THE SYNCHROPHASER, SLAVE PULSES ARE COMPARED WITH THE MASTER PULSES, AND ERROR VOLTAGES ARE FED DIRECTLY TO THE TWO-PHASE MOTOR IN THE SERVO CONTROL ASSEMBLY.

D. PULSES FROM PROPELLERS ARE FED TO THE SYNCHROPHASER, SLAVE PULSES ARE COMPARED WITH THE MASTER PULSES, ERROR VOLTAGES ARE ROUTED TO THE AMPLIFIER, THE SPEED BIAS SERVOMOTOR REACTS TO THE AMPLIFIER SIGNAL, AND THE SLAVE ENGINE SPEED CHANGES.

Figure 6A

IN ANSWERING QUESTION 6-40, REFER TO FIGURE 6A.

6-48. Of the sequences listed, which one results in the propellers of the synchrophasing system becoming synchronized?

1. A
2. B
3. C
4. D

6-49. Refer to figure 5-37 in your text. During a propeller underspeed condition, V206A experiences which of the following input voltage changes?

1. A slow change from positive to negative
2. A sudden change from negative to positive
3. A sudden change from positive to negative
4. A slow change from negative to positive

6-50. Refer to figures 5-37 and 5-40 in your text. Zener diodes VR405 and VR408 function to connect the speed-error circuit to the summing point when an off-speed condition exists. What is their function, if any, during an on-speed condition?

1. To connect the speed-error circuit potentiometer to ground
2. To prevent formation of transients in the speed-error circuit potentiometer
3. To isolate the speed-error circuit potentiometer from the signal summing point
4. None; they function identically during on- and off-speed conditions

6-51. What synchrophaser circuit prevents the slave engine from following an overspeeding or underspeeding master engine?

1. The 2% limiting circuit
2. The 20% limiting circuit
3. The speed bias servo assembly
4. The throttle lever anticipation potentiometer

6-52. What is the purpose of resynchrophasing?

1. To overcome small errors of lead and lag about a set point
2. To provide for antihunt by correcting for overshoot
3. To move the feedback potentiometer and cancel a portion of the error signal
4. To correct for accumulated one-direction errors

Learning Objective: Recognize the operating principles and characteristics of the propeller control l nd approach power compensator systems.

6-53. What assembly maintains the minimum desired low-pitch angle?

1. Magnetic latching
2. Hydraulic lever
3. Electrical solenoid
4. Low-pitch stop

6-54. What is the purpose of the Beta follow-up stop?

1. To provide a secondary stop setting at the 15° blade angle only
2. To provide a secondary low-pitch stop
3. To prevent negative-torque system failure
4. To prevent minor reductions in blade angle

6-55. The function of the pitchlock mechanism in the propeller is to prevent which of the following conditions?

1. Propeller overspeeding
2. Low-pitch oscillations
3. Propeller gyrations
4. High-pitch oscillations

6-56. Pitchlock is blocked out between blade angles of +57° and +86°. What action does this permit?

1. RPM surges during approaches
2. RPM changes during landings
3. The blade angle reduction for takeoffs and landings
4. The blade angle reduction for air starting

6-57. If the fuel governor and the propeller pitchlock test switch were to be placed in the TEST position, what would be the result?

1. The blade angle would be reset to the proper angle for an air start
2. The propeller governor RPM would be reset to permit ground check of pitchlock and fuel governor functions
3. A momentary blockout of the pitchlock mechanism
4. An increase in pitch

6-58. When needed, the negative torque system functions in what way?

1. To eliminate propeller cycling actions
2. To generate a negative torque
3. To limit positive horsepower
4. To increase blade angle

6-59. If the negative torque system fails during in-flight unfeather operations, what system limits negative torque?

1. NTS INOP warning
2. Feather position activation
3. Airstart blade angle
4. Emergency override

6-60. The process of aligning the propeller to the airstream to minimize drag during engine shutdown conditions is known as

1. negative torquing
2. feathering
3. pitchlock
4. Beta follow-up

6-61. The function of the feather pump pressure cutout override switch is to bypass the feather pressure switch to prevent which of the following occurrences?

1. The premature commencement of the minimum feather position
2. The late commencement of the minimum feather position
3. The premature termination of the full feather position
4. The late termination of the full feather position

6-62. When is the automatic feathering system used?

1. During takeoffs only
2. During landings only
3. During takeoffs and landings
4. During emergencies

6-63. To activate the thrust signal device to cause autofeathering, what must be the condition of (a) the autofeathering arming switch and (b) the power lever quadrant switch?

1. (a) Closed (b) open
2. (a) Open (b) closed
3. (a) Closed (b) closed
4. (a) Open (b) open

6-64. What condition is indicated when the four autofeather system indicator lamps are illuminated?

1. All autofeather systems are armed
2. The entire autofeather system is malfunctioning
3. Only one of the propellers is being automatically feathered
4. All of the propellers are being automatically feathered

6-65. When the power levers (throttles) are set in the taxi range, the propeller blade pitch and engine fuel flow are controlled by which of the following means?

1. The prop governors control the prop pitch, and the temp datum system controls the engine fuel flow
2. The synchrophaser system controls the prop pitch, and the power levers control the engine fuel flow
3. The temp datum system controls both the blade pitch and the engine fuel flow through hydromechanical linkage
4. The power levers control both the blade pitch and the engine fuel flow through the hydromechanical linkage

6-66. Which of the following is a function of the approach power compensator system?

1. To position the aircraft control surfaces automatically during landing approaches
2. To provide sudden surges of fuel for additional altitude when required
3. To control the engine power automatically during landing approaches
4. To maintain the speed of the aircraft in moderate turbulence within ±10 knots

6-67. In the approach power compensator system, what component/aircraft system provides the computer with aircraft approach angle information?

1. The pitot-static system
2. The static system
3. The angle-of-attack indicator
4. The angle-of-attack transducer

6-68. Which of the following statements describes the approach power compensator system?

1. The computer provides no corrective signal to reposition the throttle as long as the acceleration is 1 g, and the angle of attack is optimum for landing approaches
2. The system is capable of operating in three ambient temperature ranges to control engine performance
3. The rotary actuator motor positions the engine control linkage after receiving a corrective signal from the computer
4. Each of the above

6-69. After spreading the blades on the H-60 helicopter, the bladefold actuators run in the fold direction to relieve the stress on what component?

1. The bladefold actuator
2. The segment gear in the bladefold actuator
3. The blade lockpins
4. The hinge lug

6-70. At supersonic speeds greater than Mach 2, the variable inlet duct ramp system allows which of the following events to occur?

1. Supersonic air to enter the inlet duct only
2. Subsonic air to enter the engine only
3. Both subsonic l nd supersonic air to enter the inlet duct
4. Supersonic air to increase in velocity before entering the engine

A S S I G N M E N T 7

Textbook Assignment: "Aircraft Instruments." Pages 6-1 through 6-46.

Learning Objective: Recognize the operating principles and features of the pitot-static system.

7-1. Which of the following statements describes the earth's atmosphere?

1. The air molecules are closer together at the bottom of the atmosphere than at the top
2. The weight of the air pressing down from above determines the air pressure at any given altitude
3. The air is more dense on the earth's surface than at an altitude of 1,000 feet
4. Each of the above

7-2. The altimeter is part of what aircraft system?

1. Compass
2. AFCS
3. Pitot-static
4. Radio

7-3. In the pitot-static system, the term *pitot* represents what type of pressure?

1. Impact
2. Ambient
3. Barometric
4. Stationary

7-4. In computing airspeed, the airspeed indicator uses which of the following pressures?

1. Static pressure only
2. Impact pressure only
3. The sum of impact and static pressures
4. The difference between static and impact pressure

7-5. The accuracy of the airspeed indicator readings may be affected by which of the following conditions?

1. Temperature changes in the instrument
2. Air turbulence around the pitot tube
3. Imperfect scaling of the indicator dial
4. Each of the above

7-6. An aircraft's Mach indicator reads 0.5 when the airspeed indicator shows 300 knots. If the airspeed were to double to 600 knots, which statement would reflect the aircraft's speed and Mach indication?

1. The aircraft is at the speed of sound, and the Mach indication is 0.25
2. The aircraft is at the speed of sound, and the Mach indication is 1
3. The aircraft is at one-half the speed of sound, and the Mach indication is 1
4. The aircraft is at the speed of sound, and the Mach indication is 1.5

7-7. Which of the following is a meaning of the term *altitude?*

1. Elevation
2. The distance above mean sea level (MSL)
3. The distance above ground level (AGL)
4. Each of the above

7-8. At what altitude does gravity acting on the atmosphere produce a pressure of 14.70 PSI and support a column of mercury to a height of 29.92 inches?

1. Pressure altitude
2. MSL
3. Absolute altitude
4. Density altitude

7-9. The altitude reading of a properly calibrated altimeter referenced to 29.92 inches of mercury (Hg) is known as the

1. true altitude
2. absolute altitude
3. pressure altitude
4. indicated altitude

7-10. If, at sea level, there is a barometric change of 0.03 inches, the altimeter reading would change by how many feet?

1. 9 feet
2. 15 feet
3. 27 feet
4. 36 feet

7-11. At what altitude does the barometric pressure setting for aircraft altimeters change from the local barometric pressure to 29.92 inches?

1. 8,000 feet
2. 13,000 feet
3. 18,000 feet
4. 23,000 feet

7-12. For the pilot to obtain the best performance from the aircraft engine, which of the following altitudes should be known?

1. True
2. Density
3. Indicated
4. Calibrated

7-13. If an aircraft is in level flight, what will the vertical speed indicator (VSI) pointer indicate?

1. -0.5
2. 0.0
3. +0.5
4. +1.0

7-14. In a VSI indicator, the pointer is driven by

1. the difference between diaphragm and case pressures
2. the difference between pitot and static pressures
3. a pneumatically driven motor
4. a calibrated leak

Learning Objective: Recognize the principles and features of the airspeed indicating system.

7-15. What is the purpose of the air data computer (ADC)?

1. To provide accurate air data that is free of aircraft configuration errors
2. To compute air data information that is gathered from sensors isolated from air data disturbances
3. To sense the characteristics of the air surrounding the aircraft
4. To sense the characteristics of the air surrounding the aircraft and correct the data to compensate for aircraft induced errors

7-16. What are the four data sense inputs to the ADC?

1. Pitot pressure, static pressure, total temperature, and AOA
2. Pitot pressure, static pressure, angle of attack, and total pressure
3. Pitot pressure, total temperature, cabin pressure, and angle of attack
4. Static pressure, cabin pressure, total pressure, and pneumatic differential pressure

7-17. Refer to table 6-1 in your text. What symbol represents the correct impact pressure?

1. PSI
2. Hp
3. Pt
4. Qc

7-18. Which of the following is the meaning of the term *angle of attack?*

1. The difference between the leading edge of the wing and nose of the aircraft relative to the air through which it is passing
2. The angle at which the leading edge of the wing must pass to provide adequate lift for sustained flight
3. The angle at which the leading edge of the wing encounters the air mass
4. The angle of the air passing over the elevators to provide more lift

7-19. What is the purpose of the potentiometers in the angle-of-attack transmitter?

1. To provide an electrical indication of the aircraft fuselage in reference to the angle of attack
2. To provide a means for converting voltage into mechanical motion
3. To convert electrical signals into mechanical signals indicative of the angle of attack
4. To convert mechanical motion into proportional electrical signals

7-20. What is the purpose of the angle-of-attack system?

1. To indicate aircraft total pressure with respect to ambient pressure
2. To indicate the aircraft attitude with respect to the surrounding air mass
3. To provide indications of the air data sensor outputs
4. To compute the air data information for the ADCS

7-21. Static pressure errors become a significant factor in the accuracy of pressure indications at what relative speeds?

1. Supersonic only
2. Transonic only
3. Supersonic and transonic
4. Subsonic and transonic

7-22. There are two variables that cause the most significant errors in indicated static pressure as detected by the aircraft static ports. One of these is the Mach number (aircraft speed) and the other one is the

1. angle of attack
2. altitude
3. total temperature
4. ambient temperature

7-23. What is meant by impact pressure (Qc)?

1. The weight of the air on the aircraft
2. Atmospheric pressure, including disturbances
3. The force of the air against the aircraft
4. Atmospheric pressure free of disturbances

7-24. The two temperatures that make up the total temperature are the ambient temperature plus the

1. temperature of the engine intake ram air
2. temperature increase created by the motion of the aircraft
3. temperature decrease created by the surrounding air
4. temperatures of the ram air external to the aircraft and the engine intake ram air

7-25. What is the function of the AICS?

1. To accelerate subsonic air for the engines
2. To accelerate supersonic air and provide it to the engine
3. To decelerate subsonic air and provide it to the engine
4. To decelerate supersonic air to provide subsonic air for the engine

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Learning Objective: Recognize the operating principles and features of the automatic altitude reporting system.

7-26. In the automatic altitude reporting system, position and altitude reporting is accomplished by which of the following components?

1. Transponders
2. Transformers
3. Flashing beacons
4. Tachometer generators

7-27. The automatic altitude reporting system provides the aircraft's altitude in which of the following increments?

1. 50 feet
2. 100 feet
3. 150 feet
4. 250 feet

7-28. What total number of dimensions is/are automatically displayed on a radar presentation by the semiautomatic air traffic control system?

1. One
2. Two
3. Three
4. Four

7-29. Which of the following is the primary reason for the development of the AIMS system?

1. To improve radar maintenance
2. To shorten the interval between carrier landings
3. To reduce the number of aircraft in the air at any one time
4. To improve air traffic control within the United States

7-30. The maximum allowable difference between the aircraft's altitude and the ground display altitude in the AIMS system is what total number of feet?

1. ±50 feet
2. ±125 feet
3. ±250 feet
4. ±200 feet

7-31. Most high-performance naval aircraft use which of the following altimeters as part of the AIMS system?

1. AAU-18/A
2. AAJ-19/A
3. AAU-21/A
4. AAU-24/A

7-32. What are the operational limits for the CPU-46/A altitude computer?

1. 25,000 feet altitude and Mach 8
2. 25,000 feet altitude and Mach 2.5
3. 80,000 feet altitude and Mach 2.5
4. 80,000 feet altitude and Mach 3

7-33. If the CPU-46/A altitude computer were to fail, what would happen to the AAU-19/A altimeter and the altitude reporting encoder?

1. The altimeter automatically reverts to the pneumatic standby mode, and the encoder is deactivated
2. The altimeter becomes inoperative and must be switched to the standby mode; the encoder continues to operate
3. The altimeter and encoder are inoperative
4. The altimeter is inoperative, and the encoder continues to function

7-34. The AAU-19/A altimeter operates as a standard altimeter when it is placed in which of the following modes?

1. Reset
2. Servoed
3. Baroset
4. Standby

7-35. What components in the AAU-24/A altimeter overcome the effects of the stop-and-jump friction?

1. Servos
2. Synchros
3. Transponders
4. Vibrators

7-36. When turning the baroset knob on the AAU-24/A altimeter, what device drives the barometric counter?

1. A counter-drum assembly
2. A spur gear
3. A magnetic coupler
4. An aneroid assembly

Learning Objective: Recognize the operating principles and features of the angle-of-attack (AOA) indicating and stall warning systems and gyroscopic instruments.

7-37. When used in naval aircraft, the angle-of-sideslip system is used along with which of the following systems?

1. Crosswind landing system
2. Gun firing system
3. Bombing system
4. Rocket firing system

7-38. The angle-of-attack indicating system operates by detecting

1. earth field variation
2. airflow differential pressure
3. the altitude/speed pressure gradient
4. the airflow/altitude change rate

7-39. If the angle-of-arrack of an air-craft is changed, which of the following actions occur(s) in the self-balancing bridge circuit of the AOA system?

1. An error voltage will exist between the transmitter and receiver potentiometers in the circuit
2. A servomotor drives the receiver potentiometer to return the bridge circuit to null
3. Both 1 and 2 above
4. A servomotor drives the transmitter potentiometer to return the bridge circuit to null

7-40. If the red arrow on the pilot's AOA indexer illuminates, which of the following conditions exist?

1. The aircraft is nose low
2. The aircraft is nose high
3. The aircraft is at optimum AOA
4. There is a failure in the system

7-41. On most naval aircraft, the stall warning *system* is activated by which of the following systems?

1. Pitot-static system
2. Angle-of-attack system
3. Air data computer system
4. Angle-of-sideslip system

7-42. Which of the following groups of general characteristics is the most desirable for an instrument gyroscope?

1. Light weight for small size and low speed of rotation
2. Light weight, small size, and high speed of rotation
3. Heavy weight, large size, and high speed of rotation
4. Heavy weight for small size and high speed of rotation

7-43. For a gyro to have two degrees of freedom, the platform must have what total number of gimbals?

1. One
2. Two
3. Three
4. Four

7-44. What are the two fundamental properties for gyroscopic action?

1. Stability and rigidity in space
2. Precession and centrifugal force
3. Stability and centrifugal force
4. Rigidity in space and precession

7-45. A spinning gyro precesses when subjected to a deflecting force. Which of the following actions will make the gyro precess at a faster rate?

1. A decrease in the speed of the rotor
2. An increase in the force applied
3. Both 1 and 2 above
4. An increase in the speed of the rotor

7-46. What action does the gyro horizon have, relative to its case, to indicate aircraft attitude?

1. The case revolves about the gyro
2. The case and gyro spin axis are both free to move with respect to the aircraft
3. The gyro spin axis revolves about the case
4. The gyro and case are held stationary, and the needles are free to move

7-47. The sphere in the attitude indicator may be centered by a control on the face of the indicator to correct for which of the following flight attitudes?

1. Yaw
2. Roll
3. Pitch
4. Each of the above

7-48. In a turn-and-bank indicator, what factor(s) determine(s) the position of the ball?

1. Natural forces
2. Gyroscopic precession
3. Earth's magnetic lines of force
4. Electrical tilting of the plate on which the indicator mounts

7-49. In a flight-coordinated turn, the ball of a turn-and-bank indicator will be in which of the following positions?

1. The center
2. To the left showing a slip
3. To the right showing a skid
4. Either 2 or 3 above, depending on the direction of the turn

7-50. As the aircraft turns, the turn-and-bank indicator frame moves to the side opposite the turn. However the indicator needle moves in the direction of the turn for which of the following reasons?

1. Centrifugal force and gyro precession are in opposition to each other
2. Gravity is greater than centrifugal force in any aircraft attitude other than straight-and-level flight
3. The needle is connected to the frame in such a manner to cause the two to move in opposite directions
4. The centrifugal force applied to the needle is in the direction opposite to the centrifugal force applied to the frame

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Learning Objective: Recognize the operating principles and features of miscellaneous flight instruments, to include accelerometer indicators, clocks, direct-reading magnetic compasses, standby attitude indicators, and outside air temperature indicators.

7-51. What instrument does the pilot use to reduce the possibility of damage to the aircraft from excessive stress?

1. The turn-and-bank indicator
2. The accelerometer
3. The angle-of-attack indicator
4. The vertical gyro indicator

7-52. What is the reading on the accelerometer of an aircraft weighing 40,000 pounds and traveling in straight-and-level flight?

1. +2 g
2. +1 g
3. 0 g
4. -1 g

7-53. An aircraft weighed 10,000 pounds and has a lift equal to 20,000 Pounds. Which of the following readings will the accelerometer show?

1. -2 g
2. 0 g
3. +1 g
4. +2 g

7-54. The standard Navy aircraft clock has what type of movement?

1. 12-hour, 8-day
2. 24-hour, 8-day
3. 12-hour, 12-day
4. 24-hour, 12-day

7-55. What is the purpose of filling the bowl of an aircraft direct-reading compass with a liquid?

1. To keep the surface of the compass card smooth
2. To slow the movement o+ the compass card
3. To compensate for pressure changes
4. To magnify the compass card

7-56. What is the purpose of the lubber line on the direct-reading compass?

1. To reduce card oscillations
2. To lock the card into position
3. To serve as a reference mark when reading the card
4. To enable the compass to be used as a standby unit

7-57. The standby attitude indicator is capable of displaying a maximum of how many degrees of roll?

1. 79°
2. 92°
3. 180°
4. 360°

Learning Objective: Recognize the operating principles and characteristics of various engine instrument systems, including tachometer, temperature indicating, fuel flow, oil pressure, fuel pressure, oil temperature, exhaust nozzle indicating, and torquemeter. (This objective is continued in assignment 8.)

7-58. A jet engine's tachometer is referenced to a percentage of what RPM?

1. Flight idle
2. Cruise
3. Takeoff
4. Military

7-59. The indicator in a tachometer system is designed to respond to changes in

1. frequency
2. current
3. voltage polarity
4. voltage amplitude

7-60. What is the principle difference between a two-pole and a four-pole tachometer generator?

1. The way their outputs are fed to the indicator
2 The way they mount on the engine
3. The way their stators are constructed
4. The polarity of their rotors

IN (ANSWERING QUESTIONS 7-61 AND 7-62, REFER TO FIGURE 6-45 IN YOUR TEXT.

7-61. At high speeds, the armature of a synchronous motor is brought into synchronism by which of the following components?

1. Hysteresis disk
2. Hysteresis disk and the permanent magnet
3. Drag disk
4. Hysteresis and drag disks

7-62. What is the purpose of concentrating the flux near the outside edge of the drag disk?

1. To provide the maximum torque to weight ratio
2. To stabilize the armature rotational speed
3. To eliminate the effects of temperature changes
4. To minimize the amount of friction encountered by the armature

7-63. Which of the following are characteristics of the vertical scale indicator?

1. Its small size and light weight
2. Its light weight and ease of maintenance
3. Its compactness and easily readable scale
4. Its compactness and ease of maintenance

7-64. Activation of the test switch in a vertical scale indicating system will cause the RPM indicator to read what percentage of RPM?

1. 40%
2. 60%
3. 80%
4. 100%

IN ANSWERING QUESTIONS 7-65 AND 7-66, REFER TO FIGURE 6-48 IN YOUR TEXT.

7-65. When the galvanometers in a Whetstone bridge thermometer indicates zero, which of the following circuit conditions exist?

1. The bulb current and current through resistor Y are equal
2. The sum of the voltage drop across X and Z equals the sum of the voltage across the bulb and Y
3. The combined resistance of X plus Y equals the resistance of Z, plus bulb resistance
4. Each of the above

7-66. Which of the following quantities is indicated on the meter scale?

1. Resistance of X
2. Temperature of the bulb
3. Voltage between A and B
4. Current flow between A and B

7-67. Refer to figure 6-49 in your text. In normal operation, an unbalance in the radiometer bridge circuit is caused by a change of resistance in which of the following components?

1. R1
2. The thermometer bulb
3. The centering potentiometer
4. R2

7-68. Thermocouple indicators operate on which of the following principles?

1. Dissimilar metal junctions produce an electromotive force when heated
2. Changes in temperature cause changes in junction adhesion, producing an electromotive force
3. Changes in temperature cause changes in junction size, producing an electromotive force
4. Different metals bend at different rates when heated, producing an electromotive force

7-69. A total of how many dual-unit thermocouples are mounted in each engine turbine inlet casing of the P-3 aircraft?

1. 12
2. 18
3. 24
4. 36

7-70. What is the purpose of routing engine turbine inlet temperature thermocouple wiring through a separate harness to the TIT indicator?

1. To shield the thermocouples from heat
2. To concentrate heat on the thermocouples
3. To protect the bridge circuit of the cold junction compensator
4. To prevent outside signals from changing the average voltage produced by the thermocouples

A S S I G N M E N T 8

Textbook Assignment: "Aircraft Instruments" and "Compass and Inertial Navigation Systems." Pages 6-45 through 7-20.

Learning Objective (Continued): Recognize the operating principles and characteristics of various engine instrument systems, including tachometer, temperature indicating, fuel flow, oil pressure, fuel pressure, oil temperature, exhaust nozzle indicating, and torquemeter.

8-1. Thermocouples in an engine exhaust system convert exhaust gas temperature into which of the following units of measurement?

1. Millivolts
2. Milliamperes
3. Milliwatts
4. Milliohms

IN ANSWERING QUESTIONS 8-2 AND 8-3, REFER TO FIGURE 6-53 IN YOUR TEXT.

8-2. In a fuel flow transmitter, the incoming fuel is directed against what component?

1. Ring magnet assembly
2. Synchro transmitter
3. Hairspring
4. Vane

8-3. What force moves component 4 of the fuel flow transmitter?

1. The rotation of component 3
2. The mechanical force of component 2
3. The magnetic force of component 5
4. The electrical power of component 8

8-4. When the input fuel pressure to the fuel flow transmitter becomes excessively high, the instrument is bypassed by what transmitter component?

1. Relief valve
2. Baffle valve
3. Check valve
4. Intake valve

8-5. The fuel flow transmitter converts fuel flow into an electrical signal, which represents the fuel flow in pounds per hour. This signal is transmitted to what component in the system?

1. The transmitter synchro receiver
2. The fuel control regulator
3. The synchro receiver in the fuel flow indicator
4. The bypass valve solenoid in the fuel control regulator

8-6. In the fuel flow transmitter, what component eliminates the swirling motion of the incoming fuel?

1. Spiral springs
2. Straightening vanes
3. Rotating impeller
4. Drum magnets

8-7. Refer to figure 6-54, view B, in your text. What quantity of fuel is remaining in the fuel cells?

1. 99 pounds
2. 999 pounds
3. 9,990 pounds
4. 99,900 pounds

8-8. In the fuel flow totalizer indicator, what component causes the pointer to deflect proportionally to the fuel being consumed?

1. The friction clutch of the motor shaft
2. The magnetic drum and cup linkage
3. The mechanical gear train
4. The direct coupling of the motor to the shaft

8-9. In a synchro oil pressure system, the movement of the indicator needle depends on which of the following conditions?

1. Oil pressure in the engine
2. Sensing the action of the oil pressure transmitter
3. Voltages set up in the synchro stators
4. Each of the above

8-10. Refer to figure 6-60 in your text. What is the purpose of the vent on the fuel pressure transmitter?

1. To allow the transmitter to accurately measure the differential pressure between the pump and the atmosphere
2. To ensure synchro cooling when aircraft engines are running
3. To equalize pressure in the transmitter with that in the pressure converter
4. To vent moisture in the transmitter case due to condensation

8-11. Refer to figure 6-61 in your text, Movement of the transmitter potentiometer will have which of the following results?

1. Removes 28 volts from one of the coils in the indicator
2. Removes 28 volts from both coils in the indicator
3. Moves the nozzle position indicator to the OFF position
4. Applies a signal to the nozzle position indicator

8-12. The torquemeter system operates on the principle that engine loading will have which of the following results?

1. Produce a measurable change in engine RPM
2. Produce a measurable coupler change between the splines of the two shafts
3. Create a slight twist, which is detected by magnetic pickups and measured electronically
4. Creates shaft twist, which causes two magnets to measure the distance from two toothed flanges

Learning Objective: Recognize the operating principles and characteristics of miscellaneous aircraft instrument systems, including fuel quantity, hydraulic pressure, and position indicating systems.

8-13. In what units of measurement do capacitive-type fuel quantity gauges indicate the fuel quantity in a tank?

1. Gallons
2. Pounds
3. Cubic inches
4. Percentages

8-14. Refer to figure 6-65 in your text. The capacitance of the fuel gauge capacitor depends on which of the following factors?

1. The area of the plates
2. The distance between the plates
3. The dielectric constant
4. Each of the above

8-15. Refer to figure 6-65 in your text. Which of the following conditions exists in the circuit as the fuel quantity increases?

1. Tank unit capacitance increases, tank unit leg current decreases, and transformer voltage and voltage across the voltmeter are in phase
2. Tank unit capacitance increases, tank unit leg current increases, and transformer voltage and voltage across the voltmeter are in phase
3. Tank unit capacitance decreases, tank unit leg current decreases, and transformer voltage and voltage across the voltmeter are out of phase
4. Tank unit capacitance decreases, tank unit leg current increases, and transformer voltage and voltage across the voltmeter are out of phase

8-16. The indicator’s motor direction of rotation is determined by a comparison of what characteristics of two voltages?

1. Polarity
2. Phase
3. Amplitude
4. Frequency

8-17. Refer to figure 6-67 in your text. As the fuel level varies, the balance of the bridge is maintained by the automatic adjustment of what variable resistor?

1. R121
2. R122
3. R128
4. R129

8-18. If two or more fuel tank units are connected in parallel, the effects of what condition is minimized?

1. A decrease in fuel
2. An increase in fuel
3. Variations in aircraft attitude
4. Irregularities in fuel tank shape

8-19. Which of the following conditions will cause the dielectric constant and fuel density to deviate?

1. Weight and temperature of the fuel
2. Temperature and composition of the fuel
3. Composition of the fuel and shape of the fuel tank
4. Temperature of the fuel and shape of the fuel tank

8-20. What unit of measurement is indicated by hydraulic pressure indicators in most naval aircraft?

1. Pounds per square inch
2. Pounds per square foot
3. Pounds per second
4. Pounds per minute

8-21. In a dc position-indicating system, what is the purpose of the copper cylinder in the indicator?

1. To aid the magnetic field
2. To maintain equal coil spacing
3. To dampen pointer oscillation
4. To position the transmitter brushes

Learning Objective: Identify the various procedures used to maintain, troubleshoot, test, interchange, protect, ship, and handle aircraft instruments.

8-22. Which of the following procedures should you follow to ensure the accuracy of aircraft instruments?

1. Replace them rather than adjust them
2. Replace them at regular intervals
3. Periodically subject them to functional tests
4. Periodically readjust the adjustable mechanisms

8-23. What is indicated by a red mark on an instrument glass?

1. The normal operating range of the instrument
2. Glass slippage
3. A critical limit
4. A maximum limit

8-24. What is the purpose of the white index mark painted at the bottom center of all instruments color-marked for operating ranges?

1. To set the pointer at zero reference
2. To designate the 6 o'clock position of the indicator for mounting purposes
3. To be used as a guide for mounting the lighting masks
4. To show whether or not the glass cover has moved after the operating ranges have been marked

8-25. You should perform which of the following checks during the daily inspection of an aircraft's instrument panel?

1. For the proper operation of caging and setting knobs
2. For the proper operation of lights
3. For loose or cracked cover glass
4. Each of the above

8-26. Which of the following statements about the lubrication of aircraft instruments is correct?

1. Lubrication is limited to that required for the bearings
2. Squadron personnel rarely lubricate any part of the instruments
3. Lubrication is done by AMs under the direction of AEs
4. Lubrication is limited to that required by the shafts

8-27. To what publication should you refer for detailed information on aircraft tubing and tubing repair?

1. NAVAIR 01-1A-8
2. NAVAIR 16-1-540
3. NAVEDTRA 10349-E
4. NAVEDTRA 10348-F

8-28. Rigid tubing in modern aircraft may be made from which of the following metals/alloys?

1. Copper
2. Aluminum alloy
3. Corrosion-resistant steel
4. Both 2 and 3 above

8-29. Where are identification markings located on rigid tubing used in naval aircraft?

1. Near the fittings and in each compartment
2. Midway between each pair of fittings
3. Not more than 1 inch from and on both sides of each fitting
4. Anywhere on the fittings

8-30. When identification tape is used on rigid tubing in military aircraft, the function of the tubing is identified by the

1. wording on the 3/4-inch-wide tape
2. color, wording, and symbols on 1-inch-wide tape
3. color of a 1/2-inch tape
4. color and wording on a 1-inch tape

8-31. Refer to table 6-3 in your text. Of the following groupings, which one consists of material classified as physically dangerous and should have PHDAN printed on identifying tape or lines carrying the material?

1. Carbon dioxide, gaseous oxygen~ nitrogen gas, and freon
2. Carbon dioxide, liquid nitrogen, liquid oxygen, and alcohol
3. Carbon dioxide, liquid nitrogen, nitrogen gas, and JP-4 fuel
4. Carbon dioxide, liquid nitrogen, gaseous oxygen, and liquid petroleum gas

8-32. What method is used to identify the specifications of flexible tubing installed on naval aircraft?

1. The type of fittings
2. Colored tape bands applied to the tubing
3. A code of dots and dashes printed on the tubing
4. Color-coded bands of paint printed on the tubing

8-33. Which of the following statements about the replacement of high- and low-pressure flexible hose is correct?

1. Low-pressure hose may be fabricated locally, and high-pressure hose must be obtained through supply
2. Both types of hose must be obtained through supply
3. High-pressure hose may be fabricated locally, and low-pressure hose must be obtained through supply
4. Both types of hose may be fabricated locally

8-34. What action should you take to prevent flexible hose from being pulled loose from the engine due to engine movement during hose installment?

1. Use cushion clips to hold the hose
2. Use support mounts every 24 inches
3. Allow slack between the last hose support and the connection to the engine
4. Properly shroud the hose

8-35. Refer to table 6-5 in your text. The pointer on the fuel flow indicator swings to the side of the dial and a squeal is heard from the instrument. Which of the following conditions could cause this malfunction?

1. A short in the system
2. Power leads reversed to the stator
3. Both 1 and 2 above
4. An open stator lead

8-36. When it is necessary to substitute one aircraft instrument for another, which of the following precautions should you take?

1. Make sure that the instruments have the same stock number
2. Make sure that the instruments have the same manufacturer's part number
3. Make sure that the instruments have the same stock number and manufacturer's part number
4. Flake sure the instruments are made by the same manufacturer

8-37. What method should you use to dispose of containers in which instruments are received?

1. Return them to supply
2. Route them to salvage for final disposition
3. Destroy them or label them NOT FOR REUSE FOR INSTRUMENTS
4. Retain them for future use in packaging instruments

Learning Objective: Recognize the navigation-related terms and definitions that are basic to compass and inertial navigation systems.

8-38. Which of the following statements describes the purpose of air navigation equipment?

1. It is used to measure distance and time
2. It is uses to determine aircraft position
3. It is used to determine the direction an aircraft must fly to reach its destination
4. Each of the above

IN ANSWERING QUESTIONS 8-39 THROUGH 8-42, SELECT FROM COLUMN B THE TERM FOR EACH DEFINITION LISTED IN COLUMN A. ALL ANSWERS ARE USED.

	A. DEFINITION	B. TERM
8-39.	The intended horizontal direction of travel	1. Course
		2. Heading
8-40.	The horizontal direction of one terrestrial point from another	3. Bearing
		4. Distance
8-41.	The horizontal direction in which an aircraft is pointed	
8-42.	The separation between two points measured in some scaler quantity	

8-43. Planes that pass through the earth perpendicular to the earth's rotational axis and intersect with the earth's surface to form circles are known as

1. parallels
2. perpendiculars
3. meridians
4. prime meridians

8-44. Relative to the earth's surface, if an aircraft were at latitude 37° S and longitude 83° E, it would be at which of the following positions?

1. 37° south of Greenwich, England, and 83° east of the equator
2. 83° east arid 37° south of Greenwich, England
3. 83° east of Greenwich, England, and 37° south of the equator
4. 37° south and 83° east of the equator

8-45. Convert the following coordinates from decimal form to degree/ minutes/seconds form:

Latitude--47.7° N
Longitude--131.45° E

1. 47°60'4" N and 131°45' E, respectively
2. 42°36' N and 48°36' E, respectively
3. 47°42' N and 131°27' E, respectively
4. 48°15' N and 131°75' E, respectively

IN ANSWERING QUESTIONS 8-46 THROUGH 8-49, SELECT FROM COLUMN B THE TERM FOR EACH DEFINITION LISTED IN COLUMN A. ALL ANSWERS ARE USED.

	A. DEFINITION	B. TERM
8-46.	An irregular line connecting points on a map of the earth, indicating where a compass points to true north	1. Variation
		2. Agonic line
		3. Isogonic line
8-47.	An irregular line connecting points on a map of the earth, indicating where there is the same variation from true north	4. Deviation
8-48.	The angular difference between the directions of true north and magnetic north at a particular location	
8-49.	The angular difference between the direction of the earth's magnetic field and the compass reading due to nearby electromagnetic influences	

8-50. If variation is 6° west and deviation is 1° west, the compass error is equal to

1. -6° + 1° = 5° east
2. -6° - 1° = 7° east
3. 6° + 1° = 7° west
4. 6° - 1° = 5° west

8-51. If variation is (-) 3° and deviation is (+) 4°, the compass error is equal to

1. (-)3° + (+)4° = (+)1° or 1° east
2. (-)3° - (+)4° = (-)7° or 7° east
3. (-)3° + (+)4° = (+)1° or 1° west
4. (-)3° - (+)4° = (-)7° or 7° west

8-52. The difference between the direction of the earth's magnetic field and the horizontal at any location on the earth's surface is known as the

1. magnetic dip
2. magnetic variation
3. surface variation
4. surface deviation

8-53. A line on a map that connects all places having equal dip angles is known as an

1. agonic line
2. aclinic line
3. isobaric line
4. isoclinic line

8-54. The aircraft navigator is plotting the present position by using aircraft course and speed, last known position, elapsed time, and any changes in speed and course since the last known position. What type of navigation is the navigator using?

1. Mapping
2. Pilotage
3. Inertial
4. Dead reckoning

8-55. Accelerometers in inertial navigation equipment are mounted on a platform that remains perpendicular to the earth's gravitational field at all times to sense

1. gravity changes only
2. vehicle accelerations only
3. gravity changes and vehicle accelerations

Learning Objective: Recognize the operating principles and features of compass systems, the attitude reference system, and associated sensors and indicators.

QUESTIONS 8-56 AND 8-57 RELATE TO A COMPASS SYSTEM THAT PROVIDES AIRCRAFT HEADING INFORMATION IN ELECTRICAL SIGNAL FORM.

8-56. In the compass system, what unit senses the direction of the flux lines of the earth's magnetic field?

1. The gyro amplifier
2. The flux valve
3. The magnetic amplifier
4. The direct-reading compass

8-57. A displacement gyro provides which of the following electrical signals?

1. Azimuth and pitch only
2. Pitch and roll only
3. Roll and azimuth only
4. Azimuth, pitch, and roll

QUESTIONS 8-58 THROUGH 8-60 RELATE TO VERTICAL GYROSCOPE OPERATION. IN ANSWERING THESE QUESTIONS, SELECT FROM COLUMN B THE CONTROL TRANSMITTER THAT INITIATES EACH OF THE SIGNALS LISTED IN COLUMN A. ALL ANSWERS ARE NOT USED.

	A. SIGNALS	B. CONTROL TRANSMITTERS
8-58.	Roll signals to the AFCS control amplifier	1. Outer roll control transmitter
8-59.	Roll signals to indicators	2. Pitch the control transmitter
8-60.	Pitch signals to the indicators	3. Roll control transmitter
		4. Pitch servo control transmitter

8-61. The directional gyro pitch gimbal is maintained perpendicular to the surface of the earth by a motor-generator that is driven by the amplified output of

1. microswitches
2. a generator dampened by a pendulum-type weight
3. the vertical gyro's pitch servo control transmitter
4. electrolytic switches mounted on the directional gyro's pitch gimbal

8-62. The aircraft horizontal situation indicator will provide which of the following items of information?

1. The selected course to an electronic ground station
2. The aircraft's deviation from a selected course
3. The pictorial bearing and the distance in nautical miles to an electronic ground station
4. Each of the above

8-63. The distance counter of the bearing-distance-heading indicator displays which of the following information?

1. Distance to base
2. Distance to target
3. Distance to a ground electronic station
4. Each of the above

IN ANSWERING QUESTIONS 8-64 THROUGH 8-67, SELECT FROM COLUMN B THE MODES THAT SHOULD BE USED FOR THE CONDITIONS LISTED IN COLUMN A. ALL ANSWERS ARE USED.

	A. CONDITIONS	B. MODES
8-64.	Used in areas where the earth's magnetic field is appreciably distorted	1. SLAVED
		2. FREE
		3. COMPASS
8-65.	Used in normal conditions	
8-66.	Used when the displacement gyro's signals are not reliable	
8-67.	Used when the flux valve signal is unreliable	

8-68. What component provides the timing, switching, and voltages used for erection, monitoring, and leveling the AHRS displacement gyroscopes?

1. Compass system controller
2. Amplifier power supply
3. Compass adapter compensator
4. Displacement gyro motor-generator

8-69. The compass adapter compensator provides correct heading information to the attitude indicator when it is operating in which of the following modes?

1. FREE
2. COMPASS
3. SLAVED
4. Each of the above

8-70. The latitude degrees control on the compass controller provides a signal to the directional gyroscope for compensation of

1. mechanical drift
2. gyroscope rigidity
3. apparent drift
4. magnetic variation

8-71. In which of the following modes of operation will the directional gyro provide only azimuth information to the indicator?

1. FREE
2. COMPASS
3. SLAVED
4. Each of the above