

breakdown. Insulate wires that must run through hot areas with a high-temperature insulation material, such as fiberglass or PTFE. Avoid high-temperature areas when using cables with soft plastic insulation, such as polyethylene, because these materials are subject to deterioration and deformation at elevated temperatures. Many coaxial cables have this type of insulation.

#### *Protection Against Solvents & Fluids*

An arcing fault between an electrical wire and a metallic flammable fluid line may puncture the line and result in a fire. Every effort must be made to avoid this hazard by physical separation of the wire from lines and equipment containing oxygen, oil, fuel, hydraulic fluid, or alcohol. Wiring must be routed above these lines and equipment with a minimum separation of 6 inches or more whenever possible. When such an arrangement is not practicable, wiring must be routed so that it does not run parallel to the fluid lines. A minimum of 2 inches must be maintained between wiring and such lines and equipment, except when the wiring is positively clamped to maintain at least  $\frac{1}{2}$ -inch separation, or when it must be connected directly to the fluid-carrying equipment. Install clamps as shown in *Figure 9-133*. These clamps should not be used as a means of supporting the wire bundle. Additional clamps should be installed to support the wire bundle and the clamps fastened to the same structure used to support the fluid line(s) to prevent relative motion.

Wires, or groups of wires, should enter a junction box, or terminate at a piece of equipment in an upward direction where practicable. Ensure that a trap, or drip loop, is provided to prevent fluids or condensation from running into wire or cable ends that slope downward toward a connector, terminal block, panel, or junction block. A drip loop is an area where the wire(s) are made to travel downward and then up to the connector. [*Figure 9-134*] Fluids and moisture will flow along the wires to the bottom of the loop and be trapped there to drip or evaporate without affecting electrical conductivity in the wire, junction, or connected device.

Where wires must be routed downwards to a junction box or electrical unit and a drip loop is not possible, the entrance should be sealed according to manufacturer's specifications to prevent moisture from entering the box/unit. Wires and cables installed in bilges and other locations where fluids collect must be routed as far from the lowest point as possible or otherwise be provided with a moisture-proof covering.

#### *Protection of Wires in Wheel Well Areas*

Wires located on landing gear and in the wheel well area can be exposed to many hazardous conditions if not suitably protected. Where wire bundles pass flex points, there must not be any strain on attachments or excessive slack when parts

are fully extended or retracted. The wiring and protective tubing must be inspected frequently and replaced at the first sign of wear.

Wires should be routed so that fluids drain away from the connectors. When this is not practicable, connectors must be potted. Wiring which must be routed in wheel wells or other external areas must be given extra protection in the form of harness jacketing and connector strain relief. Conduits or flexible sleeving used to protect wiring must be equipped with drain holes to prevent entrapment of moisture.

The technician should check during inspections that wires and cables are adequately protected in wheel wells and other areas where they may be exposed to damage from impact of



**Figure 9-133.** Positive separation of wire and fluid lines and wire clamps.



**Figure 9-134.** Drip loop.



**Figure 9-135.** Wire clamps.

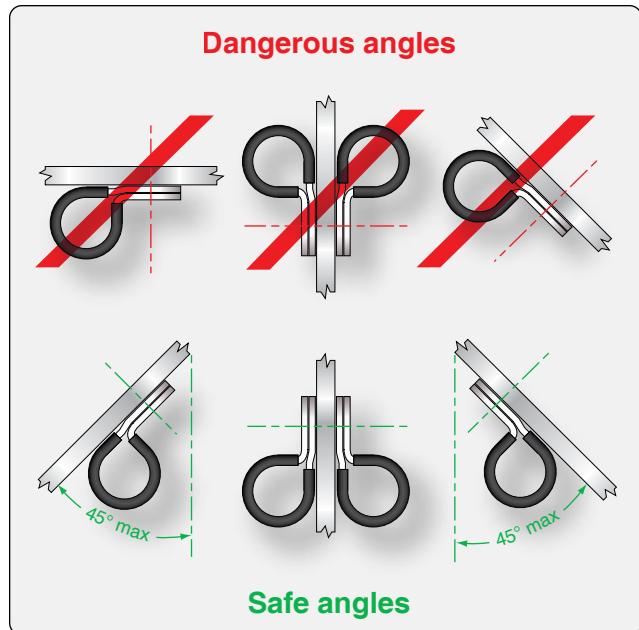
rocks, ice, mud, etc. (If rerouting of wires or cables is not practical, protective jacketing may be installed). This type of installation must be held to a minimum.

#### Clamp Installation

Wires and wire bundles must be supported by clamps or plastic cable straps. [Figure 9-135] Clamps and other primary support devices must be constructed of materials that are compatible with their installation and environment, in terms of temperature, fluid resistance, exposure to ultraviolet (UV) light, and wire bundle mechanical loads. They should be spaced at intervals not exceeding 24 inches. Clamps on wire bundles should be selected so that they have a snug fit without pinching wires. [Figures 9-136 through 9-138]

**Caution:** The use of metal clamps on coaxial RF cables may cause problems, if clamp fit is such that RF cable's original cross section is distorted.

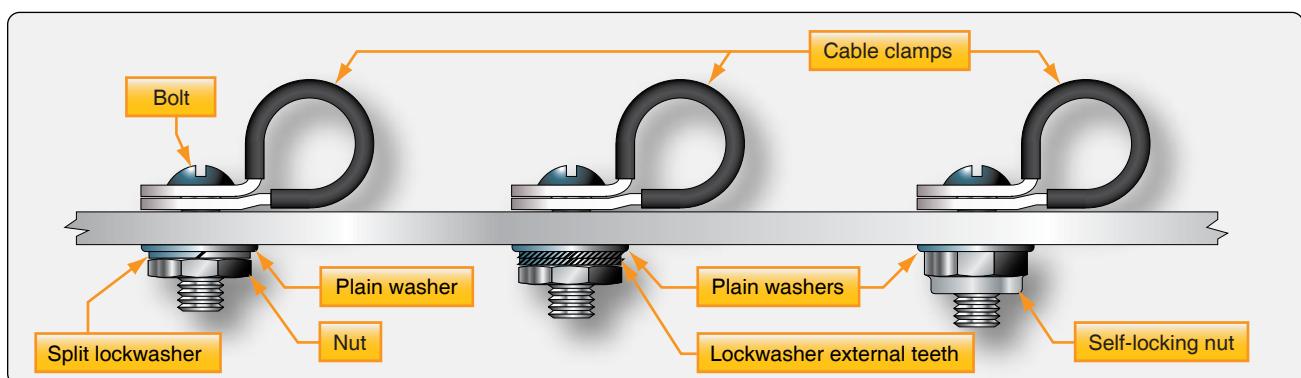
Clamps on wire bundles should not allow the bundle to move through the clamp when a slight axial pull is applied. Clamps on RF cables must fit without crushing and must



**Figure 9-136.** Safe angle for cable clamps.

be snug enough to prevent the cable from moving freely through the clamp, but may allow the cable to slide through the clamp when a light axial pull is applied. The cable or wire bundle may be wrapped with one or more turns of electrical tape when required to achieve this fit. Plastic clamps or cable ties must not be used where their failure could result in interference with movable controls, wire bundle contact with movable equipment, or chafing damage to essential or unprotected wiring. They must not be used on vertical runs where inadvertent slack migration could result in chafing or other damage. Clamps must be installed with their attachment hardware positioned above them, wherever practicable, so that they are unlikely to rotate as the result of wire bundle weight or wire bundle chafing. [Figure 9-136]

Clamps lined with nonmetallic material should be used to support the wire bundle along the run. Tying may be used



**Figure 9-137.** Typical mounting hardware for MS-21919 cable clamps.

between clamps, but should not be considered as a substitute for adequate clamping. Adhesive tapes are subject to age deterioration and, therefore, are not acceptable as a clamping means. [Figure 9-137]

The back of the clamp, whenever practical, should be rested against a structural member. [Figure 9-138] Stand-offs should be used to maintain clearance between the wires and the structure. Clamps must be installed in such a manner that the electrical wires do not come in contact with other parts of the aircraft when subjected to vibration. Sufficient slack should be left between the last clamp and the electrical equipment to prevent strain at the terminal and to minimize adverse effects on shock-mounted equipment. Where wires or wire bundles pass through bulkheads or other structural members, a grommet or suitable clamp should be provided to prevent abrasion.

When a wire bundle is clamped into position, if there is less than  $\frac{3}{8}$ -inch of clearance between the bulkhead cutout and the wire bundle, a suitable grommet should be installed as indicated in Figure 9-139. The grommet may be cut at a  $45^{\circ}$  angle to facilitate installation, provided it is cemented in place and the slot is located at the top of the cutout.

#### *Wire & Cable Clamp Inspection*

Inspect wire and cable clamps for proper tightness. Where cables pass through structure or bulkheads, inspect for proper clamping and grommets. Inspect for sufficient slack between the last clamp and the electronic equipment to prevent strain at the cable terminals and to minimize adverse effects on shock-mounted equipment. Wires and cables are supported by suitable clamps, grommets, or other devices at intervals of not more than 24 inches, except when contained in troughs, ducts, or conduits. The supporting devices should be of a suitable size and type, with the wires and cables held securely in place without damage to the insulation.

Use metal stand-offs to maintain clearance between wires and structure. Tape or tubing is not acceptable as an alternative to stand-offs for maintaining clearance. Install phenolic blocks, plastic liners, or rubber grommets in holes, bulkheads, floors, or structural members where it is impossible to install off-angle clamps to maintain wiring separation. In such cases, additional protection in the form of plastic or insulating tape may be used.

Properly secure clamp retaining bolts so the movement of wires and cables is restricted to the span between the points of support and not on soldered or mechanical connections at terminal posts or connectors.

#### *Movable Controls Wiring Precautions*

Clamping of wires routed near movable flight controls must be attached with steel hardware and must be spaced so that failure of a single attachment point cannot result in interference with controls. The minimum separation between wiring and movable controls must be at least  $\frac{1}{2}$  inch when the bundle is displaced by light hand pressure in the direction of the controls.

#### *Conduit*

Conduit is manufactured in metallic and nonmetallic materials and in both rigid and flexible forms. Primarily, its purpose is for mechanical protection of cables or wires. Conduit size should be selected for a specific wire bundle application to allow for ease in maintenance, and possible future circuit expansion, by specifying the conduit inner diameter (ID) about 25 percent larger than the maximum diameter of the wire bundle. [Figure 9-140]

Conduit problems can be avoided by following these guidelines:

- Do not locate conduit where passengers or maintenance personnel might use it as a handhold or footstep.
- Provide drain holes at the lowest point in a conduit run. Drilling burrs should be carefully removed.
- Support conduit to prevent chafing against structure and to avoid stressing its end fittings.

#### *Rigid Conduit*

Damaged conduit sections should be repaired to preclude injury to the wires or wire bundle that may consume as much as 80 percent of the tube area. Minimum acceptable tube bend radii for rigid conduit are shown in Figure 9-141. Kinked or wrinkled bends in rigid conduits are not recommended and should be replaced. Tubing bends that have been flattened into an ellipse and have a minor diameter of less than 75 percent of the nominal tubing diameter should be replaced, because the tube area has been reduced by at least 10 percent. Tubing that has been formed and cut to final length should be deburred to prevent wire insulation damage. When installing replacement tube sections with fittings at both ends, care should be taken to eliminate mechanical strain.

#### *Flexible Conduit*

Flexible aluminum conduit conforming to specification MIL-C-6136 is available in two types: Type I, bare flexible conduit, and Type II, rubber-covered flexible conduit. Flexible brass conduit conforming to specification MIL-C-7931 is available and normally used instead of flexible aluminum where necessary to minimize radio interference. Also available is a plastic flexible tubing. (Reference MIL-T-8191A.) Flexible conduit may be used where it is impractical to use rigid conduit,

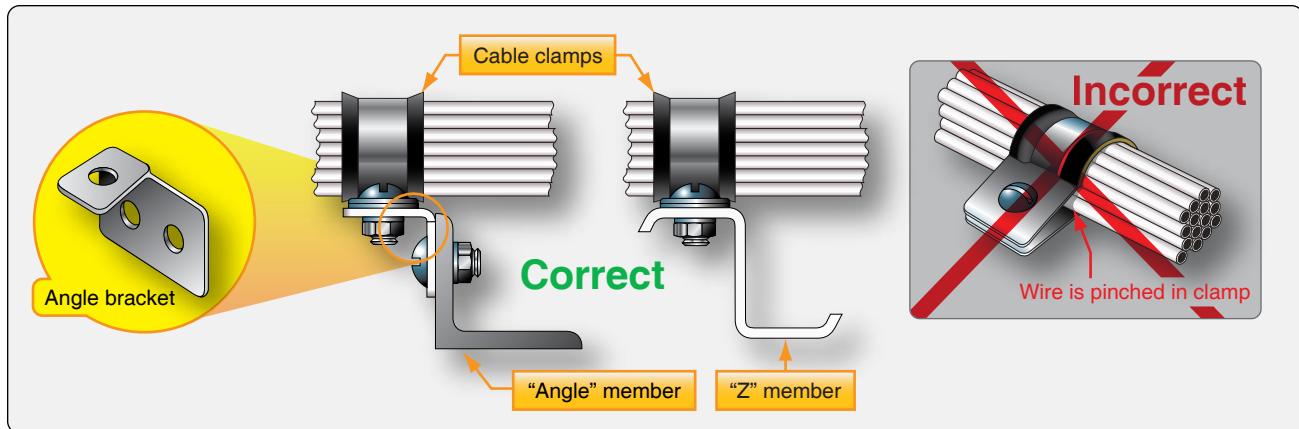


Figure 9-138. Installing cable clamp to structure.

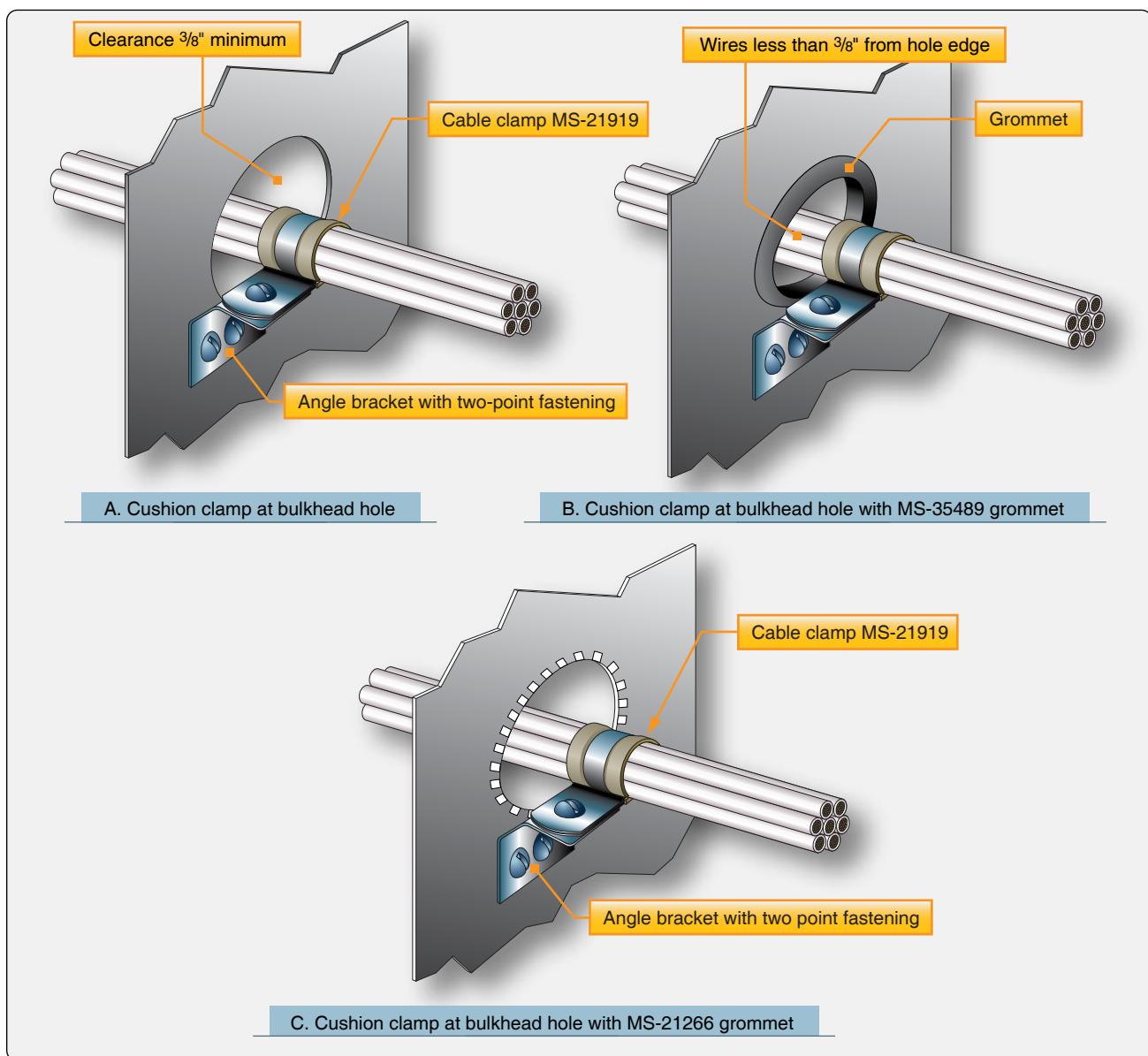


Figure 9-139. Clamping at a bulkhead hole.



**Figure 9-140.** Flexible conduit.

Nominal tube OD (inches)	Minimum bend radius (inches)
1/8	3/8
3/16	7/16
1/4	9/16
3/8	15/16
1/2	1 1/4
5/8	1 1/2
3/4	1 3/4
1	3
1 1/4	3 3/4
1 1/2	5
1 3/4	7
2	8

**Figure 9-141.** Minimum bend radii for rigid conduit.

such as areas that have motion between conduit ends or where complex bends are necessary.

The use of transparent adhesive tape is recommended when cutting flexible tubing with a hacksaw to minimize fraying of the braid. The tape should be centered over the cutting reference mark with the saw cutting through the tape. After cutting the flexible conduit, the transparent tape should be removed, the frayed braid ends trimmed, burrs removed from inside the conduit, and coupling nut and ferrule installed. Minimum acceptable bending radii for flexible conduit are shown in *Figure 9-142*.

### Wire Shielding

In conventional wiring systems, circuits are shielded individually, in pairs, triples, or quads depending on each circuit's shielding requirement called out for in the engineering documentation. A wire is normally shielded when it is anticipated that the circuit can be affected by another circuit in the wire harness. When the wires come

Nominal ID of conduit (inches)	Minimum bending radius inside (inches)
3/16	2 1/4
1/4	2 3/4
3/8	3 3/4
1/2	3 3/4
5/8	3 3/4
3/4	4 1/4
1	5 3/4
1 1/4	8
1 1/2	8 1/4
1 3/4	9
2	9 3/4
2 1/2	10

**Figure 9-142.** Minimum bending radii for flexible aluminum or brass conduit.

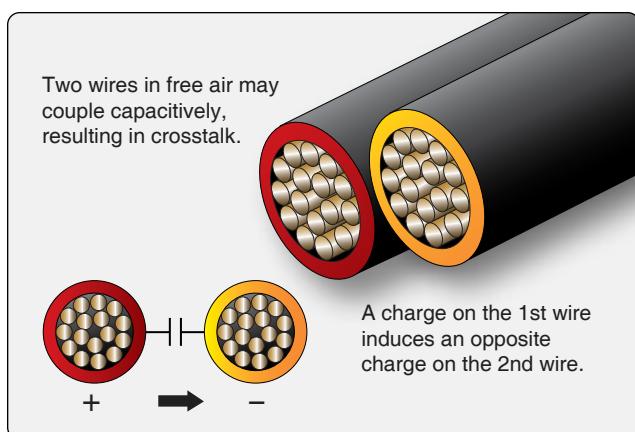
close together, they can couple enough interference to cause a detrimental upset to attached circuitry. This effect is often called crosstalk. Wires must come close enough for their fields to interact, and they must be in an operating mode that produces the crosstalk effect. However, the potential for crosstalk is real, and the only way to prevent crosstalk is to shield the wire. [*Figure 9-143*]

### Bonding & Grounding

One of the more important factors in the design and maintenance of aircraft electrical systems is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, EMI, electrostatic discharge damage to sensitive electronics, personnel shock hazard, or damage from lightning strike.

### Grounding

Grounding is the process of electrically connecting conductive objects to either a conductive structure or some



**Figure 9-143.** Crosstalk.

other conductive return path for the purpose of safely completing either a normal or fault circuit. [Figure 9-144]

If wires carrying return currents from different types of sources, such as signals of DC and AC generators, are connected to the same ground point or have a common connection in the return paths, an interaction of the currents occurs. Mixing return currents from various sources should be avoided because noise is coupled from one source to another and can be a major problem for digital systems. To minimize the interaction between various return currents, different types of ground should be identified and used. As a minimum, the design should use three ground types: (1) AC returns, (2) DC returns, and (3) all others.

For distributed power systems, the power return point for an alternative power source would be separated. For example, in a two-AC generator (one on the right side and the other on the left side) system, if the right AC generator was supplying backup power to equipment located on the left side, (left equipment rack) the backup AC ground return should be labeled "AC Right." The return currents for the left generator should be connected to a ground point labeled "AC Left."

The design of the ground return circuit should be given as much attention as the other leads of a circuit. A requirement for proper ground connections is that they maintain an impedance that is essentially constant. Ground return circuits should have a current rating and voltage drop adequate for satisfactory operation of the connected electrical and electronic equipment. EMI problems that can be caused by a system's power wire can be reduced substantially by locating the associated ground return near the origin of the power wiring (e.g., circuit breaker panel) and routing the power wire and its ground return in a twisted pair. Special care should be exercised to ensure replacement on ground return leads. The use of numbered insulated wire leads instead of

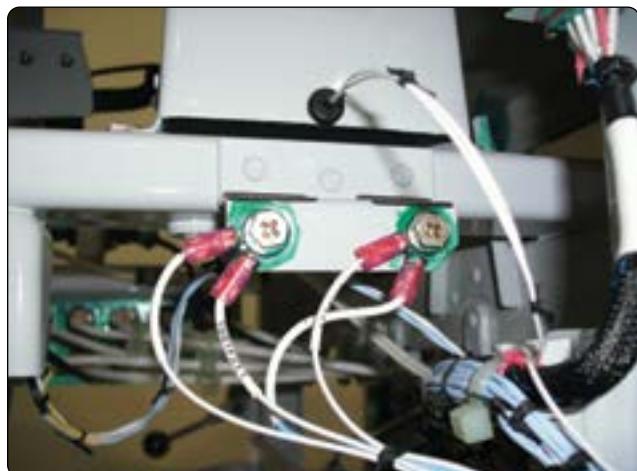


Figure 9-144. Ground wires.

bare grounding jumpers may aid in this respect. In general, equipment items should have an external ground connection, even when internally grounded. Direct connections to a magnesium structure must not be used for ground return because they may create a fire hazard.

Power ground connections for generators, transformer rectifiers, batteries, external power receptacles, and other heavy-current loads must be attached to individual grounding brackets that are attached to aircraft structure with a proper metal-to-metal bonding attachment. This attachment and the surrounding structure must provide adequate conductivity to accommodate normal and fault currents of the system without creating excessive voltage drop or damage to the structure. At least three fasteners, located in a triangular or rectangular pattern, must be used to secure such brackets in order to minimize susceptibility to loosening under vibration. If the structure is fabricated of a material, such as carbon fiber composite (CFC), that has a higher resistivity than aluminum or copper, it is necessary to provide an alternative ground path(s) for power return current. Special attention should be considered for composite aircraft.

Power return or fault current ground connections within flammable vapor areas must be avoided. If they must be made, make sure these connections do not arc, spark, or overheat under all possible current flow or mechanical failure conditions, including induced lightning currents. Criteria for inspection and maintenance to ensure continued airworthiness throughout the expected life of the aircraft should be established. Power return fault currents are normally the highest currents flowing in a structure. These can be the full generator current capacity. If full generator fault current flows through a localized region of the carbon fiber structure, major heating and failure can occur. CFC and other similar low-resistive materials must not be used in power return paths. Additional voltage drops in the return path can cause voltage regulation problems. Likewise, repeated localized material heating by current surges can cause material degradation. Both problems may occur without warning and cause no repeatable failures or anomalies.

The use of common ground connections for more than one circuit or function should be avoided except where it can be shown that related malfunctions that could affect more than one circuit do not result in a hazardous condition. Even when the loss of multiple systems does not, in itself, create a hazard, the effect of such failure can be quite distracting to the crew.

#### Bonding

Bonding is the electrical connecting of two or more conducting objects not otherwise adequately connected.

The following bonding requirements must be considered:

- Equipment bonding—low-impedance paths to aircraft structure are normally required for electronic equipment to provide radio frequency return circuits and for most electrical equipment to facilitate reduction in EMI. The cases of components that produce electromagnetic energy should be grounded to structure. To ensure proper operation of electronic equipment, it is particularly important to conform the system's installation specification when interconnections, bonding, and grounding are being accomplished.
- Metallic surface bonding—all conducting objects on the exterior of the airframe must be electrically connected to the airframe through mechanical joints, conductive hinges, or bond straps capable of conducting static charges and lightning strikes. Exceptions may be necessary for some objects, such as antenna elements, whose function requires them to be electrically isolated from the airframe. Such items should be provided with an alternative means to conduct static charges and/or lightning currents, as appropriate.
- Static bonds—all isolated conducting parts inside and outside the aircraft, having an area greater than 3 square inches and a linear dimension over 3 inches, that are subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion, should have a mechanically secure electrical connection to the aircraft structure of sufficient conductivity to dissipate possible static charges. A resistance of less than 1 ohm when clean and dry generally ensures such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.

#### *Testing of Bonds & Grounds*

The resistance of all bond and ground connections should be tested after connections are made before re-finishing. The resistance of each connection should normally not exceed 0.003 ohm. A high quality test instrument, an AN/USM-21A or equivalent, is required to accurately measure the very low resistance values.

#### *Bonding Jumper Installation*

Bonding jumpers should be made as short as practicable, and installed in such a manner that the resistance of each connection does not exceed .003 ohm. The jumper should not interfere with the operation of movable aircraft elements, such as surface controls, nor should normal movement of these elements result in damage to the bonding jumper. [Figure 9-145]

- Bonding connections—to ensure a low-resistance connection, nonconducting finishes, such as paint and anodizing films, should be removed from the

attachment surface to be contacted by the bonding terminal. Electrical wiring should not be grounded directly to magnesium parts.

- Corrosion protection—one of the more frequent causes of failures in electrical system bonding and grounding is corrosion. The areas around completed connections should be post-finished quickly with a suitable finish coating.
- Corrosion prevention—electrolytic action may rapidly corrode a bonding connection if suitable precautions are not taken. Aluminum alloy jumpers are recommended for most cases; however, copper jumpers should be used to bond together parts made of stainless steel, cadmium-plated steel, copper, brass, or bronze. Where contact between dissimilar metals cannot be avoided, the choice of jumper and hardware should be such that corrosion is minimized; the part likely to corrode should be the jumper or associated hardware.
- Bonding jumper attachment—the use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. Proper choice of clamp material should minimize the probability of corrosion.
- Ground return connection—when bonding jumpers carry substantial ground return current, the current rating of the jumper should be determined to be adequate, and a negligible voltage drop is produced. [Figure 9-146]

#### **Lacing & Tying Wire Bundles**

Ties, lacing, and straps are used to secure wire groups or bundles to provide ease of maintenance, inspection, and installation. Straps may not be used in areas of SWAMP, such as wheel wells, near wing flaps, or wing folds. They



Figure 9-145. Bonding jumpers.

Aluminum Terminal and Jumper					
Structure	Screw or bolt and nut plate	Locknut	Washer A	Washer B	Washer C
Aluminum alloys	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel or aluminum	None	Cadmium-plated steel or aluminum
Magnesium alloys	Cadmium-plated steel	Cadmium-plated steel	Magnesium-alloy	None or magnesium alloy	Cadmium-plated steel or aluminum
Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel or aluminum
Corrosion-resisting steel	Corrosion-resisting steel or Cadmium-plated steel	Cadmium-plated steel	Corrosion-resisting steel	Cadmium-plated steel	Cadmium-plated steel or aluminum

Tinned Copper Terminal and Jumper					
Aluminum alloys	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Aluminum alloys <sup>2</sup>	Cadmium-plated steel
Magnesium alloys <sup>1</sup>					
Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	none	Cadmium-plated steel
Corrosion-resisting steel	Corrosion-resisting steel or cadmium-plated steel	Cadmium-plated steel	Corrosion-resisting steel	none	Cadmium-plated steel

<sup>1</sup>Avoid connecting copper to magnesium.

<sup>2</sup>Use washers with a conductive finish treated to prevent corrosion, such as AN960JD10L.

**Figure 9-146.** Bolt and nut bonding or grounding to flat surface.

may not be used in high vibration areas where failure of the strap would permit wiring to move against parts that could damage the insulation and foul mechanical linkages or other moving mechanical parts. They also may not be used where they could be exposed to UV light, unless the straps are resistant to such exposure. [Figure 9-147]

The single cord-lacing method and tying tape may be used for wire groups of bundles 1 inch in diameter or less. The recommended knot for starting the single cord-lacing method is a clove hitch secured by a double-looped overhand knot. [Figure 9-148, step A] Use the double cord-lacing method on wire bundles 1 inch in diameter or larger. When using the double cord-lacing method, employ a bowline-on-a-bight as the starting knot. [Figure 9-149, step A]

### Tying

Use wire group or bundle ties where the supports for the wire are more than 12 inches apart. A tie consists of a clove hitch around the wire group or bundle, secured by a square knot. [Figure 9-150]

### Wire Termination

#### Stripping Wire

Before wire can be assembled to connectors, terminals, splices, etc., the insulation must be stripped from connecting ends to expose the bare conductor. Copper wire can be stripped in a number of ways depending on the size and insulation.

Aluminum wire must be stripped using extreme care, since individual strands break very easily after being nicked. The following general precautions are recommended when



**Figure 9-147.** Wire lacing.

stripping any type of wire:

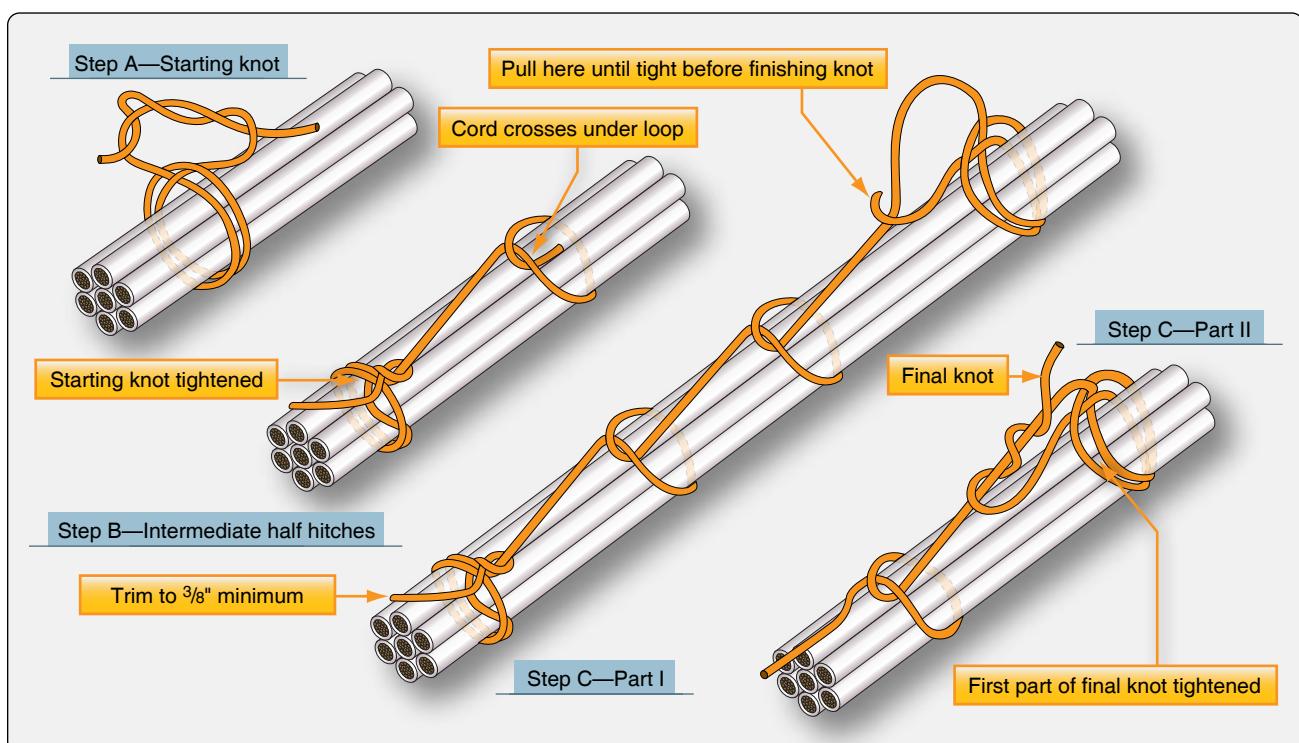
1. When using any type of wire stripper, hold the wire so that it is perpendicular to cutting blades.
2. Adjust automatic stripping tools carefully; follow the manufacturer's instructions to avoid nicking, cutting, or otherwise damaging strands. This is especially important for aluminum wires and for copper wires smaller than No. 10. Examine stripped wires for damage. Cut off and restrip (if length is sufficient), or reject and replace any wires having more than the allowable number of nicked or broken strands listed

in the manufacturer's instructions.

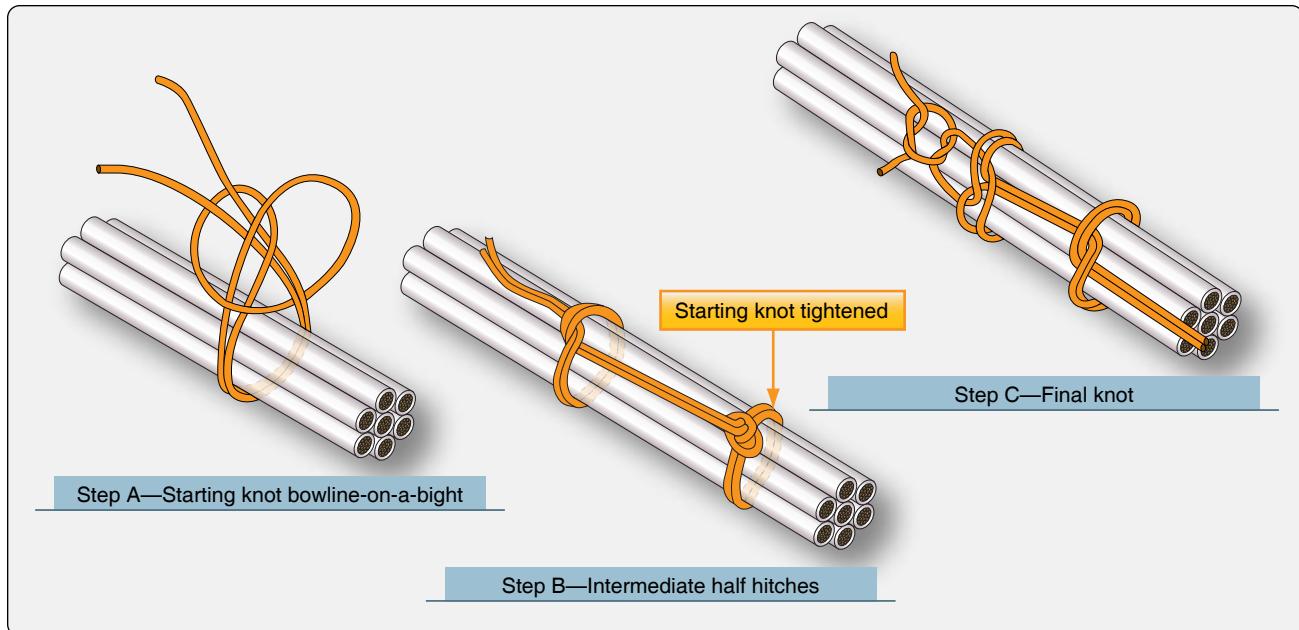
3. Make sure insulation is clean-cut with no frayed or ragged edges. Trim, if necessary.
4. Make sure all insulation is removed from stripped area. Some types of wire are supplied with a transparent layer of insulation between the conductor and the primary insulation. If this is present, remove it.
5. When using hand-plier strippers to remove lengths of insulation longer than  $\frac{1}{4}$  inch, it is easier to accomplish in two or more operations.
6. Retwist copper strands by hand or with pliers, if necessary, to restore natural lay and tightness of strands.

A pair of handheld wire strippers is shown in *Figure 9-151*. This tool is commonly used to strip most types of wire. The following general procedures describe the steps for stripping wire with a hand stripper.

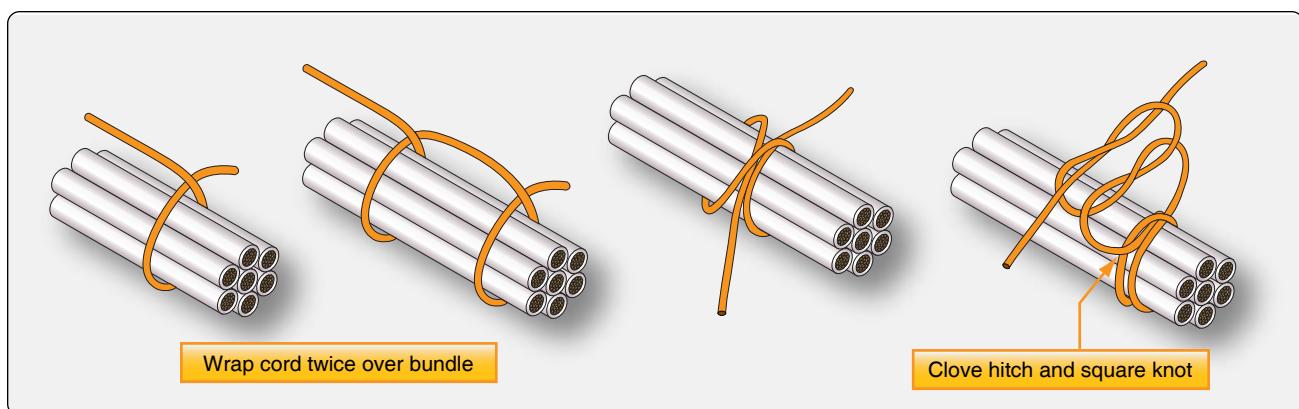
1. Insert wire into exact center of correct cutting slot for wire size to be stripped. Each slot is marked with wire size.
2. Close handles together as far as they will go.
3. Release handles, allowing wire holder to return to the open position.
4. Remove stripped wire.



**Figure 9-148.** Single cord-lacing method.



**Figure 9-149.** Double cord-lacing.



**Figure 9-150.** Tying.



**Figure 9-151.** Wire strippers.



**Figure 9-152.** Ring-tongue terminals.

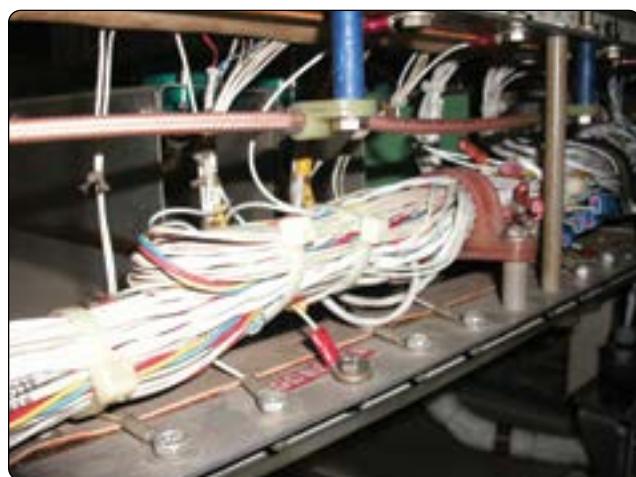
Terminals are attached to the ends of electrical wires to facilitate connection of the wires to terminal strips or items of equipment. [Figure 9-152] The tensile strength of the wire-to-terminal joint should be at least equivalent to the tensile strength of the wire itself, and its resistance negligible relative to the normal resistance of the wire.

The following should be considered in the selection of wire terminals: current rating, wire size (gauge) and insulation diameter, conductor material compatibility, stud size, insulation material compatibility, application environment, and solder versus solderless.

Preinsulated crimp-type ring-tongue terminals are preferred. The strength, size, and supporting means of studs and binding posts, as well as the wire size, may be considered when determining the number of terminals to be attached to any one post. In high-temperature applications, the terminal temperature rating must be greater than the ambient temperature plus current related temperature rise. Use of nickel-plated terminals and of uninsulated terminals with high-temperature insulating sleeves should be considered. Terminal blocks should be provided with adequate electrical clearance or insulation strips between mounting hardware and conductive parts.

### **Terminal Strips**

Wires are usually joined at terminal strips. [Figure 9-153] A terminal strip fitted with barriers may be used to prevent the terminals on adjacent studs from contacting each other. Studs should be anchored against rotation. When more than four terminals are to be connected together, a small metal bus should be mounted across two or more adjacent studs. In all cases, the current should be carried by the terminal contact surfaces and not by the stud itself. Defective studs should be replaced with studs of the same size and material since terminal



**Figure 9-153.** Terminal strip.

strip studs of the smaller sizes may shear due to overtightening the nut. The replacement stud should be securely mounted in the terminal strip and the terminal securing nut should be tight. Terminal strips should be mounted in such a manner that loose metallic objects cannot fall across the terminals or studs. It is good practice to provide at least one spare stud for future circuit expansion or in case a stud is broken.

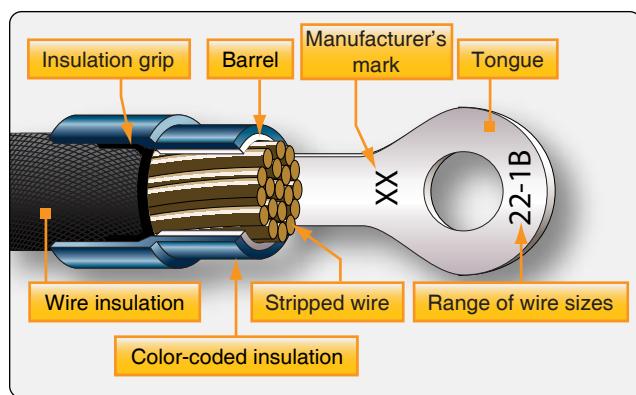
Terminal strips that provide connection of radio and electronic systems to the aircraft electrical system should be inspected for loose connections, metallic objects that may have fallen across the terminal strip, dirt and grease accumulation, etc. These conditions can cause arcing, which may result in a fire or system failures.

### **Terminal Lugs**

Wire terminal lugs should be used to connect wiring to terminal block studs or equipment terminal studs. No more than four terminal lugs, which includes the three terminal lugs and a bus bar, should be connected to any one stud. The total number of terminal lugs per stud always includes a common bus bar joining adjacent studs. Four terminal lugs plus a common bus bar are not permitted on one stud. Terminal lugs should be selected with a stud hole diameter that matches the diameter of the stud. However, when the terminal lugs attached to a stud vary in diameter, the greatest diameter should be placed on the bottom and the smallest diameter on top. Tightening terminal connections should not deform the terminal lugs or the studs. Terminal lugs should be positioned so that bending the terminal lug is not required to remove the fastening screw or nut, and movement of the terminal lugs tighten the connection.

### **Copper Wire Terminals**

Solderless crimp-style, copper wire, terminal lugs may be used which conform to MIL-T-7928. Spacers or washers should not be used between the tongues of terminal lugs. [Figure 9-154]



**Figure 9-154.** Wire terminal.

### *Aluminum Wire Terminals*

The aluminum terminal lugs should be crimped to aluminum wire only. The tongue of the aluminum terminal lugs, or the total number of tongues of aluminum terminal lugs when stacked, should be sandwiched between two flat washers when terminated on terminal studs. Spacers or washers should not be used between the tongues of terminal lugs. Special attention should be given to aluminum wire and cable installations to guard against conditions that would result in excessive voltage drop and high resistance at junctions that may ultimately lead to failure of the junction. Examples of such conditions are improper installation of terminals and washers, improper torsion (torquing of nuts), and inadequate terminal contact areas.

### *Pre-Insulated Splices*

Pre-insulated terminal lugs and splices must be installed using a high-quality crimping tool. Such tools are provided with positioners for the wire size and are adjusted for each wire size. It is essential that the crimp depth be appropriate for each wire size. If the crimp is too deep, it may break or cut individual strands. If the crimp is not deep enough, it may not be tight enough to retain the wire in the terminal or connector. Crimps that are not tight enough are also susceptible to high resistance due to corrosion buildup between the crimped terminal and the wire. [Figure 9-155]

### *Crimping Tools*

Hand, portable, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel to the conductor, and simultaneously form the insulation support to the wire insulation. [Figure 9-156]

### *Emergency Splicing Repairs*

Broken wires can be repaired by means of crimped splices, by using terminal lugs from which the tongue has been cut off, or by soldering together and potting broken strands. These repairs are applicable to copper wire. Damaged aluminum wire must not be temporarily spliced. These repairs are for temporary emergency use only and should

be replaced as soon as possible with permanent repairs. Since some manufacturers prohibit splicing, the applicable manufacturer's instructions should always be consulted.



**Figure 9-156.** Crimping pliers.

### *Junction Boxes*

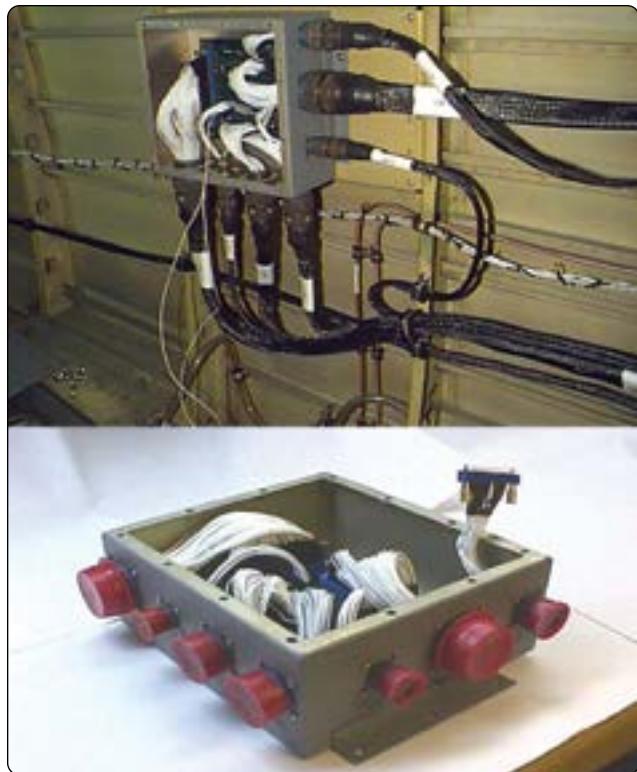
Junction boxes are used for collecting, organizing, and distributing circuits to the appropriate harnesses that are attached to the equipment. [Figure 9-157] Junction boxes are also used to conveniently house miscellaneous components, such as relays and diodes. Junction boxes that are used in high-temperature areas should be made of stainless steel. Replacement junction boxes should be fabricated using the same material as the original or from a fire-resistant, nonabsorbent material, such as aluminum, or an acceptable plastic material. Where fireproofing is necessary, a stainless steel junction box is recommended. Rigid construction prevents oil-canning of the box sides that could result in internal short circuits. In all cases, drain holes should be provided in the lowest portion of the box. Cases of electrical power equipment must be insulated from metallic structure to avoid ground fault related fires.

The junction box arrangement should permit easy access to any installed items of equipment, terminals, and wires. Where marginal clearances are unavoidable, an insulating material should be inserted between current carrying parts and any grounded surface. It is not good practice to mount equipment on the covers or doors of junction boxes, since inspection for internal clearance is impossible when the door or cover is in the closed position.

Junction boxes should be securely mounted to the aircraft structure in such a manner that the contents are readily accessible for inspection. When possible, the open side should face downward or at an angle so that loose metallic objects,



**Figure 9-155.** Terminal splices.



**Figure 9-157.** Junction boxes.

such as washers or nuts, tend to fall out of the junction box rather than wedge between terminals.

Junction box layouts should take into consideration the necessity for adequate wiring space and possible future additions. Electrical wire bundles should be laced or clamped inside the box so that cables do not touch other components, prevent ready access, or obscure markings or labels. Cables at entrance openings should be protected against chafing by using grommets or other suitable means.

### ***AN/MS Connectors***

Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. There is a multitude of types of connectors. The connector types that use crimped contacts are generally used on aircraft. Some of the more common types are the round cannon type, the rectangular, and the module blocks. Environmentally resistant connectors should be used in applications subject to fluids, vibration, heat, mechanical shock, and/or corrosive elements.

When HIRF/lightning protection is required, special attention should be given to the terminations of individual or overall shields. The number and complexity of wiring systems have resulted in an increased use of electrical connectors. [Figure 9-158] The proper choice and application of connectors is a significant part of the aircraft wiring



**Figure 9-158.** Electrical connectors.

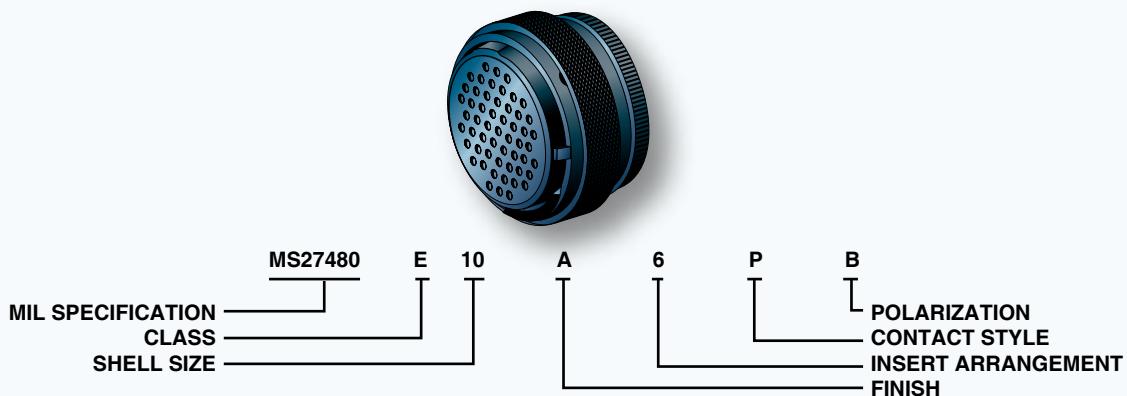
system. Connectors must be kept to a minimum, selected, and installed to provide the maximum degree of safety and reliability to the aircraft. For the installation of any particular connector assembly, the specification of the manufacturer or the appropriate governing agency must be followed.

#### *Types of Connector*

Connectors must be identified by an original identification number derived from MIL Specification (MS) or OEM specification. Figure 9-159 provides information about MS style connectors.

Environment-resistant connectors are used in applications where they are probably subjected to fluids, vibration, heat, mechanical shock, corrosive elements, etc. Firewall class connectors incorporating these same features should, in addition, be able to prevent the penetration of the fire through the aircraft firewall connector opening and continue to function without failure for a specified period of time when exposed to fire. Hermetic connectors provide a pressure seal for maintaining pressurized areas. When EMI/RFI protection is required, special attention should be given to the termination of individual and overall shields. Backshell adapters designed for shield termination, connectors with conductive finishes, and EMI grounding fingers are available for this purpose.

Rectangular connectors are typically used in applications where a very large number of circuits are accommodated in a single mated pair. [Figure 9-160] They are available with a great variety of contacts, which can include a mix of standard, coaxial, and large power types. Coupling is accomplished by various means. Smaller types are secured with screws which hold their flanges together. Larger ones have integral guide pins that ensure correct alignment, or jackscrews that both align and lock the connectors. Rack and panel connectors



MS27472 Wall mount receptacle  
 MS27473 Straight plug  
 MS27474 Jam nut receptacle  
 MS27475 Hermetic wall mount receptacle  
 MS27476 Hermetic box mount receptacle  
 MS27477 Hermetic jam nut receptacle  
 MS27478 Hermetic solder mount receptacle  
 MS27479 Wall mount receptacle (note 1)  
 MS27480 Straight plug (note 1)  
 MS27481 Jam nut receptacle (note 1)  
 MS27482 Hermetic wall mount receptacle (note 1)  
 MS27483 Hermetic jam nut receptacle (note 1)

MS27484 Straight plug, EMI grounding  
 MS27497 Wall receptacle, back panel mounting  
 MS27499 Box mounting receptacle  
 MS27500 90° Plug (note 1)  
 MS27503 Hermetic solder mount receptacle (note 1)  
 MS27504 Box mount receptacle (note 1)  
 MS27508 Box mount receptacle, back panel mounting  
 MS27513 Box mount receptacle, long grommet  
 MS27664 Wall mount receptacle, back panel mounting  
 (note 1)  
 MS27667 Thru-bulkhead receptacle

#### NOTE

1. Active	Supersedes
MS27472	MS27479
MS27473	MS27480
MS27474	MS27481
MS27475	MS27482
MS27477	MS27483
MS27473 with MS27507 elbow	MS27500
MS27478	MS27503
MS27499	MS27504
MS27497	MS27664

#### CLASS

- E Environment-resisting box and thru-bulkhead mounting types only (see class T)
- P Potting—includes potting form and short rear grommet
- T Environment-resisting wall and jam-nut mounting receptacle and plug types: thread and teeth for accessory attachment
- Y Hermetically sealed

#### FINISH

- A Silver to light iridescent yellow color cadmium plate over nickel (conductive) -65 °C to +150 °C (inactive for new design)

B Olive drab cadmium plate over suitable underplate (conductive), -65 °C to 175 °C

C Anodic (nonconductive), -65 °C to +175 °C  
 D Fused tin, carbon steel (conductive), -65 °C to +150 °C  
 E Corrosion resistant steel (cres), passivated (conductive), -65 °C to +200 °C  
 F Electroless nickel coating (conductive), -65 °C to +200 °C  
 N Hermetic seal or environment resisting cres (conductive plating), -65 °C to +200 °C

#### CONTACT STYLE

- A Without pin contacts
- B Without socket contacts
- C Feed through
- P Pin contact—including hermetics with solder cups
- S Socket contacts—including hermetics with solder cups
- X Pin contacts with eyelet (hermetic)
- Z Socket contacts with eyelet (hermetic)

#### POLARIZATION

- A, B Normal—no letter required
- C, or D

Figure 9-159. MS connector information sheet.

use integral or rack-mounted pins for alignment and box mounting hardware for couplings.

Module blocks are types of junctions that accept crimped contacts similar to those on connectors. Some use internal busing to provide a variety of circuit arrangements. They

are useful where a number of wires are connected for power or signal distribution. When used as grounding modules, they save and reduce hardware installation on the aircraft. Standardized modules are available with wire end grommet seals for environmental applications and are track mounted. Function module blocks are used to provide an easily



**Figure 9-160.** Rectangular connectors.

wired package for environment-resistant mounting of small resistors, diodes, filters, and suppression networks. Inline terminal junctions are sometimes used in lieu of a connector when only a few wires are terminated and when the ability to disconnect the wires is desired. The inline terminal junction is environment resistant. The terminal junction splice is small and may be tied to the surface of a wire bundle when approved by the OEM.

#### *Voltage & Current Rating*

Selected connectors must be rated for continuous operation under the maximum combination of ambient temperature and circuit current load. Hermetic connectors and connectors used in circuit applications involving high-inrush currents should be derated. It is good engineering practice to conduct preliminary testing in any situation where the connector is to operate with most or all of its contacts at maximum rated current load. When wiring is operating with a high conductor temperature near its rated temperature, connector contact sizes should be suitably rated for the circuit load. This may require an increase in wire size. Voltage derating is required when connectors are used at high altitude in non-pressurized areas.

#### *Spare Contacts for Future Wiring*

To accommodate future wiring additions, spare contacts are normally provided. Locating the unwired contacts along the outer part of the connector facilitates future access. A good practice is to provide two spares on connectors with 25 or fewer contacts; 4 spares on connectors with 26 to 100 contacts; and 6 spares on connectors with more than 100 contacts. Spare contacts are not normally provided on receptacles of components that are unlikely to have added wiring. Connectors must have all available contact cavities filled with wired or unwired contacts. Unwired contacts should be provided with a plastic grommet sealing plug.

#### *Wire Installation into the Connector*

Wires that perform the same function in redundant systems must be routed through separate connectors. On systems critical to flight safety, system operation wiring should be routed through separate connectors from the wiring used for system failure warning. It is also good practice to route a system's indication wiring in separate connectors from its failure warning circuits to the extent practicable. These steps can reduce an aircraft's susceptibility to incidents that might result from connector failures.

#### *Adjacent Locations*

Mating of adjacent connectors should not be possible. In order to ensure this, adjacent connector pairs must be different in shell size, coupling means, insert arrangement, or keying arrangement. When such means are impractical, wires should be routed and clamped so that incorrectly mated pairs cannot reach each other. Reliance on markings or color stripes is not recommended as they are likely to deteriorate with age. [Figure 9-161]

#### *Sealing*

Connectors must be of a type that excludes moisture entry through the use of peripheral and interfacial seal that are compressed when the connector is mated. Moisture entry through the rear of the connector must be avoided by correctly matching the wire's outside diameter with the connector's rear grommet sealing range. It is recommended that no more than one wire be terminated in any crimp style contact. The use of heat-shrinkable tubing to build up the wire diameter, or the application of potting to the wire entry area as additional means of providing a rear compatibility with the rear grommet is recommended. These extra means have inherent penalties and should be considered only where other means cannot be used. Unwired spare contacts should have a correctly sized plastic plug installed.



**Figure 9-161.** Connector arrangement to avoid wrong connection.

### *Drainage*

Connectors must be installed in a manner that ensures moisture and fluids drain out of and not into the connector when unmated. Wiring must be routed so that moisture accumulated on the bundle drains away from connectors. When connectors must be mounted in a vertical position, as through a shelf or floor, the connectors must be potted or environmentally sealed. In this situation, it is better to have the receptacle faced downward so that it is less susceptible to collecting moisture when unmated.

### *Wire Support*

A rear accessory back shell must be used on connectors that are not enclosed. Connectors with very small size wiring, or subject to frequent maintenance activity, or located in high-vibration areas must be provided with a strain-relief-type back shell. The wire bundle should be protected from mechanical damage with suitable cushion material where it is secured by the clamp. Connectors that are potted or have molded rear adapters do not normally use a separate strain relief accessory. Strain relief clamps should not impart tension on wires between the clamp and contact. [Figure 9-162]

Sufficient wire length must be provided at connectors to ensure a proper drip loop and that there is no strain on termination after a complete replacement of the connector and its contacts.

### *Coaxial Cable*

All wiring needs to be protected from damage. However, coaxial and triaxial cables are particularly vulnerable to certain types of damage. Personnel should exercise care while handling or working around coaxial. [Figure 9-163] Coaxial damage can occur when clamped too tightly, or when they are bent sharply (normally at or near connectors). Damage can also be incurred during unrelated maintenance actions around the coaxial cable. Coaxial cable can be severely damaged on the inside without any evidence of damage on the outside. Coaxial cables with solid center conductors should not be used. Stranded center coaxial cables can be used as a direct replacement for solid center coaxial. [Figure 9-164] Coaxial cable precautions include:

- Never kink coaxial cable.
- Never drop anything on coaxial cable.
- Never step on coaxial cable.
- Never bend coaxial cable sharply.
- Never loop coaxial cable tighter than the allowable bend radius.
- Never pull on coaxial cable except in a straight line.
- Never use coaxial cable for a handle, lean on it, or hang things on it (or any other wire).



**Figure 9-162.** Backshells with strain relief.



**Figure 9-163.** Coaxial cables.

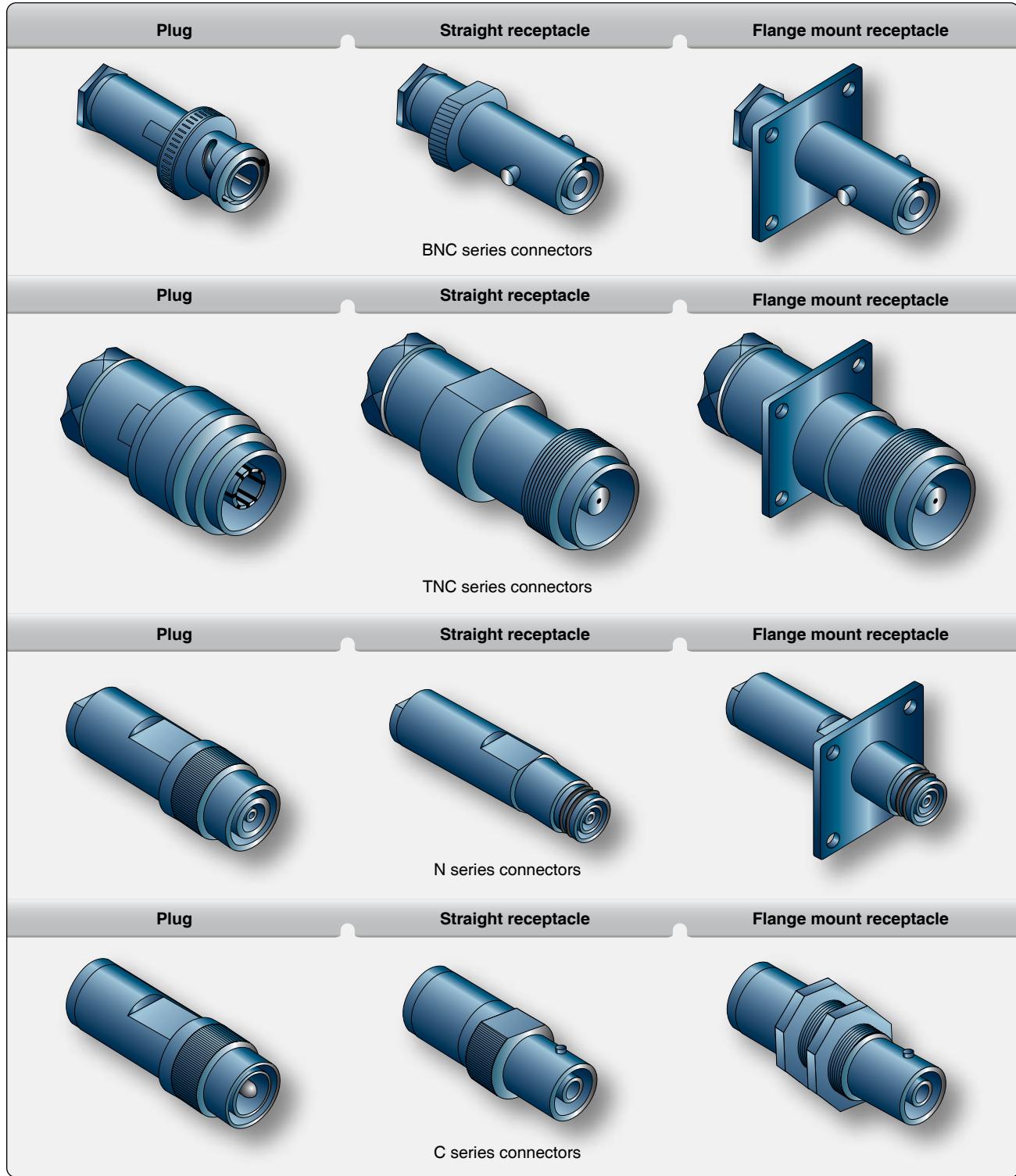
### **Wire Inspection**

Aircraft service imposes severe environmental condition on electrical wire. To ensure satisfactory service, inspect wire annually for abrasions, defective insulation, condition of terminations, and potential corrosion. Grounding connections for power, distribution equipment, and electromagnetic shielding must be given particular attention to ensure that electrical bonding resistance has not been significantly increased by the loosening of connections or corrosion.

## **Electrical System Components**

### **Switches**

Switches are devices that open and close circuits. They consist of one or more pair of contacts. The current in the circuit flows when the contacts are closed. Switches with momentary contacts actuate the circuit temporarily, and they return to the normal position with an internal spring when the switch is released. Switches with continuous contacts remain in position when activated. Hazardous errors in switch operation can be avoided by logical and consistent installation. Two-position on/off switches should be mounted



**Figure 9-164.** Coaxial cable connectors.

so that the on position is reached by an upward or forward movement of the toggle. When the switch controls movable aircraft elements, such as landing gear or flaps, the toggle should move in the same direction as the desired motion. Inadvertent operation of a switch can be prevented by

mounting a suitable guard over the switch. [Figure 9-165]

A specifically designed switch should be used in all circuits where a switch malfunction would be hazardous. Such switches are of rugged construction and have sufficient

contact capacity to break, make, and carry continuously the connected load current. Snap action design is generally preferred to obtain rapid opening and closing of contacts regardless of the speed of the operating toggle or plunger, thereby minimizing contact arcing. The nominal current rating of the conventional aircraft switch is usually stamped on the switch housing. This rating represents the continuous current rating with the contacts closed. Switches should be derated from their nominal current rating for the following types of circuits:

1. High rush-in circuits—contain incandescent lamps that can draw an initial current 15 times greater than the continuous current. Contact burning or welding may occur when the switch is closed.
2. Inductive circuits—magnetic energy stored in solenoid coils or relays is released and appears as an arc when the control switch is opened.
3. Motors—DC motors draw several times their rated current during starting, and magnetic energy stored in their armature and field coils is released when the control switch is opened.

*Figure 9-166* is used for selecting the proper nominal switch rating when the continuous load current is known. This



**Figure 9-165.** Switch guard.

selection is essentially a derating to obtain reasonable switch efficiency and service life.

### Type of Switches

Single-pole single-throw (SPST)—opens and closes a single circuit. Pole indicates the number of separate circuits that can be activated, and throw indicates the number of current paths.

Double-pole single-throw (DPST)—turn two circuits on and off with one lever.

Single-pole double-throw (SPDT)—route circuit current to either of two paths. The switch is ON in both positions. For example, switch turns on red lamp in one position and turns on green lamp in the other position.

Double-pole double-throw (DPDT)—activates two separate circuits at the same time.

Double-throw switches—have either two or three positions.

Two-position switch—pole always connected to one of the two throws. Three-position switches have a center OFF position that disconnects the pole from both throws.

Spring-loaded switches—available in two types: 1) normally open (NO) and 2) normally closed (NC). The contacts of the NO switch are disconnected in the normal position and become closed when the switch is activated. The switch returns to the normal position when the applied force to the switch is released. The contacts of the NC switch are connected in the normal position and become open when the switch is activated. The switch returns to the normal position when the applied force to the switch is released.

### Toggle & Rocker Switches

Toggle and rocker switches control most of aircraft's electrical components. [Figure 9-167] Aircraft that are outfitted with a glass flight deck often use push buttons to control electrical components.

Nominal system voltage (DC)	Type of load	Derating factor
28V	Lamp	8
28V	Inductive	4
28V	Resistive	2
28V	Motor	3
12V	Lamp	5
12V	Inductive	2
12V	Resistive	1
12V	Motor	2

**Figure 9-166.** Derating table for switches.



**Figure 9-167.** Toggle and rocker switches.

### **Rotary Switches**

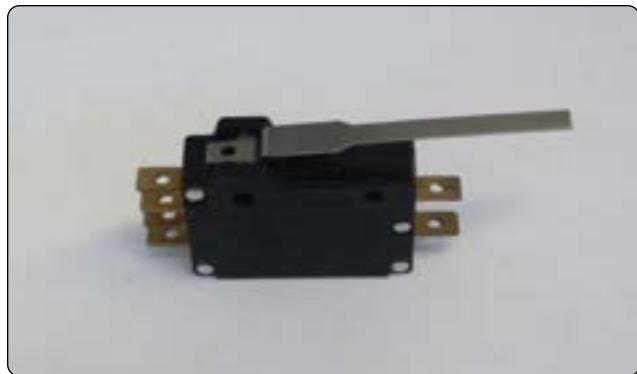
Rotary switches are activated by twisting a knob or shaft and are commonly found on radio control panels. Rotary switches are utilized for controlling more than two circuits.

### **Precision (Micro) Switches**

Micro switches require very little pressure to activate. These types of switches are spring loaded, once the pressure is removed, the contacts return to the normal position. These types of switches are typically single-pole double-throw (SPDT) or double-pole double-throw (DPDT) and have three contacts: normally open, normally closed, and common. Micro switches are used to detect position or to limit travel of moving parts, such as landing gear, flaps, spoilers, etc. [Figure 9-168]

### **Relays & Solenoids (Electromagnetic Switches)**

Relays are used to control the flow of large currents using a small current. A low-power DC circuit is used to activate the relay and control the flow of large AC currents. They are used to switch motors and other electrical equipment on and off and to protect them from overheating. A solenoid is a special



**Figure 9-168.** A micro switch.

type of relay that has a moving core. The electromagnet core in a relay is fixed. Solenoids are mostly used as mechanical actuators but can also be used for switching large currents. Relays are only used to switch currents.

### **Solenoids**

Solenoids are used as switching devices where a weight reduction can be achieved or electrical controls can be simplified. The foregoing discussion of switch ratings is generally applicable to solenoid contact ratings. Solenoids have a movable core/armature that is usually made of steel or iron, and the coil is wrapped around the armature. The solenoid has an electromagnetic tube and the armature moves in and out of the tube. [Figure 9-169]

### **Relays**

The two main types of relays are electromechanical and solid state. Electromechanical relays have a fixed core and a moving plate with contacts on it, while solid-state relays work similar to transistors and have no moving parts. Current flowing through the coil of an electromechanical relay creates a magnetic field that attracts a lever and changes the switch contacts. The coil current can be on or off so relays have two switch positions. These can be made as a single throw or double throw switch. Residual magnetism is a common problem and the contacts may stay closed or are opened by a slight amount of residual magnetism. A relay is an electrically operated switch and is therefore subject to dropout under low system voltage conditions. Relays allow one circuit to switch a second circuit that can be completely separate from the first. For example, a low voltage DC battery circuit can use a relay to switch a 110-volt three-phase AC circuit. There is no electrical connection inside the relay between the two circuits; the link is magnetic and mechanical. [Figure 9-170]

### **Current Limiting Devices**

Conductors should be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of the electrical equipment specifies the fuse or circuit breaker to be used when installing



**Figure 9-169.** Solenoid.

equipment. The circuit breaker or fuse should open the circuit before the conductor emits smoke. To accomplish this, the time current characteristic of the protection device must fall below that of the associated conductor. Circuit protector characteristics should be matched to obtain the maximum utilization of the connected equipment. *Figure 9-171* shows a chart used in selecting the circuit breaker and fuse protection for copper conductors. This limited chart is applicable to a specific set of ambient temperatures and wire bundle sizes and is presented as typical only. It is important to consult such guides before selecting a conductor for a specific purpose. For example, a wire run individually in the open air may be protected by the circuit breaker of the next higher rating to that shown on the chart.

### Fuses

A fuse is placed in series with the voltage source and all current must flow through it. [*Figure 9-172*] The fuse consists of a strip of metal that is enclosed in a glass or plastic housing. The metal strip has a low melting point and is usually made of lead, tin, or copper. When the current exceeds the capacity of the fuse the metal strip heats up and breaks. As a result of this, the flow of current in the circuit stops.



**Figure 9-170.** Relay.

Wire AWG gauge copper	Circuit breaker amperage	Fuse amperage
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	30	20
10	40	30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150

**Figure 9-171.** Wired and circuit protection chart.

There are two basic types of fuses: fast acting and slow blow. The fast-acting type opens very quickly when their particular current rating is exceeded. This is important for electric devices that can quickly be destroyed when too much current flows through them for even a very small amount of time. Slow blow fuses have a coiled construction inside. They are designed to open only on a continued overload, such as a short circuit.

### Circuit Breakers

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by an overload or short circuit. Its basic function is to detect a fault condition and immediately discontinue electrical flow. Unlike a fuse that operates once and then has to be replaced, a circuit breaker can be reset to resume normal operation. All resettable circuit breakers should open the circuit in which they are installed regardless of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as trip-free. Automatic reset circuit breakers automatically reset themselves. They should not be used as circuit protection devices in aircraft. When a circuit breaker trips, the electrical circuit should be checked and the fault removed before the circuit breaker is reset. Sometimes circuit breakers trip for no apparent



**Figure 9-172.** A fuse.

reason, and the circuit breaker can be reset one time. If the circuit breaker trips again, there exists a circuit fault and the technician must troubleshoot the circuit before resetting the circuit breaker. [Figure 9-173]

Some new aircraft designs use a digital circuit protection architecture. This system monitors the amperage through a particular circuit. When the maximum amperage for that circuit is reached, the power is rerouted away from the circuit. This system reduces the use of mechanical circuit breakers. The advantages are weight savings and the reduction of mechanical parts.

## Aircraft Lighting Systems

Aircraft lighting systems provide illumination for both exterior and interior use. Lights on the exterior provide illumination for such operations as landing at night, inspection of icing conditions, and safety from midair collision. Interior lighting provides illumination for instruments, flight decks, cabins, and other sections occupied by crewmembers and passengers. Certain special lights, such as indicator and warning lights, indicate the operation status of equipment.

### Exterior Lights

Position, anticollision, landing, and taxi lights are common examples of aircraft exterior lights. Some lights are required for night operations. Other types of exterior lights, such as wing inspection lights, are of great benefit for specialized flying operations.

### Position Lights

Aircraft operating at night must be equipped with position lights that meet the minimum requirements specified by Title 14 of the Code of Federal Regulations. A set of position lights consist of one red, one green, and one white light. [Figures 9-174 and 9-175]



Figure 9-173. Circuit breaker panel.

On some types of installations, a switch in the flight deck provides for steady or flashing operation of the position lights. On many aircraft, each light unit contains a single lamp mounted on the surface of the aircraft. Other types of position light units contain two lamps and are often streamlined into the surface of the aircraft structure. The green light unit is always mounted at the extreme tip of the right wing. The red unit is mounted in a similar position on the left wing. The white unit is usually located on the vertical stabilizer in a position where it is clearly visible through a wide angle from the rear of the aircraft. Figure 9-176 illustrates a schematic diagram of a position light circuit. Position lights are also known as navigation lights.

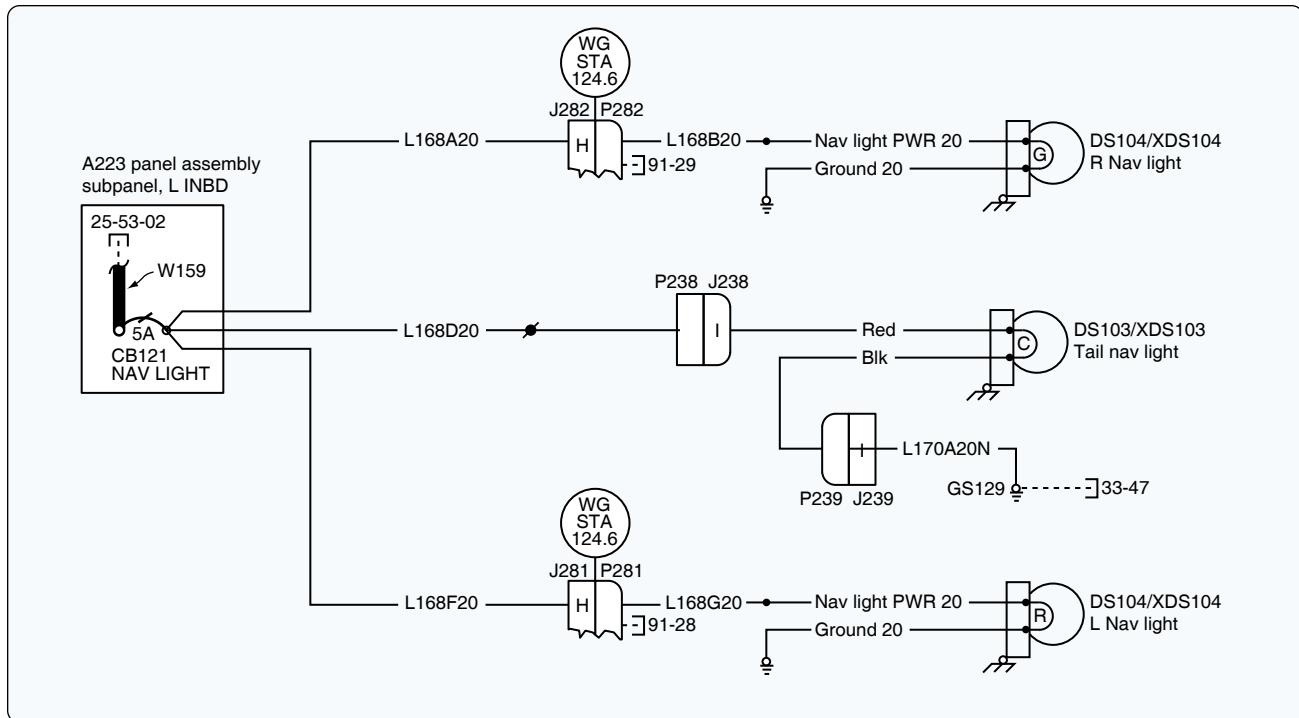
There are, of course, many variations in the position light circuits used on different aircraft. All circuits are protected by fuses or circuit breakers, and many circuits include flashing and dimming equipment. Small aircraft are usually equipped



Figure 9-174. A left wing tip position light (red) and a white strobe light.



Figure 9-175. A right wing tip position light, also known as a navigation light.



**Figure 9-176.** Navigation light system schematic.

with a simplified control switch and circuitry. In some cases, one control knob or switch is used to turn on several sets of lights; for example, one type utilizes a control knob, the first movement of which turns on the position lights and the instrument panel lights. Further rotation of the control knob increases the intensity of only the panel lights. A flasher unit is seldom included in the position light circuitry of very light aircraft but is used in small twin-engine aircraft. Traditional position lights use incandescent light bulbs. LED lights have been introduced on modern aircraft because of their good visibility, high reliability, and low power consumption.

### Anticollision Lights

An anticollision light system may consist of one or more lights. They are rotating beam lights that are usually installed on top of the fuselage or tail in such a location that the light does not affect the vision of the crewmember or detract from the visibility of the position lights. Large transport type aircraft use an anticollision light on top and one on the bottom of the aircraft. *Figure 9-177* shows a typical anticollision light installation in a vertical stabilizer.

An anticollision light unit usually consists of one or two rotating lights operated by an electric motor. The light may be fixed but mounted under rotating mirrors inside a protruding red glass housing. The mirrors rotate in an arc, and the resulting flash rate is between 40 and 100 cycles per minute. Newer aircraft designs use a LED type of anticollision light. The anticollision light is a safety light to warn other aircraft,

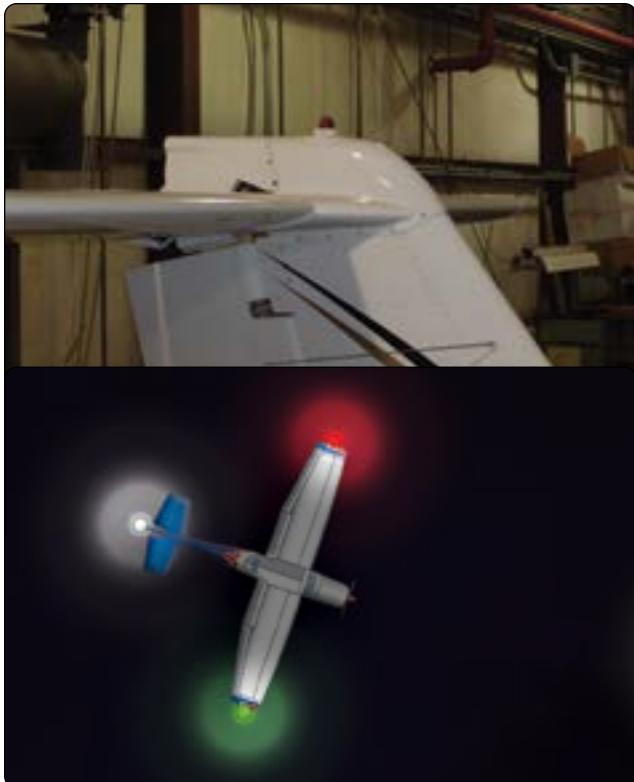
especially in congested areas.

A white strobe light is a second type of anti-collision light that is also common. Usually mounted at the wing tips and, possibly, at empennage extremities, strobe lights produce an extremely bright intermittent flash of white light that is highly visible. The light is produced by a high voltage discharge of a capacitor. A dedicated power pack houses the capacitor and supplies voltage to a sealed xenon-filled tube. The xenon ionizes with a flash when the voltage is applied. A strobe light is shown in *Figure 9-174*.

### Landing & Taxi Lights

Landing lights are installed in aircraft to illuminate runways during night landings. These lights are very powerful and are directed by a parabolic reflector at an angle providing a maximum range of illumination. Landing lights of smaller aircraft are usually located midway in the leading edge of each wing or streamlined into the aircraft surface. Landing lights for larger transport category aircraft are usually located in the leading edge of the wing close to the fuselage. Each light may be controlled by a relay, or it may be connected directly into the electric circuit. On some aircraft, the landing light is mounted in the same area with a taxi light. [*Figure 9-178*] A sealed beam, halogen, or high intensity xenon discharge lamp is used.

Taxi lights are designed to provide illumination on the ground while taxiing or towing the aircraft to or from a runway, taxi



**Figure 9-177.** Anticollision lights.

strip, or in the hangar area. [Figure 9-179] Taxi lights are not designed to provide the degree of illumination necessary for landing lights. On aircraft with tricycle landing gear, either single or multiple taxi lights are often mounted on the non-steerable part of the nose landing gear. They are positioned at an oblique angle to the center line of the aircraft to provide illumination directly in front of the aircraft and also some illumination to the right and left of the aircraft's path. On some aircraft, the dual taxi lights are supplemented by wingtip clearance lights controlled by the same circuitry. Taxi lights are also mounted in the recessed areas of the wing leading edge, often in the same area with a fixed landing light.

Many small aircraft are not equipped with any type of taxi light, but rely on the intermittent use of a landing light to illuminate taxiing operations. Still other aircraft utilize a dimming resistor in the landing light circuit to provide reduced illumination for taxiing. A typical circuit for taxi lights is shown in *Figure 9-180*.

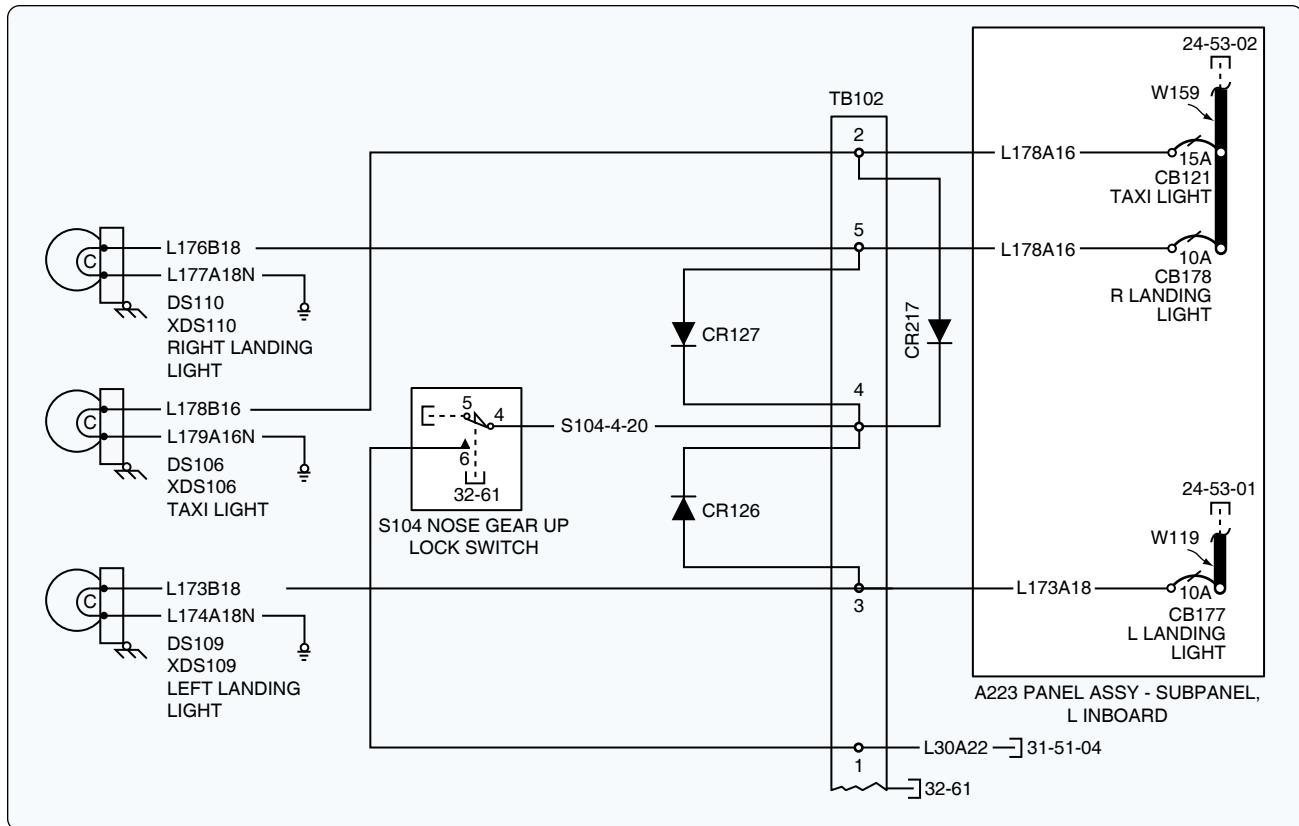
Some large aircraft are equipped with alternate taxi lights located on the lower surface of the aircraft, aft of the nose radome. These lights, operated by a separate switch from the main taxi lights, illuminate the area immediately in front of and below the aircraft nose.



**Figure 9-178.** Landing lights.



**Figure 9-179.** Taxi lights.



**Figure 9-180.** Taxi light circuit.

### Wing Inspection Lights

Some aircraft are equipped with wing inspection lights to illuminate the leading edge of the wings to permit observation of icing and general condition of the ~~se~~ areas in flight. These lights permit visual detection of ice formation on wing leading edges while flying at night. They are usually controlled through a relay by an on/off toggle switch in the flight deck. Some wing inspection light systems may include or be supplemented by additional lights, sometimes called nacelle lights, that illuminate adjacent areas, such as a cowl flaps or the landing gear. These are normally the same type of lights and can be controlled by the same circuits.

### Interior Lights

Aircraft are equipped with interior lights to illuminate the cabin. [Figure 9-181] Often white and red light settings are provided. Commercial aircraft have a lighting system that illuminates the main cabin, an independent lighting system so that passengers can read when the cabin lights are off, and an emergency lighting system on the floor of the aircraft to aid passengers during an emergency.

### Maintenance & Inspection of Lighting Systems

Inspection of an aircraft's lighting system normally includes checking the condition and security of all visible wiring,

connections, terminals, fuses, and switches. A continuity light or meter can be used in making these checks, since the cause of many troubles can often be located by systematically testing each circuit for continuity.



**Figure 9-181.** Interior flight deck and cabin light system.

# Chapter 10

# Aircraft Systems

## Introduction

Since the beginning of manned flight, it has been recognized that supplying the pilot with information about the aircraft and its operation could be useful and lead to safer flight. The Wright Brothers had very few instruments on their Wright Flyer, but they did have an engine tachometer, an anemometer (wind meter), and a stop watch. They were obviously concerned about the aircraft's engine and the progress of their flight. From that simple beginning, a wide variety of instruments have been developed to inform flight crews of different parameters. Instrument systems now exist to provide information on the condition of the aircraft, engine, components, the aircraft's attitude in the sky, weather, cabin environment, navigation, and communication. *Figure 10-1* shows various instrument panels from the Wright Flyer to a modern jet airliner.

The ability to capture and convey all of the information a pilot may want, in an accurate, easily understood manner, has been a challenge throughout the history of aviation. As the range of desired information has grown, so too have the size and complexity of modern aircraft, thus expanding even further the need to inform the flight crew without sensory overload or overcluttering the flight deck. As a result, the old flat panel in the front of the flight deck with various individual instruments attached to it has evolved into a sophisticated computer-controlled digital interface with flat-panel display screens and prioritized messaging. A visual comparison between a conventional flight deck and a glass flight deck is shown in *Figure 10-2*.

There are usually two parts to any instrument or instrument system. One part senses the situation and the other part displays it. In analog instruments, both of these functions often take place in a single unit or instrument (case). These are called direct-sensing instruments. Remote-sensing requires the information to be sensed, or captured, and then sent to a separate display unit in the flight deck. Both analog and digital instruments make use of this method. [*Figure 10-3*]

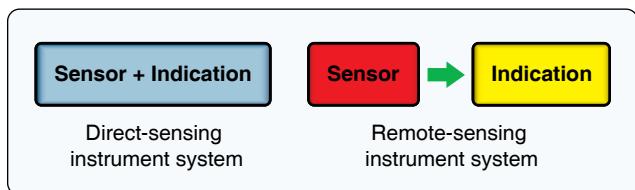
The relaying of important bits of information can be done in various ways. Electricity is often used by way of wires that carry sensor information into the flight deck. Sometimes pneumatic lines are used. In complex, modern aircraft, this can lead to an enormous amount of tubing and wiring terminating behind the instrument display panel. More efficient information transfer has been accomplished via the



**Figure 10-1.** From top to bottom: instruments of the Wright Flyer, instruments on a World War I era aircraft, a late 1950s/early 1960s Boeing 707 airliner flight deck, and an Airbus A380 glass flight deck.



**Figure 10-2.** A conventional instrument panel of the C-5A Galaxy (top) and the glass flight deck of the C-5B Galaxy (bottom).



**Figure 10-3.** There are two parts to any instrument system—the sensing mechanism and the display mechanism.

use of digital data buses. Essentially, these are wires that share message carrying for many instruments by digitally encoding the signal for each. This reduces the number of wires and weight required to transfer remotely sensed information for the pilot's use. Flat-panel computer display screens that can be controlled to show only the information desired are also lighter in weight than the numerous individual gauges it would take to display the same information simultaneously. An added bonus is the increased reliability inherent in these solid-state systems.

It is the job of the aircraft technician to understand and maintain all aircraft, including these various instrument systems. Accordingly, in this chapter, discussions begin

with analog instruments and refer to modern digital instrumentation when appropriate.

## Classifying Instruments

There are three basic kinds of instruments classified by the job they perform: flight instruments, engine instruments, and navigation instruments. There are also miscellaneous gauges and indicators that provide information that do not fall into these classifications, especially on large complex aircraft. Flight control position, cabin environmental systems, electrical power, and auxiliary power units (APUs), for example, are all monitored and controlled from the flight deck via the use of instrument systems.

## Flight Instruments

The instruments used in controlling the aircraft's flight attitude, altitude, speed, and direction are known as the flight instruments. There are basic flight instruments, such as the altimeter that displays aircraft altitude; the airspeed indicator; and the magnetic direction indicator, a form of compass. Additionally, an artificial horizon, turn coordinator, and vertical speed indicator are flight instruments present in most aircraft. Much variation exists for these instruments, which is explained throughout this chapter. Over the years, flight instruments have come to be situated similarly on the instrument panels in most aircraft. This basic T arrangement for flight instruments is shown in *Figure 10-4*. The top center position directly in front of the pilot and copilot is the basic display position for the artificial horizon even in modern glass flight decks (those with solid-state, flat-panel screen indicating systems).

Original analog flight instruments are operated by air pressure and the use of gyroscopes. This avoids the use of



**Figure 10-4.** The basic T arrangement of analog flight instruments. At the bottom of the T is a heading indicator that functions as a compass but is driven by a gyroscope and not subject to the oscillations common to magnetic direction indicators.

electricity, which could put the pilot in a dangerous situation if the aircraft lost electrical power. Development of sensing and display techniques, combined with advanced aircraft electrical systems, has made it possible for reliable primary and secondary instrument systems that are electrically operated. Nonetheless, often a pneumatic altimeter, a gyro artificial horizon, and a magnetic direction indicator are retained somewhere in the instrument panel for redundancy. [Figure 10-5]



**Figure 10-5.** This electrically operated flat screen display instrument panel, or glass flight deck, retains an analog airspeed indicator, a gyroscope-driven artificial horizon, and an analog altimeter as a backup should electric power be lost, or a display unit fails.

## Engine Instruments

Engine instruments are those designed to measure operating parameters of the aircraft's engine(s). These are usually quantity, pressure, speed, and temperature indications. The most common engine instruments are the fuel and oil quantity and pressure gauges, tachometers, and temperature gauges. Figure 10-6 contains various engine instruments found on reciprocating and turbine-powered aircraft.

Engine instrumentation is often displayed in the center of the flight deck where it is easily visible to the pilot and copilot. [Figure 10-7] On light aircraft requiring only one flight crewmember, this may not be the case. Multiengine aircraft

often use a single gauge for a particular engine parameter, but it displays information for all engines through the use of multiple pointers on the same dial face.

## Navigation Instruments

Navigation instruments are those that contribute information used by the pilot to guide the aircraft along a definite course. This group includes compasses of various kinds, some of which incorporate the use of radio signals to define a specific course while flying the aircraft en route from one airport to another. Other navigational instruments are designed specifically to direct the pilot's approach to landing at an airport. Traditional navigation instruments include a clock and a magnetic compass. Along with the airspeed indicator and wind information, these can be used to calculate navigational progress. Radios and instruments sending locating information via radio waves have replaced these manual efforts in modern aircraft. Global position systems (GPS) use satellites to pinpoint the location of the aircraft via geometric triangulation. This technology is built into some aircraft instrument packages for navigational purposes. Many of these aircraft navigational systems are discussed in chapter 11 of this handbook. [Figure 10-8]

Instruments can also be classified according to the principle upon which they operate. Some use mechanical methods to measure pressure and temperature. Some utilize magnetism and electricity to sense and display a parameter. Others depend on the use of gyroscopes in their primary workings. Still others utilize solid state sensors and computers to process and display important information. In the following sections, the different operating principles for sensing parameters are explained. Then, an overview of many of the engine, flight, and navigation instruments is given.

## Pressure Measuring Instruments

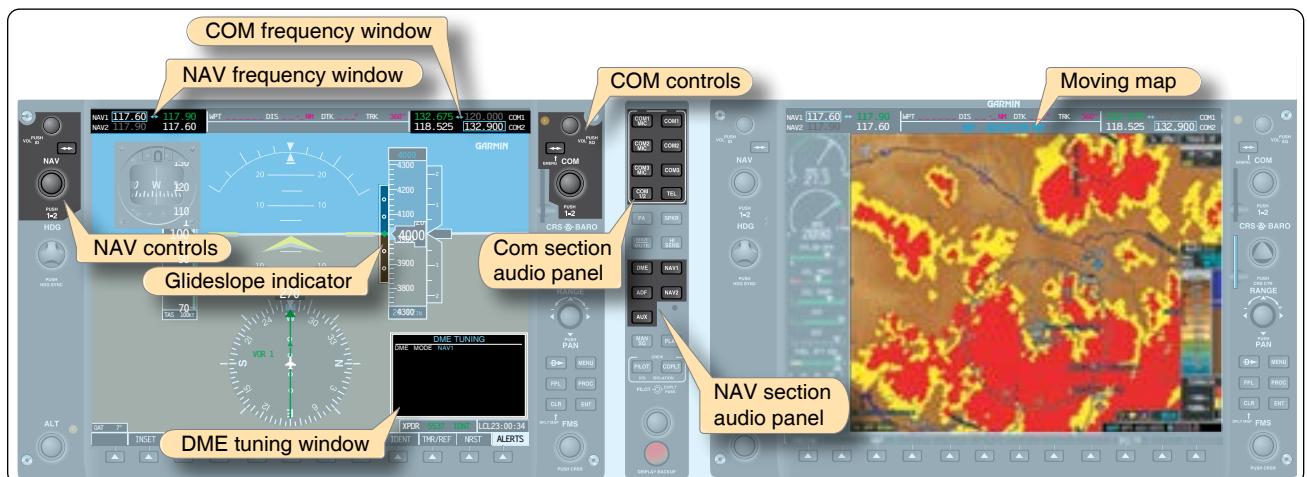
A number of instruments inform the pilot of the aircraft's condition and flight situations through the measurement of

Reciprocating engines	Turbine engines
Oil pressure	Oil pressure
Oil temperature	Exhaust gas temperature (EGT)
Cylinder head temperature (CHT)	Turbine inlet temperature (TIT) or turbine gas temperature (TGT)
Manifold pressure	Engine pressure ratio (EPR)
Fuel quantity	Fuel quantity
Fuel pressure	Fuel pressure
Tachometer	Fuel flow
Carburetor temperature	Tachometer (percent calibrated) N <sub>1</sub> and N <sub>2</sub> compressor speeds Torquemeter (on turboprop and turboshaft engines)

**Figure 10-6.** Common engine instruments. Note: For example purposes only. Some aircraft may not have these instruments or may be equipped with others.



**Figure 10-7.** An engine instrumentation located in the middle of the instrument panel is shared by the pilot and co-pilot.



**Figure 10-8.** Navigation instruments.

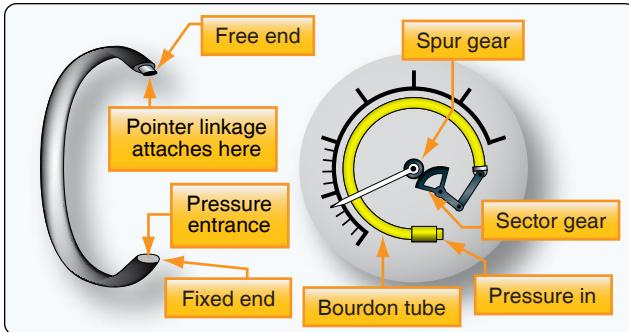
pressure. Pressure-sensing instruments can be found in the flight group and the engine group. They can be either direct reading or remote sensing. These are some of the most critical instruments on the aircraft and must accurately inform the pilot to maintain safe operations. Pressure measurement involves some sort of mechanism that can sense changes in pressure. A technique for calibration and displaying the information is then added to inform the pilot. The type of pressure needed to be measured often makes one sensing mechanism more suited for use in a particular instance. The three fundamental pressure-sensing mechanisms used in aircraft instrument systems are the Bourdon tube, the diaphragm or bellows, and the solid-state sensing device.

A Bourdon tube is used to measure relatively high pressures and is illustrated in *Figure 10-9*. The open end of this coiled tube is fixed in place and the other end is sealed and free to move. When pressure is directed into the open end of the

tube, the unfixated portion of the coiled tube tends to straighten out. The higher the pressure, the more the tube straightens. When the pressure is reduced, the tube recoils. A pointer is attached to this moving end of the tube, usually through a linkage of small shafts and gears. By calibrating this motion of the straightening tube, a face or dial of the instrument can be created. Thus, by observing the pointer movement along the scale of the instrument face positioned behind it, pressure increases and decreases are communicated to the pilot.

The Bourdon tube is the internal mechanism for many pressure gauges used on aircraft. Most Bourdon tubes are made from brass, bronze, or copper. Alloys of these metals can be made to coil and uncoil the tube consistently numerous times.

Bourdon tube gauges are simple and reliable. Some of the instruments that use a Bourdon tube mechanism include the

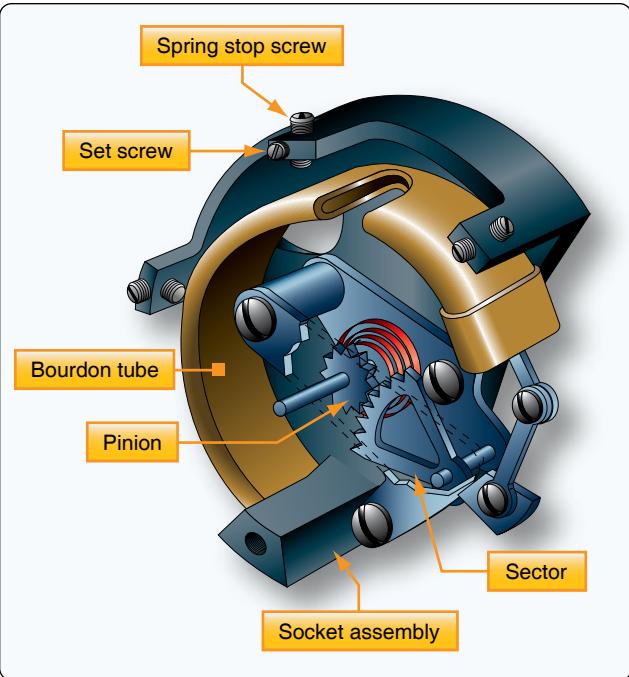


**Figure 10-9.** The Bourdon tube is one of the basic mechanisms for sensing pressure.

engine oil pressure gauge, hydraulic pressure gauge, oxygen tank pressure gauge, and deice boot pressure gauge. Since the pressure of a heated liquid or gas increases as temperature increases, Bourdon tube mechanisms can also be used to measure temperature. This is done by calibrating the pointer connecting linkage and relabeling the face of the gauge with a temperature scale. Oil temperature gauges often employ Bourdon tube mechanisms. [Figure 10-10]

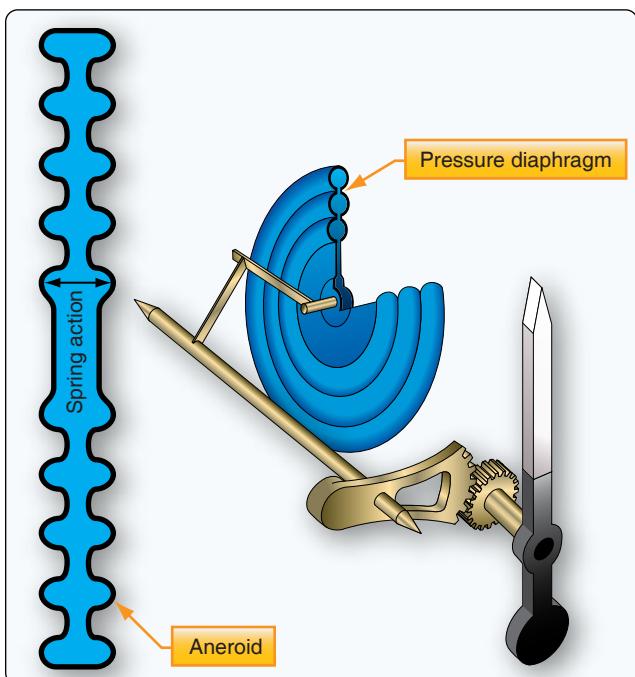
Since the sensing and display of pressure or temperature information using a Bourdon tube mechanism usually occurs in a single instrument housing, they are most often direct reading gauges. But the Bourdon tube sensing device can also be used remotely. Regardless, it is necessary to direct the fluid to be measured into the Bourdon tube. For example, a common direct-reading gauge measuring engine oil pressure and indicating it to the pilot in the flight deck is mounted in the instrument panel. A length of small tube connects a pressurized oil port on the engine, runs though the firewall, and into the back of the gauge. This setup is especially functional on light, single-engine aircraft in which the engine is mounted just forward of the instrument panel in the forward end of the fuselage. However, a remote sensing unit can be more practical on twin-engine aircraft where the engines are a long distance from the flight deck pressure display. Here, the Bourdon tube's motion is converted to an electrical signal and carried to the flight deck display via a wire. This is lighter and more efficient, eliminating the possibility of leaking fluids into the passenger compartment of the aircraft.

The diaphragm and bellows are two other basic sensing mechanisms employed in aircraft instruments for pressure measurement. They are most often used to measure relatively low pressures. The diaphragm is a hollow, thin-walled metal disc, usually corrugated. When pressure is introduced through an opening on one side of the disc, the entire disc expands. By placing linkage in contact against the other side of the disc, the movement of the pressurized diaphragm can be transferred to a pointer that registers the movement against the scale on the instrument face. [Figure 10-11]



**Figure 10-10.** The Bourdon tube mechanism can be used to measure pressure or temperature by recalibrating the pointer's connecting linkage and scaling instrument face to read in degrees Celsius or Fahrenheit.

Diaphragms can also be sealed. The diaphragm can be evacuated before sealing, retaining absolutely nothing inside. When this is done, the diaphragm is called an aneroid. Aneroids are used in many flight instruments. A diaphragm can also be filled with a gas to standard atmospheric pressure



**Figure 10-11.** A diaphragm used for measuring pressure. An evacuated sealed diaphragm is called an aneroid.

and then sealed. Each of these diaphragms has their uses, which are described in the next section. The common factor in all is that the expansion and contraction of the side wall of the diaphragm is the movement that correlates to increasing and decreasing pressure.

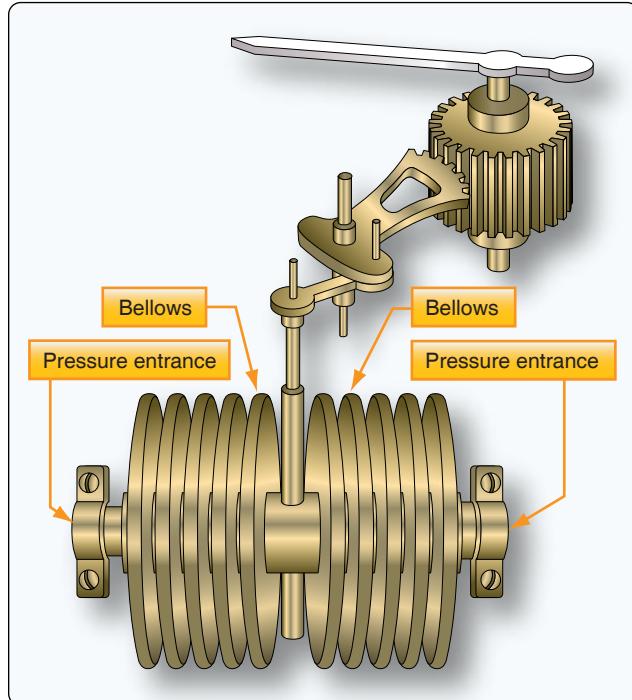
When a number of diaphragm chambers are connected together, the device is called a bellows. This accordion-like assembly of diaphragms can be very useful when measuring the difference in pressure between two gases, called differential pressure. Just as with a single diaphragm, it is the movement of the side walls of the bellows assembly that correlates with changes in pressure and to which a pointer linkage and gearing is attached to inform the pilot. [Figure 10-12]

Diaphragms, aneroids, and bellows pressure sensing devices are often located inside the single instrument housing that contains the pointer and instrument dial read by the pilot on the instrument panel. Thus, many instruments that make use of these sensitive and reliable mechanisms are direct reading gauges. But, many remote sensing instrument systems also make use of the diaphragm and bellows. In this case, the sensing device containing the pressure sensitive diaphragm or bellows is located remotely on the engine or airframe. It is part of a transducer that converts the pressure into an electrical signal. The transducer, or transmitter, sends the

signal to the gauge in the flight deck, or to a computer, for processing and subsequent display of the sensed condition. Examples of instruments that use a diaphragm or bellows in a direct reading or remote sensing gauge are the altimeter, vertical speed indicator, cabin differential pressure gauge (in pressurized aircraft), and manifold pressure gauge.

Solid-state microtechnology pressure sensors are used in modern aircraft to determine the critical pressures needed for safe operation. Many of these have digital output ready for processing by electronic flight instrument computers and other onboard computers. Some sensors produce small electric signals that are converted to digital format for use by computers. As with the analog sensors described above, the key to the function of solid-state sensors is their consistent property changes as pressure changes.

The solid-state sensors used in most aviation applications exhibit varying electrical output or resistance changes when pressure changes occur. Crystalline piezoelectric, piezoresistor, and semiconductor chip sensors are most common. In the typical sensor, tiny wires are embedded in the crystal or pressure-sensitive semiconductor chip. When pressure deflects the crystal(s), a small amount of electricity is created or, in the case of a semiconductor chip and some crystals, the resistance changes. Since the current and resistance changes vary directly with the amount of deflection, outputs can be calibrated and used to display pressure values.



**Figure 10-12.** A bellows unit in a differential pressure gauge compares two different pressure values. End movement of the bellows away from the side with the highest pressure input occurs when the pressures in the bellows are not equal. The indicator linkage is calibrated to display the difference.

Nearly all of the pressure information needed for engine, airframe, and flight instruments can be captured and/or calculated through the use of solid-state pressure sensors in combination with temperature sensors. But continued use of aneroid devices for comparisons involving absolute pressure is notable. Solid-state pressure-sensing systems are remote sensing systems. The sensors are mounted on the aircraft at convenient and effective locations.

### Types of Pressure

Pressure is a comparison between two forces. Absolute pressure exists when a force is compared to a total vacuum, or absolutely no pressure. It is necessary to define absolute pressure, because the air in the atmosphere is always exerting pressure on everything. Even when it seems there is no pressure being applied, like when a balloon is deflated, there is still atmospheric pressure inside and outside of the balloon. To measure that atmospheric pressure, it is necessary to compare it to a total absence of pressure, such as in a vacuum. Many aircraft instruments make use of absolute pressure values, such as the altimeter, the rate-of-climb indicator, and the manifold pressure gauge. As stated, this is usually done with an aneroid.

The most common type of pressure measurement is gauge pressure. This is the difference between the pressure to be measured and the atmospheric pressure. The gauge pressure inside the deflated balloon is therefore 0 pounds per square inch (psi) because the pressure inside the balloon is equal to the pressure outside the balloon. Gauge pressure is easily measured and is obtained by ignoring the fact that the atmosphere is always exerting its pressure on everything. For example, a tire is filled with air to 32 psi at a sea level location and checked with a gauge to read 32 psi, which is the gauge pressure. The approximately 14.7 psi of air pressing on the outside of the tire is ignored. The absolute pressure in the tire is 32 psi plus the 14.7 psi that is needed to balance the 14.7 psi on the outside of the tire. So, the tire's absolute pressure is approximately 46.7 psi. If the same tire is inflated to 32 psi at a location 10,000 feet above sea level, the air pressure on the outside of the tire would only be approximately 10 psi, due to the thinner atmosphere. The pressure inside the tire required to balance this would be 32 psi plus 10 psi, making the absolute pressure of the tire 42 psi. So, the same tire with the same amount of inflation and performance characteristics has different absolute pressure values. Gauge pressure, however, remains the same, indicating the tires are inflated identically. In this case, gauge pressure is more useful in informing us of the condition of the tire.

Gauge pressure measurements are simple and widely useful. They eliminate the need to measure varying atmospheric pressure to indicate or monitor a particular pressure situation. Gauge pressure should be assumed, unless otherwise indicated, or unless the pressure measurement is of a type known to require absolute pressure.

In many instances in aviation, it is desirable to compare the pressures of two different elements to arrive at useful information for operating the aircraft. When two pressures are compared in a gauge, the measurement is known as differential pressure and the gauge is a differential pressure gauge. An aircraft's airspeed indicator is a differential pressure gauge. It compares ambient air pressure with ram air pressure to determine how fast the aircraft is moving through the air. A turbine's engine pressure ratio (EPR) gauge is also a differential pressure gauge. It compares the pressure at the inlet of the engine with that at the outlet to indicate the thrust developed by the engine. Both of these differential pressure gauges and others are discussed further in this chapter and throughout this handbook.

In aviation, there is also a commonly used pressure known as standard pressure. Standard pressure refers to an established or standard value that has been created for atmospheric pressure. This standard pressure value is 29.92 inches of mercury ("Hg), 1,013.2 hectopascal (hPa), or 14.7 psi. It is

part of a standard day that has been established that includes a standard temperature of 15 °C at sea level. Specific standard day values have also been established for air density, volume, and viscosity. All of these values are developed averages since the atmosphere is continuously fluctuating. They are used by engineers when designing instrument systems and are sometimes used by technicians and pilots. Often, using a standard value for atmospheric pressure is more desirable than using the actual value. For example, at 18,000 feet and above, all aircraft use 29.92 "Hg as a reference pressure for their instruments to indicate altitude. This results in altitude indications in all flight decks being identical. Therefore, an accurate means is established for maintaining vertical separation of aircraft flying at these high altitudes.

## Pressure Instruments

### *Engine Oil Pressure*

The most important instrument used by the pilot to perceive the health of an engine is the engine oil pressure gauge. [Figure 10-13] Oil pressure is usually indicated in pounds per square inch (psi). The normal operating range is typically represented by a green arc on the circular gauge. For exact acceptable operating range, consult the manufacturer's operating and maintenance data.

In reciprocating and turbine engines, oil is used to lubricate and cool bearing surfaces where parts are rotating or sliding past each other at high speeds. A loss of pressurized oil to these areas would rapidly cause excessive friction and over-temperature conditions, leading to catastrophic engine



**Figure 10-13.** An analog oil pressure gauge is driven by a Bourdon tube. Oil pressure is vital to engine health and must be monitored by the pilot.

failure. As mentioned, aircraft using analog instruments often use direct reading Bourdon tube oil pressure gauges. *Figure 10-13* shows the instrument face of a typical oil pressure gauge of this type. Digital instrument systems use an analog or digital remote oil pressure sensing unit that sends output to the computer, driving the display of oil pressure value(s) on the aircraft's flight deck display screens. Oil pressure may be displayed in a circular or linear gauge fashion and may even include a numerical value on screen. Often, oil pressure is grouped with other engine parameter displays on the same page or portion of a page on the display. *Figure 10-14* shows this grouping on a Garmin G1000 digital instrument display system for general aviation aircraft.

### **Manifold Pressure**

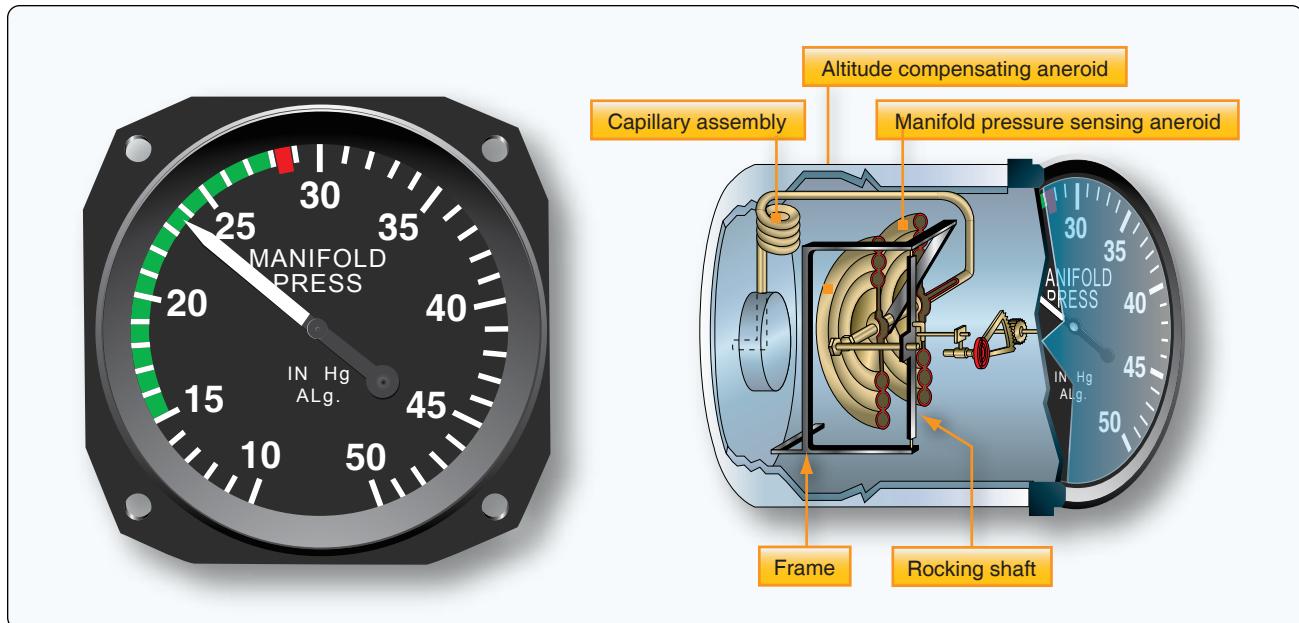
In reciprocating engine aircraft, the manifold pressure gauge indicates the pressure of the air in the engine's induction manifold. This is an indication of power being developed by the engine. The higher the pressure of the fuel air mixture going into the engine, the more power it can produce. For normally aspirated engines, maximum manifold pressure would be slightly less than the ambient atmospheric pressure.

Turbocharged or supercharged engines pressurize the air being mixed with the fuel, so full power indications are above the ambient atmospheric pressure.

Most manifold pressure gauges are calibrated in inches of mercury, although digital displays may have the option to display in a different scale. A typical analog gauge makes use of an aneroid described above. When atmospheric pressure acts on the aneroid inside the gauge, the connected pointer indicates the current air pressure. A line running from the intake manifold into the gauge presents intake manifold air pressure to the aneroid, so the gauge indicates the absolute pressure in the intake manifold. An analog manifold pressure gauge, along with its internal workings, is shown in *Figure 10-15*. The digital presentation of manifold pressure is at the top of the engine instruments displayed on the Garmin G1000 multifunctional display in *Figure 10-14*. The aircraft's operating manual contains data on managing manifold pressure in relation to fuel flow and propeller pitch and for achieving various performance profiles during different phases of run-up and flight.



**Figure 10-14.** Oil pressure indication with other engine-related parameters shown in a column on the left side of this digital flight deck display panel.



**Figure 10-15.** An analog manifold pressure indicator instrument dial calibrated in inches of mercury (left). The internal workings of an analog manifold pressure gauge are shown on the right. Air from the intake manifold surrounds the aneroid causing it to deflect and indicate pressure on the dial through the use of linkage to the pointer (right).

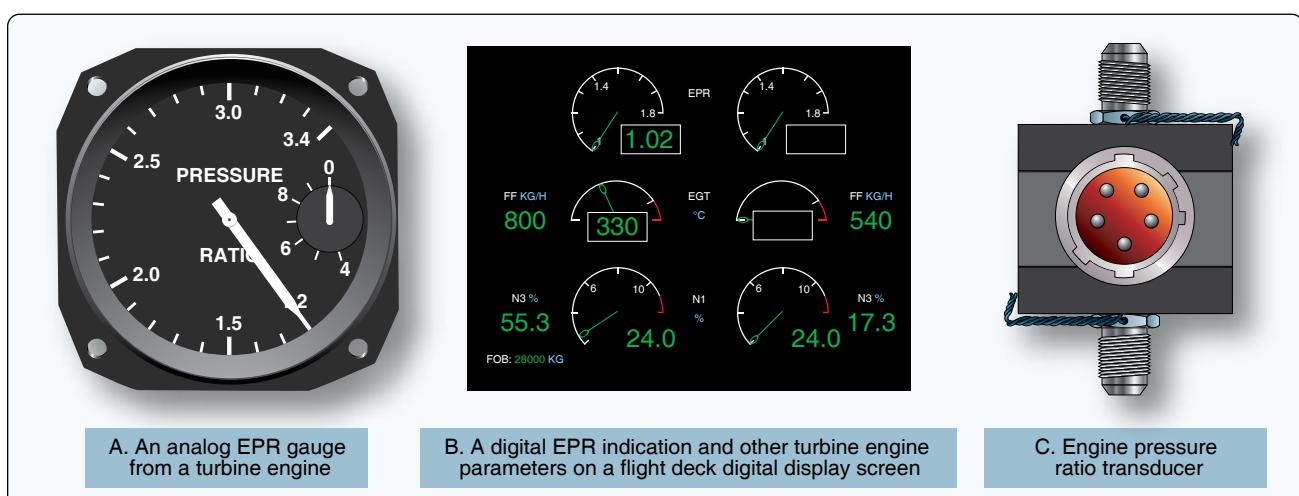
### Engine Pressure Ratio (EPR)

Turbine engines have their own pressure indication that relates the power being developed by the engine. It is called the engine pressure ratio (EPR) indicator (EPR gauge). This gauge compares the total exhaust pressure to the pressure of the ram air at the inlet of the engine. With adjustments for temperature, altitude, and other factors, the EPR gauge presents an indication of the thrust being developed by the engine. Since the EPR gauge compares two pressures, it is a differential pressure gauge. It is a remote-sensing instrument that receives its input from an engine pressure ratio transmitter or, in digital instrument systems displays, from a computer. The pressure ratio transmitter contains the

bellows arrangement that compares the two pressures and converts the ratio into an electric signal used by the gauge for indication. [Figure 10-16]

### Fuel Pressure

Fuel pressure gauges also provide critical information to the pilot. [Figure 10-17] Typically, fuel is pumped out of various fuel tanks on the aircraft for use by the engines. A malfunctioning fuel pump, or a tank that has been emptied beyond the point at which there is sufficient fuel entering the pump to maintain desired output pressure, is a condition that requires the pilot's immediate attention. While direct-sensing fuel pressure gauges using Bourdon tubes, diaphragms,



**Figure 10-16.** Engine pressure ratio gauges.



**Figure 10-17.** A typical analog fuel pressure gauge.

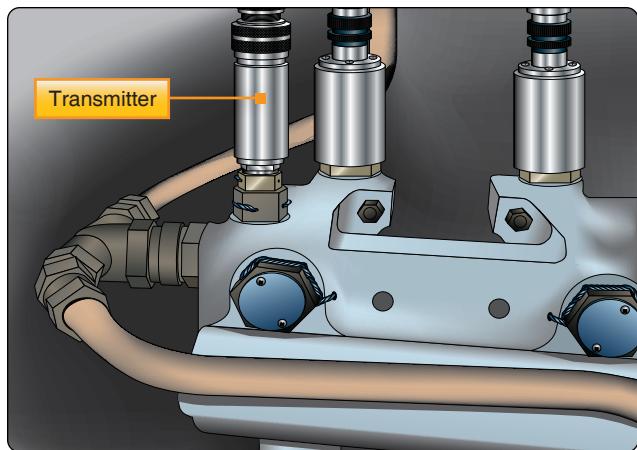
and bellows sensing arrangements exist, it is particularly undesirable to run a fuel line into the flight deck, due to the potential for fire should a leak develop. Therefore, the preferred arrangement is to have whichever sensing mechanism that is used be part of a transmitter device that uses electricity to send a signal to the indicator in the flight deck. Sometimes, indications monitoring the fuel flow rate are used instead of fuel pressure gauges. Fuel flow indications are discussed in the fuel system chapter of this handbook.

### Hydraulic Pressure

Numerous other pressure monitoring gauges are used on complex aircraft to indicate the condition of various support systems not found on simple light aircraft. Hydraulic systems are commonly used to raise and lower landing gear, operate flight controls, apply brakes, and more. Sufficient pressure in the hydraulic system developed by the hydraulic pump(s) is required for normal operation of hydraulic devices. Hydraulic pressure gauges are often located in the flight deck and at or near the hydraulic system servicing point on the airframe. Remotely located indicators used by maintenance personnel are almost always direct reading Bourdon tube type gauges. Flight deck gauges usually have system pressure transmitted from sensors or computers electrically for indication. *Figure 10-18* shows a hydraulic pressure transmitter in place in a high-pressure aircraft hydraulic system.

### Vacuum Pressure

Gyro pressure gauge, vacuum gauge, or suction gauge are all terms for the same gauge used to monitor the vacuum developed in the system that actuates the air driven gyroscopic flight instruments. Air is pulled through the instruments, causing the gyroscopes to spin. The speed at



**Figure 10-18.** A hydraulic pressure transmitter senses and converts pressure into an electrical output for indication by the flight deck gauge or for use by a computer that analyzes and displays the pressure in the flight deck when requested or required.

which the gyros spin needs to be within a certain range for correct operation. This speed is directly related to the suction pressure that is developed in the system. The suction gauge is extremely important in aircraft relying solely on vacuum-operated gyroscopic flight instruments.

Vacuum is a differential pressure indication, meaning the pressure to be measured is compared to atmospheric pressure through the use of a sealed diaphragm or capsule. The gauge is calibrated in inches of mercury. It shows how much less pressure exists in the system than in the atmosphere. *Figure 10-19* shows a suction gauge calibrated in inches of mercury.

### Pressure Switches

In aviation, it is often sufficient to simply monitor whether the pressure developed by a certain operating system is too high or too low, so that an action can take place should one of these conditions occur. This is often accomplished through the use of a pressure switch. A pressure switch is a simple device usually made to open or close an electric circuit when a certain pressure is reached in a system. It can be manufactured so that the electric circuit is normally open and can then close when a certain pressure is sensed, or the circuit can be closed and then opened when the activation pressure is reached. [*Figure 10-20*]

Pressure switches contain a diaphragm to which the pressure being sensed is applied on one side. The opposite side of the diaphragm is connected to a mechanical switching mechanism for an electric circuit. Small fluctuations or a buildup of pressure against the diaphragm move the diaphragm, but not enough to throw the switch. Only when pressure meets or exceeds a preset level designed into the structure of the switch does the diaphragm move far enough



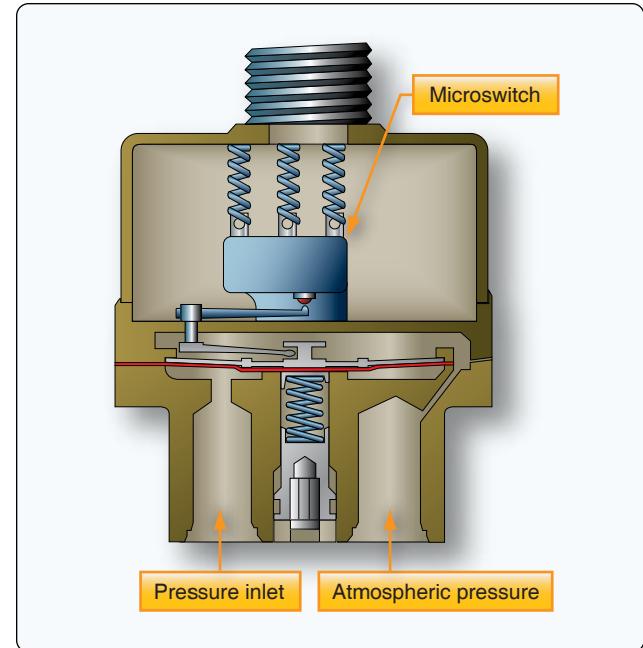
**Figure 10-19.** Vacuum suction gauge.



**Figure 10-20.** A pressure switch can be used in addition to, or instead of, a pressure gauge.

for the mechanical device on the opposite side to close the switch contacts and complete the circuit. [Figure 10-21] Each switch is rated to close (or open) at a certain pressure and must only be installed in the proper location.

A low oil pressure indication switch is a common example of how pressure switches are employed. It is installed in an engine so pressurized oil can be applied to the switch's diaphragm. Upon starting the engine, oil pressure increases and the pressure against the diaphragm is sufficient to hold the contacts in the switch open. As such, current does not flow through the circuit and no indication of low oil pressure is



**Figure 10-21.** A normally open pressure switch positioned in an electrical circuit causes the circuit to be open as well. The switch closes, allowing electricity to flow when pressure is applied beyond the switch's preset activation point. Normally, closed pressure switches allow electricity to flow through the switch in a circuit but open when pressure reaches a preset activation point, thus opening the electrical circuit.

given in the flight deck. Should a loss of oil pressure occur, the pressure against the diaphragm becomes insufficient to hold the switched contacts open. When the contacts close, they close the circuit to the low oil pressure indicator, usually a light, to warn the pilot of the situation.

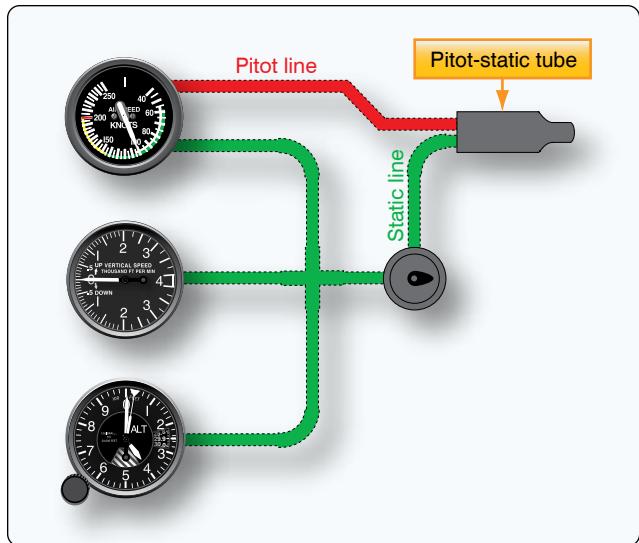
Pressure gauges for various components or systems work similarly to those mentioned above. Some sort of sensing device, appropriate for the pressure being measured or monitored, is matched with an indicating display system. If appropriate, a properly rated pressure switch is installed in the system and wired into an indicating circuit. Further discussion of specific instruments occurs throughout this handbook as the operation of various systems and components are discussed.

### Pitot-Static Systems

Some of the most important flight instruments derive their indications from measuring air pressure. Gathering and distributing various air pressures for flight instrumentation is the function of the pitot-static system.

### Pitot Tubes & Static Vents

On simple aircraft, this may consist of a pitot-static system head or pitot tube with impact and static air pressure ports and leak-free tubing connecting these air pressure pick-up points to the instruments that require the air for their



**Figure 10-22.** A simple pitot-static system is connected to the primary flight instruments.

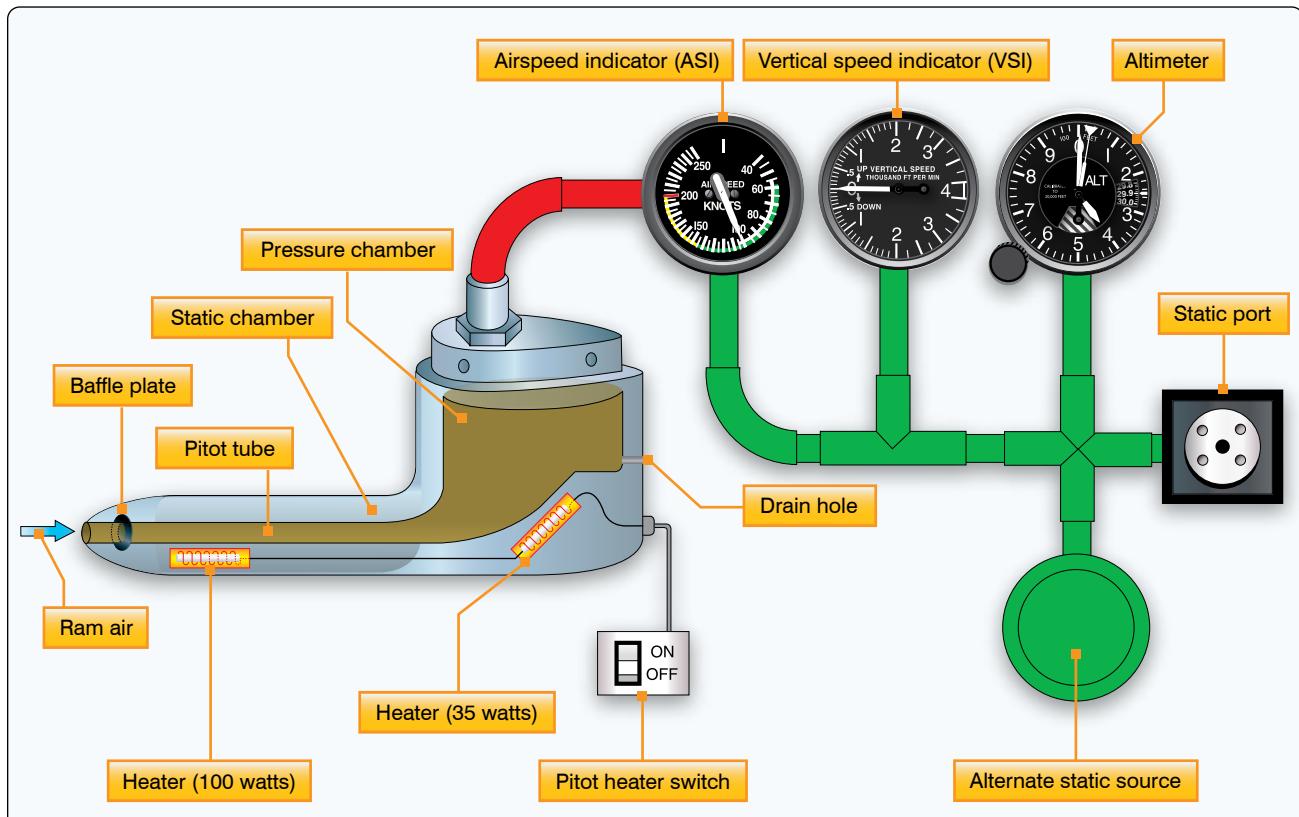
indications. The altimeter, airspeed indicator, and vertical speed indicator are the three most common pitot-static instruments. *Figure 10-22* illustrates a simple pitot-static system connected to these three instruments. All three instruments are connected to the static pressure system. The airspeed indicator is additionally connected to the pitot

pressure system. The altimeter is connected to the static pressure system.

A pitot tube is open and faces into the airstream to receive the full force of the impact air pressure as the aircraft moves forward. This air passes through a baffled plate designed to protect the system from moisture and dirt entering the tube. Below the baffle, a drain hole is provided, allowing moisture to escape. The ram air is directed aft to a chamber in the shark fin of the assembly. An upright tube, or riser, leads this pressurized air out of the pitot assembly to the airspeed indicator.

The aft section of the pitot tube is equipped with small holes on the top and bottom surfaces that are designed to collect air pressure that is at atmospheric pressure in a static, or still, condition. The static section also contains a riser tube and the air is run out the pitot assembly through tubes and is connected to the altimeter, the airspeed indicator, and the vertical speed indicator. [*Figure 10-23*]

Many pitot-static tube heads contain heating elements to prevent icing during flight. The pilot can send electric current to the element with a switch in the flight deck when ice-forming conditions exist. The pitot tube heat switch may be wired so that when the ignition switch is turned off when



**Figure 10-23.** A typical pitot-static system head, or pitot tube, collects ram air and static pressure for use by the flight instruments.

the aircraft is shut down, a pitot tube heater inadvertently left on does not continue to draw current and drain the battery. Caution should be exercised when near the pitot tube, as these heating elements make the tube too hot to be touched without receiving a burn.

The pitot-static tube is mounted on the outside of the aircraft at a point where the air is least likely to be turbulent. It is pointed in a forward direction parallel to the aircraft's line of flight. The location may vary. Some are on the nose of the fuselage and others may be located on a wing. A few may even be found on the empennage. Various designs exist but the function remains the same, to capture impact air pressure and static air pressure and direct them to the proper instruments. [Figure 10-24]

Most aircraft equipped with a pitot-static tube have an alternate source of static air pressure provided for emergency use. The pilot may select the alternate with a switch in the flight deck should it appear the flight instruments are not providing accurate indications. On low-flying unpressurized aircraft, the alternate static source may simply be air from the cabin. [Figure 10-25] On pressurized aircraft, cabin air pressure may be significantly different than the outside ambient air pressure. If used as an alternate source for static air, instrument indications would be grossly inaccurate. In this case, multiple static vent pickup points are employed. All are located on the outside of the aircraft and plumbed so the pilot can select which source directs air into the instruments.



**Figure 10-24.** Pitot-static system heads, or pitot tubes, can be of various designs and locations on airframes.



**Figure 10-25.** On unpressurized aircraft, an alternate source of static air is cabin air.

On electronic flight displays, the choice is made for which source is used by the computer or by the flight crew.

Another type of pitot-static system provides for the location of the pitot and static sources at separate positions on the aircraft. The pitot tube in this arrangement is used only to gather ram air pressure. Separate static vents are used to collect static air pressure information. Usually, these are located flush on the side of the fuselage. [Figure 10-26] There may be two or more vents. A primary and alternate source vent is typical, as well as separate dedicated vents for the pilot and first officer's instruments. Also, two primary vents may be located on opposite sides of the fuselage and connected with Y tubing for input to the instruments. This is done to compensate for any variations in static air pressure on the vents due to the aircraft's attitude. Regardless of the number and location of separate static vents, they may be heated as well as the separate ram air pitot tube to prevent icing.



**Figure 10-26.** Heated primary and alternate static vents located on the sides of the fuselage.

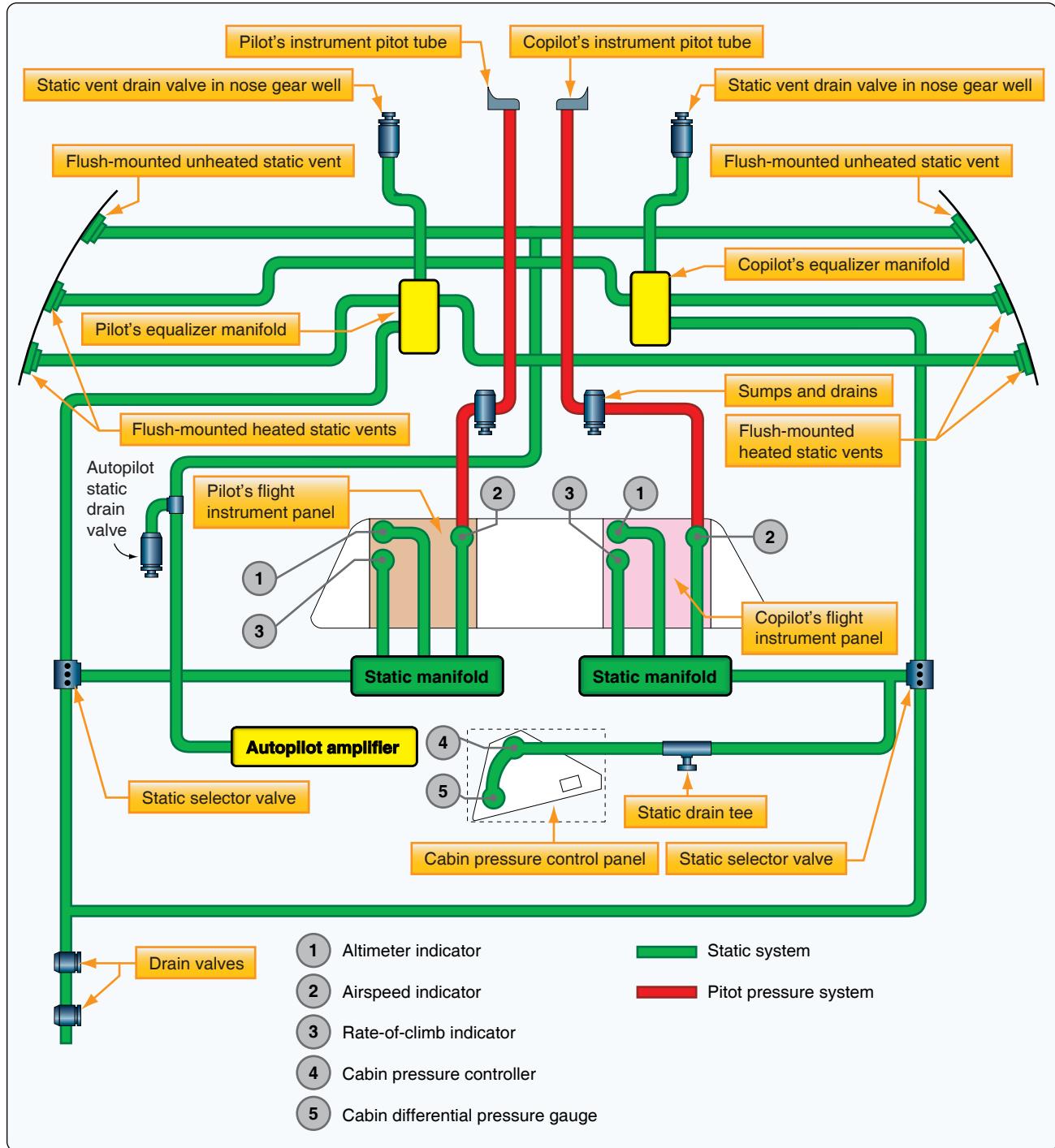


Figure 10-27. Schematic of a typical pitot-static system on a pressurized multiengine aircraft.

The pitot-static systems of complex, multiengine, and pressurized aircraft can be elaborate. Additional instruments, gauges, the autopilot system, and computers may need pitot and static air information. Figure 10-27 shows a pitot-static system for a pressurized multiengine aircraft with dual analog instrument panels in the flight deck. The additional set of flight instruments for the copilot alters and complicates the pitot-static system plumbing. Additionally, the autopilot

system requires static pressure information, as does the cabin pressurization unit. Separate heated sources for static air pressure are taken from both sides of the airframe to feed independent static air pressure manifolds; one each for the pilot's flight instruments and the copilot's flight instruments. This is designed to ensure that there is always one set of flight instruments operable in case of a malfunction.

## Air Data Computers (ADC) & Digital Air Data Computers (DADC)

High performance and jet transport category aircraft pitot-static systems may be more complicated. These aircraft frequently operate at high altitude where the ambient temperature can exceed 50 °F below zero. The compressibility of air is also altered at high speeds and at high altitudes. Airflow around the fuselage changes, making it difficult to pick up consistent static pressure inputs. The pilot must compensate for all factors of air temperature and density to obtain accurate indications from instruments. While many analog instruments have compensating devices built into them, the use of an air data computer (ADC) is common for these purposes on high-performance aircraft. Moreover, modern aircraft utilize digital air data computers (DADC). The conversion of sensed air pressures into digital values makes them more easily manipulated by the computer to output accurate information that has compensated for the many variables encountered. [Figure 10-28]

Essentially, all pressures and temperatures captured by sensors are fed into the ADC. Analog units utilize transducers to convert these to electrical values and manipulate them in various modules containing circuits designed to make the proper compensations for use by different instruments and systems. A DADC usually receives its data in digital format. Systems that do not have digital sensor outputs will first convert inputs into digital signals via an analog-to-digital converter. Conversion can take place inside the computer or in a separate unit designed for this function. Then, all calculation and compensations are performed digitally by the computer. Outputs from the ADC are electric to drive servo motors or for use as inputs in pressurization systems, flight control units, and other systems. DADC outputs are

distributed to these same systems and the flight deck display using a digital data bus.

There are numerous benefits of using ADCs. Simplification of pitot-static plumbing lines creates a lighter, simpler, system with fewer connections, so it is less prone to leaks and easier to maintain. One-time compensation calculations can be done inside the computer, eliminating the need to build compensating devices into numerous individual instruments or units of the systems using the air data. DADCs can run a number of checks to verify the plausibility of data received from any source on the aircraft. Thus, the crew can be alerted automatically of a parameter that is out of the ordinary. Change to an alternate data source can also be automatic so accurate flight deck and systems operations are continuously maintained. In general, solid-state technology is more reliable and modern units are small and lightweight. Figure 10-29 shows a schematic of how a DADC is connected into the aircraft's pitot-static and other systems.

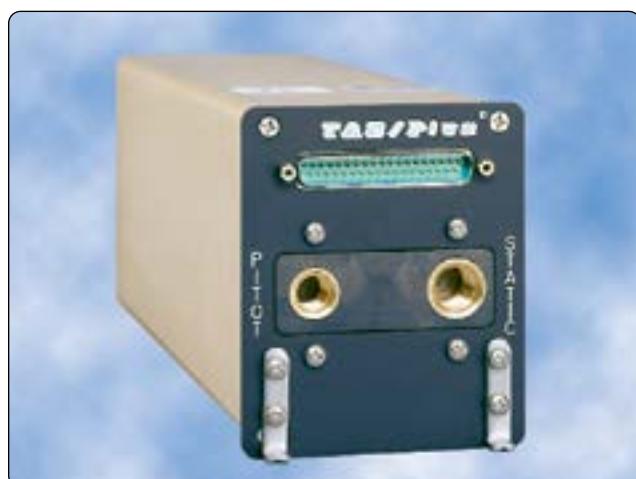
## Pitot-Static Pressure-Sensing Flight Instruments

The basic flight instruments are directly connected to the pitot-static system on many aircraft. Analog flight instruments primarily use mechanical means to measure and indicate various flight parameters. Digital flight instrument systems use electricity and electronics to do the same. Discussion of the basic pitot-static flight instruments begins with analog instruments to which further information about modern digital instrumentation is added.

### Altimeters & Altitude

An altimeter is an instrument that is used to indicate the height of the aircraft above a predetermined level, such as sea level or in the case of a radio/radar altimeter, the height of terrain beneath the aircraft. The most common way to measure this distance is rooted in discoveries made by scientists centuries ago. Seventeenth century work proving that the air in the atmosphere exerted pressure on the things around us led Evangelista Torricelli to the invention of the barometer. Also in that century, using the concept of this first atmospheric air pressure measuring instrument, Blaise Pascal was able to show that a relationship exists between altitude and air pressure. As altitude increases, air pressure decreases. The amount that it decreases is measurable and consistent for any given altitude change. Therefore, by measuring air pressure, altitude can be determined. [Figure 10-30]

Altimeters that measure the aircraft's altitude by measuring the pressure of the atmospheric air are known as pressure altimeters. A pressure altimeter is made to measure the ambient air pressure at any given location and altitude. In aircraft, it is connected to the static vent(s) via tubing in the pitot-static system. The relationship between the measured



**Figure 10-28.** Teledyne's 90004 TAS/Plus air data computer (ADC) computes air data information from the pitot-static pneumatic system, aircraft temperature probe, and barometric correction device to help create a clear indication of flight conditions.

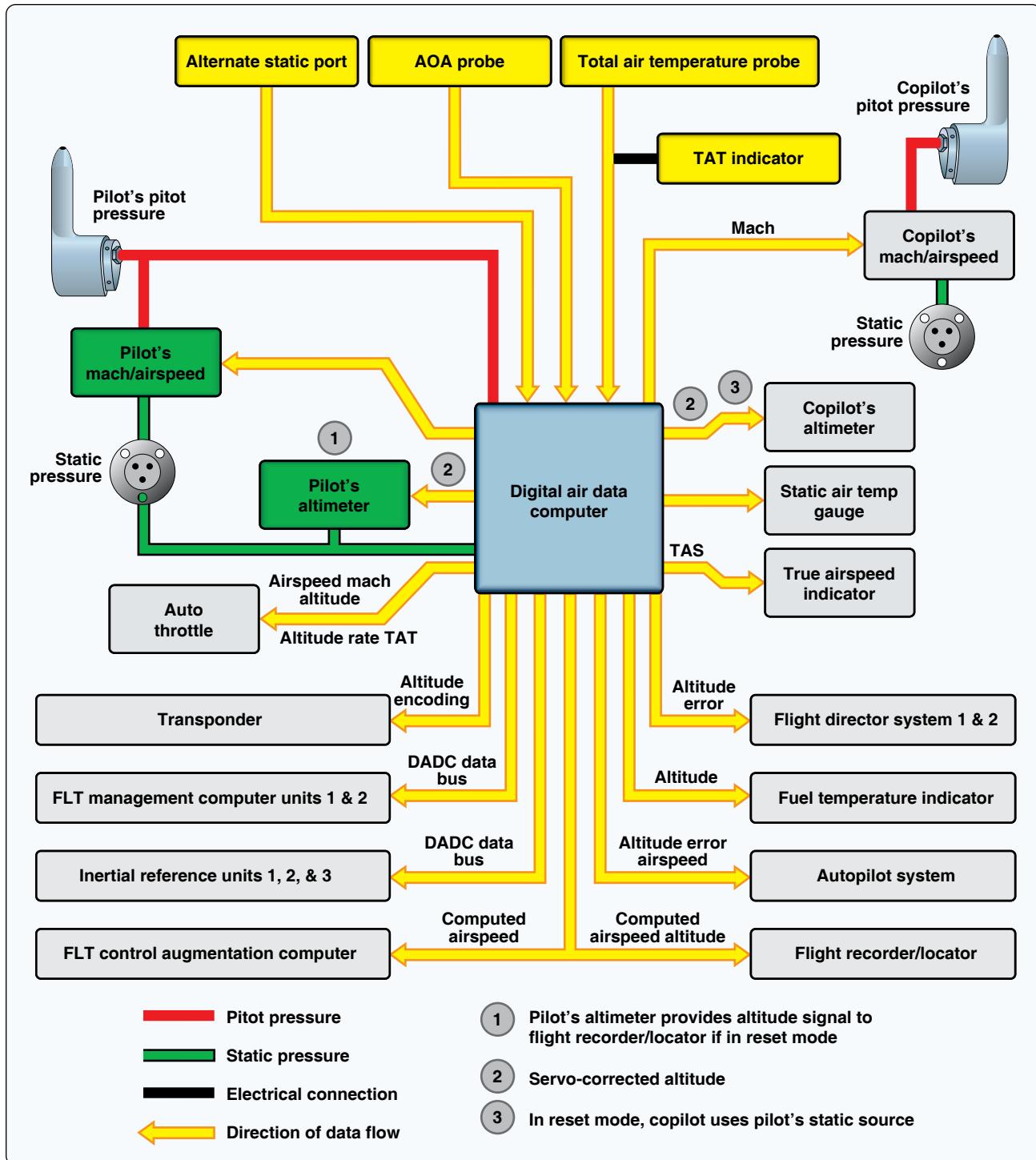


Figure 10-29. ADCs receive input from the pitot-static sensing devices and process them for use by numerous aircraft systems.

pressure and the altitude is indicated on the instrument face, which is calibrated in feet. These devices are direct-reading instruments that measure absolute pressure. An aneroid or aneroid bellows is at the core of the pressure altimeter's inner workings. Attached to this sealed diaphragm are the linkages and gears that connect it to the indicating pointer. Static air pressure enters the airtight instrument case and surrounds the aneroid. At sea level, the altimeter indicates zero when

this pressure is exerted by the ambient air on the aneroid. As air pressure is reduced by moving the altimeter higher in the atmosphere, the aneroid expands and displays altitude on the instrument by rotating the pointer. As the altimeter is lowered in the atmosphere, the air pressure around the aneroid increases and the pointer moves in the opposite direction. [Figure 10-31]

Atmosphere pressure	
Altitude (ft)	Pressure (psi)
Sea level	14.69
2,000	13.66
4,000	12.69
6,000	11.77
8,000	10.91
10,000	10.10
12,000	9.34
14,000	8.63
16,000	7.96
18,000	7.34
20,000	6.75
22,000	6.20
24,000	5.69
26,000	5.22
28,000	4.77
30,000	4.36
32,000	3.98
34,000	3.62
36,000	3.29
38,000	2.99
40,000	2.72
42,000	2.47
44,000	2.24
46,000	2.04
48,000	1.85
50,000	1.68

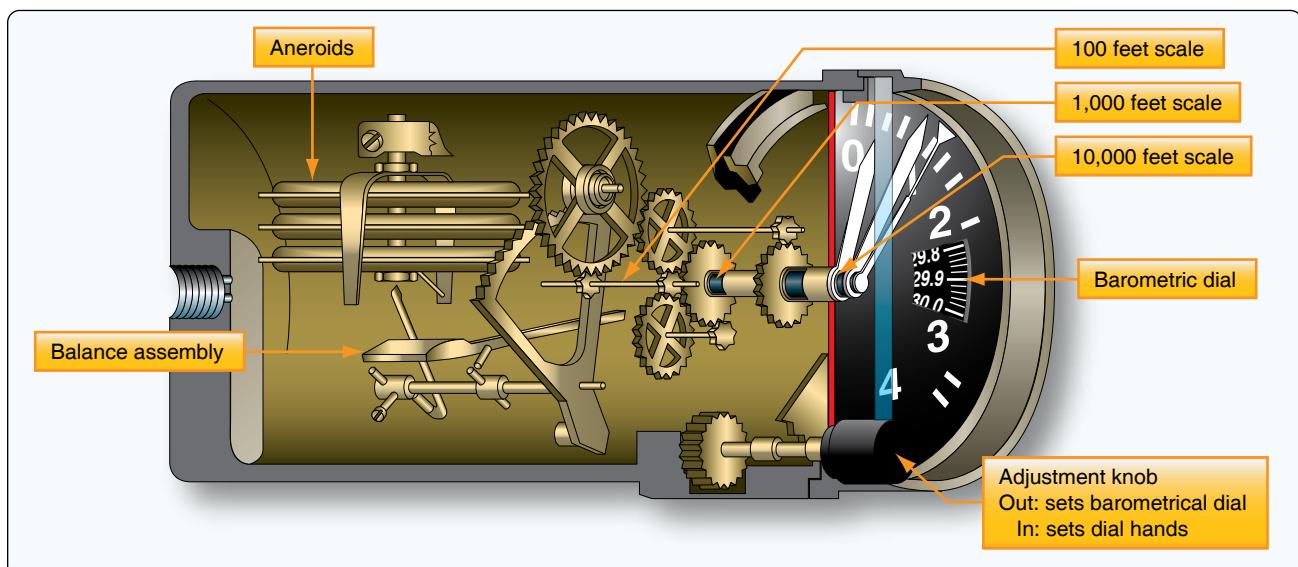
**Figure 10-30.** Air pressure is inversely related to altitude. This consistent relationship is used to calibrate the pressure altimeter.

The face, or dial, of an analog altimeter is read similarly to a clock. As the longest pointer moves around the dial, it is registering the altitude in hundreds of feet. One complete revolution of this pointer indicates 1,000 feet of altitude.

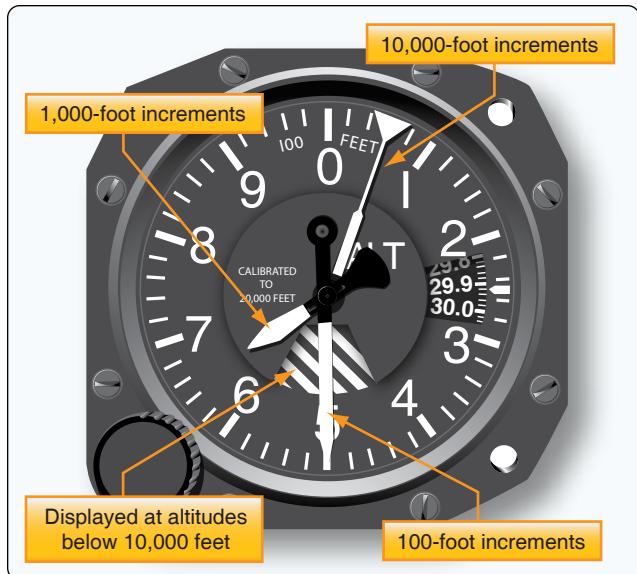
The second-longest point moves more slowly. Each time it reaches a numeral, it indicates 1,000 feet of altitude. Once around the dial for this pointer is equal to 10,000 feet. When the longest pointer travels completely around the dial one time, the second-longest point moves only the distance between two numerals—indicating 1,000 feet of altitude has been attained. If so equipped, a third, shortest or thinnest pointer registers altitude in 10,000 foot increments. When this pointer reaches a numeral, 10,000 feet of altitude has been attained. Sometimes a black-and-white or red-and-white cross-hatched area is shown on the face on the instrument until the 10,000 foot level has been reached. [Figure 10-32]

Many altimeters also contain linkages that rotate a numerical counter in addition to moving pointers around the dial. This quick reference window allows the pilot to simply read the numerical altitude in feet. The motion of the rotating digits or drum-type counter during rapid climb or descent makes it difficult or impossible to read the numbers. Reference can then be directed to the classic clock-style indication. Figure 10-33 illustrates the inner workings behind this type of mechanical digital display of pressure altitude.

True digital instrument displays can show altitude in numerous ways. Use of a numerical display rather than a reproduction of the clock-type dial is most common. Often a



**Figure 10-31.** The internal arrangement of a sealed diaphragm pressure altimeter. At sea level and standard atmospheric conditions, the linkage attached to the expandable diaphragm produces an indication of zero. When altitude increases, static pressure on the outside of the diaphragm decreases and the aneroid expands, producing a positive indication of altitude. When altitude decreases, atmospheric pressure increases. The static air pressure on the outside of the diaphragm increases and the pointer moves in the opposite direction, indicating a decrease in altitude.



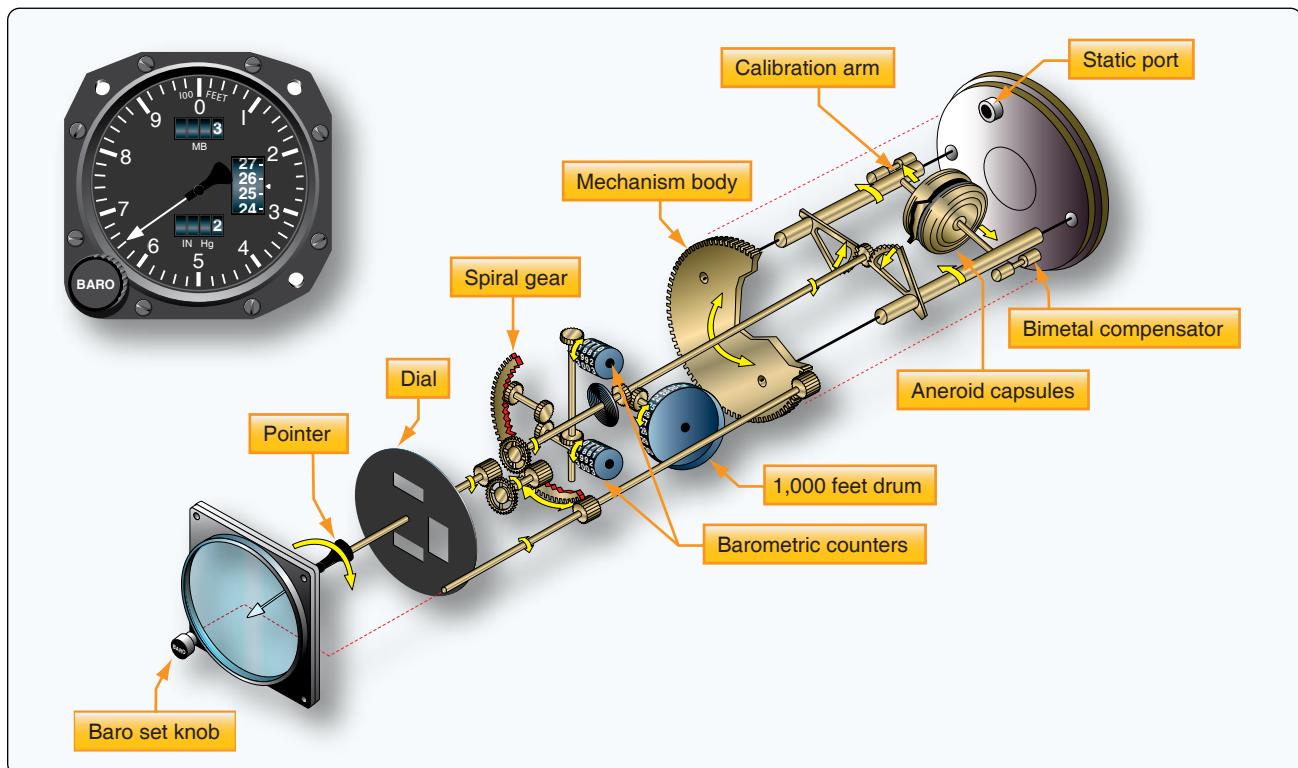
**Figure 10-32.** A sensitive altimeter with three pointers and a cross-hatched area displayed during operation below 10,000 feet.

digital numeric display of altitude is given on the electronic primary flight display near the artificial horizon depiction. A linear vertical scale may also be presented to put this hard numerical value in perspective. An example of this type of display of altitude information is shown in *Figure 10-34*.

Accurate measurement of altitude is important for numerous reasons. The importance is magnified in instrument flight rules (IFR) conditions. For example, avoidance of tall obstacles and rising terrain relies on precise altitude indication, as does flying at a prescribed altitude assigned by air traffic control (ATC) to avoid colliding with other aircraft. Measuring altitude with a pressure measuring device is fraught with complications. Steps are taken to refine pressure altitude indication to compensate for factors that may cause an inaccurate display.

A major factor that affects pressure altitude measurements is the naturally occurring pressure variations throughout the atmosphere due to weather conditions. Different air masses develop and move over the earth's surface, each with inherent pressure characteristics. These air masses cause the weather we experience, especially at the boundary areas between air masses known as fronts. Accordingly, at sea level, even if the temperature remains constant, air pressure rises and falls as weather system air masses come and go. The values in *Figure 10-30*, therefore, are averages for theoretical purposes.

To maintain altimeter accuracy despite varying atmospheric pressure, a means for setting the altimeter was devised. An adjustable pressure scale visible on the face of an analog altimeter known as a barometric or Kollsman window is set to read the existing atmospheric pressure that has been



**Figure 10-33.** A drum-type counter can be driven by the altimeter's aneroid for numerical display of altitude. Drums can also be used for the altimeter's setting indications.



**Figure 10-34.** This primary flight display unit of a Garmin 1000 series glass flight deck instrumentation package for light aircraft indicates altitude using a vertical linear scale and a numerical counter. As the aircraft climbs or descends, the scale behind the black numerical altitude readout changes.

corrected to mean sea level (MSL). This tells the altimeter what barometric pressure is considered zero feet in altitude. The instrument will then indicate the altitude of the aircraft above mean sea level. This altitude, adjusted for atmospheric pressure changes due to weather and air mass pressure inconsistency, is known as the indicated altitude.

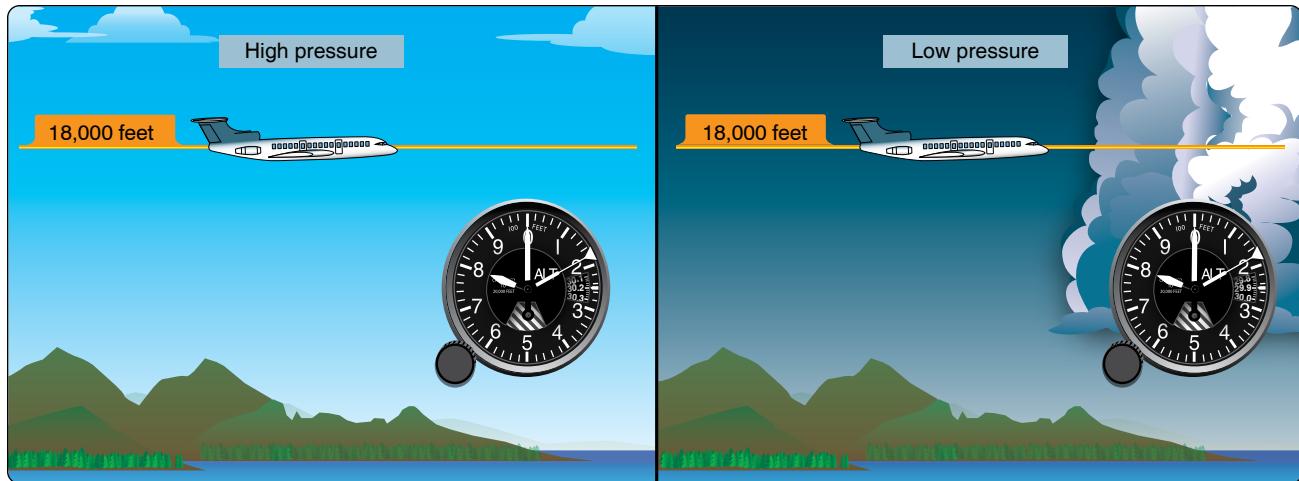
It must be noted that in flight below 18,000 feet, the altimeter setting is changed to match that of the closest available weather reporting station or airport. This keeps the altimeter accurate as the flight progresses.

While there was little need for exact altitude measurement in early fixed wing aviation, knowing one's altitude provided the pilot with useful references while navigating in the three dimensions of the atmosphere. As air traffic grew and the desire to fly in any weather conditions increased, exact altitude measurement became more important and the altimeter was refined. In 1928, Paul Kollsman invented the means for adjusting an altimeter to reflect variations in air pressure from standard atmospheric pressure. The very next year, Jimmy Doolittle made his successful flight demonstrating the feasibility of instrument flight with no visual references outside of the flight deck using a Kollsman sensitive altimeter.

The term “pressure altitude” is used to describe the indication an altimeter gives when 29.92 is set in the Kollsman window. When flying in U.S. airspace above 18,000 feet mean sea level (MSL), pilots are required to set their altimeters to 29.92. With all aircraft referencing this standard pressure level, vertical separation between aircraft assigned to different altitudes by ATC should be assured. This is the case if all altimeters are functioning properly and pilots hold their assigned altitudes. The actual, or true altitude, is less important than keeping aircraft from colliding, which is accomplished by all aircraft above 18,000 feet referencing the same barometric pressure (29.92 "Hg) on their altimeters. [Figure 10-35]

Temperature also affects the accuracy of an altimeter. The aneroid diaphragms used in altimeters are usually made of metal. Their elasticity changes as their temperature changes. This can lead to a false indication, especially at high altitudes when the ambient air is very cold. A bimetallic compensating device is built into many sensitive altimeters to correct for varying temperature. Figure 10-33 shows one such device on a drum-type altimeter.

Temperature also affects air density, which has great impact on the performance of an aircraft. Although this does not



**Figure 10-35.** Above 18,000 feet MSL, all aircraft are required to set 29.92 as the reference pressure in the Kollsman window. The altimeter then reads pressure altitude. Depending on the atmospheric pressure that day, the true or actual altitude of the aircraft may be above or below what is indicated (pressure altitude).

cause the altimeter to produce an errant reading, flight crews must be aware that performance changes with temperature variations in the atmosphere. The term density altitude describes altitude corrected for nonstandard temperature. That is, the density altitude is the standard day altitude (pressure altitude) at which an aircraft would experience similar performance as it would on the non-standard day currently being experienced. For example, on a very cold day, the air is denser than on a standard day, so an aircraft performs as though it is at a lower altitude. The density altitude is lower than that day. On a very hot day, the reverse is true, and an aircraft performs as though it were at a higher elevation where the air is less dense. The density altitude is higher than that day.

Conversion factors and charts have been produced so pilots can calculate the density altitude on any particular day. Inclusion of nonstandard air pressure due to weather systems and humidity can also be factored. So, while the effects of temperature on aircraft performance do not cause an altimeter to indicate falsely, an altimeter indication can be misleading in terms of aircraft performance if these effects are not considered. [Figure 10-36]

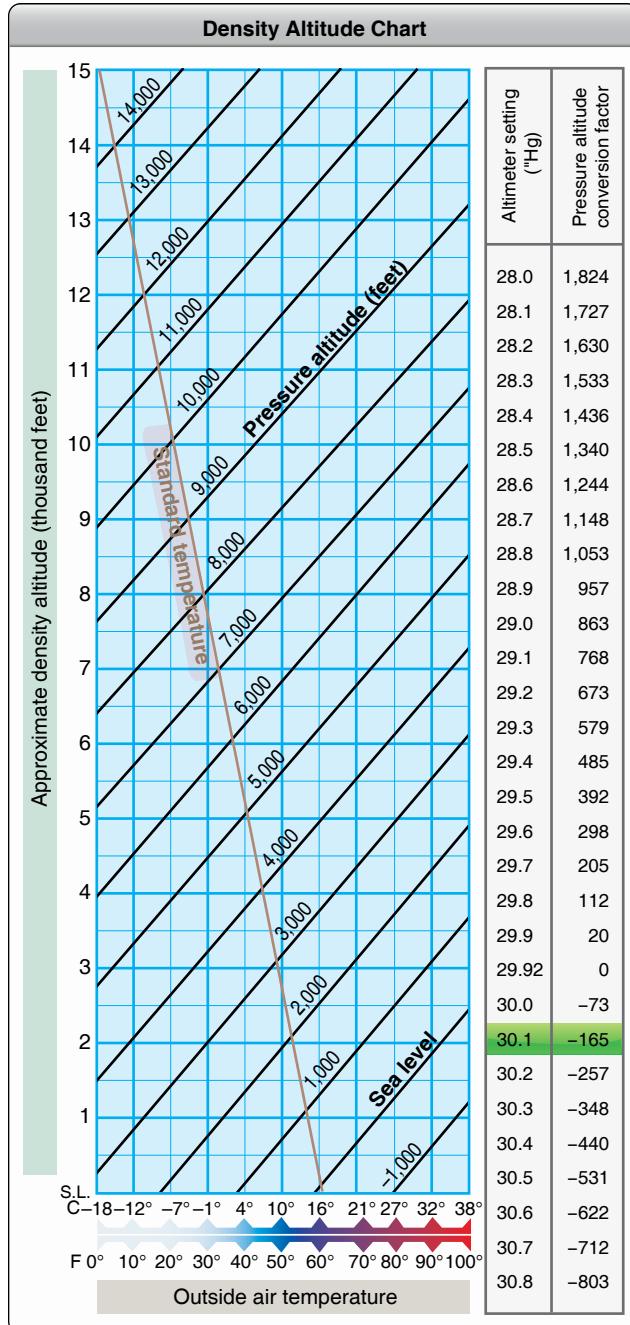
Other factors can cause an inaccurate altimeter indication. Scale error is a mechanical error whereby the scale of the instrument is not aligned so the altimeter pointers indicate correctly. Periodic testing and adjustment by trained technicians using calibrated equipment ensures scale error is kept to a minimum.

The pressure altimeter is connected to the pitot-static system and must receive an accurate sample of ambient air pressure to indicate the correct altitude. Position error, or installation error, is that inaccuracy caused by the location of the static

vent that supplies the altimeter. While every effort is made to place static ports in undisturbed air, airflow over the airframe changes with the speed and attitude of the aircraft. The amount of this air pressure collection error is measured in test flights, and a correction table showing the variances can be included with the altimeter for the pilot's use. Normally, location of the static vents is adjusted during these test flights so that the position error is minimal. [Figure 10-37] Position error can be removed by the ADC in modern aircraft, so the pilot need not be concerned about this inaccuracy.

Static system leaks can affect the static air input to the altimeter or ADC resulting in inaccurate altimeter indications. It is for this reason that static system maintenance includes leak checks every 24 months, regardless of whether any discrepancy has been noticed. See the instrument maintenance section toward the end of this chapter for further information on this mandatory check. It should also be understood that analog mechanical altimeters are mechanical devices that often reside in a hostile environment. The significant vibration and temperature range swings encountered by the instruments and the pitot static system (i.e., the tubing connections and fittings) can sometime create damage or a leak, leading to instrument malfunction. Proper care upon installation is the best preventive action. Periodic inspection and testing can also assure integrity.

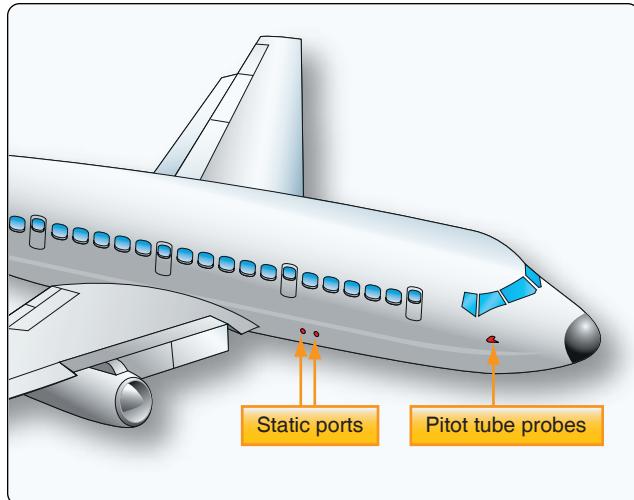
The mechanical nature of the analog altimeter's diaphragm pressure measuring apparatus has limitations. The diaphragm itself is only so elastic when responding to static air pressure changes. Hysteresis is the term for when the material from which the diaphragm is made takes a set during long periods of level flight. If followed by an abrupt altitude change, the indication lags or responds slowly while expanding or contracting during a rapid altitude change. While temporary,



**Figure 10-36.** The effect of air temperature on aircraft performance is expressed as density altitude.

this limitation does cause an inaccurate altitude indication.

It should be noted that many modern altimeters are constructed to integrate into flight control systems, autopilots, and altitude monitoring systems, such as those used by ATC. The basic pressure-sensing operation of these altimeters is the same, but a means for transmitting the information is added.



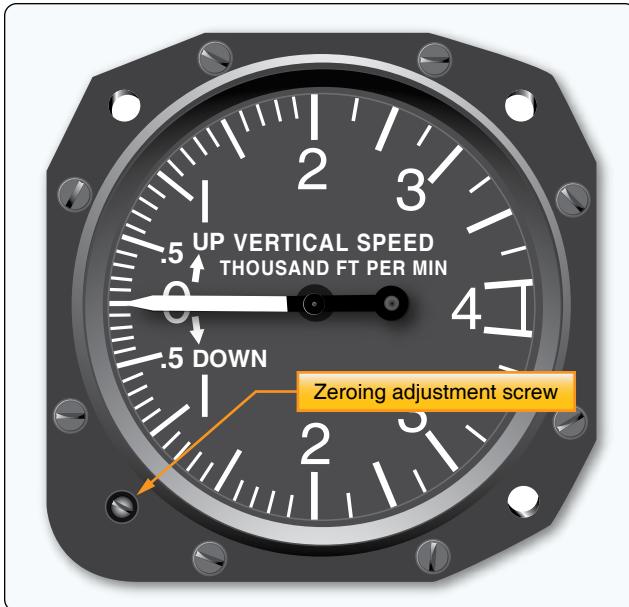
**Figure 10-37.** The location of the static ports is selected to keep altimeter position error to a minimum.

### Vertical Speed Indicator

An analog vertical speed indicator (VSI) may also be referred to as a vertical velocity indicator (VVI), or rate-of-climb indicator. It is a direct reading, differential pressure gauge that compares static pressure from the aircraft's static system directed into a diaphragm with static pressure surrounding the diaphragm in the instrument case. Air is free to flow unrestricted in and out of the diaphragm but is made to flow in and out of the case through a calibrated orifice. A pointer attached to the diaphragm indicates zero vertical speed when the pressure inside and outside the diaphragm are the same. The dial is usually graduated in 100s of feet per minute. A zeroing adjustment screw, or knob, on the face of the instrument is used to center the pointer exactly on zero while the aircraft is on the ground. [Figure 10-38]

As the aircraft climbs, the unrestricted air pressure in the diaphragm lowers as the air becomes less dense. The case air pressure surrounding the diaphragm lowers more slowly, having to pass through the restriction created by the orifice. This causes unequal pressure inside and outside the diaphragm, which in turn causes the diaphragm to contract a bit and the pointer indicates a climb. The process works in reverse for an aircraft in a descent. If a steady climb or descent is maintained, a steady pressure differential is established between the diaphragm and case pressure surrounding it, resulting in an accurate indication of the rate of climb via graduations on the instrument face. [Figure 10-39]

A shortcoming of the rate-of-climb mechanism as described is that there is a lag of six to nine seconds before a stable differential pressure can be established that indicates the actual climb or descent rate of the aircraft. An instantaneous vertical speed indicator (IVSI) has a built-in mechanism to reduce this lag. A small, lightly sprung dashpot, or piston,



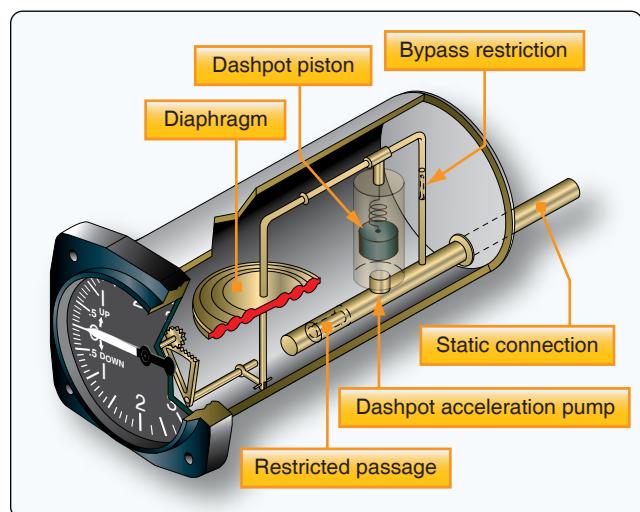
**Figure 10-38.** A typical vertical speed indicator.

reacts to the direction change of an abrupt climb or descent. As this small accelerometer does so, it pumps air into or out of the diaphragm, hastening the establishment of the pressure differential that causes the appropriate indication. [Figure 10-40]

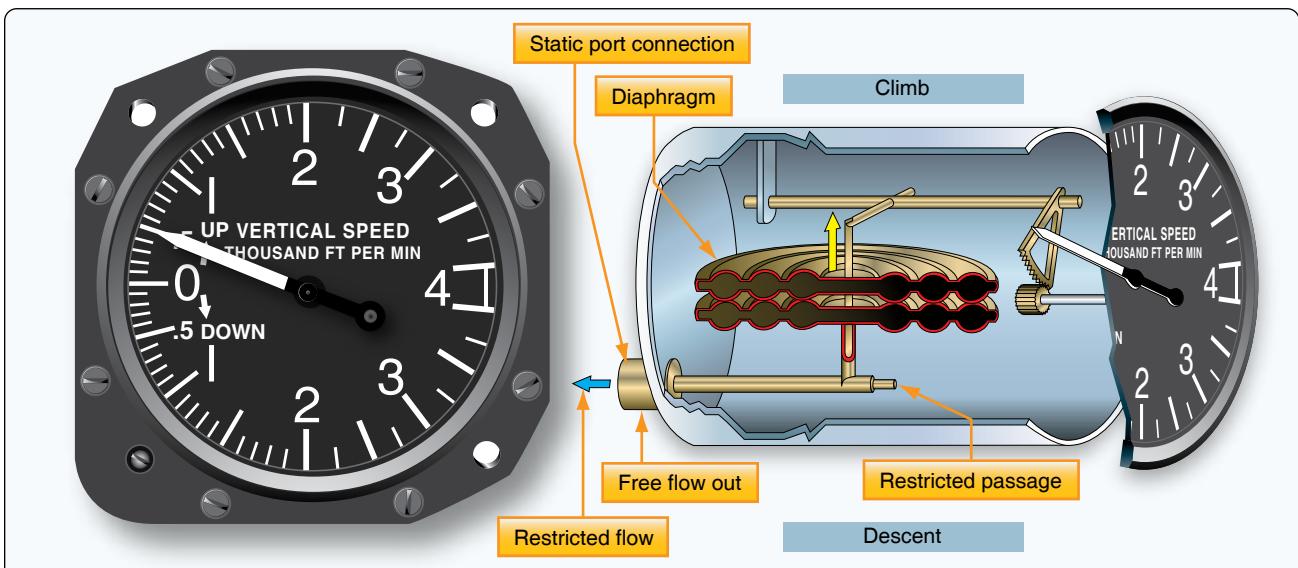
Gliders and lighter-than-air aircraft often make use of a variometer. This is a differential VSI that compares static pressure with a known pressure. It is very sensitive and gives an instantaneous indication. It uses a rotating vane with a pointer attached to it. The vane separates two chambers. One is connected to the aircraft's static vent or is open to

the atmosphere. The other is connected to a small reservoir inside the instrument that is filled to a known pressure. As static air pressure increases, the pressure in the static air chamber increases and pushes against the vane. This rotates the vane and pointer, indicating a descent since the static pressure is now greater than the set amount in the chamber with reservoir pressure. During a climb, the reservoir pressure is greater than the static pressure; the vane is pushed in the opposite direction, causing the pointer to rotate and indicate a climb. [Figure 10-41]

The rate-of-climb indication in a digitally displayed instrument system is computed from static air input to the ADC. An aneroid, or solid-state pressure sensor, continuously



**Figure 10-40.** The small dashpot in this IVSI reacts abruptly to a climb or descent pumping air into or out of the diaphragm causing an instantaneously vertical speed indication.



**Figure 10-39.** The VSI is a differential pressure gauge that compares free-flowing static air pressure in the diaphragm with restricted static air pressure around the diaphragm in the instrument case.

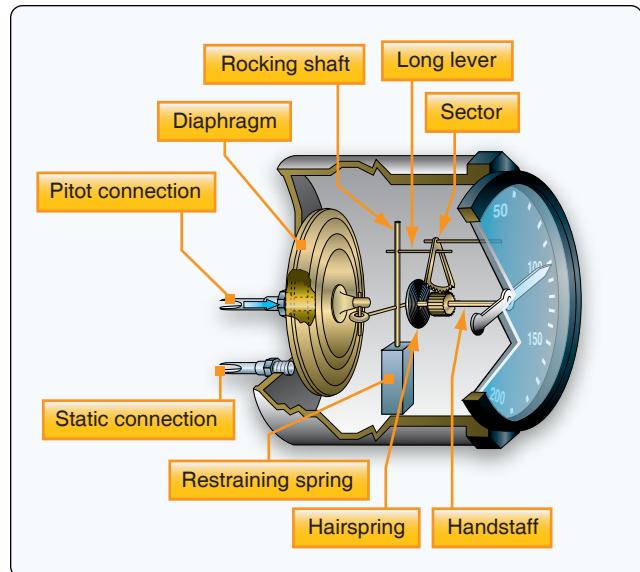
reacts to changes in static pressure. The digital clock within the computer replaces the calibrated orifice found on an analog instrument. As the static pressure changes, the computer's clock can be used to develop a rate for the change. Using the known lapse rate conversion for air pressure as altitude increases or decreases, a figure for climb or descent in fpm can be calculated and sent to the flight deck. The vertical speed is often displayed near the altimeter information on the primary flight display. [Figure 10-34]

### Airspeed Indicators

The airspeed indicator is another primary flight instrument that is also a differential pressure gauge. Ram air pressure from the aircraft's pitot tube is directed into a diaphragm in an analog airspeed instrument case. Static air pressure from the aircraft static vent(s) is directed into the case surrounding the diaphragm. As the speed of the aircraft varies, the ram air pressure varies, expanding or contracting the diaphragm. Linkage attached to the diaphragm causes a pointer to move over the instrument face, which is calibrated in knots or miles per hour (mph). [Figure 10-42]

The relationship between the ram air pressure and static air pressure produces the indication known as indicated airspeed (IAS). As with the altimeter, there are other factors that must be considered in measuring airspeed throughout all phases of flight. These can cause inaccurate readings or indications that are not useful to the pilot in a particular situation. In analog airspeed indicators, the factors are often compensated for with ingenious mechanisms inside the case and on the instrument dial face. Digital flight instruments can have calculations performed in the ADC so the desired accurate indication is displayed.

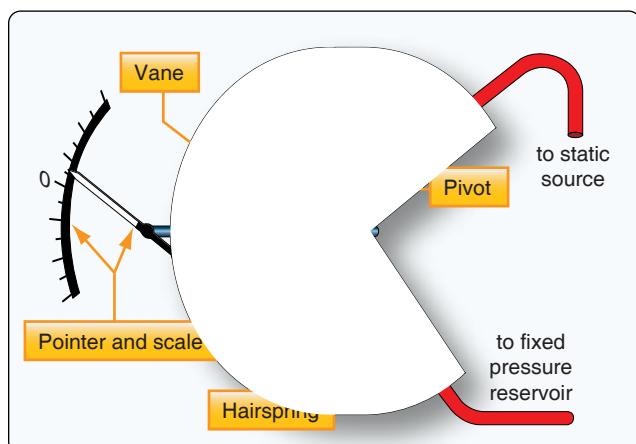
While the relationship between ram air pressure and static air



**Figure 10-42.** An airspeed indicator is a differential pressure gauge that compares ram air pressure with static pressure.

pressure is the basis for most airspeed indications, it can be more accurate. Calibrated airspeed (CAS) takes into account errors due to position error of the pitot static pickups. It also corrects for the nonlinear nature of the pitot static pressure differential when it is displayed on a linear scale. Analog airspeed indicators come with a correction chart that allows cross-referencing of indicated airspeed to calibrated airspeed for various flight conditions. These differences are typically very small and often are ignored. Digital instruments have these corrections performed in the ADC.

More importantly, indicated airspeed does not take into account temperature and air pressure differences needed to indicate true airspeed (TAS). These factors greatly affect airspeed indication. True airspeed, therefore, is the same as indicated airspeed when standard day conditions exist. But when atmospheric temperature or pressure varies, the relationship between the ram air pressure and static pressure alters. Analog airspeed instruments often include bimetallic temperature compensating devices that can alter the linkage movement between the diaphragm and the pointer movement. There can also be an aneroid inside the airspeed indicator case that can compensate for non-standard pressures. Alternatively, true airspeed indicators exist that allow the pilot to set temperature and pressure variables manually with external knobs on the instrument dial. The knobs rotate the dial face and internal linkages to present an indication that compensates for non-standard temperature and pressure, resulting in a true airspeed indication. [Figure 10-43]



**Figure 10-41.** A variometer uses differential pressure to indicate vertical speed. A rotating vane separating two chambers (one with static pressure, the other with a fixed pressure reservoir), moves the pointer as static pressure changes.

Digital flight instrument systems perform all of the calculations for true airspeed in the ADC. Ram air from the pitot tube and static air from the static vent(s) are run into

the sensing portion of the computer. Temperature information is also input. This information can be manipulated and calculations performed so a true airspeed value can be digitally sent to the flight deck for display. Refer to *Figure 10-34* for the display of airspeed information on the primary flight display on a light aircraft. Note that similar to its position in the standard T configuration of an analog flight deck, the airspeed indication is just left of the artificial horizon display. Refer to *Figure 10-4* showing T configuration.

Complications continue when considering airspeed indications and operating limitations. It is very important to keep high-speed aircraft from traveling faster than the speed of sound if they are not designed to do so. Even as an aircraft approaches the speed of sound, certain parts on the airframe may experience airflows that exceed it. The problem with this is that near the speed of sound, shock waves can develop that can affect flight controls and, in some cases, can literally tear the aircraft apart if not designed for supersonic airflow. A further complication is that the speed of sound changes with altitude and temperature. So, a safe true airspeed at sea level could put the aircraft in danger at altitude due to the lower speed of sound. [*Figure 10-44*]

In order to safeguard against these dangers, pilots monitor airspeed closely. A maximum allowable speed is established for the aircraft during certification flight testing. This speed is known the critical Mach number or  $M_{crit}$ . Mach is a term for the speed of sound. The critical Mach number is expressed as a decimal of Mach such as 0.8 Mach. This means  $\%_0$  of the speed of sound, regardless of what the actual speed of sound is at any particular altitude.



**Figure 10-43.** An analog true airspeed indicator. The pilot manually aligns the outside air temperature with the pressure altitude scale, resulting in an indication of true airspeed.

Standard Altitude, Temperature, and the Speed of Sound		
Altitude (feet)	Temperature (°F)	Speed of sound (knots)
Sea level	59	661
2,000	52	657
4,000	48	652
6,000	38	648
8,000	30	643
10,000	23	638
12,000	16	633
14,000	9	629
16,000	2	624
18,000	-5	619
20,000	-12	614
22,000	-19	609
24,000	-27	604
26,000	-34	599
28,000	-41	594
30,000	-48	589
32,000	-55	584
34,000	-62	579
36,000	-69	574
38,000	-70	574
40,000	-70	574
42,000	-70	574
44,000	-70	574
46,000	-70	574
48,000	-70	574
50,000	-70	574

**Figure 10-44.** As temperatures fall at higher altitudes, the speed of sound is reduced.

Many high performance aircraft are equipped with a Machmeter for monitoring  $M_{crit}$ . The Machmeter is essentially an airspeed instrument that is calibrated in relation to Mach on the dial. Various scales exist for subsonic and supersonic aircraft. [*Figure 10-45*] In addition to the ram air/static air diaphragm arrangement, Machmeters also contain an altitude sensing diaphragm. It adjusts the input to the pointer so changes in the speed of sound due to altitude are incorporated into the indication. Some aircraft use a Mach/airspeed indicator as shown in *Figure 10-46*. This two-in-one instrument contains separate mechanisms to display the airspeed and Mach number. A standard white pointer is used to indicate airspeed in knots against one scale. A red and white striped pointer is driven independently to display the maximum allowable speed. Should the aircraft exceed this speed, it would result in an overspeed warning.

### Remote Sensing & Indication

It is often impractical or impossible to utilize direct reading gauges for information needed to be conveyed in the flight deck. Placing sensors at the most suitable location on the airframe or engine and transmitting the collected data electrically through wires to the displays in the flight deck is a widely used method of remote-sensing and indicating on aircraft. Many remote sensing instrument systems



**Figure 10-45.** A Machmeter indicates aircraft speed relative to the speed of sound.



**Figure 10-46.** A combination Mach/airspeed indicator shows airspeed with a white pointer and Mach number with a red and white striped pointer. Each pointer is driven by separate internal mechanisms.

consist simply of the sensing device, transmitter unit, and the flight deck indicator unit connected to each other by wires. For pressure flight instruments, the ADC and pickup devices (pitot tubes, static vents, etc.) comprise the sensing and transmitter unit. Many aircraft collect sensed data in dedicated engine and airframe computers. There, the information can be processed. An output section of the computer then transmits it electrically or digitally to the flight deck for display. Remote-sensing instrument systems operate with high reliability and accuracy. They are powered by the aircraft's electrical system.

Small electric motors inside the instrument housings are used to position the pointers, instead of direct-operating mechanical linkages. They receive electric current from the output section of the ADC or other computers. They also receive input from sensing transmitters or transducers that are remotely located on the aircraft. By varying the electric signal, the motors are turned to the precise location needed to reflect the correct indication. Direct electric transmission of information from different types of sensors is accomplished with a few reliable and relatively simple techniques. Note that digital flight deck displays receive all of their input from a digital air data computer (DADC) and other computers, via a digital data bus and do not use electric motors. The data packages transmitted via the bus contain the instructions on how to illuminate the display screen.

### Synchro-Type Remote-Indicating Instruments

A synchro system is an electric system used for transmitting information from one point to another. The word "synchro" is a shortened form of the word "synchronous," and refers to any one of a number of similarly operating two-unit electrical systems capable of measuring, transmitting, and indicating a certain parameter on the aircraft. Most position-indicating instruments are designed around a synchro system, such as the flap position indicator. Fluid pressure indicators also commonly use synchro systems. Synchro systems are used as remote position indicators for landing gear, autopilot systems, radar, and many other remote-indicating applications. The most common types of synchro system are the autosyn, selsyn, and magnesyn synchro systems.

These systems are similar in construction, and all operate by exploiting the consistent relationship between electricity and magnetism. The fact that electricity can be used to create magnetic fields that have definite direction, and that magnetic fields can interact with magnets and other electromagnetic fields, is the basis of their operation.

### DC Selsyn Systems

On aircraft with direct current (DC) electrical systems, the DC selsyn system is widely used. As mentioned, the selsyn system consists of a transmitter, an indicator, and connecting wires. The transmitter consists of a circular resistance winding and a rotatable contact arm. The rotatable contact arm turns on a shaft in the center of the resistance winding. The two ends of the arm are brushes and always touch the winding on opposite sides. [Figure 10-47] On position indicating systems, the shaft to which the contact arm is fastened protrudes through the end of transmitter housing and is attached to the unit whose position is to be transmitted (e.g., flaps, landing gear). The transmitter is often connected to the moving unit through a mechanical linkage. As the unit moves, it causes the transmitter shaft to turn. The arm is turned so that voltage is applied through the brushes to any two points

around the circumference of the resistance winding. The rotor shaft of DC selsyn systems, measuring other kinds of data, operates the same way, but may not protrude outside of the housing. The sensing device, which imparts rotary motion to the shaft, could be located inside the transmitter housing.

Referring to *Figure 10-47*, note that the resistance winding of the transmitter is tapped off in three fixed places, usually  $120^\circ$  apart. These taps distribute current through the toroidal windings of the indicator motor. When current flows through these windings, a magnetic field is created. Like all magnetic fields, a definite north and south direction to the field exists.

As the transmitter rotor shaft is turned, the voltage-supplying contact arm moves. Because it contacts the transmitter resistance winding in different positions, the resistance between the supply arm and the various tapoffs changes. This causes the voltage flowing through the tapoffs to change as the resistance of sections of the winding become longer or shorter. The result is that varied current is sent via the tapoffs to the three windings in the indicator motor.

The resultant magnetic field created by current flowing through the indicator coils changes as each receives varied current from the tapoffs. The direction of the magnetic field also changes. Thus, the direction of the magnetic field across the indicating element corresponds in position to the moving arm in the transmitter. A permanent magnet is attached to the centered rotor shaft in the indicator, as is the indicator pointer. The magnet aligns itself with the direction of the magnetic field and the pointer does as well. Whenever the magnetic field changes direction, the permanent magnet and pointer realign with the new position of the field. Thus, the position of the aircraft device is indicated.

Landing gear contain mechanical devices that lock the gear up, called an up-lock, or down, called a down-lock. When

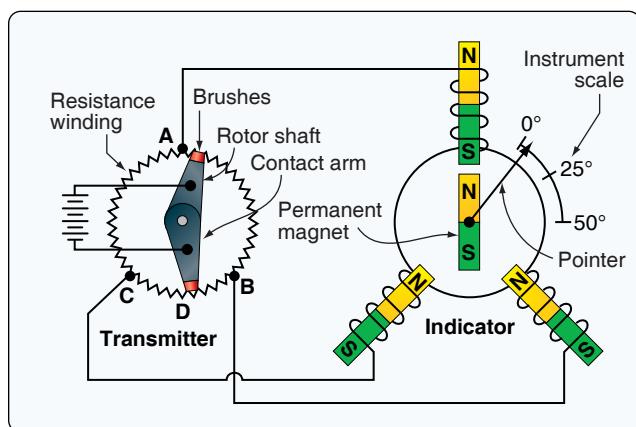
the DC selsyn system is used to indicate the position of the landing gear, the indicator can also show that the up-lock or down-lock is engaged. This is done by again varying the current flowing through the indicator's coils. Switches located on the actual locking devices close when the locks engage. Current from the selsyn system described above flows through the switch and a small additional circuit. The circuit adds an additional resistor to one of the transmitter winding sections created by the rotor arm and a tapoff. This changes the total resistance of that section. The result is a change in the current flowing through one of the indicator's motor coils. This, in turn, changes the magnetic field around that coil. Therefore, the combined magnetic field created by all three motor coils is also affected, causing a shift in the direction of the indicator's magnetic field. The permanent magnet and pointer align with the new direction and shift to the locked position on the indicator dial. *Figure 10-48* shows a simplified diagram of a lock switch in a three-wire selsyn system and an indicator dial.

### AC Synchro Systems

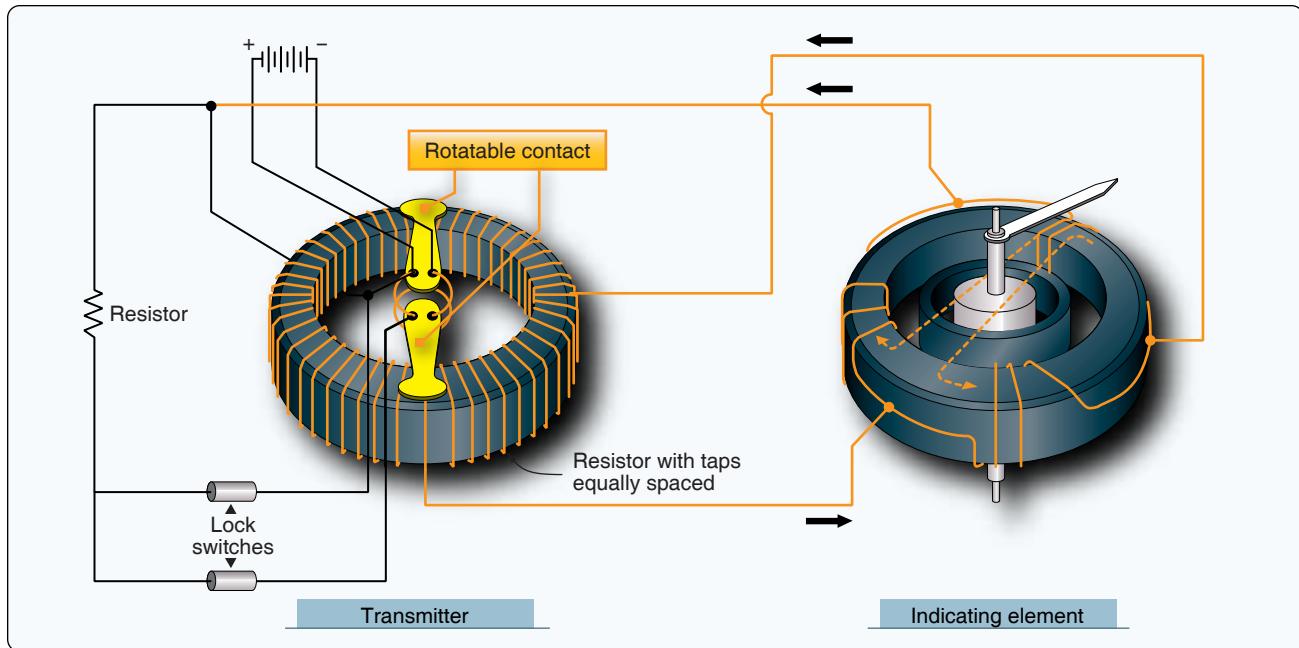
Aircraft with alternating current (AC) electrical power systems make use of autosyn or magnasyn synchro remote indicating systems. Both operate in a similar way to the DC selsyn system, except that AC power is used. Thus, they make use of electric induction, rather than resistance current flows defined by the rotor brushes. Magnasyn systems use permanent magnet rotors such as those found in the DC selsyn system. Usually, the transmitter magnet is larger than the indicator magnet, but the electromagnetic response of the indicator rotor magnet and pointer remains the same. It aligns with the magnetic field set up by the coils, adopting the same angle of deflection as the transmitter rotor. [*Figure 10-49*]

Autosyn systems are further distinguished by the fact that the transmitter and indicator rotors used are electro-magnets rather than permanent magnets. Nonetheless, like a permanent magnet, an electro-magnet aligns with the direction of the magnetic field created by current flowing through the stator coils in the indicator. Thus, the indicator pointer position mirrors the transmitter rotor position. [*Figure 10-50*]

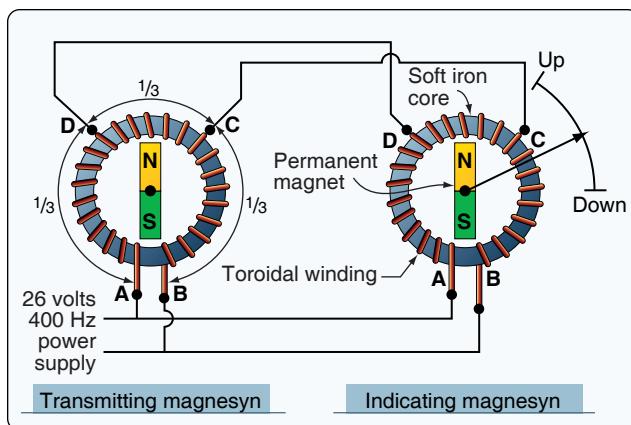
AC synchro systems are wired differently than DC systems. The varying current flows through the transmitter and indicator stator coils are induced as the AC cycles through zero and the rotor magnetic field flux is allowed to flow. The important characteristic of all synchro systems is maintained by both the autosyn and magnasyn systems. That is, the position of the transmitter rotor is mirrored by the rotor in the indicator. These systems are used in many of the same applications as the DC systems and more. Since they are usually part of instrumentation for high performance aircraft, adaptations of autosyn and magnasyn synchro systems are frequently used in directional indicators and in autopilot systems.



**Figure 10-47.** A schematic of a DC selsyn remote indicating system.



**Figure 10-48.** A lock switch circuit can be added to the basic DC selsyn synchro system when used to indicate landing gear position and up- and down-locked conditions on the same indicator.

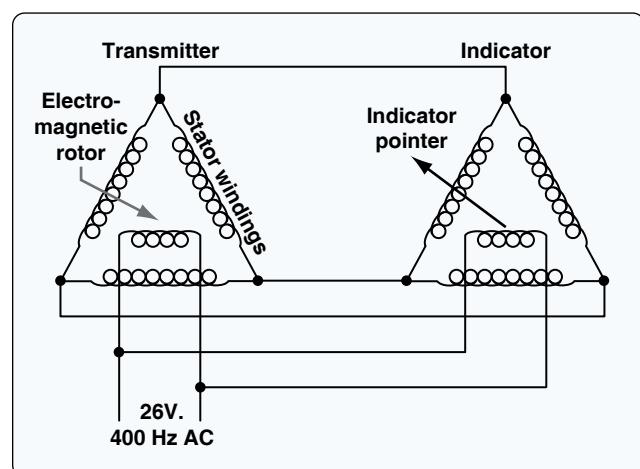


**Figure 10-49.** A magnasyn synchro remote-indicating system uses AC. It has permanent magnet rotors in the transmitter and indicator.

### Remote Indicating Fuel & Oil Pressure Gauges

Fuel and oil pressure indications can be conveniently obtained through the use of synchro systems. As stated previously, running fuel and oil lines into the cabin to direct reading gauges is not desirable due to the possibility of leaking fluid. Additionally, there is an increased risk of fire in the cabin.

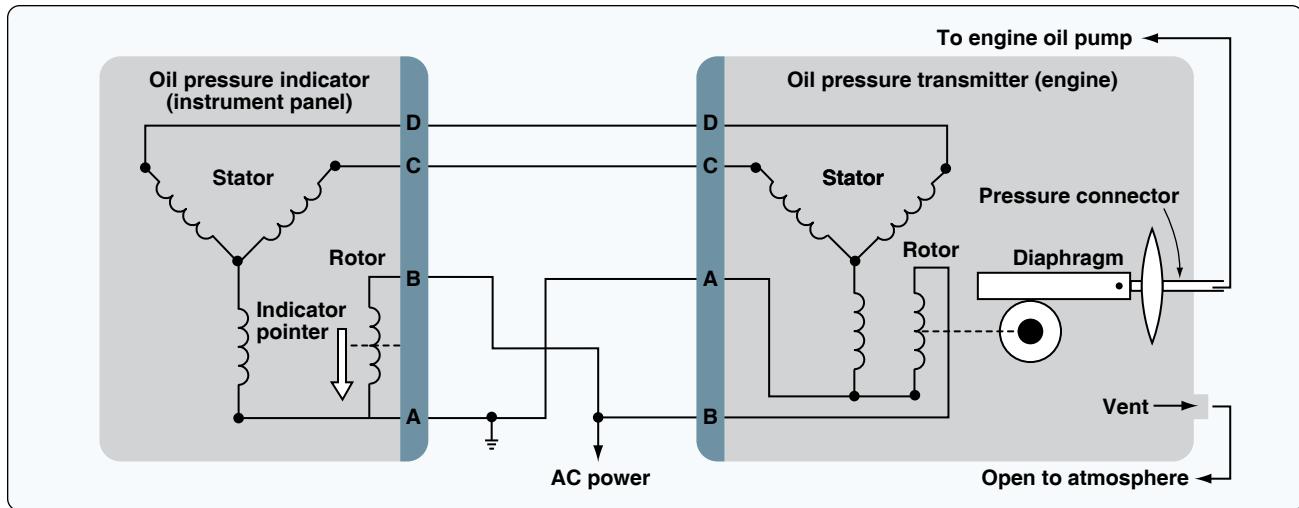
By locating the transmitter of a synchro system remotely, fluid pressure can be directed into it without a long tubing run. Inside the transmitter, the motion of a pressure bellows can be geared to the transmitter rotor in such a way as to make the rotor turn. [Figure 10-51] As in all synchros, the transmitter rotor turns proportional to the pressure sensed, which varies the voltages set up in the resistor windings of the synchro



**Figure 10-50.** An autosyn remote-indicating system utilizes the interaction between magnetic fields set up by electric current flow to position the indicator pointer.

stator. These voltages are transmitted to the indicator coils that develop the magnetic field that positions the pointer.

Often on twin-engine aircraft, synchro mechanisms for each engine can be used to drive separate pointers on the same indicator. By placing the coils one behind the other, the pointer shaft from the rear indicator motor can be sent through the hollow shaft of the forward indicator motor. Thus, each pointer responds with the magnet's alignment in its own motor's magnetic field while sharing the same gauge housing. Labeling the pointer's engine 1 or 2 removes any doubt about which indicator pointer is being observed. A similar principle is employed in an indicator that has side-by-side indications



**Figure 10-51.** Remote pressure sensing indicators change linear motion to rotary motion in the sensing mechanism part of the synchro transmitter.

for different parameters, such as oil pressure and fuel pressure in the same indicator housing. Each parameter has its own synchro motor for positioning its pointer.

Aircraft with digital instrumentation make use of pressure-sensitive solid-state sensors that output digital signals for collection and processing by dedicated engine and airframe computers. Others may retain their analog sensors but may forward this information through an analog to digital converter unit from which the appropriate computer can obtain digital information to process and illuminate the digital display. Many more instruments utilize the synchro remote-indicating systems described in this section or similar synchros. Sometimes simple, more suitable, or less expensive technologies are also employed.

### Mechanical Movement Indicators

There are many instruments on an aircraft that indicate the mechanical motion of a component, or even the aircraft itself. Some utilize the synchro remote-sensing and indicating systems described above. Other means for capturing and displaying mechanical movement information are also used. This section discusses some unique mechanical motion indicators and groups instruments by function. All give valuable feedback to the pilot on the condition of the aircraft in flight.

#### Tachometers

The tachometer, or tach, is an instrument that indicates the speed of the crankshaft of a reciprocating engine. It can be a direct- or remote-indicating instrument, the dial of which is calibrated to indicate revolutions per minutes (rpm). On reciprocating engines, the tach is used to monitor engine power and to ensure the engine is operated within certified limits.

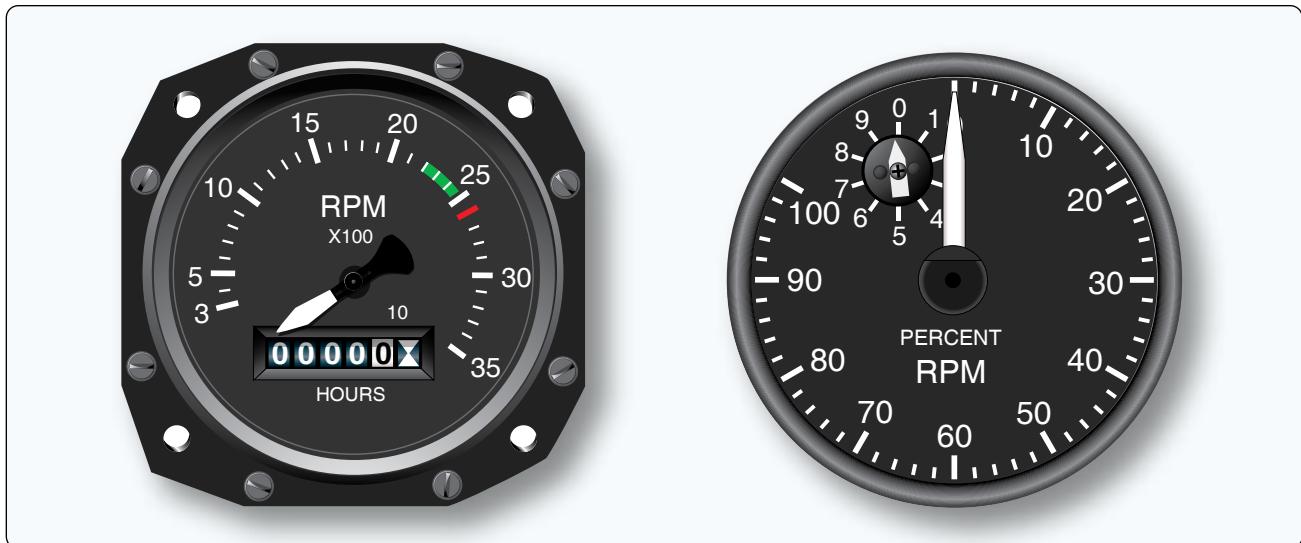
Gas turbine engines also have tachometers. They are used to monitor the speed(s) of the compressor section(s) of the engine. Turbine engine tachometers are calibrated in percentage of rpm with 100 percent corresponding to optimum turbine speed. This allows similar operating procedures despite the varied actual engine rpm of different engines. [Figure 10-52]

In addition to the engine tachometer, helicopters use a tachometer to indicator main rotor shaft rpm. It should also be noted that many reciprocating-engine tachometers also have built-in numeric drums that are geared to the rotational mechanism inside. These are hour meters that keep track of the time the engine is operated. There are two types of tachometer system in wide use today: mechanical and electrical.

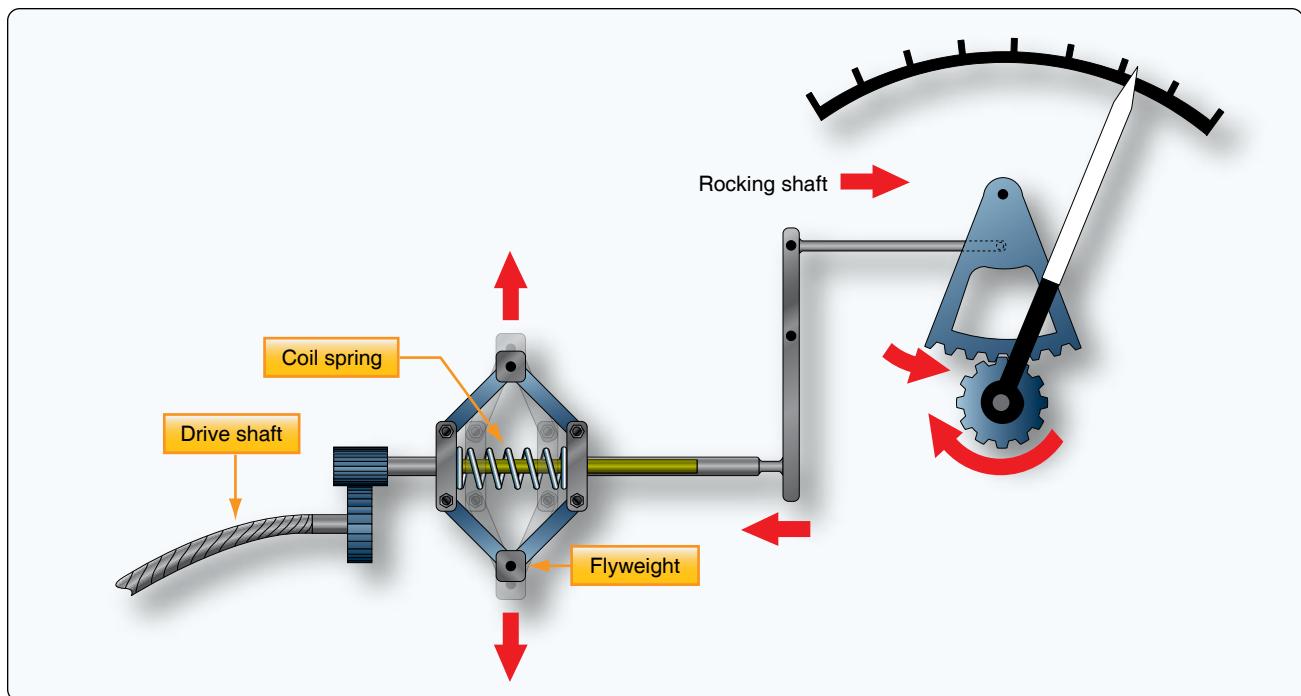
#### Mechanical Tachometers

Mechanical tachometer indicating systems are found on small, single-engine light aircraft in which a short distance exists between the engine and the instrument panel. They consist of an indicator connected to the engine by a flexible drive shaft. The drive shaft is geared into the engine so that when the engine turns, so does the shaft. The indicator contains a flyweight assembly coupled to a gear mechanism that drives a pointer. As the drive shaft rotates, centrifugal force acts on the flyweights and moves them to an angular position. This angular position varies with the rpm of the engine. The amount of movement of the flyweights is transmitted through the gear mechanism to the pointer. The pointer rotates to indicate this movement on the tachometer indicator, which is directly related to the rpm of the engine. [Figure 10-53]

A more common variation of this type of mechanical tachometer uses a magnetic drag cup to move the pointer in



**Figure 10-52.** A tachometer for a reciprocating engine is calibrated in rpm. A tachometer for a turbine engine is calculated in percent of rpm.



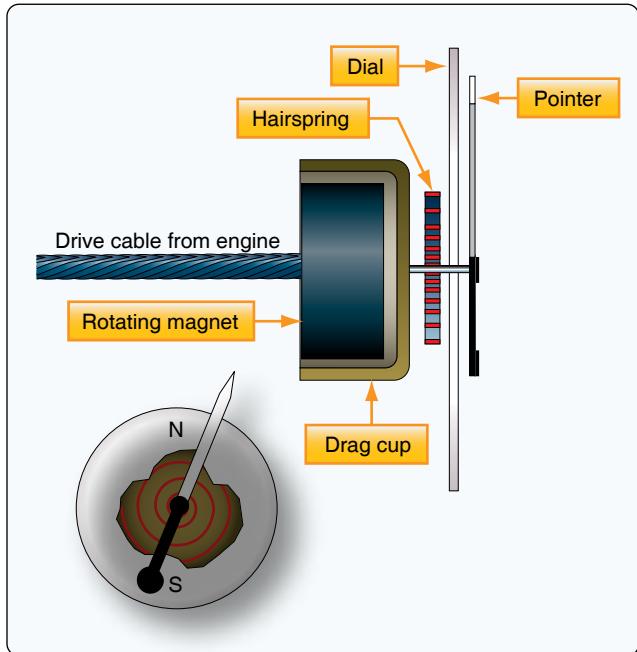
**Figure 10-53.** The simplified mechanism of a flyweight type mechanical tachometer.

the indicator. As the drive shaft turns, it rotates a permanent magnet in a close-tolerance aluminum cup. A shaft attached to the indicating point is attached to the exterior center of the cup. As the magnet is rotated by the engine flex drive cable, its magnetic field cuts through the conductor surrounding it, creating eddy currents in the aluminum cup. This current flow creates its own magnetic field, which interacts with the rotating magnet's flux field. The result is that the cup tends to rotate, and with it, the indicating pointer. A calibrated restraining spring limits the cup's rotation to the arc of motion of the pointer across the scale on the instrument face. [Figure 10-54]

### Electric Tachometers

It is not practical to use a mechanical linkage between the engine and the rpm indicator on aircraft with engines not mounted in the fuselage just forward of the instrument panel. Greater accuracy with lower maintenance is achieved through the use of electric tachometers. A wide variety of electric tachometer systems can be employed, so manufacturer's instructions should be consulted for details of each specific tachometer system.

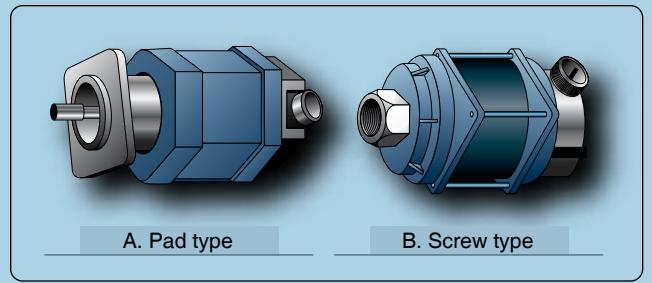
A popular electric tachometer system makes use of a small AC



**Figure 10-54.** A simplified magnetic drag cup tachometer indicating device.

generator mounted to a reciprocating engine's gear case or the accessory drive section of a turbine engine. As the engine turns, so does the generator. The frequency output of the generator is directly proportional to the speed of the engine. It is connected via wires to a synchronous motor in the indicator that mirrors this output. A drag cup, or drag disc link, is used to drive the indicator as in a mechanical tachometer. [Figure 10-55] Two different types of generator units, distinguished by their type of mounting system, are shown in Figure 10-56]

The dual tachometer consists of two tachometer indicator units housed in a single case. The indicator pointers show simultaneously, on one or two scales, the rpm of two engines. A dual tachometer on a helicopter often shows the rpm of

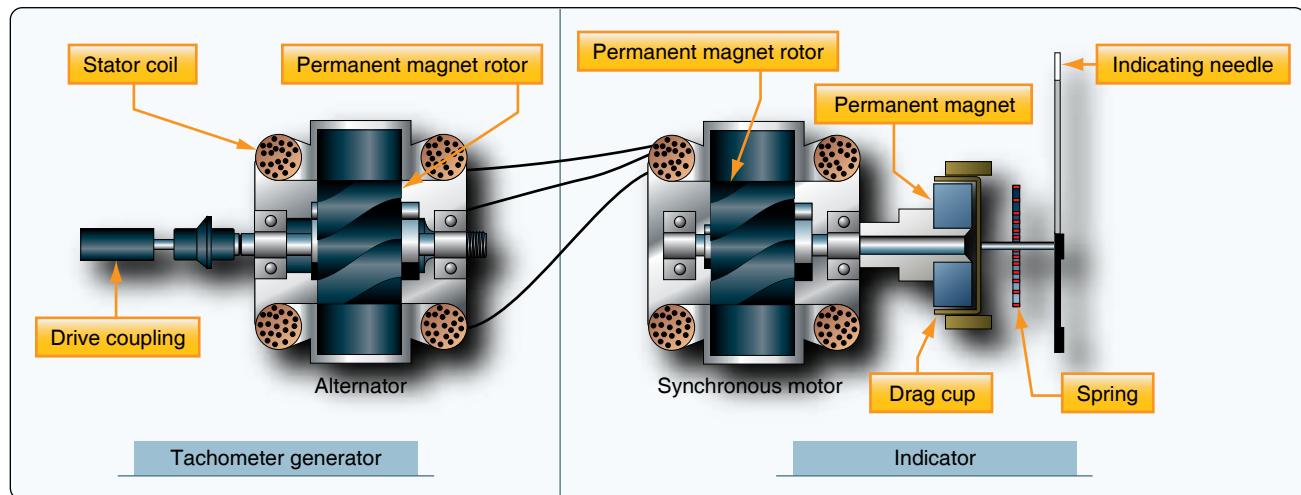


**Figure 10-56.** Different types of tach generators.

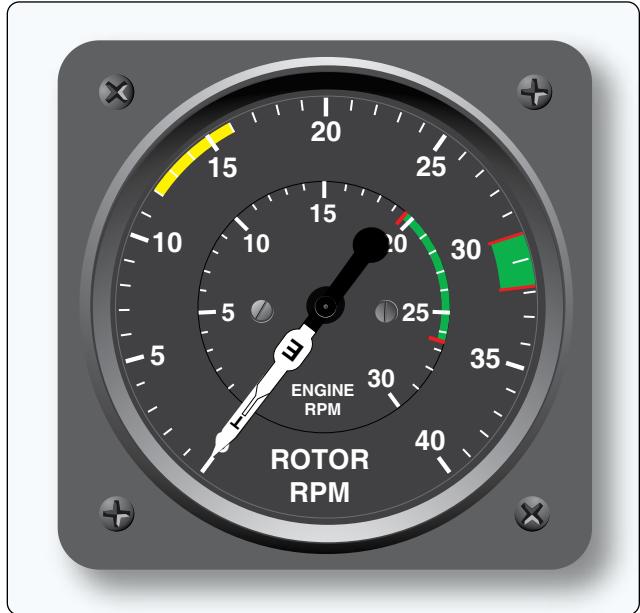
the engine and the rpm of the main rotor. A comparison of the voltages produced by the two tach generators of this type of helicopter indicator gives information concerning clutch slippage. A third indication showing this slippage is sometimes included in the helicopter tachometer. [Figure 10-57]

Some turbine engines use tachometer probes for rpm indication, rather than a tach generator system. They provide a great advantage in that there are no moving parts. The probes are sealed units that are mounted on a flange and protrude into the compressor section of the engine. A magnetic field is set up inside the probe that extends through pole pieces and out the end of the probe. A rotating gear wheel, which moves at the same speed as the engine compressor shaft, alters the magnetic field flux density as it moves past the pole pieces at close proximity. This generates voltage signals in coils inside the probe. The amplitude (voltage) of the signals vary directly with the speed of the engine.

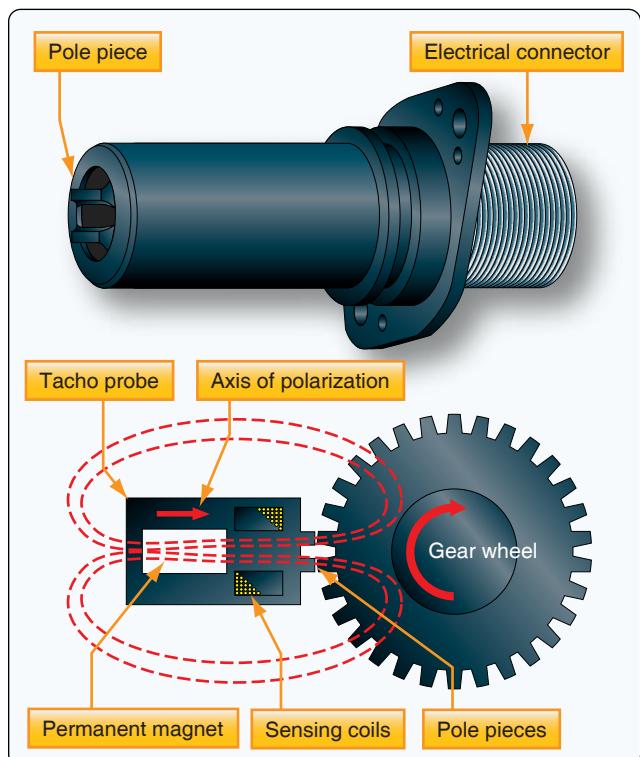
The tachometer probe's output signals need to be processed in a remotely located module. They must also be amplified to drive a servo motor type indicator in the flight deck. They may also be used as input for an autothrottle or flight data acquisition system. [Figure 10-58]



**Figure 10-55.** An electric tachometer system with synchronous motors and a drag cup indicator.



**Figure 10-57.** A helicopter tachometer with engine rpm, rotor rpm, and slippage indications.



**Figure 10-58.** A tacho probe has no moving parts. The rate of magnetic flux field density change is directly related to engine speed.

### Synchroscope

The synchroscope is an instrument that indicates whether two or more rotating devices, such as engines, are synchronized. Since synchrosopes compare rpm, they utilize the output from tachometer generators. The instrument consists of a small electric motor that receives electrical current from the

generators of both engines. Current from the faster running engine controls the direction in which the synchroscope motor rotates.

If both engines are operating at exactly the same speed, the synchroscope motor does not operate. If one engine operates faster than the other, its tach generator signal causes the synchroscope motor to turn in a given direction. Should the speed of the other engine then become greater than that of the first engine, the signal from its tach generator causes the synchroscope motor to reverse itself and turn in the opposite direction. The pilot makes adjustments to steady the pointer so it does not move.

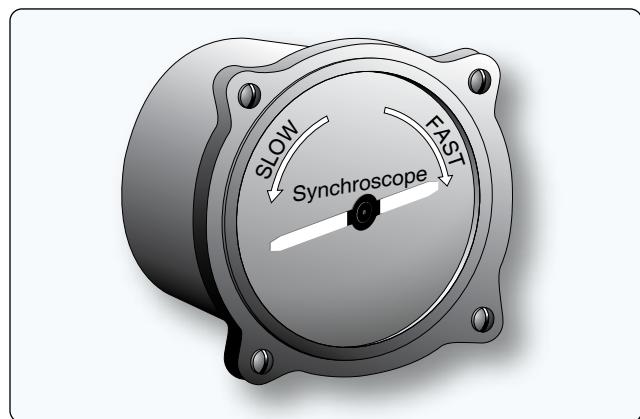
One use of synchroscope involve designating one of the engines as a master engine. The rpm of the other engine(s) is always compared to the rpm of this master engine. The dial face of the synchroscope indicator looks like *Figure 10-59*. “Slow” and “fast” represent the other engine’s rpm relative to the master engine, and the pilot makes adjustments accordingly.

### Accelerometers

An accelerometer is an instrument that measures acceleration. It is used to monitor the forces acting upon an airframe. Accelerometers are also used in inertial reference navigation systems. The installation of accelerometers is usually limited to high-performance and aerobatic aircraft.

Simple accelerometers are mechanical, direct-reading instruments calibrated to indicate force in Gs. One G is equal to one times the force of gravity. The dial face of an accelerometer is scaled to show positive and negative forces. When an aircraft initiates a rapid climb, positive G force tends to push one back into one’s seat. Initiating a rapid decent causes a force in the opposite direction, resulting in a negative G force.

Most accelerometers have three pointers. One is continuously



**Figure 10-59.** This synchroscope indicates the relative speed of the slave engine to the master.