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CHAPTER 2

ELECTRICAL MAINTENANCE AND TROUBLESHOOTING

Aircraft maintenance falls into two broad categories; scheduled maintenance and unscheduled maintenance. Scheduled maintenance is the action taken to reduce or eliminate failure and prolong the useful life of the equipment. Unscheduled maintenance is the action 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 Aviation Electrician's Mate (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 (NAVAIR), 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 (OJT), and from training manuals.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify safety precautions regarding aircraft, personnel, material, and tools.
2. Restate troubleshooting techniques, including how to analyze, detect, and correct faults in electrical equipment.
3. Describe the various types of general-purpose test equipment associated with aircraft electrical maintenance, and identify tests the AE will make using these equipment.
4. Recognize aircraft wire and cable characteristics and various means of identifying and splicing wires and cables.
5. List the use and characteristics of aircraft electrical and mechanical hardware.
6. Explain the aircraft electrical motor and generator maintenance procedures.
7. Specify the characteristics of printed circuits, including modules and potted components, and recognize circuit construction features.
8. Describe the functions, capabilities, and operating characteristics of various types of aircraft test equipment.
9. Identify the hazards to Electrostatic Discharge (ESD) sensitive devices and their preventative measures through proper handling and packaging techniques.

SAFETY

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.

Knowledge of first aid procedures is important. 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). The life of a shipmate could easily depend upon your CPR and first aid skills.

You should study the CPR training section of *Basic Military Requirements (BMR),* NAVEDTRA 14325. CPR training is a MANDATORY requirement for all AE's. Personnel could also benefit from additional first aid training. CPR training and certification is available at most commands, many Navy medical facilities, as well as local fire stations and Red Cross or American Heart Association agencies. It is important for you to be currently certified in the special skills of CPR. You must remain current on your CPR certification.

WARNING

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

Cooperation of personnel and being vigilant prevents most accidents that occur in noncombat operations. You can learn more about general aviation safety by studying *Aviation Electricity and Electronics—Maintenance Fundamentals Reference,* NAVEDTRA 14318.

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 circuit breakers, 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 and in the electrical or battery shop. In addition to these, you need to know the authorized fire-fighting methods for electrical fires, procedures for treatment of burns, and artificial respiration.

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

- *Airman,* NAVEDTRA 14014
- *Navy Safety and Occupational Health (SOH) Program Manual for Forces Afloat,* OPNAVINST 5100.19 (series)
- *Navy Safety and Occupational Health Program Manual,* OPNAVINST 5100.23 (series)

These publications contain a variety of operations and functions in the Navy; therefore, they are basic and general in nature. Activities use these manuals 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 anti-collision 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.

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 non-conducting 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 CPR should be standing by in case of injury due to electrical shock.

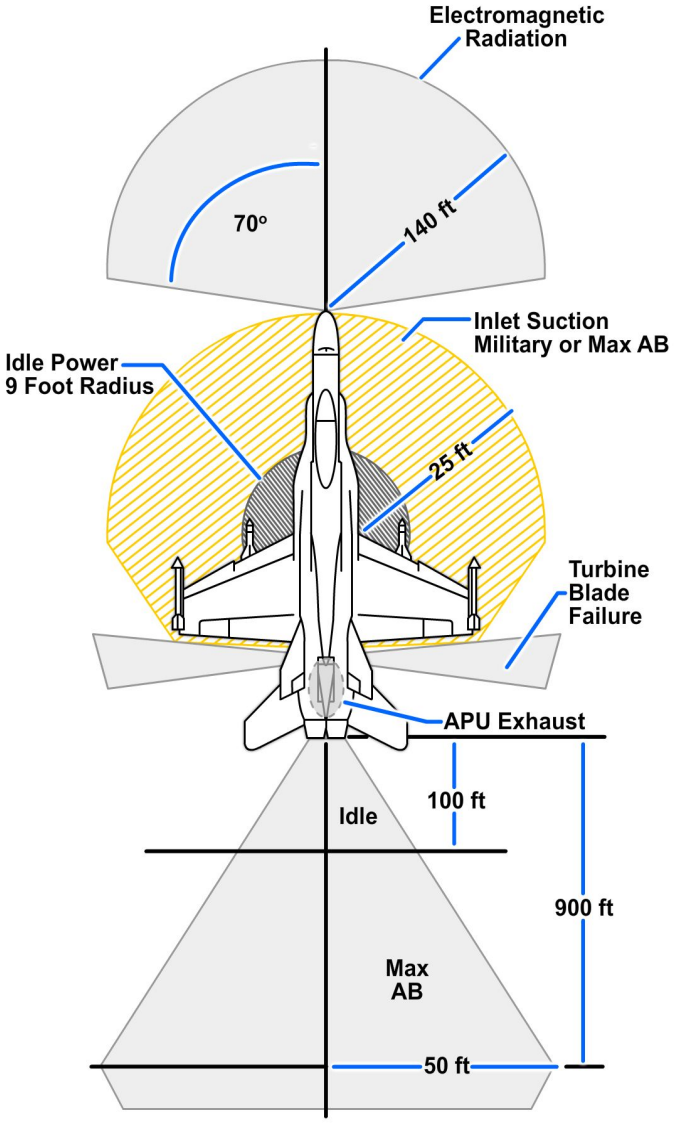


Figure 2-1 — Radiation, intake, exhaust, and turbine blade failure danger areas.

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. Always use authorized tools, utilization of locally manufactured tools and insulation devices are explicitly unauthorized except as prescribed by applicable instructions and manuals.

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 non-conducting soles when available. Don't wear flammable articles.

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 and treat low voltage equipment with the same precautions as high voltage equipment. 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.

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 Alpha, Bravo, and Charlie. Class Alpha fires involve wood, paper, cotton and wool fabrics, rubbish, and the like. Class Bravo fires involve oil, grease, gasoline and aircraft fuels, paints, and oil-soaked materials. Class Charlie 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 Alpha or Bravo fires. Since class Charlie fires involve electrical circuits, electrical shock is an added hazardous condition. Whenever possible, immediately de-energize any electrical equipment exposed to class Alpha or class Bravo 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 (CO2) 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, chiefly composed of potassium bicarbonate (more commonly known as Purple-K Powder or PKP), 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.

WARNING

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 electronic equipment spaces. The fog is a fine diffusion or mist of water particles, with very little conductivity. However, there is still 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 pounds per square inch (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 C02 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 keeps 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 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

Prior to use of any chemical compound ensure that you have reviewed and understand all hazards, precautions and treatments provided by the Material Safety Data Sheets (MSDS) for that compound. MSDSs will be available in a central location for all compounds used within a work center or command spaces, see your supervisor or Hazardous Materials (HAZMAT) Program Manager for details pertaining to your command.

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 non-operating 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. When cleaning of equipment or spaces is required use only authorized cleaning materials and quantities.

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 vaporize 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. 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 your skin, it may irritate the skin, particularly under soaked clothing or gloves. Repeated contact with gasoline removes protective oils from the skin, causing drying, roughening, chapping, and cracking, and in some cases, infection. Remove clothing or shoes soaked with gasoline at once. Wash gasoline from the skin with soap and water. 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 shares some of the characteristics of gasoline. Due to other 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. Blown 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 shall 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. It is recommended that AE's 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. It’s not safe to lean against any machine that is started or may start to move. Don’t start a machine until you fully understand its operation. Treat a machine with respect; there is no need to fear it.

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.

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, 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. Authorized insulated tools are available through supply. Only utilize authorized tools; do not modify tools except as specifically prescribed by applicable instructions or maintenance manuals.

> **WARNING**
>
> Unauthorized modification of tools may present hazards due to unknown insulating material limitations and properties.

Power Tools

Working as an AE, you will use 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 people, causing burns, 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.

Significant lead exposures can occur during soldering with torches. Lead has long been a recognized health hazard. Lead can damage the nervous system, kidneys and reproductive systems. Chronic lead exposure can initially damage the blood forming organs. Higher levels can result in reproductive dysfunction in both men and women, and it can cause peripheral nerve and central nervous system changes. Lead inhibits heme synthesis (red blood cell production) and at high levels leads to anemia.

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 digital fluke meter 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 ground line.

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.

TROUBLESHOOTING TECHNIQUES

You will spend most of your time troubleshooting the equipment in squadron aircraft. You will 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. Review the system operation and components in the MIMs.
2. Analyze the symptom.
3. Detect and isolate the trouble.
4. 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:

1. MIMs
2. Schematics
3. Records on the equipment

Detect and Isolate

The first things to do when troubleshooting is to review the system in the MIM then 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 this occurs reset or replace the circuit protector as required 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.

Utilizing the applicable MIM, you can identify which pin in a connector provides 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 digital multimeter to find out if a power circuit is delivering power to the proper place. However, the digital multimeter volts selection only indicates the absence of voltage. The ohms selection on the digital multimeter can identify the type of fault, including 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 are used when the fault in the unit under test is hard to determine or 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 include switch actuators, mounting assemblies, mechanical linkages, and any type of hardware that is part of an electrical system. Even though you cannot check this equipment with a digital fluke meter, 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, which 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; they 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 prevent 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. Where applicable, you may also 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 and Repair Practices,* NAVAIR 01-1A-505 (series). 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 electronic components 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 lose or misplace small parts. They may be 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 ensure the work is inspected by qualified personnel, maintenance/production control is notified and that all Work Orders or maintenance action forms are completed. Officially, the aircraft is down until the proper people are notified and the paperwork is complete.

USE OF BASIC TEST 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 Navy Electricity and Electronics Training Series (NEETS), Module 16, *Introduction to Test Equipment*, NAVEDTRA 14188. Also, when making tests on equipment, you should adhere to the following rules:

1. Always connect a digital fluke meter (current scale) in series—never in parallel.
2. Always connect a digital fluke meter (voltage scale) in parallel—never in series.
3. Never take resistance reading with energized circuitry.
4. On test meters, select the highest range first, and then switch to lower ranges as needed.
5. When you use a digital fluke meter, select a scale that gives a near midscale reading, since midscale is where the meter is most accurate.
6. Turn meter OFF when not in use.
7. Observe polarity when measuring dc voltage or current.
8. Do not place meters in the presence of strong magnetic fields.
9. Never measure the resistance of a meter or a circuit with a meter in it. The high current required for meter operation may damage the meter. This also applies to circuits with low-filament-current tubes and to some types of semiconductors.
10. 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.
11. 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 a digital fluke meter. 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 digital fluke meter 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 digital fluke meter 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 digital fluke meter. The digital fluke meter digital display shows a low resistance (.001 Ohms) because no break exists in conductors A, B, or C. However, checking conductor D, as shown by the reading in the figure, reveals an open. The digital fluke meter shows maximum resistance because current cannot flow in an open circuit. With an open circuit, the digital fluke meter digital display reads 0.L megohms of resistance.

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.

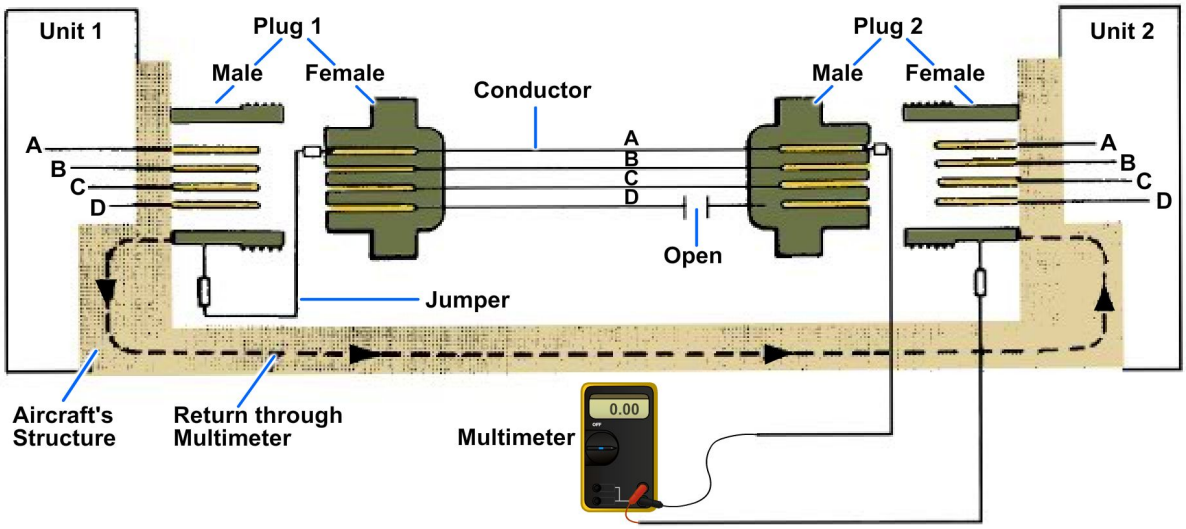


Figure 2-2 — Continuity test.

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.

When testing for grounds, you use a digital fluke meter 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. However, it is possible to have a short between two cables carrying signals and the short not blow the fuse.

You use the resistance setting 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, but also 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.

For the applicable ac or dc voltages, the digital fluke meter is used to test voltages. When you use the digital fluke meter, make sure the meter selection is the correct one for the type of 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 digital fluke meter 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 a digital fluke meter. Where practical, use resistance readings 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 digital fluke meter from the test point to ground. If the suspected stage is good, the digital fluke meter 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 digital fluke meter of the same sensitivity (or greater) as that specified. This is to be sure the digital fluke meter 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 digital fluke meter’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 digital fluke multimeter. Therefore, you must determine the choice of ohmmeter by the resistance ranges available in the various digital fluke multimeters. Small multimeters 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 (*Figure 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. The galvanometer (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 galvanometer reading is 0.

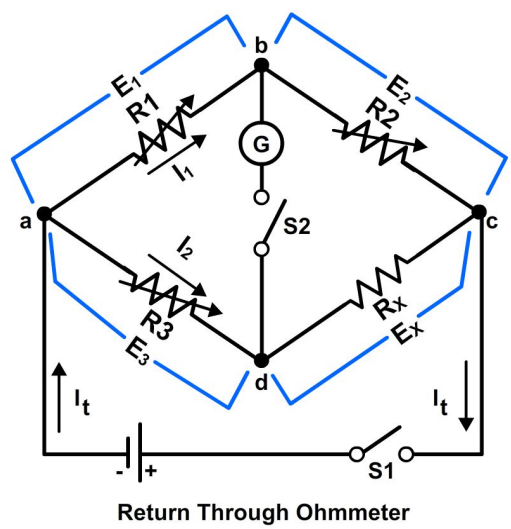


Figure 2-3 — Wheatstone bridge.

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 Rx. The two currents, I1 and I2, unite at point c and return to the positive terminal of the battery. The value of I1 depends on the resistance of R1 and R2, and the value of I2 depends on the resistances of R3 and RX. 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 galvanometer shows no deflection, there is no difference in potential between point's 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.

$$E_1 = E_3$$

$$E_1 R_1 = I_2 R_3$$

$$E_2 = E_X$$

$$I_1 R_2 = I_2 R_X$$

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:

$$\frac{I_1 R_1}{I_1 R_1} = \frac{I_2 R_3}{I_2 R_x}$$

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:

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

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:

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

$$R_X = \frac{100 \text{ x } 200}{60}$$

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

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

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. NEETS, Module 16, *Introduction to Test Equipment,* NAVEDTRA 14188 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 input impedance higher than the vacuum tube voltmeter.

You can use any multi-range 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:

$$E = \frac{\frac{E2 - E1}{E_1 R}}{E_2} + E_2$$

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:

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

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

Digital Multimeters

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. Some digital multimeters have a battery pack for the portable operation.

The Fluke ® model 8808A digital multimeter *(Figure 2-4, view A)* is representative of a portable multimeter presently used in the fleet. It is a small, compact unit capable of measuring 200 mV to 750 Vac and dc voltages 200 mV to 1000 Vdc, resistance 200 ohms (Ω) to 100 MΩ, maximum current range up to 10A, continuity and diode test and frequency range 20hz to 1 Mhz. Standard features provided by the 8808A model include a 5 $\frac{1}{2}$ digit dual fluorescent display that allows two properties of an input signal to be displayed at the same time, measurement rates of 2.5, 20 and 100 samples/second, front-panel setup key for single key access to saved setups, a compare mode to determine if a measurement is within defined limits, and remote operation via the RS-232 interface terminal. The 8808A digital multimeter uses three fuses, one fuse to protect the line-power input and two fuses to protect the current-measurement inputs. Accessories and options besides the premium test lead set are a RS-232 interface cable, a precision electronic probe set, a 2x4 wire ohms 1000 V test lead and switched ac/dc current shunts.

During organizational level troubleshooting, you will often measure voltage, current, and resistance. Rather than using three or more separate meters for these measurements, you can use the Fluke ® digital multimeter 170 series *(Figure 2-4, view B)*. The Fluke ® 170 series digital multimeter gives the operator true voltage and current measurements, 6000 count resolution, manual and automatic ranging and provides frequency capacitance, resistance, continuity and diode measurements. A digital fluke 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 provides one-handed operation.

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.

Safety is a vital concern when working around or near electrical circuits and cannot be overemphasized. To avoid possible electric shock or personal injury while using the VOM, follow these simple guidelines:

1. Do not use multimeters or test leads that appear damaged or not operating properly.
2. Check the test leads for continuity prior to use.
3. Always use proper terminal, switch position and range for measurements.
4. Verify the multimeter's operation by measuring a known voltage.
5. Do not apply more than the rated voltage than the meter is capable of reading.
6. Disconnect circuit power supply and discharge all high-voltage before testing resistance, continuity, diodes, or capacitance.
7. Avoid working alone.

(A) **(B)**

Figure 2-4 — Digital multimeters.

Megger

Ordinary digital fluke multimeters 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 a digital fluke meter. This potential is placed between the conductor and the outside of the insulation. You will use a megger (megohmmeter) for these tests.

The megger *(Figure 2-5)* 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 *Figure 2-5, 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.

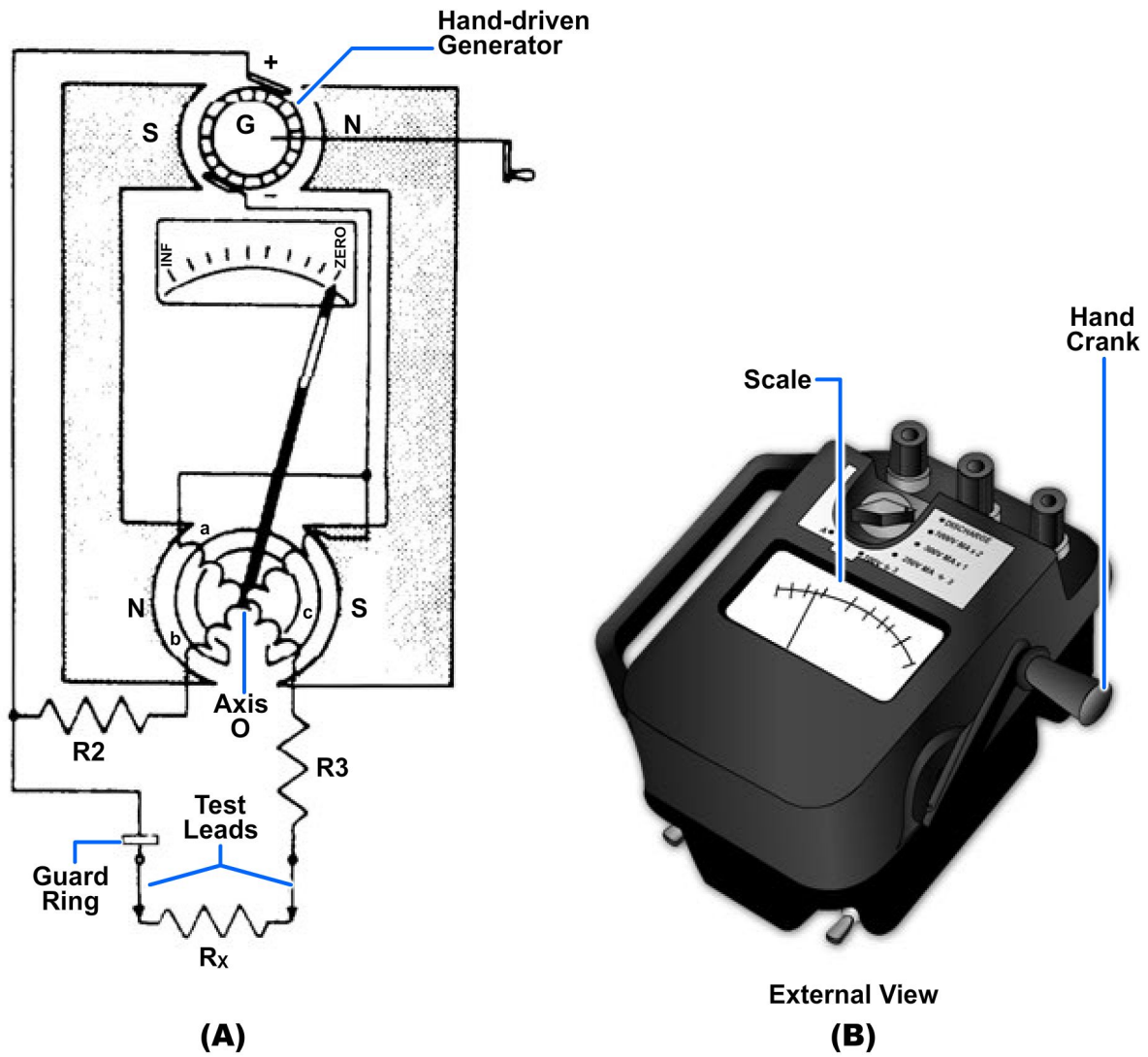


Figure 2-5 — Megger internal circuit and external view.

Coil a connects in series with R3 and unknown resistance RX. The combination of coil a, R3, and RX 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 2-5, 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 RX, 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, 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 RX, 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 2-5, 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.

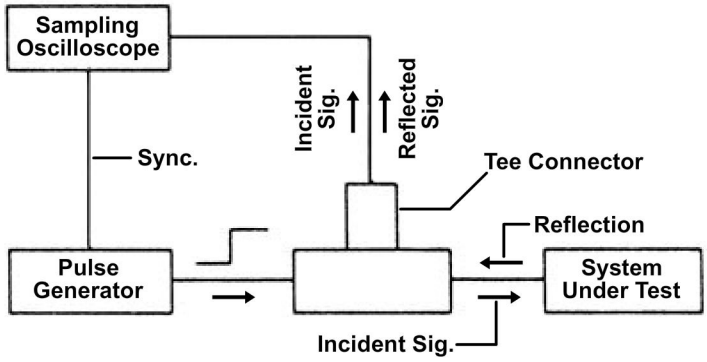


Figure 2-6 — Typical time domain reflectometer.

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 (*Figure 2-6*). 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 feed point 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 limited 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.

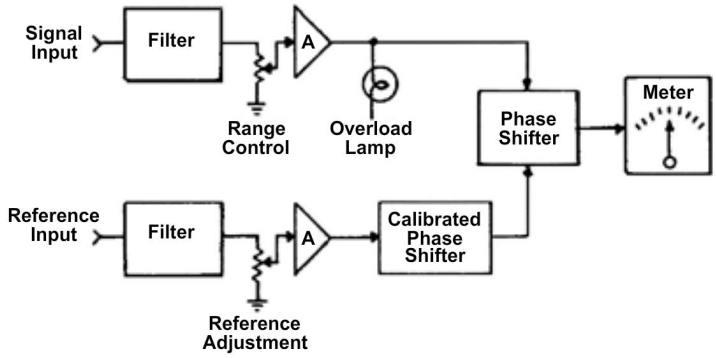


Figure 2-7 — Phase angle voltmeter, block diagram.

The basic block diagram of a phase angle voltmeter is shown in *Figure 2-7*. 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 with the single input, the phase detector output is zero (the cosine of the angle is zero).

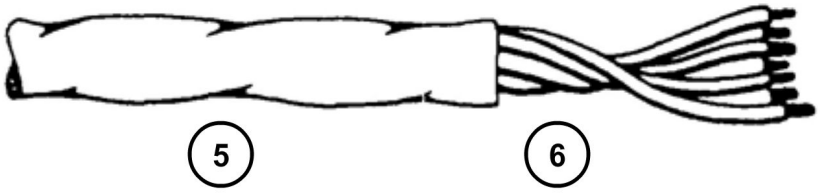
The point where the two signals are in phase or 180 degrees out of phase is the point of maximum deflection on the meter. The difference between the in-phase and 180 degrees out-of-phase points is in the direction of needle swing, not the distance it swings. Upon approaching the point of maximum deflection, 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 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 set up 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.

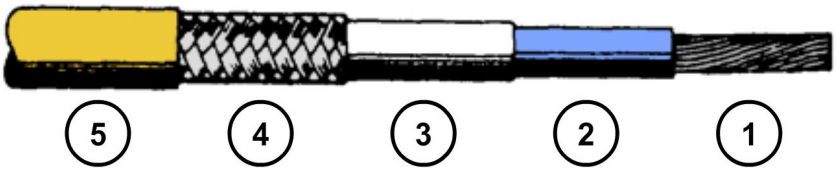
AIRCRAFT WIRE AND CABLES

An important part of aircraft electrical maintenance is determining the correct wire or cable *(Figure 2-8)* 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:

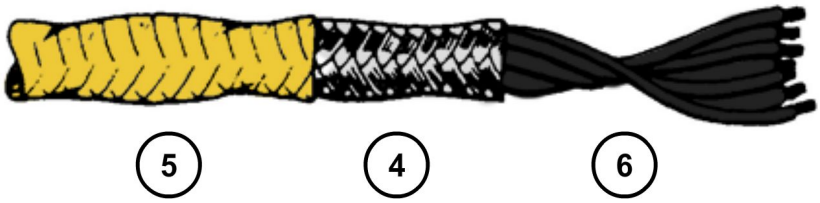
- Two or more insulated conductors contained in the same jacket (multiconductor cable)
- Two or more insulated conductors twisted together
- One or more insulated conductors covered with a metallic braided shield (shielded cable)
- A single insulated center conductor with a metallic braided outer conductor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



A. Multi-Conductor Cable / Jacketed / Twisted



B. Shielded Single Conductor Cable



C. Shielded Multi-Conductor Cable / Jacketed / Twisted

NOTE: Make as required by twisting single conductors

D. Unshielded / Unjacketed / Twisted

1. Conductor
2. Primary Insulation
3. Wire Jacket
4. Braided Tinned Copper Shield
5. Protective Outer Jacket
6. Color Coded Wires (MIL-W-22759, -25030, -81044, -81381)

Figure 2-8 — 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, *Introduction to Electrical Conductors, Wiring Techniques,* and *Installation and Repair Practices,* NAVAIR 01-1A-505 (series). The procedures specified in NAVAIR 01-1A-505 (series) 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 needed to determine 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/point of voltage regulation and load
4. The maximum voltage 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

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 & copper alloy for size 24 through 26.

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 (series) before selecting wires and cables for weight discrepancies.

See below for various wires and cable descriptions:

- **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. Unshielded/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.

Aluminum is softer than copper. 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 unusual because it forms an electrically resistant oxide film on all of its surfaces. 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 deal with this film. Refer to *Cleaning and Corrosion Control,* NAVAIR 01-1A-509 (series). 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 between the two metals, an electrical differential is created, 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 hardens aluminum. This will lead to broken/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 type of 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 2-9*. 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. Multi-conductor cable
4. High-temperature wire with insulation difficult to mark, such as Tetrafluoroethylene (TFE), fiber glass, etc.

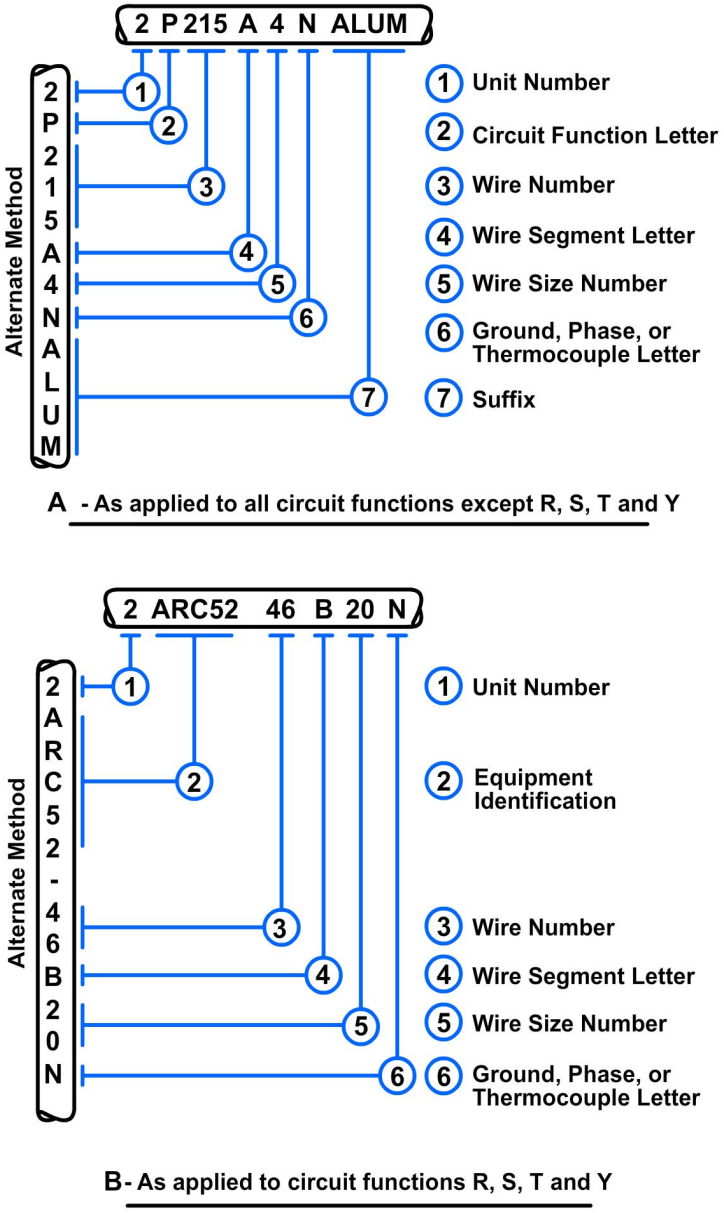


Figure 2-9 — Examples of wire identification coding.

⚠ 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 *(Figure 2-10)*. Also, stamp wires within 3 inches of each junction (except permanent splices) and at each ending 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.

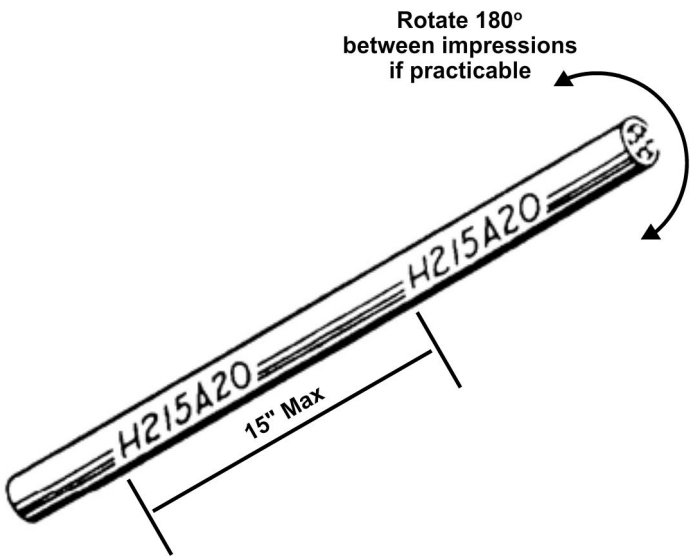


Figure 2-10 — Spacing of identification stamping on wire and cable.

Wiring and Cable Identification Codes

To make maintenance easier, each of the connecting wires in an aircraft have identification. The identification is a combination of letters and numbers that 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 that it is improper to refer to aircraft wire as AWG.
>
> For an in-depth study of wiring specifications, limitations, and repair, you should refer to NAVAIR 01-1A-505 (series).

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 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 are more than 24 segments. Two permanently spliced wires do not require separate segment letters if the splice is for modification or repair.

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, & de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous (electrical)
P	Dc power (wiring in the dc power / power control system is identified by the circuit function letter "P")
Q	Fuel & oil
R	Radio (pulse technique)
S	Radar (navigation & communication)
T	Special electronic
U	Miscellaneous (electronic)
V	Dc power cables & dc control cables for ac systems are identified by the circuit function letter "V".
W	Warning & 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

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→B→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 2-11.*

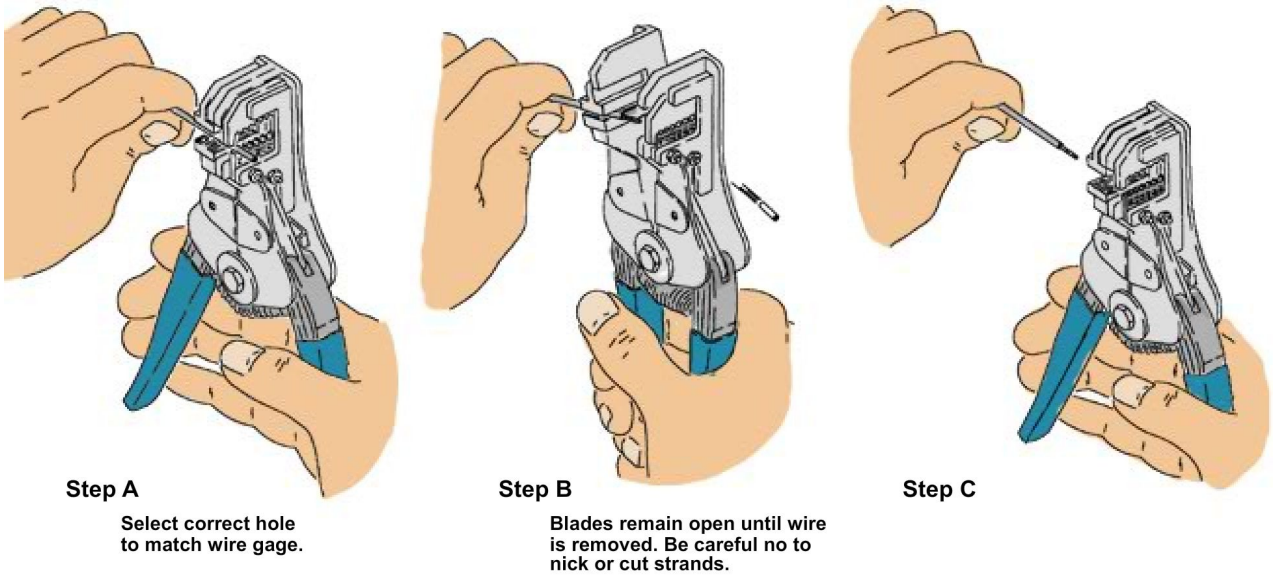


Figure 2-11 — Wire stripping method.

The operation of this basic tool is efficient, 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 2-12* 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 (series) 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.

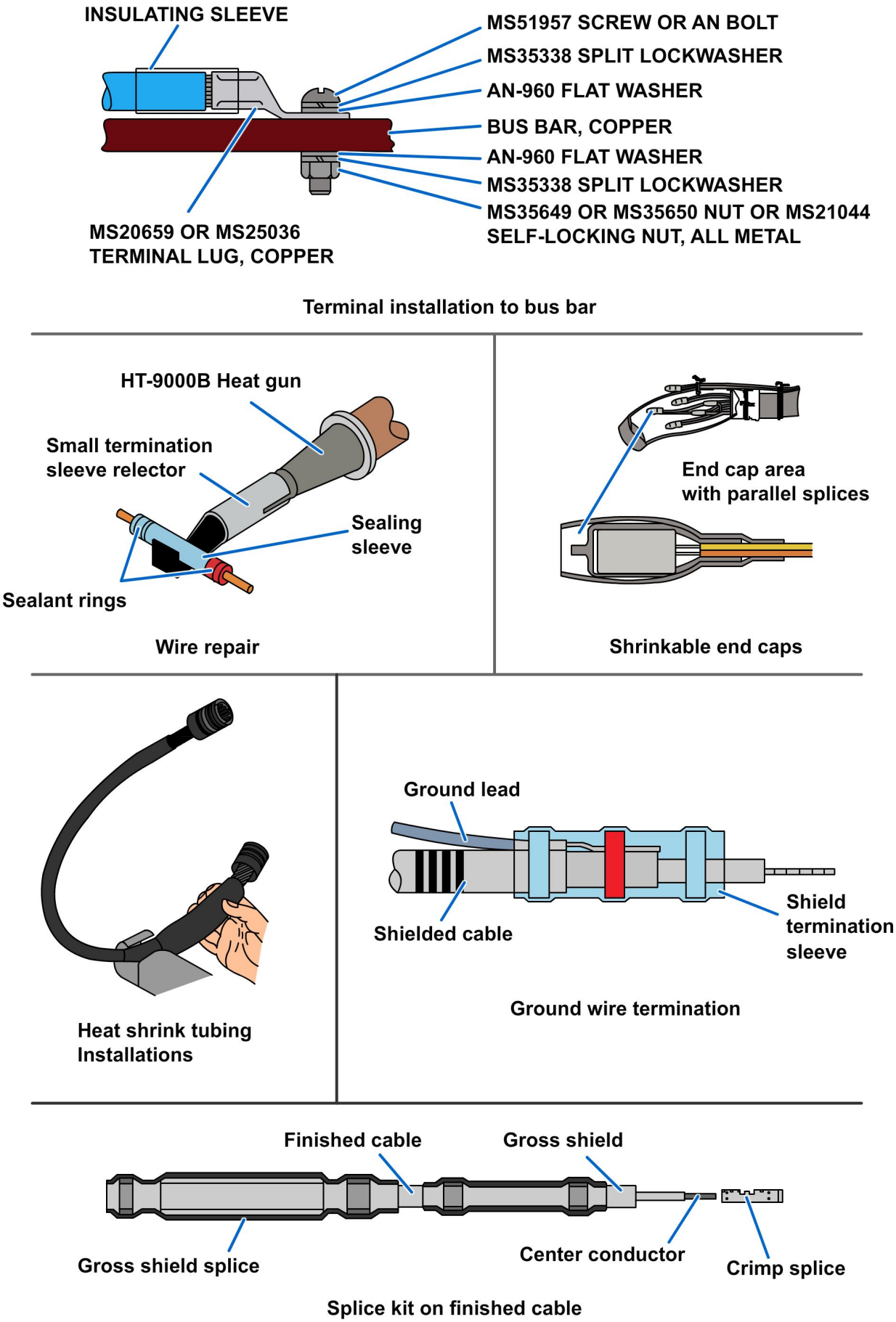


Figure 2-12 — Typical heat shrinkable tubing.

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.

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 & #18	200 Watts

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

AIRCRAFT ELECTRICAL HARDWARE

You shouldn't always reuse 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 the instructions; 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 and Repair Practices*, NAVAIR 01-1A-505 (series), 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 available in various styles. It is usually easy to find screws and bolts that are the same in all respects except the head type. 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 2-13, 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. If you use a mount designed for a lighter unit, it can easily pull away from the base and damage the unit.

The isolation washers in *Figure 2-13, view B,* are used with a particular piece of equipment. You replace these types of washers individually. The vibration isolator washers are made of hollow rubber and locked into place between the top and bottom of the isolator when installed. Inspect these isolators for cracks or splits. If you find damage, replace the complete set all at once.

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 *Figure 2-13, view A*. You need to inspect the bonding strap when inspecting the shock mounts. Replace or repair defective or ineffective bonding straps.

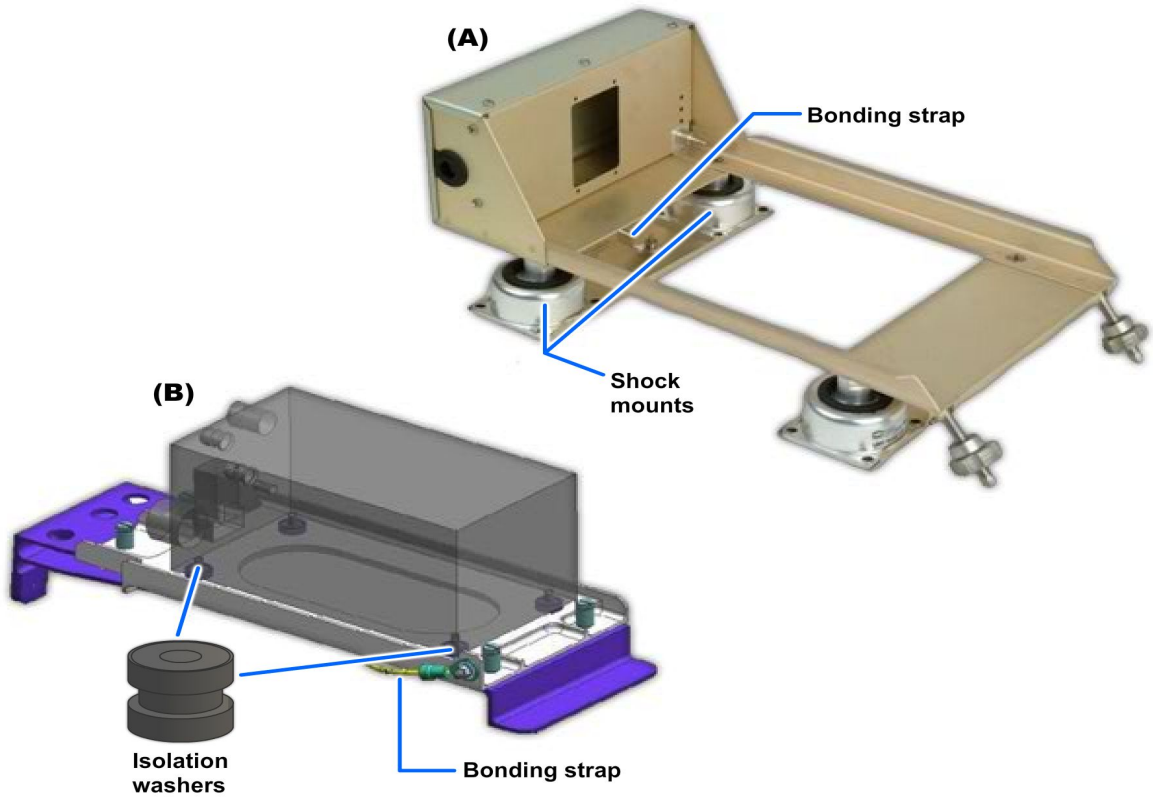


Figure 2-13 — Typical shock mounts.

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 and Repair Practices,* NAVAIR 01-1A-505 (series).

Some common types of subminiature connectors are shown in *Figure 2-14*. They are used on instruments, switches, transformers, amplifiers, relays, etc.

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; every effort must be taken to 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 *(Figure 2-15)*. 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 moisture-proof the connector, if necessary. Fabricating instructions are contained in NAVAIR 01-1A-505 (series).

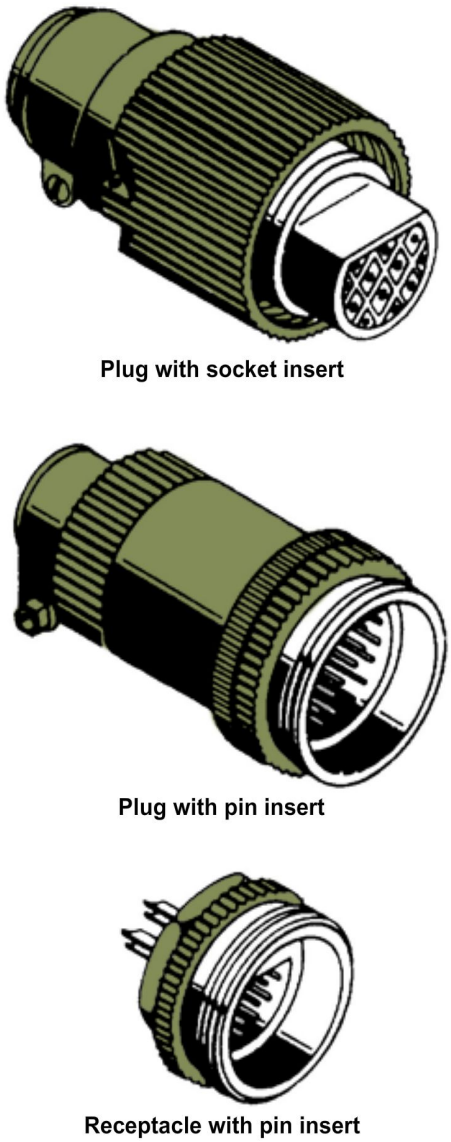


Figure 2-14 — Subminiature connectors.

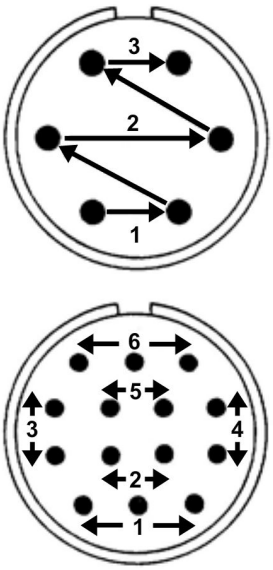


Figure 2-15 — Connector soldering sequence.

Moisture proofing

Present Navy practice is to use potted connectors (moisture-proof or environment-proof connectors). All jet and carrier-type aircraft have potted connectors. On other aircraft, use moisture-proofing sealant on electrical connectors in areas where a chance of failure exists. All 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, moisture-proof all connectors that interconnect flight/basic navigation equipment.

Vibration and lateral pressure fatigue wires at the solder cup. Moisture-proofing 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 2-16. View A* uses a standard non-locking nut. In this installation method, the use of a lock washer is necessary. *Figure 2-16, view B* shows the preferred method.

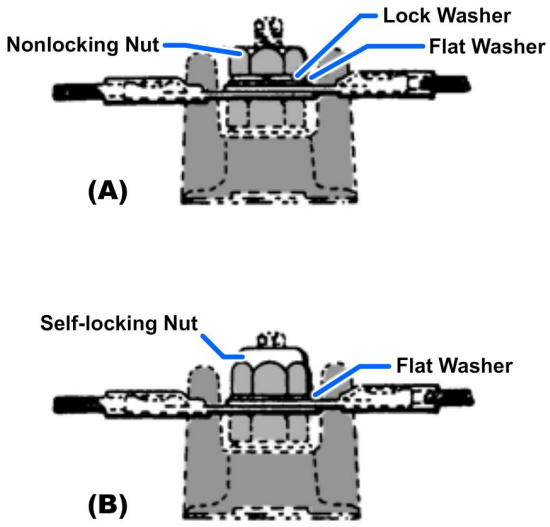


Figure 2-16 — Installation of cable terminals on terminal

When using an anchor nut, or self-locking nut, you omit the lock washer. 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 the equipment with which they are associated. Junction boxes, except boxes labeled "vapor tight", have a drain hole, at the lowest point to drain water, oil, condensate, or other liquids. *Figure 2-17* shows a representative junction box for housing and securing a multitude of relays.

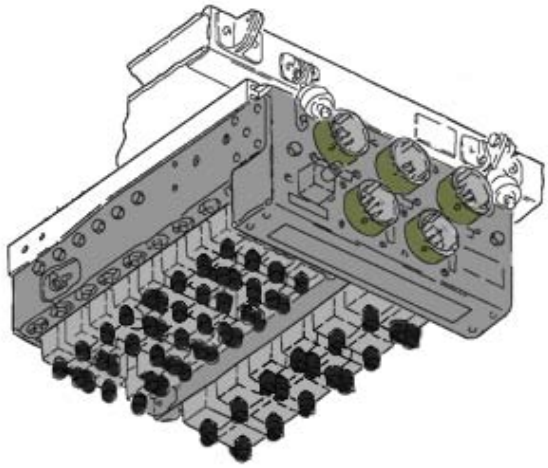


Figure 2-17 — Aircraft junction box.

When you install a junction box, make sure the screw or bolt heads are inside the box. The junction box has fasteners or knobs to secure the assembly; make sure they are tight and the assembly attaches to the radio frequency ground contact strips, if provided. 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 *(Figure 2-18, view A)*; that is, there is a provision for electrical contact between the clamp and conduit. Use unbent clips for the support of open wiring.

A strap-type clamp *(Figure 2-18, view B)* or an AN 742 *(Figure 2-18, 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 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.

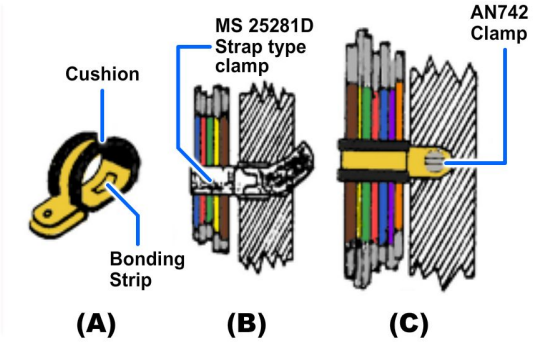


Figure 2-18 — Cable clamps.

When cables pass through lightening holes, the installation should conform to the examples shown in *Figure 2-19*. Lightening holes are openings cut into a strengthening member that decreases its weight without significantly reducing its strength. These are useful in aircraft application when routing wire and cable bundles.

In each case, the MS21919 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 1/4 inch to the edge of the lightening hole, use a grommet (a rubber cushion) to protect the wires.

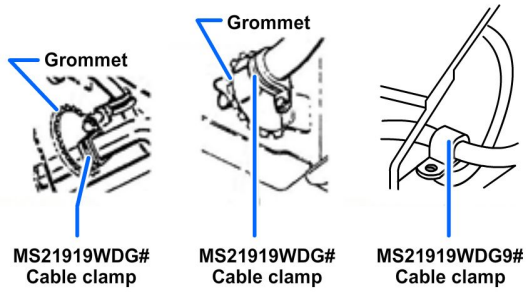


Figure 2-19 — Routing cables through lightening holes

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 bundle as handholds or footsteps
- Damage due to shifting cargo wire

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 2-20*.

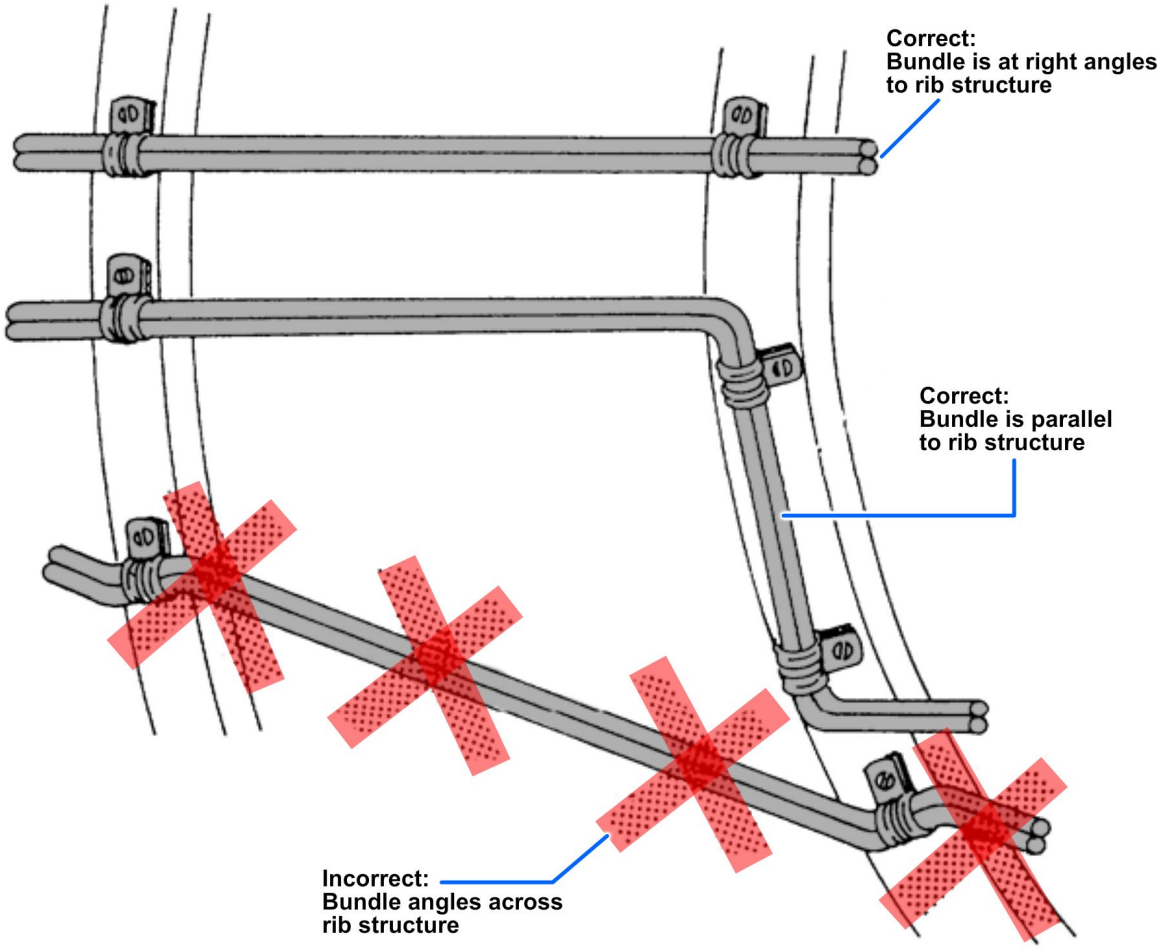


Figure 2-20 — Routing cables.

Don't install single wires or wire bundles with excessive slack. Slack between support points, such as cable clamps, should not normally exceed 1/2 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, making the electrical system less vulnerable to gunfire. However, some current aircraft, especially those with limited space for wire routing, use conduit.

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 swaged 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 equipment. 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

Current naval aircraft design keeps 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 *Figure 2-21.*

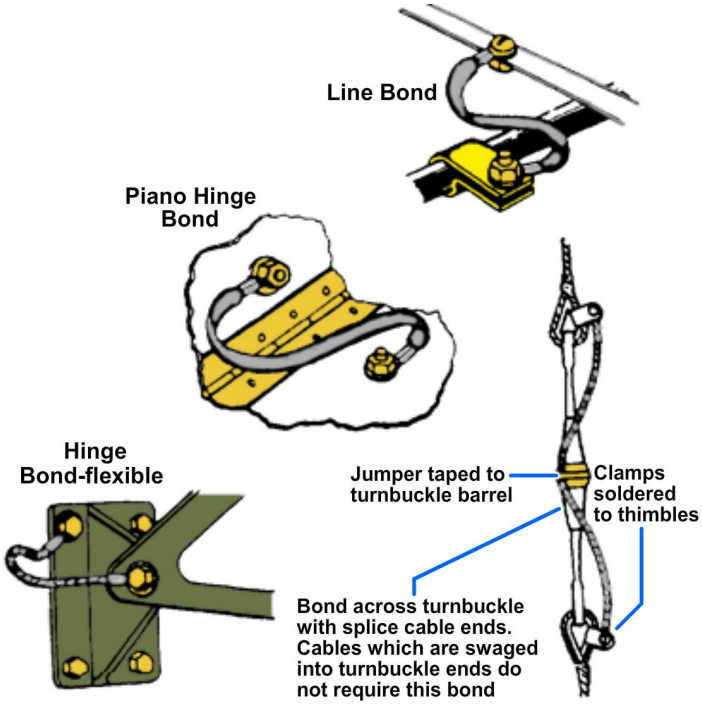


Figure 2-21 — Bonding methods.

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 produces minimum corrosion. You should make connections so that if there is corrosion, it's 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 (series) for detailed information about bonding procedures.

Cable Lacing and Tying

Wire groups and bundles are laced or tied to provide ease of installation, maintenance, and inspection. This process is commonly referred to as spot tying. Spot 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 is 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 moisture-proofing. Don't use sleeving on connectors that have a sealing grommet that covers the soldered connection. Refer to the NAVAIR 01-1A-505 (series) for all sleeving applications.

Sleeving 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 *(Figure 2-22, view A).*

You can protect open and over braided harness wires with damaged shielding with an Electromagnetic Interference (EMI) shielded wrap. This two layer sleeving provides a wraparound repair application and is for single shielded wire harnesses only *(Figure 2-22, view B).* The external layer is Nomex and provides mechanical protection with a nickel plated copper internal layer, which provides EMI protection. A blue tracer differentiates this from the unshielded version. In preparation, this must be cut to length, trimmed, and tightly installed on harness using split rings (not shown) and a 90 degree overlap past the starting point. The external layer is secured with lacing tie approximately every 1-2 inches. Terminate the sleeving within 0.5 inches of the ends using metal bands.

To cover a permanent splice resulting from a damaged single conductor wire *(Figure 2-22, view C)*, slip the sleeving on the wire before the splicing operation. After completing the splice, center the sleeving to cover the finished splice, and then heat from middle to the ends until sealant melts and begins to flow out of ends using approved compressed air/ nitrogen heating tool with a small termination sleeve reflector.

You will use a slightly different arrangement of sleeving for continuous chafe protection using a tube-like Expando sleeve. Expando sleeving *(Figure 2-22, view D)* is usually installed at the initial build of the harness. However, while harness is in service, connector de-pinning (size best suited for application) allows the Expando sleeve to slide over the harness wires and terminates under the clamp fingers and applying teflon barrier tape to the ends and securing with tie string.

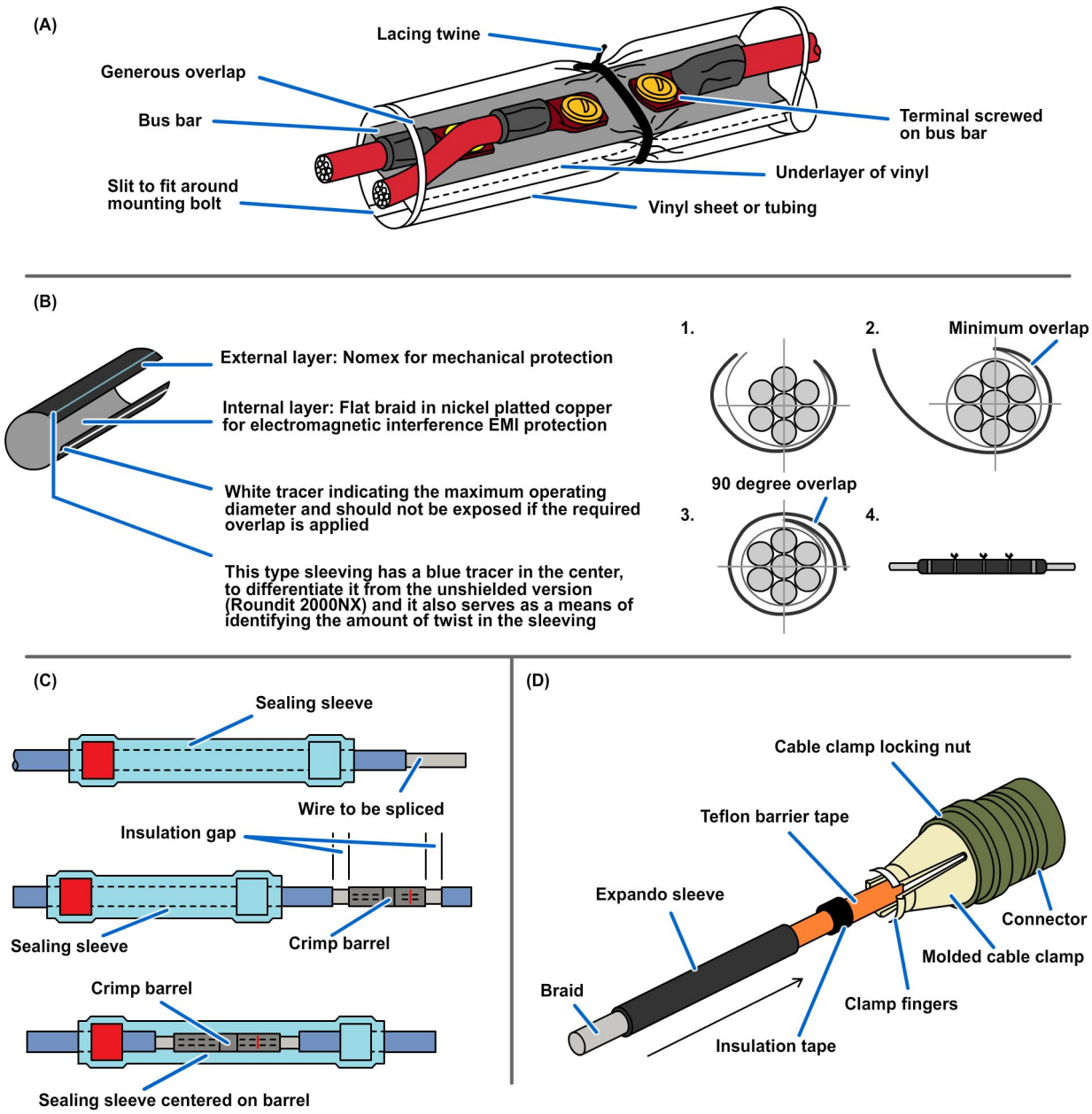


Figure 2-22 — Typical use of sleeving.

MAINTENANCE OF MOTORS AND GENERATORS

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 pre-lubricated 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 cleaning operations, use the correct cleaning solvents. As a final check, conduct an operational inspection of the motor, using the applicable MIM.

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. Refer to *Cleaning and Corrosion Control*, NAVAIR 01-1A-509 (series) manual for information on cleaning agents and their use.

In addition to approved dry-cleaning solvents, you can use trichloroethylene and inhibited methyl chloroform to clean electrical and electronic equipment. Inhibited methyl chloroform (trichloroethane) does present hazards to personnel and insulation. For information on such hazards, refer to *Naval Ships' Technical Manual (NSTM),* 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 phenolic, 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 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, oversaturation, 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

The move toward replaceable units has led 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

Photo etching 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 exposure of the printed circuit is similar to a photographic exposure. The copper coating is covered with 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 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 2-23*. 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.

Figure 2-23 — Printed circuit module.

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 *The Naval Aviation Maintenance Program (NAMP),* COMNAVAIRFORINST 4790.2 (series), only Fleet Readiness Centers (FRCs) being certified as having the capability may perform micro-miniature circuit repair.

Activity certification means that the FRC 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 Center for Naval Aviation Technical Training (CNATT) course or equivalent contractor training course, approved and provided by NAVAIR. Each individual must be recertified periodically to assure continued quality of performance.

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.

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 of 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.

Aircraft Engine Component Test Stand (AECTS)

The Aircraft Engine Components Test Stand (AECTS), *(Figure 2-24)* is an integrated test system which provides testing capability of aircraft engine-driven accessories, such as generators and generator drive systems, which will be discussed in Chapter 5. It provides testing for a wide variety of aircraft electrical components. The AECTS design allows for tailoring to meet space constraints aboard aircraft carriers and will be deployed both afloat and ashore at Fleet Readiness Centers (FRC) and Marine Aviation Logistics Squadrons (MALS) for validating ready-for-issue status of components, verifying operation after a repair action, and troubleshooting and fault-isolating generator system components. It will provide horsepower, shaft speed, and electrical loading requirements to test all aircraft power generating system components. The AECTS, with necessary adapters, is a modular system consisting of four major assemblies; a Variable Speed Drive (VSD) System, Test Set Instrumentation, Hydraulic Cooling System, and Load Banks. The AECTS is capable of interfacing with the 440 vac, 60 Hertz, three-phase, 4-wire electrical system. The total area does not exceed

eighty square feet and facilitates shipboard installation. A means of isolating the AECTS from shipboard power is provided by an internal isolation transformer.

Figure 2-24 — Aircraft Engine Components Test Stand (AECTS).

Variable Speed Drive

The variable speed drive is capable of operating at any speed up to 31,000 RPM with a 150 horsepower output.

Test Set Instrumentation

The test set instrumentation provides the controlling, selecting, and monitoring of test parameters of the Unit Under Test (UUT). It displays both the selected and actual parameters of the VSD output speed and the ac and/or dc load of the UUT. The control console, which is part of the test set instrumentation, is approximately 1800 pounds.

Hydraulic Cooling System

The hydraulic cooling system provides conditioned oil to the gearbox, the constant speed drive, and any oil-cooled component under test. The hydraulic assembly is 36 inches high, 34 inches deep and 35 inches wide. It weighs approximately 500 pounds.

Load Bank

The load bank is capable of providing loads of infinite resolution, and has a shock load of a preset value for all existing electrical system components. It is capable of balanced phased loading, or for loading each phase separately on both resistive and reactive loads. A cooling fan maintains the load elements at a safe operating temperature. The load bank is 71 inches high, 63 inches deep and 42 inches wide, and weighs approximately 2,500 pounds.

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 a 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 pushbutton 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 lower left of the CRT *(Figure 2-25, 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 *(Figure 2-25, 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 *(Figure 2-25, view C)*.

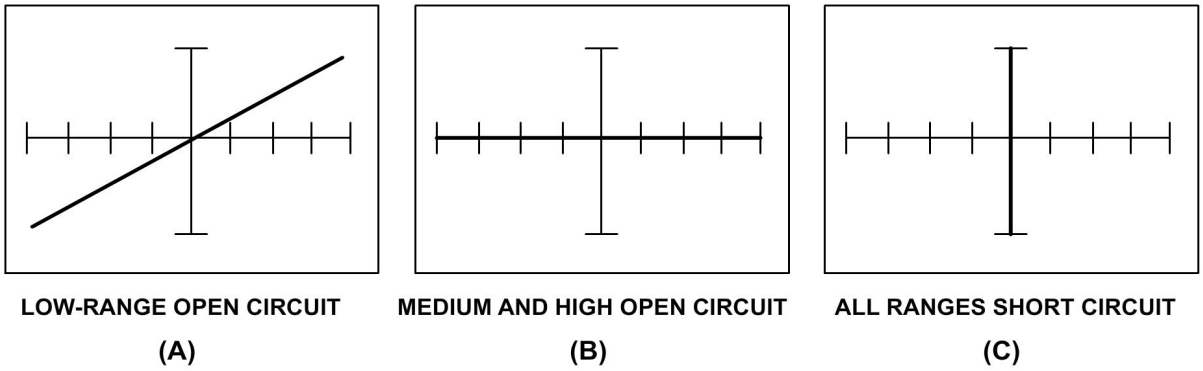


Figure 2-25 — Circuit signatures: View A – Low-range open circuit; view B – medium and high range open circuit; and view C – all ranges short circuit.

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—INTENSITY, 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 *(Figure 2-26)* is a versatile troubleshooting tool having the following features:

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

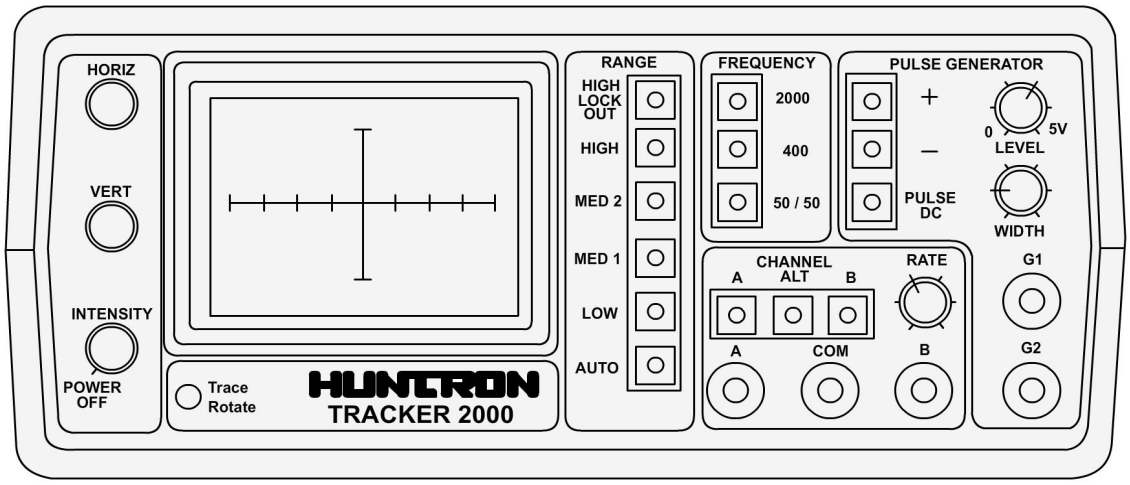


Figure 2-26 — Huntron Tracker 2000.

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 is active. Look at *Figure 2-27* and *Table 2-4* for details about each item on the front panel.

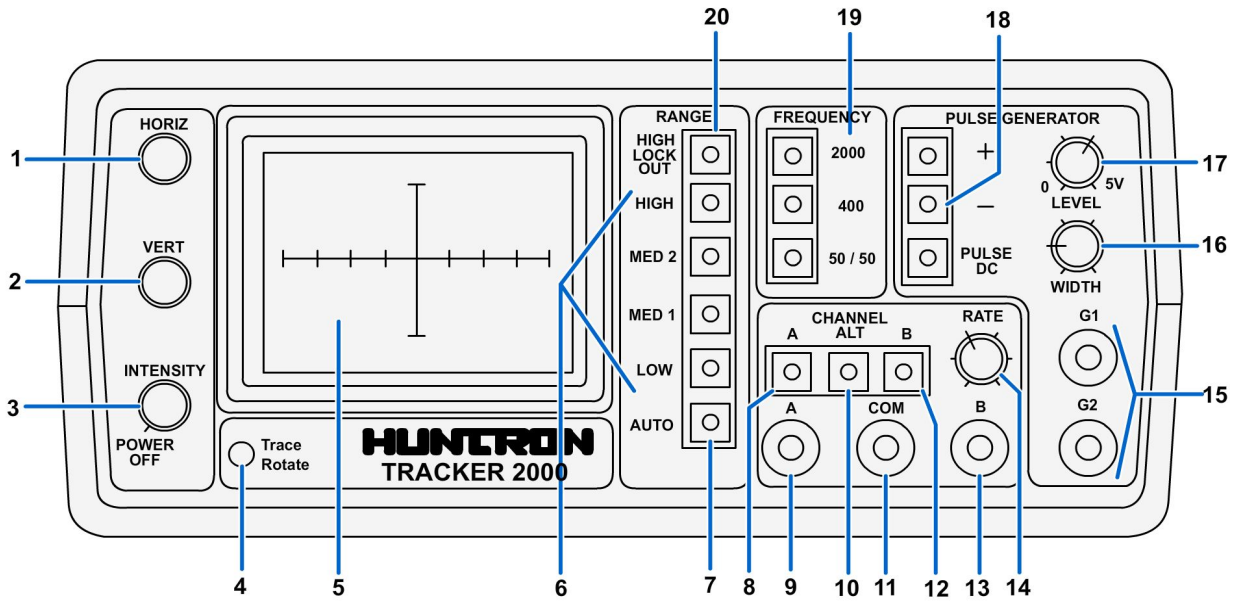


Figure 2-27 — Front panel.

Back Panel

Secondary controls and connectors are located on the back panel *(Figure 2-28 and Table 2-5)*.

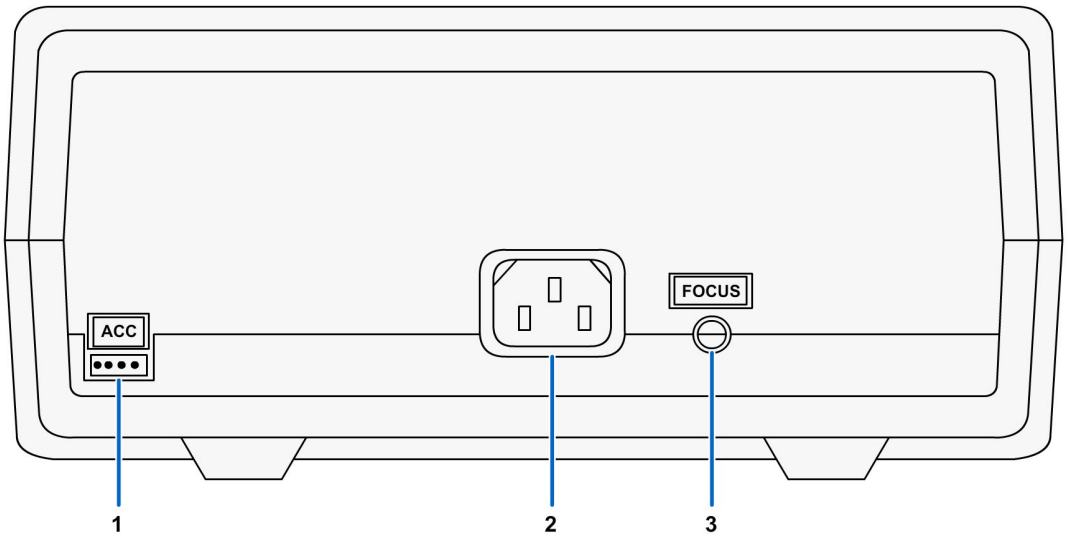


Figure 2-28 — Back panel.

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	Display the component signatures produced by the 2000.
6	Range Selectors	Push button that select one of four impedance ranges: low, medium1, medium 2, and 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 #4).
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 & channel B at a speed determined by the RATE control (see item #4).
11	COM Test Terminal	Test lead connector that is instrument common & the common reference point for both channel A & 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 &/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: +. -, PULSE/DC.
19	Frequency Selectors	Push buttons that select one of three test signal frequencies: 50/60Hz, 400Hz, 2000Hz.
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 the power and clock to the Huntron Switcher Model HSR410.
2	Power Chord Connector	IEC standard connector that mates with any CEEE-22 power cord.
3	FOCUS Control	Controls the focus on the CRT display.

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. The displays are:

- 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.

Operation of 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 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 channels 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 2-29* 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.

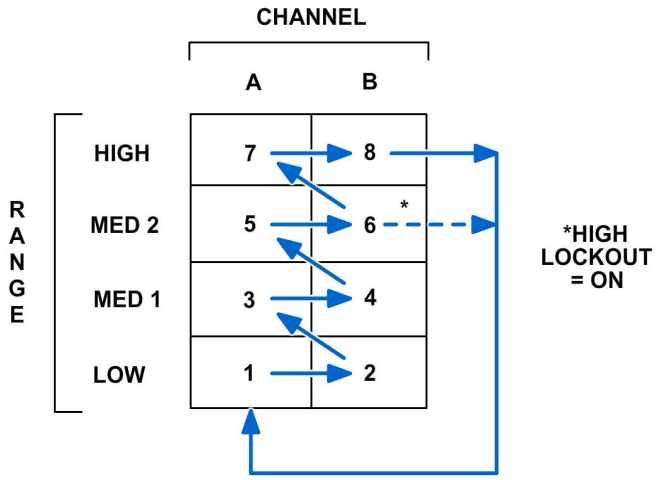


Figure 2-29 — Auto/alternate sequence.

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 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:

- 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 obvious 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. 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 produces 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, as it results from a resistive value of 4 to 10 ohms. 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.

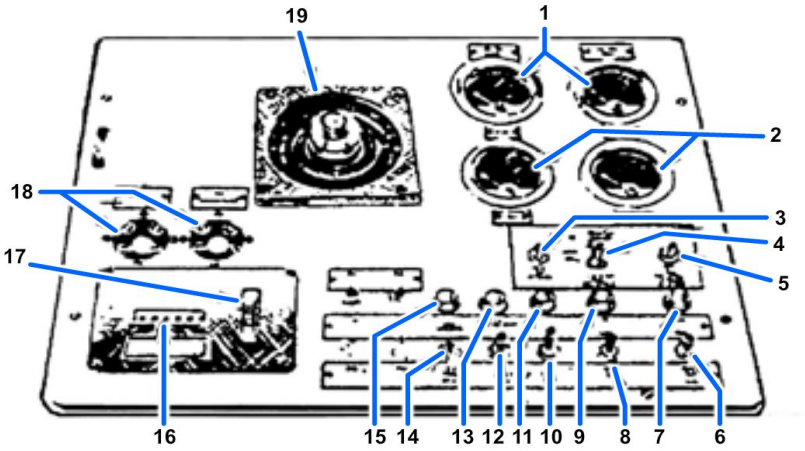
Jet Ignition System Tester

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 2-30*. 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 2-30 — Jet ignition system test panel.

Tachometer Indicator Generator Test Set TTU-27/E, Part Number 8401B

The tachometer indicator-generator test set, TTU-27/E, is used to test aircraft tachometer generators and indicators on both piston and jet engine aircraft. You can use the tachometer indicator-generator test set to make the following tests:

- Test tachometer indicators from the master generator
- Test tachometer generators both on and off-aircraft
- Test tachometer generators and indicators as a unit

Figure 2-31 shows a TTU-27/E tester completely self-contained in a light-weight aluminum case designed for portability. All the operating controls, switches, and indicators required for the tester are on the panel assembly. The variable speed drive pad, which is varied from 0-5000 rpm by a panel mounted control knob, accommodates the tachometer generator for testing. The master 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, 60-400 hertz ac power.

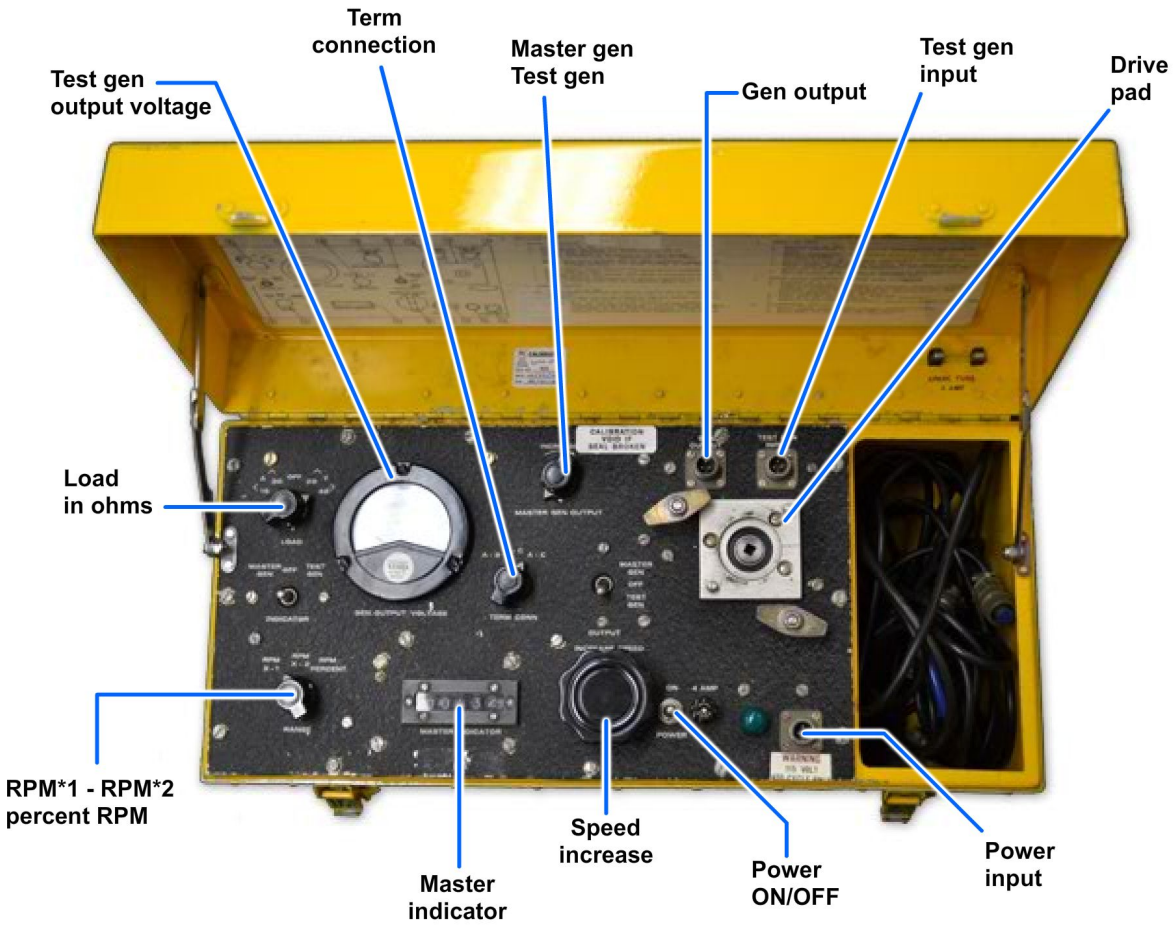


Figure 2-31 — Tachometer Indicator-Generator Test Set TTU-27/E.

A master tachometer generator is mounted inside the tester and be used to test the tachometer indicators. You can check indicator calibration by the master tachometer generator by using the INCREASE SPEED control and comparing to the MASTER INDICATOR readings with those of the indicator under test.

Internal load banks are selected to load the generator under test, and, while under load, the phase to phase voltage may be selectively displayed on the panel mounted voltmeter by selecting the A-B, B-C and A-C TERM CONNECTION switch.

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

When testing the generator and indicator as a unit, the generator is mounted to the drive pad and the indicator to the GEN OUTPUT connector. The LOAD IN OHMS is set to off during this test. When the output selector switch is in the MASTER GEN position, the indicator under test is driven by the internal master generator, as is the speed of the MASTER INDICATOR. When the switch is in the TEST GEN position, the indicator under test is being driven by the generator under test, as is also the speed MASTER

INDICATOR. For additional information on the operation and service instruction of the TTU-27/E tester, refer to NAVAIR 17-15CM-4.

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 (*Figure 2-32*) is a rugged, portable instrument made of aluminum, stainless 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.

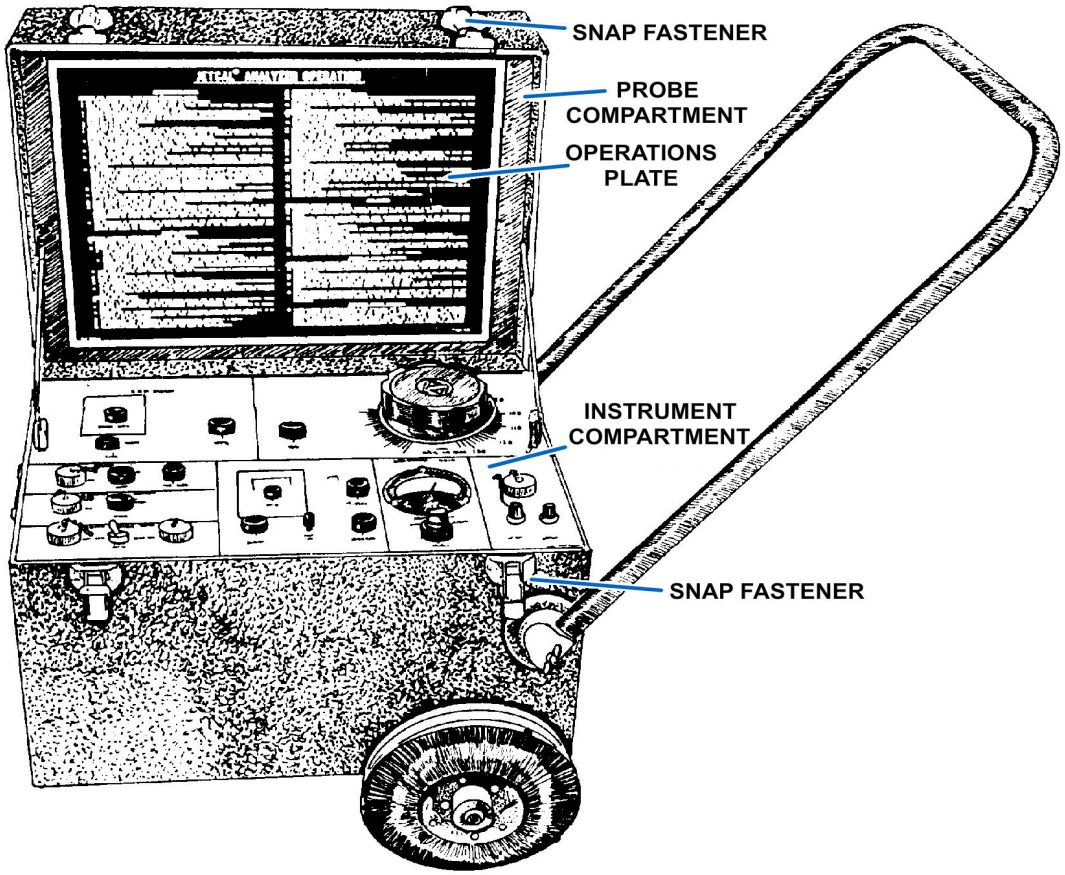


Figure 2-32 — JETCAL analyzer.

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 run-up.
- To use the RPM check (TAKCAL) and potentiometer to establish the proper relationship 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.

Synchrophaser Test Set

The synchrophaser test set (*Figure 2-33*) 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.

Figure 2-33 — Synchrophaser test set.

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.

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.

Propeller Synchronizer Tester (TTK-512), Part Number 1383AS200-1

The propeller synchrophaser system is tested using the propeller synchronizer tester *(Figure 2-34)* and is capable of testing solid state propeller synchrophaser systems on P-3, C-130, and E2/C2 type aircraft. The tester contains a microcomputer which senses switch positions during operation, and configures a test circuit which activate relays on a board. The microcomputer selects the proper signal conditioning path and conversion algorithm and displays performance data on the display panels and indicators.

The tester is a portable flight line unit, completely solid state, and consists of a panel and chassis assembly housed in a carrying case. Additionally, there is an accessory case contains the accessory cables and wiring harnesses. The panel and chassis assembly contain all of the operating controls, indicators, components and electronic circuitry. The tester is approximately 15 inches long, 14 inches high, and 15 ½ inches wide, and weighs 50 pounds.

When power is first applied to the tester, it initiates an automatic internal self- test of the components. When a zero appears after the countdown in DISPLAY # 2, the tester passed the internal self-test. If a number other than “0” appears, the tester is malfunctioning and should be rejected to the Intermediate Maintenance Activity (IMA).

The synchronizer test set uses aircraft electrical power, 28vdc or external 28vdc, and monitors voltage inputs and outputs from the synchrophaser to determine if the synchrophaser or components of the propeller synchrophaser system and aircraft electrical wiring can be suspected of malfunction.

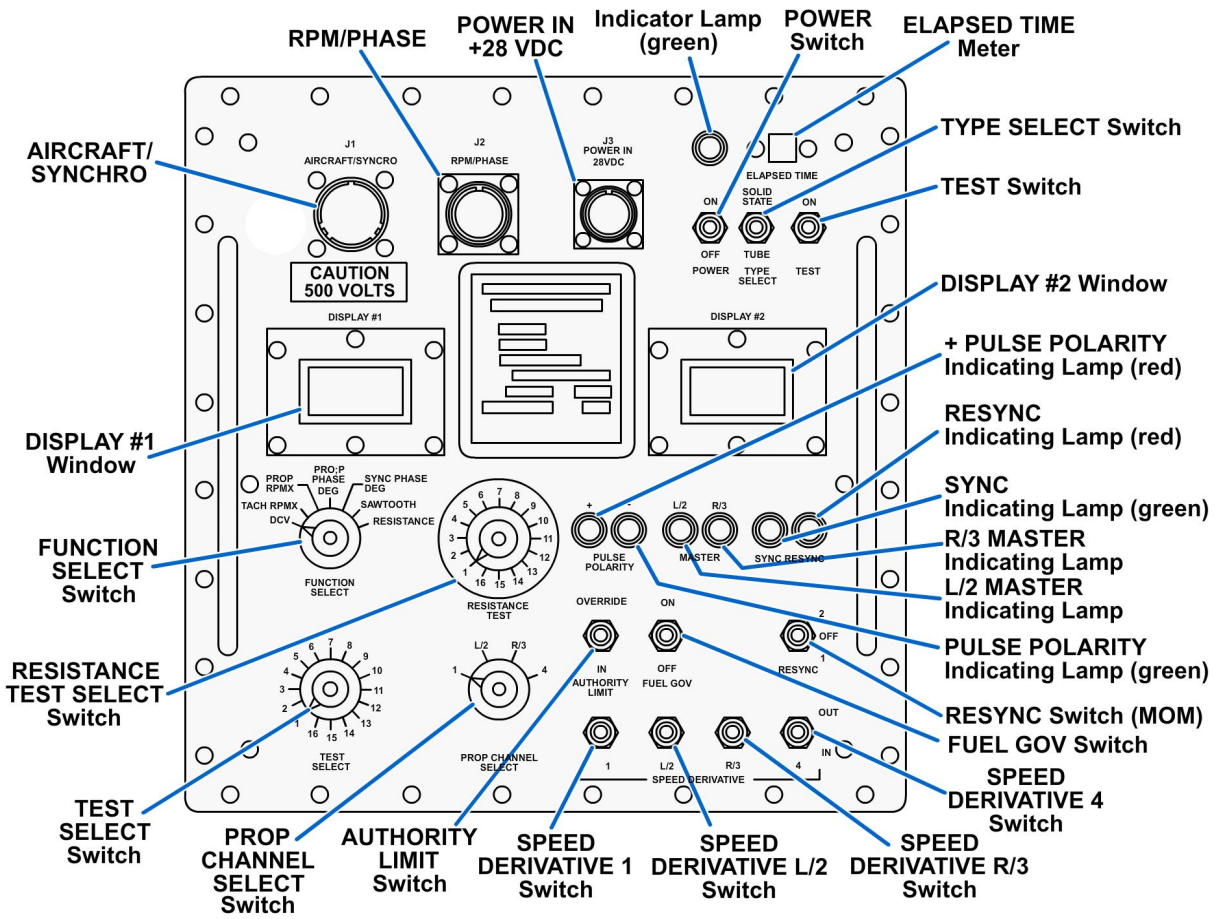


Figure 2-34 — Propeller synchronizer tester (TTK-512).

Generally, initial testing of the synchrophaser system consists of resistance and megger checks. Test data should be recorded while performing these tests. You want to ensure resistance and megger tests are completed prior to performing the voltage tests. These tests are usually performed with the engines not running. Additional tests are performed to evaluate operation, such as voltage tests on ground with the engines shut down or with the engines running at 100% RPM. Tests can also be performed in flight with engines running at 100% RPM.

Follow testing and troubleshooting procedures for current aircraft when using the propeller synchronizer test set. Procedures differ for each aircraft. For complete instructions on this tester, you should refer to the current maintenance instruction manual, AG-240AB-OMP-000.

Test Set, Air Data TS-4508/U, Part Number ADTS-405-8325-M4

The Air Data Test Set *(Figure 2-35)* is used to verify proper operating parameters of pitot and static systems of aircraft. You can also conduct dynamic tests, quantitative calibration tests, and pneumatic-system leak tests using this tester.

The Air Data Test Set consists of a rugged rack mounted on wheels within a weatherproof flight line case with a pump unit which provides regulated pressure and vacuum supplies to pitot and static pressure to related instruments, air data systems, and other auxiliary equipment. It is supplied with a standard hand terminal for one man operation which can be utilized by the operator during remote operating conditions. All the controls, indicators, switches, electrical, and pneumatic connections are on the front panel of the test set. The components are on the underside of the control panel. The test set simulates airspeed, altitude and rate of climb information, which is displayed on the front panel and hand held terminal. Refer to the NAVAIR 17-15CA-62 for additional information. *See Table 2-6* for test set particulars.

The test set has the following capabilities and features:

1. Turn-on procedures provide a self-test.
2. Provides three aircraft safety protection methods:
   - Limit checking of user entered set points.
   - Automatic regain of control if leak rate is over limit during leak testing.
   - Automatic regain of control if a leak takes the system pressures outside of limits.
3. Remote and local operation of unit.
4. The TS-4508/U can measure the following parameters:
   - Altitude measured in aeronautical units measured in ft or m.
   - Calibrated airspeed and true airspeed measured in kts or km/hr
   - MACH measured in units of math
   - Pressure Static (Ps) and Pressure total (Pt) measured in pressure units.
   - Difference in pressure between Ps and Pt (Qc) measured in pressure units.
   - Rate of change of altitude.
   - Rate of change of airspeed.
   - Rate of Ps.
   - Rate of Qc.
   - Rate of Pt.

Figure 2-35 — Test set, TS-4508/U

Table 2-6 — Test Set, Air Data TS-4508/U

POWER REQUIREMENTS	
AC Input	103 - 127 Volts, 47 - 420 Hz
Consumption	500 VA
DIMENSIONS	
Depth	12.1 inches
Width	30.0 inches
Height	18.1 inches
Weight	82 lbs
ENVIRONMENTAL	
Warm-up period	15 minutes
Operating temperature range	14 to 131 degrees F
Storage temperature range	-60 to 160 degrees F
CONTROL STABILITY	
Altitude	Greater of +/- 3 ft or +/-0.02% of simulated altitude
Speed	+/- 1 kt
ACCURACY	
ALTITUDE	
Range	-1500 to +65,000 feet
Resolution	1 ft
Accuracy	Greater of +/- 10ft or +/- 0.1% reading
ALTITUDE RATE	
Range	0-30,000 ft/min
Resolution	1.0 ft/min
Accuracy	+/- 10.0% reading
SPEED	
Range	20 to 1,000kts
Resolution	0.1 kts
Accuracy	+/- 2.0kts

> ⚠ **CAUTION** ⚠
>
> Dangerous voltages are present at system connectors. Ensure power is OFF prior to connecting or disconnecting cables.

Capacitive-Type Liquid Quantity Test Set 361046-001, Model TTU 378 A/E

The test set is used to test and adjust aircraft fuel quantity gage probes, indicators, and complete gaging systems, with the equipment under test installed in the aircraft or removed for bench tests.

The test set is housed within an aluminum combination case *(Figure 2-36)*. The body of the combination case is divided into two sections. The lower section houses the test set internal mechanism and circuitry; the upper section of the case and the test set cover provides storage space for the accessory cables. The cover is secured to the case with two removable hinges at the rear and two trunk-style latches at the front of the case. The test set is operated within the combination case with the cover fully opened or removed.

Figure 2-36 — TTU-378 A/E fuel quantity test set.

Fuel Quantity System Check

An aircraft's fuel quantity system is checked on board by connecting the test set between the indicator and tank units. In this configuration, the test set can be used to verify system operation, adjust the indicator to the tank units, or determine whether the indicator or probes are defective.

When used to check the system, the test set can be used with any known amount of fuel in the tanks; It can modify the capacitance signal sent to the indicator for full and empty indicator adjustment. The test set can also measure the capacitance of the tank units for comparison against the expected capacitance.

The testing mode for system check is controlled by the front panel CAPACITANCE FUNCTION and DISPLAY select switches. In the system check mode, only the capacitance circuitry of the test set is used. Insulation resistance is not tested in system check mode.

Test Set Adjustment and Test

The test set is adjusted and tested using standard resistors and capacitors in the set's internal circuitry. Capacitance circuitry adjustment is enabled by setting DISPLAY SELECT to CAP (PF) and CAPACITANCE RANGE (PF) to HIGH ADJ or LOW ADJ. To adjust the capacitance measuring circuitry, CAPACITANCE HIGH ADJ and LOW ADJ front panel pots are set so that the display reads the values marked on the CAP STANDARDS placard.

Resistance measuring circuitry is enabled by setting DISPLAY SELECT to RES (MEG) and RESISTANCE RANGE (MEG) to HIGH TEST or LOW TEST. When in the HIGH TEST or LOW TEST positions, internal standard resistors are applied to the resistance measuring circuitry. The reading on the display is compared with the RESISTANCE TEST placard on the front panel.

Refer to the NAVAIR 17-15BD-46 for additional information. When using this test set, you should follow the instructions in the applicable MIM for the system under test.

Fuel Control Test Set (FCTS) TTU-597/E

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. The Fuel Control Test Set (FCTS) is designed for flight line use at the Organizational level, both afloat and ashore, to accurately and reliably test aircraft fuel quantity systems *(Figure 2-37).* The FCTS is compatible with all aircraft types which have a capacitive fuel content system. Adapter cable assemblies are provided to enable the FCTS to be used with the various aircraft configurations. The FCTS is a portable test set comprised of a test unit, transit case and accessory kit. The test unit is designed to operate from an internal battery pack, aircraft 28 vdc input cable, or an external ac/dc Power Converter Pack (PCP). An internal battery management system monitors the presence of an installed battery pack.

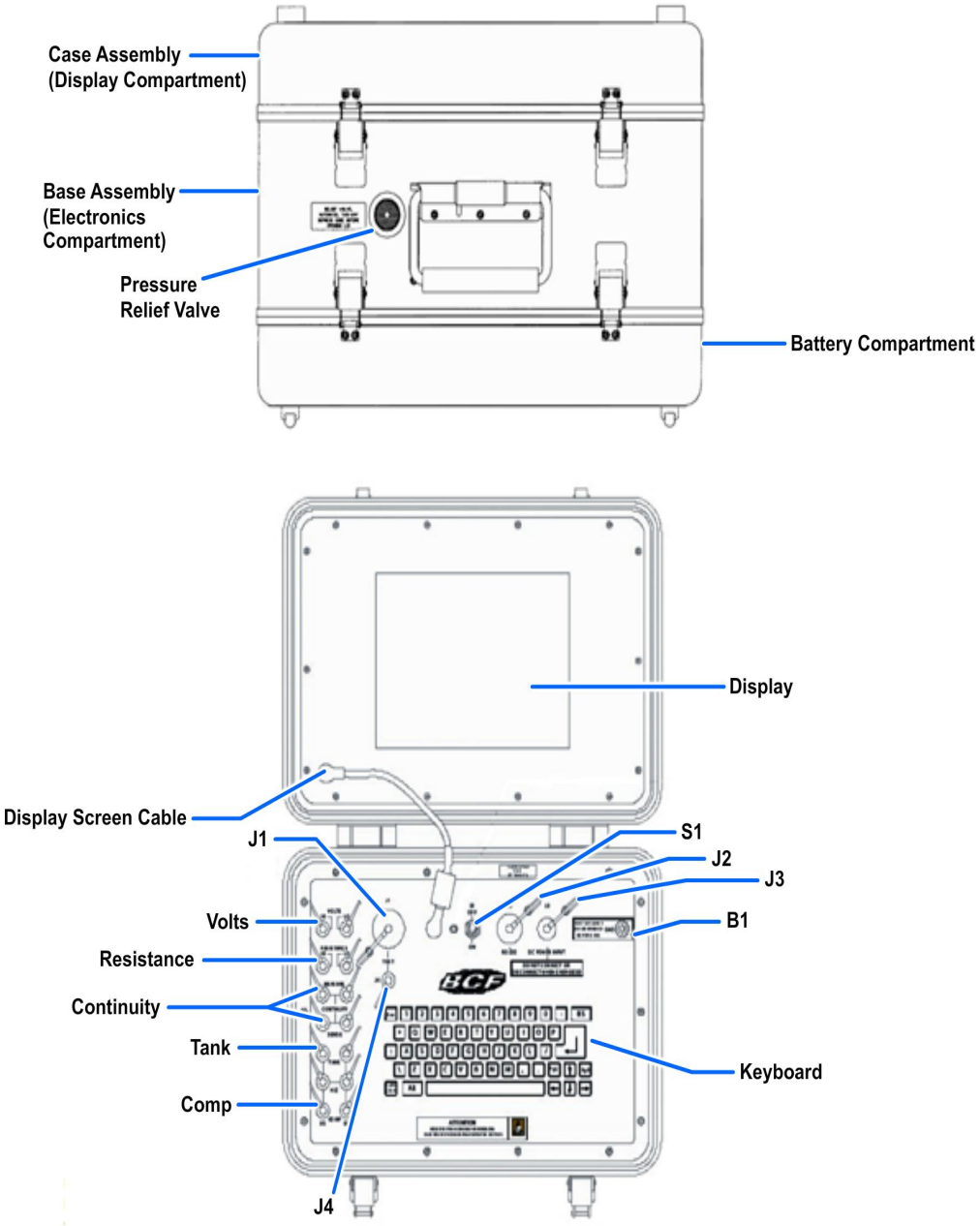


Figure 2-37 — Fuel Control Test Set (FCTS) TTU-597/E.

The test unit is housed in a seamless, sealed aluminum case equipped with an automatic pressure release valve (breather valve). The case is comprised of the display compartment, electronics compartment and battery compartment.

The case assembly (display compartment), is housed in the top portion of the test unit, which is hinged to the electronics compartment. The display is comprised of a 13-inch, 640 X 480 pixel electroluminescent screen, bezel and gasket. The display screen is connected to the electronics compartment by the display cable.

The base assembly (electronics compartment) forms the center section of the test unit and houses the solid state electronic circuitry, F1 fuse and battery pack mating connector. All external connectors for operating the Test Unit are located on the top panel.

The battery compartment is attached to the bottom of the electronics compartment. The interior of the battery compartment contains foam inserts that are formed to house the battery pack. The inserts provide a cushion surface, which prevents movement of the battery pack.

The battery pack is comprised of the battery box, battery holder, mating connector cable (for connecting the battery box to the Test Unit), a 250V 5A, Type F fuse, a charge inhibit switch and twelve nickel metal hydride (NiMH) batteries, which are wired in series to provide a nominal 14.4 vdc. As an alternate, non-rechargeable type D dry cell batteries may be used in place of the NiMH batteries; however, the current capacity reduces the time the test unit can be powered. The following provides a description of the battery pack components:

- Accessory kit – The accessory kit is comprised of the accessory bag, dc input cable, RS-232 cable and the ac/dc PCP.
- Adapter Cables Assemblies – The aircraft adapter cable assemblies provide a means of connecting the FCTS to individual aircraft fuel systems or fuel system components (bench test). Instructions for connecting and using the adapters and boxes are provided by the “on screen” menus of the FCTS. The peculiar adapter cable assemblies will be packaged in their own transit case and shipped along with the FCTS.

TTU-597/E Operation

The FCTS can be used on aircraft with ac or dc capacitance fuel systems to measure capacitance in the range 0 to 30,000pF.

The test unit is equipped with a battery management system which monitors the presence of an installed battery pack. Depending on level of charge, it requires about 1 1/2 to 2 hours to fully charge the battery pack. Fully charged NiMH batteries will provide operation for more than 4 hours of continuous use.

The FCTS is designed to operate between a temperature range of -40° to +55° C and in an environment normal to carrier flight decks. The unit has adequate shielding and filtering to withstand hazardous electromagnetic fields, both conducted and radiated.

The FCTS provides the following functions:

- AC Capacitance Measurement – The method used is to apply a known voltage at a fixed frequency to the capacitor under test and measure the current flowing through the capacitor. This current is directly proportional to the value of the capacitor. The capacitor under test is fed from a low impedance source which eliminates the effect of any stray capacitance in the system. The measurement

signal out of the capacitor is fed into a virtual earth amplifier which, again, eliminates the effects of stray capacitance. This signal is then fed to a synchronous rectifier which also acts as a narrow band digital filter. The output from the synchronous rectifier is amplified and processed through a high resolution Analog-to-Digital Converter (ADC). The ADC converts the signal to a digital format which can be processed by the test unit software to a true capacitance value which is displayed on the screen. For stability reasons, the measurement electronics are calibrated against a very accurate internal capacitor on a continual basis to alleviate any uncertainties due to drift.

- DC Capacitance – The method used for dc capacitance is very similar to the ac method. An ac voltage is applied to the capacitor under test, but in this case there are two diodes in series with the capacitor arranged so that the positive half cycles of the ac voltage pass through one diode and the negative half cycles pass through the other diode. In the case of negative dc capacitance probes, the positive current goes to ground and the negative current goes into an integrating virtual earth amplifier whose output is a dc voltage directly proportional to the value of the capacitance. This voltage is fed to the same ADC as in the ac case with the same results. The positive dc capacitance probe case is the mirror image of the negative dc case.
- Resistance Measurement – Resistance measurement is achieved by using three ranges. The lowest range from 0.1 ohms to 100 ohms uses a constant current method where the voltage across the unknown resistance is measured and the resistance calculated from knowledge of the applied current. The other two ranges use a method whereby a voltage is applied to the resistance under test via a known resistance and the voltage at the junction of these resistors measured, from this voltage the unknown resistor is calculated. In all three cases a 16 bit ADC is used for the measurement.
- Voltage Measurement – Voltage measurement is achieved in the FCTS by dividing down an input voltage of ± 50 V to give 0 ± 10 V into the 16 bit bipolar ADC via a buffering op-amp of unity gain.
- Distance To Fault – Distance to fault measurement is achieved by measuring the capacitance to ground of the Lo Z wire which is a shielded lead from the aircraft. Knowing the capacitance per foot of this lead and entering it into a display window on the tester, the resulting capacitance measurement will be displayed as the distance to fault in feet.
- Capacitance Simulation – Capacitance simulation is achieved by using a bank of very accurate and stable capacitors arranged parallel and selected under software control to provide 11 to 10,000pF for TANK and 11 to 1000pF for COMP. The nominal value of 11pF is the result of the stray capacitances experienced within the wiring of the FCTS. The TANK and COMP capacitance simulators are independent and thus may be used simultaneously.

TTU-597/E Operating Modes

Power-On Self- Test (POST) – When the test unit is first powered up, a POST is conducted during the start-up sequence. Following a successful POST, the test unit performs self-calibration after which the user is prompted to choose either auto or manual testing.

Automated Mode – In the automated mode, the user can choose to perform a test on a selected aircraft fuel system or on an aircraft fuel system component (bench test). On screen instructions will guide the operator through the testing procedure. The on screen instructions list associated equipment and cables required prior to displaying the set-up procedure. Testing will not be initiated until the set-up procedure has been accomplished.

Manual Mode – The manual mode allows the test unit to be used directly to measure insulation resistance, bonding or capacitance. A capacitor simulation output can also be provided.

Angle-Of-Attack Test Set AN/PSM-17A, Part Number SLZ9060

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 (*Figure 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.

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

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 (AOA) 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 (*Figure 2-39*) is for flight line checkout and troubleshooting of electrical 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.

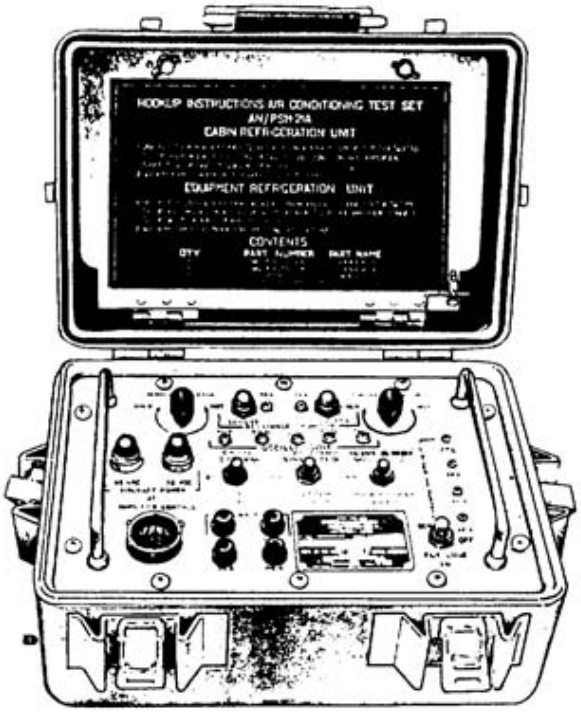
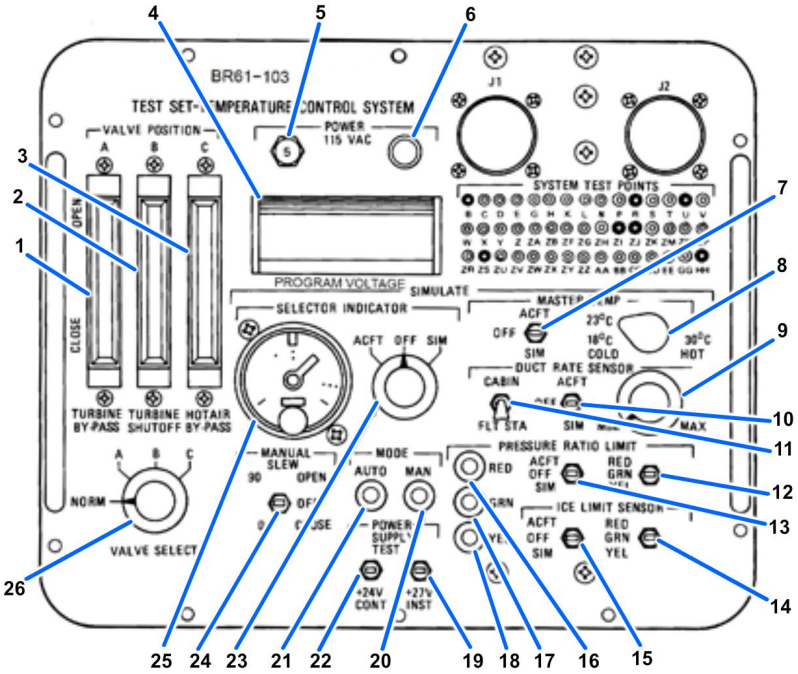


Figure 2-39 — Air-conditioning test set AN/PSM-21A.

Temperature Control System Test Set BR61-103

The Temperature Control System (TCS) Test Set, BR61-103 *(Figure 2-40)* consists of a panel of integrally mounted instruments and components, a cable assembly, a placard and self-test assembly all contained within a combination case. The combination case is divided into two sections connected by quick disconnect fasteners. The panel's components are used to operate, simulate, and monitor the aircraft cabin or flight station temperature control system. The removable lid of the combination case provides storage for the cable assembly, placard, and self- test assembly. The cable assembly is used to interface the test set with the self- test assembly and the aircraft cabin or flight station temperature control station. The test set is sixteen inches in length, fifteen inches in height, and fourteen inches wide and weighs thirty-four pounds. Power requirements are 115 vac, 400Hz. The test set is used for flight line checkout and troubleshooting of electrical components in equipment temperature control systems. To accomplish checkout of these systems, apply external electrical power to the aircraft.



1. Valve Position A Meter
2. Valve Position B Meter
3. Valve Position C Meter
4. Program Voltage Meter 4
5. Power 115 VAC Circuit Breaker
6. Power 115 VAC Light
7. Master Temp ACFT-OFF-SIM Switch
8. Master Temp Control Switch
9. Duct Rate Sensor Control
10. Duct Rate Sensor ACFT-OFF-SIM
11. Duct Rate Sensor Cabin-FLT STA Switch
12. Pressure Ratio Limit RED-GRN-YEL Switch
13. Pressure Ratio Limit ACFT-OFF-SIM Switch
14. Ice Limit Sensor RED-GRN-YEL Switch
15. Ice Limit Sensor ACFT-OFF-SIM Switch
16. Pressure Ratio Limit or Ice Limit Sensor RED Light
17. Pressure Ratio Limit or Ice Limit Sensor GRN Light
18. Pressure Ratio Limit or Ice Limit Sensor YEL Light
19. Power Supply Test +27V CONT Switch
20. Mode Man Light
21. Mode Auto Light
22. Power Supply Test +24V CONT Switch
23. Selector Indicator ACFT-OFF-SIM Switch
24. Manual Slew Switch
25. Selector Indicator
26. Valve Select Switch

Figure 2-40 — Temperature Control System (TCS) test set, BR61-103.

Modes of Operation

Temperature control of the TCS can be attained either manually or automatically. With the test set SELECTOR INDICATOR switch set to ACFT or SIM, the desired temperature and mode of operation are chosen through use of a push-pull knob on either the TCS or test set selector indicator dial. An annunciator flag on the dial displays either MAN or AUTO according to the selection. The MODE MAN or MODE AUTO indicator comes on to further display and verify the selected mode.

The desired temperature is selected by setting the index tab on the periphery of the dial which is positioned by rotating the push-pull knob. A pointer at the center of the dial is a program position indicator (PPI) that indirectly indicates the TCS A, B, and C valve positions are programmed to achieve or maintain the selected temperature. For example, if the pointer should be aligned to the two-dot position, the temperature would be approximately 23.3 ° C - program voltage would be 5 volts, and the related nominal degree of valve positions would be: A valve, 40 degrees; B valve, 80 degrees; and C valve, 20 degrees. The actual program voltage is displayed on the PROGRAM VOLTAGE meter and the VALVE POSITION A, B AND C meters indicate each of the TCS valve positions.

For complete instructions on this test set, you should refer to the current maintenance instruction manual, AG-513SA-OMP-000.

ELECTROSTATIC DISCHARGE (ESD)

The sensitivity of electronic devices and components to 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 (ESDS).

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 one with 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.

Table 2-7 — Triboelectric Series

POSITIVE (+)
ACETATE
GLASS
HUMAN HAIR
NYLON
WOOL
FUR
ALUMINUM
POLYESTER
PAPER (Small positive charge)
COTTON (No charge)
0
STEEL (No Charge)
WOOD (Small negative charge)
ACETATE FIBER
NICKEL, COPPER, & SILVER
BRASS & STAINLESS STEEL
RUBBER
ACRYLIC
POLYSTYRENE FOAM
POLYURETHANE FOAM
SARAN
POLYETHYLENE
POLYPROPYLENE
PVC (VINYL)
KEL-F
TEFLON
NEGATIVE (-)

Table 2-8 — Typical Charge Generators

Work Surfaces	Formica (waxed or highly polished) 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 & Handling	Common polyethylene (bags, wraps, envelopes, etc.) Common bubble pack, foam Common plastic trays, plastic tote Boxes & vials
Assembly, Cleaning, Test, & Repair	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

Effects of Static Electricity

The effects of ESD are not recognized. Failures due to ESD are often misanalysed 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.

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.

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 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

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 mill amperes, 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 impedance to ground.

ESD Protective Materials

There are two basic types of ESD protective materials:

1. Conductive – Conductive materials protect ESD devices from static discharges and electromagnetic fields.
2. Anti-static – Anti-static material is a static inhibiting 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 substance 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, vinyl, 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, ensure the following precautions are taken:

- 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.

NOTE

Mark the packaged unit with the ESD symbol and caution. (*Figure 2-41*)

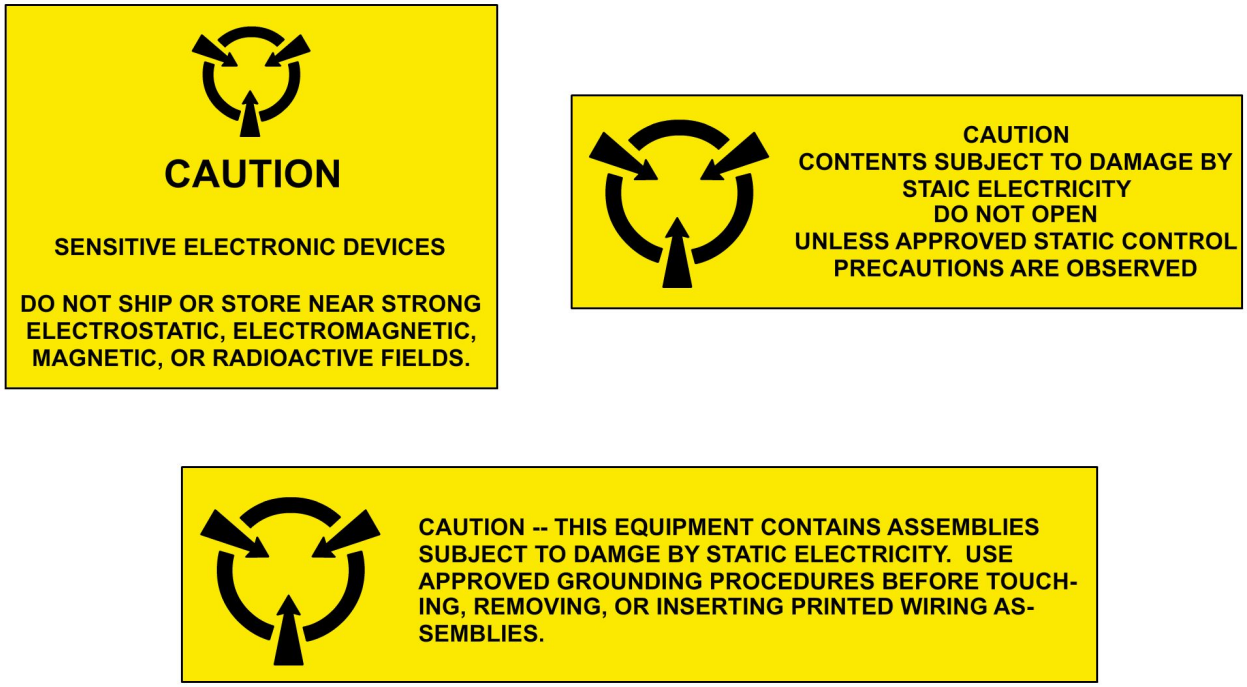


Figure 2-41 — ESDS markings.

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.
- You must use a high input impedance meter such as a Fluke Multimeter to test parts or assemblies.
- After testing, replace shorting devices and protective packaging.
- Dielectric strength tests are not permitted.

End of Chapter 2

ELECTRICAL MAINTENANCE AND TROUBLESHOOTING

Review Questions

2-1. What is one rule you should always follow when working on electric or electronic equipment?

A. Power source
B. Safety first
C. Location of equipment
D. Required tools

2-2. What should you do to the power supply when working on an electrical system?

A. Close and tag the circuit breakers and main switches
B. Open and tag the circuit breakers
C. Open and tag the circuit breakers and main switches
D. Open and tag the main switches

2-3. What is the manual that you should refer to for an illustration of the danger areas for your aircraft?

A. MIM
B. IPB
C. RTM
D. NEETS

2-4. What exterior light is required to be on during engine operation?

A. Wing lights
B. Cockpit light
C. Tail light
D. Anti-collision light

2-5. When working on a circuit, you need to have a person who is fully qualified in what standing by?

A. Search and rescue
B. CPR
C. The operation of equipment being tested
D. Microminiature circuit repair

2-6. Before touching a capacitor, you should be sure it is discharged by doing what?

A. Turning off power
B. Opening the circuit breaker
C. Short-circuiting the terminals
D. Install the capacitor safety shield

2-7. What is the preferred fire extinguishing agent for electrical fires?

A. PKP
B. H20
C. AFFF
D. CO2

2-8. What are the two basic rules you should follow when working with hand tools?

A. Use the proper tool and ensure it is properly checked out from tool issue
B. Ensure it is properly checked out from tool issue
C. Use the proper tool and keep it in working order
D. Ensure it is properly checked out from tool issue and is the proper tool

2-9. List the steps that will make your troubleshooting easier?

A. Review system operation, analyze symptom, detect and isolate the trouble
B. Review system operation, clean and inspect, detect and isolate the trouble
C. Review system operation, analyze symptom, and perform clean/inspect
D. Analyze symptom, clean and inspect, detect and isolate the problem

2-10. What test equipment is used when looking for shorts, grounds, opens, and wrong resistances?

A. Megger
B. TDR
C. Voltmeter
D. Digital multimeter

2-11. What process should never be used as a troubleshooting method because it is expensive and does not always fix the fault?

A. Seeking advice from FRC
B. Working overtime
C. Parts replacement
D. Component isolation

2-12. After removing a part, you should always look for small items from the work to ensure they do not become what type of a hazard?

A. Eye hazard
B. Foreign Object Damage (FOD)
C. Choking hazard
D. Tripping hazard

2-13. Which of the following tools would help you analyze a system?

A. MIMs, schematics, and records on the equipment
B. MIMs, schematics, and Illustration Parts Pubs
C. Illustration Parts Pubs, and equipment records
D. Illustration Parts Pubs, schematics, and equipment records

2-14. What is the first action to take when beginning to troubleshoot a piece of equipment?

A. Analyze the symptom
B. Detect and isolate the trouble
C. Perform resistance checks
D. Review the system

2-15. What types of common faults interrupt power through a circuit?

A. Intact wiring, loose terminals, faulty relays, and faulty switches
B. Broken wiring, loose terminals, faulty relays, and faulty switches
C. Broken wiring, tight terminals, faulty relays, and faulty switches
D. Intact wiring, tight terminals, faulty relays, and faulty switches

2-16. Which reference is referred to for approved maintenance procedures?

A. IPB
B. NATOPS
C. MIMs
D. NAVEDTRA

2-17. Which reference is used for procedures when removing and replacing equipment?

A. MIMs
B. NAVEDTRA
C. NATOPS
D. IPB

2-18. What is the purpose of testing a piece of equipment after it has been repaired?

A. Ensure technician skills are adequate
B. Ensure future maintenance will be not required
C. Ensure operators can properly operate equipment
D. Ensure system works properly

2-19. How would you connect a digital multimeter to a circuit that is being tested for voltage?

A. Connect in series
B. Connect in parallel
C. Connect in parallel - series
D. Connect in phase

2-20. When using a digital multimeter, you should start at what range?

A. Lowscale
B. Lowscale - midscale
C. Midscale
D. Highscale

2-21. A circuit in which current no longer flows is known as a _____.

A. short circuit
B. open circuit
C. faulty relay
D. broken switch

2-22. What test do you perform to find an open circuit?

A. Continuity test
B. Resistance check
C. Voltage check
D. Ohm test

2-23. Blown fuses and open circuit breakers are usually an indication of what type of fault?

A. Open circuit
B. Faulty relay
C. Open switch
D. Short circuit

2-24. List the two disadvantages of the volt-ohm-milliammeter (VOM)?

A. Can unload the circuit under test and damage meter movement
B. Can load the circuit under test and damage meter movement
C. Can load the circuit under test and damage equipment
D. Can unload the circuit under test and damaged equipment

2-25. What type meter should you use to test for insulation breakdown?

A. Megger
B. Ohmmeter
C. Digital multimeter
D. Ammeter

2-26. What test equipment shows you the wave shape of current or voltages?

A. Megger
B. Multimeter
C. Voltmeter
D. Oscilloscope

2-27. What is a discontinuity?

A. Normal resistance or impedance that ensures normal signal flow
B. Abnormal resistance or impedance that interferes with normal signal flow
C. Abnormal resistance or impedance which in turn ensures normal signal flow
D. Normal resistance or impedance that interferes with normal signal flow

2-28. What type of wire should you use to carry 600 to 1,000 volts with a temperature rating between 302°F to 500°F?

A. MIL-W-25038
B. MIL-W-22759
C. MIL-W-81044
D. MIL-C-27500

2-29. What type of metal used in wire forms a resistant oxide film on all its surfaces?

A. Steel
B. Copper
C. Aluminum
D. Brass

2-30. When stamping wire identification numbers, at what interval should you stamp the wire?

A. 15 inches
B. 24 inches
C. 30 inches
D. Total length of wire divided by 4 (measured in inches)

2-31. In wire identification numbers, the suffix N means the wire completes the circuit to?

A. Photographic circuits
B. Ground
C. Loaded equipment
D. Miscellaneous equipment

2-32. What is the most important item to consider when soldering?

A. Selection of the correct solder
B. Selection of the correct power supply
C. Selection of the correct flux
D. Selection of the correct iron

2-33. What publication contains information on mounting hardware for aircraft parts?

A. NAVEDTRA 14308
B. NAVAIR 01-1A-8
C. NAVAIR 01-1A-50
D. NATOPS 01-1A

2-34. When substituting hardware, what should you consider before making the substitution?

A. Location
B. Strength
C. Design
D. Manufacturer

2-35. What is the only reason for clamping a wire bundle to a plumbing line?

A. Separation of the wire bundle from the plumbing line
B. Combining of the wire bundle with the plumbing line
C. Combining of individual wires with the plumbing line
D. Separation of individual wires from the plumbing line

2-36. List the three types of safety wire:

A. Lockwire, sheen wire, & seal wire
B. Lockwire, shear wire, & seal wire
C. Lockwire, shear wire, & seam wire
D. Lockwire, sheen wire, & seam wire

2-37. What is the purpose of bonding?

A. To provide a low-resistance return path for single-wire electrical systems
B. To provide a means of masking the entire aircraft to the earth's potential
C. To increase lightning damage to the aircraft and its occupants
D. To provide for a decrease in grounding

2-38. List the manuals to which you should refer for the correct cleaning agents and procedures?

A. NATOPS 01-1A-50
B. NATOPS 01-1A-505
C. NAVAIR 01-1A-8
D. NAVAIR 01-1A-509

2-39. For a technician to repair a printed circuit board, what certification must they meet?

A. First aid
B. Microminiature circuit repair
C. CPR
D. Electronic repair

2-40. What are the two types of test equipment?

A. Common and uncommon
B. Common and unusual
C. Common or particular
D. Common or peculiar

2-41. What test equipment is used to test aircraft engine driven accessories, such as generators and generator drive systems?

A. AECTS
B. UUT
C. VSD
D. TTU-27/E

2-42. The Huntron Tracker 1000 and 2000 are for use on circuit boards and systems with all voltage sources in what condition?

A. Power off
B. Power on
C. Standby
D. Safe

2-43. What type of signal display does the Huntron Tracker 1000 and 2000 show when the signal fuse is open and the test leads shorted together?

A. Voltage phases
B. Closed circuit signatures
C. Open circuit signatures
D. Voltage amplitude

2-44. When using the Huntron Tracker 2000, why must you make good contact with the test leads?

A. Test leads are conductive only at the tips
B. Materials used for leads are not very conductive
C. Test leads are conductive only at the base of stem
D. Materials used for leads prevent transfer of current

2-45. Which piece of test equipment would you use to test an engine ignition unit output in sparks per second?

A. TTU-27/E
B. JATCAL
C. Jet Ignition System Tester
D. Hunton Tracker 2000

2-46. When testing a tachometer generator, which switch is used to select the individual phase-to-phase voltage displayed on the voltmeter?

A. RPM x 2, RPM x 1, and PERCENT RPM
B. A-B, B-C and A-C TERM CONNECTION
C. LOAD IN OHMS
D. TEST GEN INPUT

2-47. What component of the TTU-27/E is used to test and calibrate the tachometer indicator?

A. Drive pad
B. Master indicator
C. Master tachometer generator
D. Jet engine tachometer generator

2-48. What is the minimum voltage for using the TAKCAL unit of the JETCAL Analyzer?

A. 5 volts
B. 33 volts
C. 75 volts
D. 95 volts

2-49. What initial test should be performed when using the TTK-512 propeller synchronizer tester on the synchrophaser system?

A. Voltage tests
B. Tests on ground with engines running
C. Inflight tests
D. Resistance and megger tests

2-50. What piece of equipment is used to test pitot-static systems?

A. TS-4508/U
B. TTU-378 A/E
C. AN/PSM-17A
D. AN/PSM-21A

2-51. The TTU-378 A/E test set can be used to verify system operation, adjust the indicator to the tank units, or determine whether the _____ are defective.

A. unit insulation
B. accessory cables
C. indicator or probes
D. insulation resistance

2-52. The FCTS is compatible with all types of aircraft which have what type fuel system?

A. Reactive
B. Inductive
C. Electromagnetic
D. Capacitive

2-53. Which operating mode of the TTU-597/E allows the test unit to be used directly to measure insulation resistance, bonding or capacitance and provides a capacitor simulation output?

A Automated Mode
B. Manual Mode
C. Power-On Self-Test
D. Capacitance Mode

2-54. The AN/PSM-17A test set is used to test what system?

A. Navigation
B. Ignition
C. Fuel
D. Angle-of-attack

2-55. When a desired temperature is selected when operating the BR61-103, a pointer at the center of the dial is a program position indicator (PPI) that indicates what?

A. TCS A, B, and C valve positions are programmed to achieve or maintain the selected temperature.
B. TCS A, and B valve positions must be programmed for selected temperature
C. A valve, 40 degrees; B valve, 60 degrees; and C valve, 80 degrees.
D. A valve, 40 degrees; B valve, 80 degrees; and C valve, 80 degrees.

2-56. What are the dimensions for the BR61-103 test set?

A. 16 inches in length, 15 inches in height, and 14 inches wide
B. 17 inches in length, 14 inches in height, and 14 inches wide
C. 16 inches in length, 15 inches in height, and 14 inches wide
D. 16 inches in length, 15 inches in height, and 34 inches wide

2-57. What is the lowest voltage that will destroy or damage an ESD-sensitive device?

A. 10 volts
B. 20 volts
C. 30 volt
D. 25 volts

2-58. The generation of static electricity on an object by rubbing is known as the _____.

A. electrostatic charge
B. dielectric effect
C. triboelectric effect
D. prime charge

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