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Aviation Maintenance Technician Handbook–Airframe, Volume 2

U.S. Department of Transportation
Federal Aviation Administration

Bearing Handling and Lubrication

Handling of bearings is of the utmost importance. Contamination, moisture, and vibration, even while the bearing is in a static state, can ruin a bearing. Avoid conditions where these may affect bearings and be sure to install and torque bearings into place according manufacturer's instructions.

Proper lubrication is a partial deterrent to negative environmental impacts on a bearing. Use the lubricant recommended by the manufacturer. Use of a pressure bearing packing tool or adapter is also recommended as the best method to remove any contaminants from inside the bearing that may have remained after cleaning. *[Figure 13-73]*

Inspection of the Wheel Halves

A thorough visual inspection of each wheel half should be conducted for discrepancies specified in the wheel manufacturer's maintenance data. Use of a magnifying glass is recommended. Corrosion is one of the most common problems encountered while inspecting wheels. Locations where moisture is trapped should be checked closely. It is possible to dress out some corrosion according to the manufacturer's instructions. An approved protective surface treatment and finish must be applied before returning the wheel to service. Corrosion beyond stated limits is cause for rejection of the wheel.

In addition to corrosion, cracks in certain areas of the wheel are particularly prevalent. One such area is the bead seat area. *[Figure 13-74]* The high stress of landing is transferred to the wheel by the tire in this contact area. Hard landings produce distortion or cracks that are very difficult to detect. This is a concern on all wheels and is most problematic in high-pressure, forged wheels. Dye penetrant inspection is generally ineffective when checking for cracks in the bead area. There is a tendency for cracks to close up tightly once the tire is dismounted, and the stress is removed from the metal. Eddy current inspection of the bead seat area is required. Follow the wheel manufacturer's instruction when performing the eddy current check.

The wheel brake disc drive key area is another area in which cracks are common. The forces experienced when the keys drive the disc against the stopping force of the brakes are high. Generally, a dye penetrant test is sufficient to reveal cracks in this area. All drive keys should be secure with no movement possible. No corrosion is permitted in this area. *[Figure 13-75]*

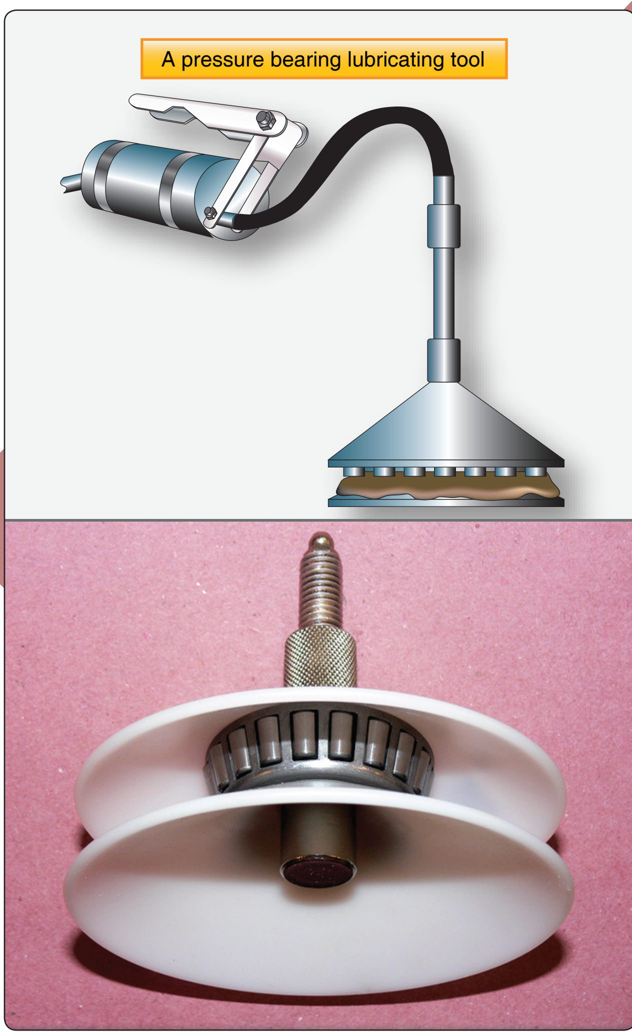


Figure 13-73. *A pressure bearing lubricating tool.*

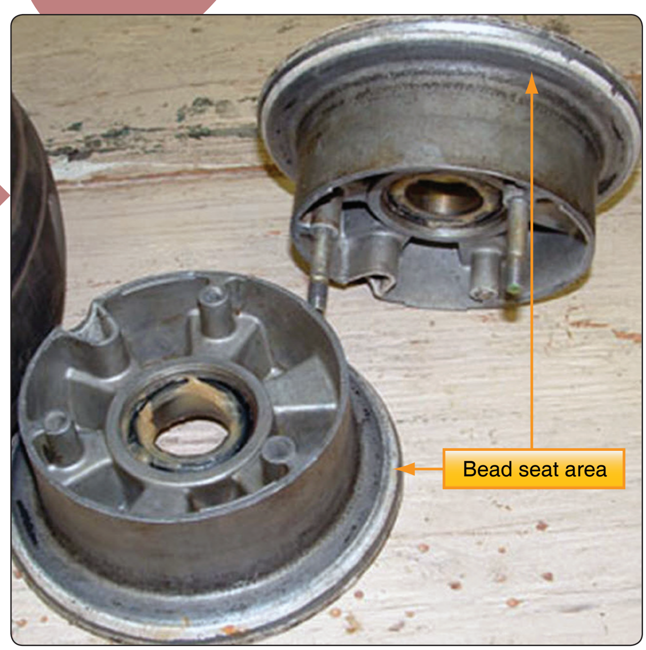


Figure 13-74. *The bead seat areas of a light aircraft wheel set. Eddy current testing for cracks in the bead seat area is common.*

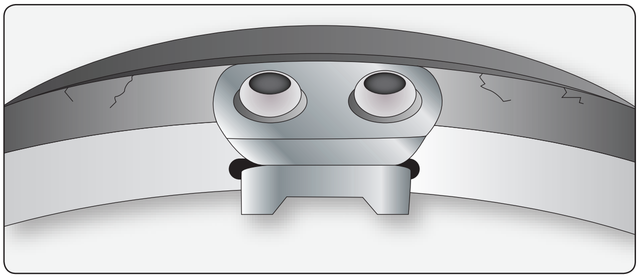


Figure 13-75. *Inspection for cracks in the wheel disc drive key area is performed with dye penetrant on many wheels.*

Wheel Tie Bolt Inspection

Wheel half tie bolts are under great stress while in service and require inspection. The tie bolts stretch and change dimension usually at the threads and under the bolt head. These are areas where cracks are most common. Magnetic particle inspection can reveal these cracks. Follow the maintenance manual procedures for inspecting tie bolts.

Key and Key Screw Inspection

On most aircraft inner wheel halves, keys are screwed or bolted to the wheel to drive the brake disc(s). The drive keys are subject to extreme forces when the brakes are applied. As mentioned, there should be no movement between the wheel and the keys. The bolts should be checked for security, and the area around the keys should be inspected for cracks. There is also a limitation on how worn the keys can be since too much wear allows excessive movement. The wheel manufacturer's maintenance instructions should be used to perform a complete inspection of this critical area.

Fusible Plug Inspection

Fusible plugs or thermal plugs must be inspected visually. These threaded plugs have a core that melts at a lower temperature than the outer part of the plug. This is to release air from the tire should the temperature rise to a dangerous level. A close inspection should reveal whether any core has experienced deformation that might be due to high temperature. If detected, all thermal plugs in the wheel should be replaced with new plugs. *[Figure 13-76]*

Balance Weights

The balance of an aircraft wheel assembly is important. When manufactured, each wheel set is statically balanced. Weights are added to accomplish this if needed. They are a permanent part of the wheel assembly and must be installed to use the wheel. The balance weights are bolted to the wheel halves and can be removed when cleaning and inspecting the wheel. They must be re-fastened in their original position. When a tire is mounted to a wheel, balancing of the wheel and tire assembly may require that additional weights be added. These are usually installed around the circumference of the outside of the wheel and should not be taken as substitutes for the factory wheel set balance weights. *[Figure 13-77]*

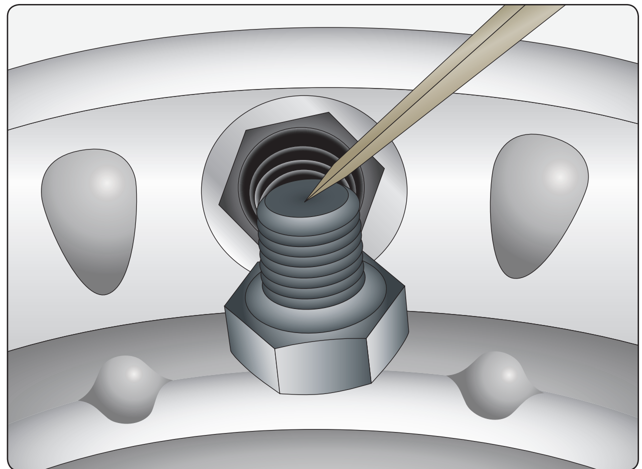


Figure 13-76. *Visually inspect the core of a thermal or fusible plug for deformation associated with heat exposure. Replace all of the plugs if any appear to have begun to deform.*

Aircraft Brakes

Very early aircraft have no brake system to slow and stop the aircraft while it is on the ground. Instead, they rely on slow speeds, soft airfield surfaces, and the friction developed by the tail skid to reduce speed during ground operation. Brake systems designed for aircraft became common after World War I as the speed and complexity of aircraft increased, and the use of smooth, paved runway surfaces proliferated. All modern aircraft are equipped with brakes. Their proper functioning is relied upon for safe operation of the aircraft on the ground. The brakes slow the aircraft and stop it in a reasonable amount of time. They hold the aircraft stationary

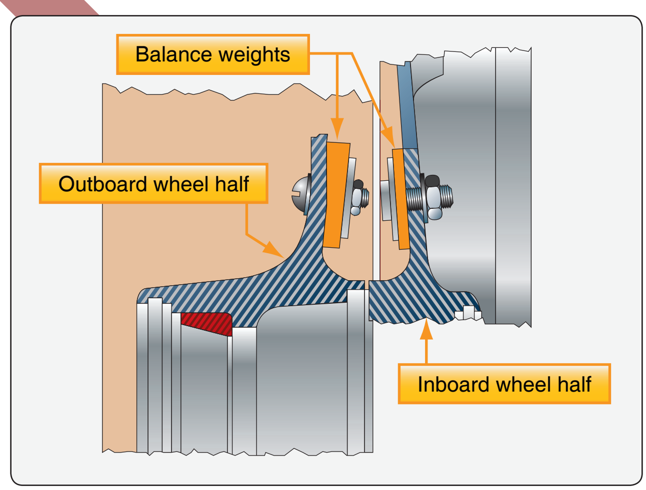


Figure 13-77. *Two piece aircraft wheels are statically balanced when manufactured and may include weights attached to each wheel half that must stay with the wheel during its entire serviceable life.*

during engine run-up and, in many cases, steer the aircraft during taxi. On most aircraft, each of the main wheels is equipped with a brake unit. The nose wheel or tail wheel does not have a brake.

In the typical brake system, mechanical and/or hydraulic linkages to the rudder pedals allow the pilot to control the brakes. Pushing on the top of the right rudder pedal activates the brake on the right main wheel(s) and pushing on the top of the left rudder pedal operates the brake on the left main wheel(s). The basic operation of brakes involves converting the kinetic energy of motion into heat energy through the creation of friction. A great amount of heat is developed and forces on the brake system components are demanding. Proper adjustment, inspection, and maintenance of the brakes is essential for effective operation.

Types and Construction of Aircraft Brakes

Modern aircraft typically use disc brakes. The disc rotates with the turning wheel assembly while a stationary caliper resists the rotation by causing friction against the disc when the brakes are applied. The size, weight, and landing speed of the aircraft influence the design and complexity of the disc brake system. Single, dual, and multiple disc brakes are common types of brakes. Segmented rotor brakes are used on large aircraft. Expander tube brakes are found on older large aircraft. The use of carbon discs is increasing in the modern aviation fleet.

Single Disc Brakes

Small, light aircraft typically achieve effective braking using a single disc keyed or bolted to each wheel. As the wheel turns, so does the disc. Braking is accomplished by applying friction to both sides of the disc from a non-rotating caliper bolted to the landing gear axle flange. Pistons in the caliper housing under hydraulic pressure force wearable brake pads or linings against the disc when the brakes are applied. Hydraulic master cylinders connected to the rudder pedals supply the pressure when the upper halves of the rudder pedals are pressed.

Floating Disc Brakes

A floating disk brake is illustrated in *Figure 13-78*. A more detailed, exploded view of this type of brake is shown in *Figure 13-79*. The caliper straddles the disc. It has three cylinders bored through the housing, but on other brakes this number may vary. Each cylinder accepts an actuating piston assembly comprised mainly of a piston, a return spring, and an automatic adjusting pin. Each brake assembly has six brake linings or pucks. Three are located on the ends of the pistons, which are in the outboard side of the caliper. They are designed to move in and out with the pistons and apply pressure to the outboard side of the disc. Three more linings

Figure 13-78. *A single disc brake is a floating-disc, fixed caliper brake.*

are located opposite of these pucks on the inboard side of the caliper. These linings are stationary.

The brake disc is keyed to the wheel. It is free to move laterally in the key slots. This is known as a floating disk. When the brakes are applied, the pistons move out from the outboard cylinders and their pucks contact the disc. The disc slides slightly in the key slots until the inboard stationary pucks also contact the disc. The result is a fairly even amount of friction applied to each side of the disc and thus, the rotating motion is slowed.

When brake pressure is released, the return spring in each piston assembly forces the piston back away from the disc. The spring provides a preset clearance between each puck and the disc. The self-adjusting feature of the brake maintains the same clearance, regardless of the amount of wear on the brake pucks. The adjusting pin on the back of each piston moves with the piston through a frictional pin grip. When brake pressure is relieved, the force of the return spring is sufficient to move the piston back away from the brake disc, but not enough to move the adjusting pin held by the friction of the pin grip. The piston stops when it contacts the head of the adjusting pin. Thus, regardless of the amount of wear, the same travel of the piston is required to apply the brake. The stem of the pin protruding through the cylinder head serves as a wear indicator. The manufacturer's maintenance information states the minimum length of the pin that needs to be protruding for the brakes to be considered airworthy. *[Figure 13-80]*

The brake caliper has the necessary passages machined into it to facilitate hydraulic fluid movement and the application of pressure when the brakes are utilized. The caliper housing also contains a bleed port used by the technician to remove

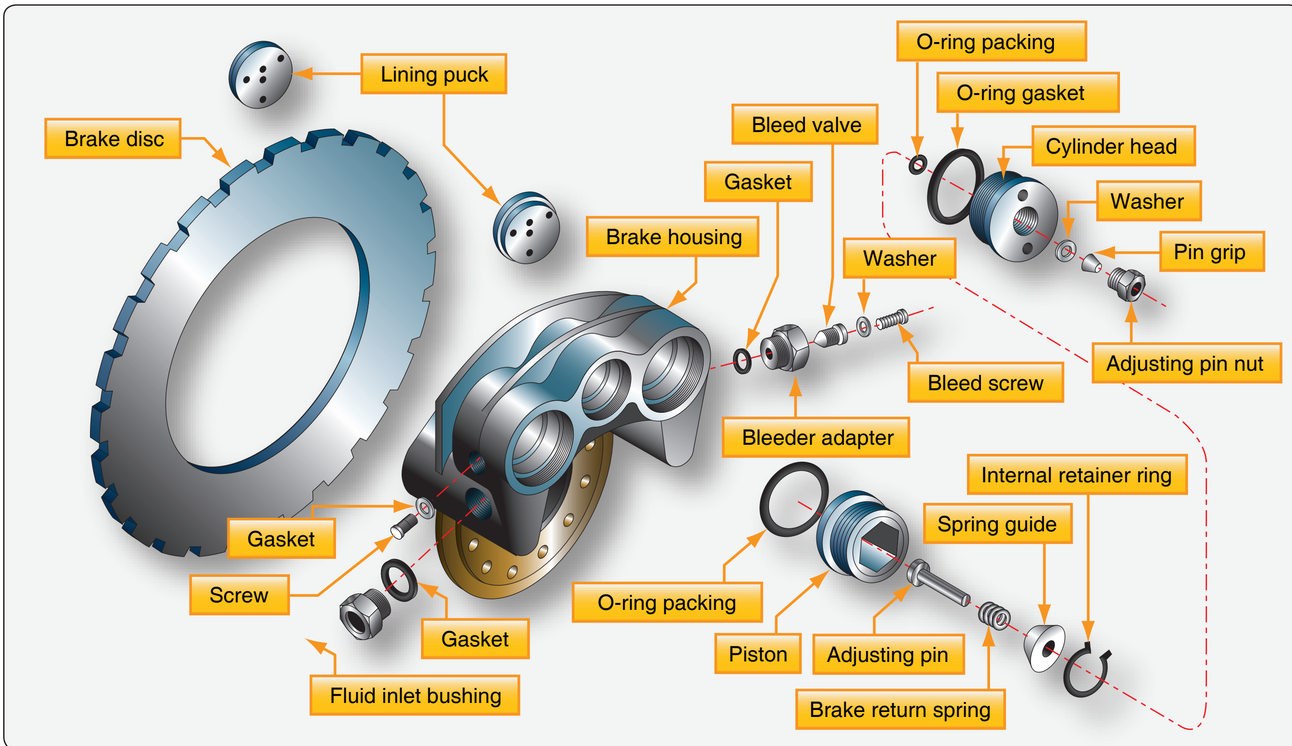


Figure 13-79. *An exploded view of a single-disc brake assembly found on a light aircraft.*

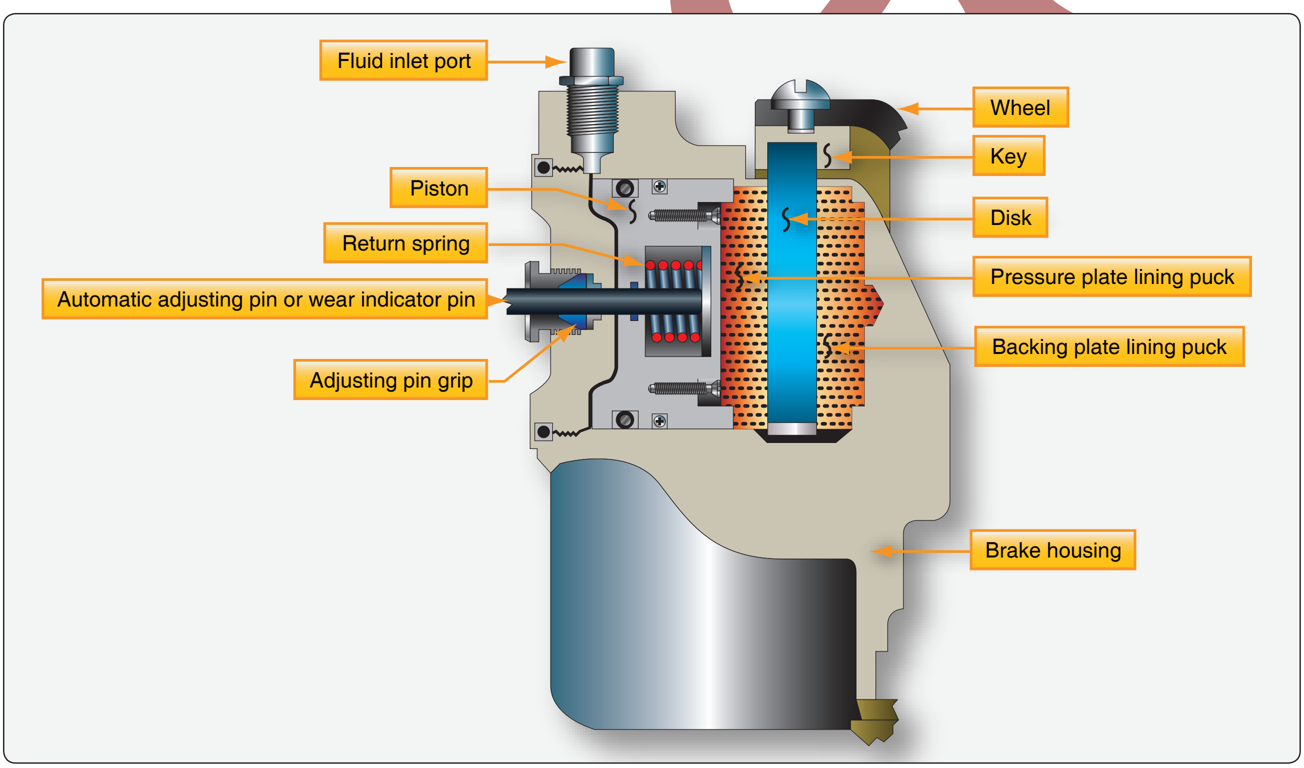


Figure 13-80. *A cross-sectional view of a Goodyear single-disc brake caliper illustrates the adjusting pin assembly that doubles as a wear indicator.*

unwanted air from the system. Brake bleeding, as it is known, should be done in accordance with the manufacturer's maintenance instructions.

Fixed-Disc Brakes

Even pressure must be applied to both sides of the brake disc to generate the required friction and obtain consistent wear properties from the brake linings. The floating disc accomplishes this as described above. It can also be accomplished by bolting the disc rigidly to the wheel and allowing the brake caliper and linings to float laterally when pressure is applied. This is the design of a common fixed-disc brake used on light aircraft. The brake is manufactured by the Cleveland Brake Company and is shown in *Figure 13-81*. An exploded detail view of the same type of brake is shown in *Figure 13-82*.

The fixed-disk, floating-caliper design allows the brake caliper and linings to adjust position in relationship to the disc. Linings are riveted to the pressure plate and backplate. Two anchor bolts that pass through the pressure plate are secured to the cylinder assembly. The other ends of the bolts are free to slide

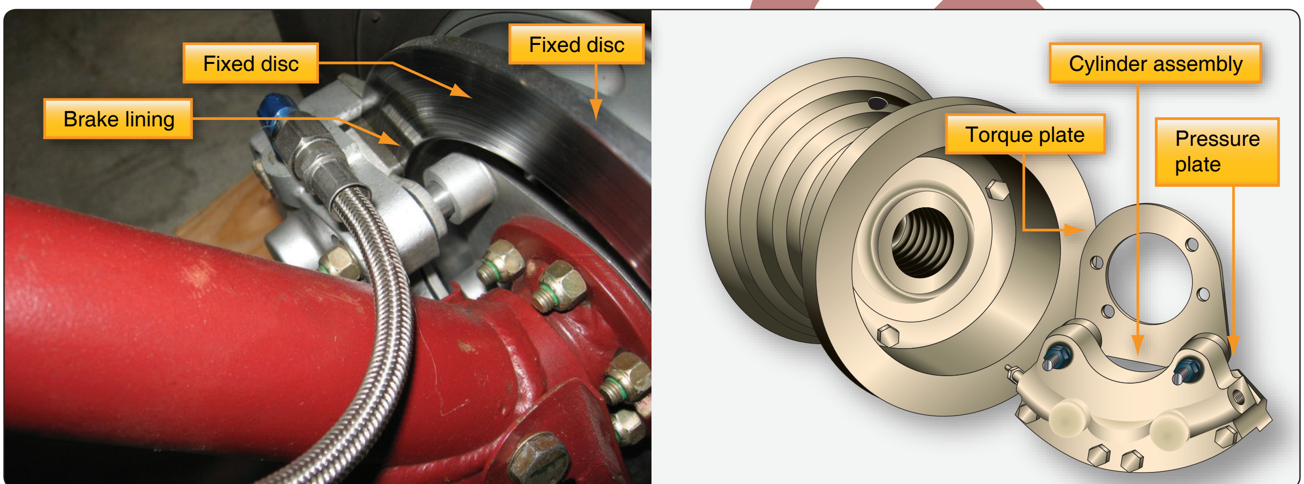


Figure 13-81. *A Cleveland brake on a light aircraft is a fixed-disc brake. It allows the brake caliper to move laterally on anchor bolts to deliver even pressure to each side of the brake disc.*

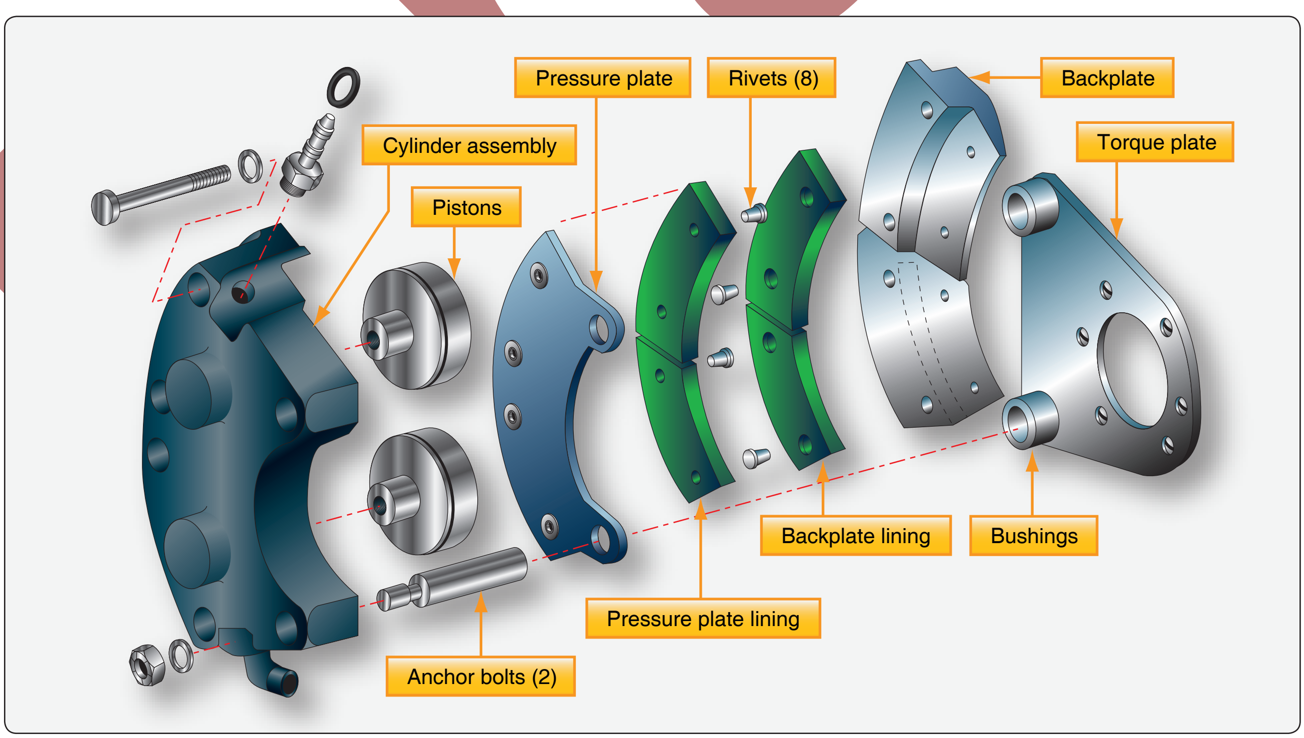


Figure 13-82. *An exploded view of a dual-piston Cleveland brake assembly.*

in and out of bushings in the torque plate, which is bolted to the axle flange. The cylinder assembly is bolted to the backplate to secure the assembly around the disc. When pressure is applied, the caliper and linings center on the disc via the sliding action of the anchor bolts in the torque plate bushings. This provides equal pressure to both sides of the disc to slow its rotation.

A unique feature of the Cleveland brake is that the linings can be replaced without removing the wheel. Unbolting the cylinder assembly from the backplate allows the anchor bolts to slide out of the torque plate bushings. The entire caliper assembly is then free and provides access to all of the components.

Maintenance requirements on all single disc brake systems are similar to those on brake systems of any type. Regular inspection for any damage and for wear on the linings and discs is required. Replacement of parts worn beyond limits is always followed by an operational check. The check is performed while taxiing the aircraft. The braking action for each main wheel should be equal with equal application of pedal pressure. Pedals should be firm, not soft or spongy, when applied. When pedal pressure is released, the brakes should release without any evidence of drag.

Dual-Disc Brakes

Dual-disc brakes are used on aircraft where a single disc on each wheel does not supply sufficient braking friction. Two discs are keyed to the wheel instead of one. A center carrier is located between the two discs. It contains linings on each side that contact each of the discs when the brakes are applied. The caliper mounting bolts are long and mount through the center carrier, as well as the backplate which bolts to the housing assembly. *[Figure 13-83]*

Multiple-Disc Brakes

Large, heavy aircraft require the use of multiple-disc brakes. Multiple-disc brakes are heavy duty brakes designed for use with power brake control valves or power boost master cylinders, which is discussed later in this chapter. The brake assembly consists of an extended bearing carrier similar to a torque tube type unit that bolts to the axle flange. It supports the various brake parts, including an annular cylinder and piston, a series of steel discs alternating with copper or bronze-plated discs, a backplate, and a backplate retainer. The steel stators are keyed to the bearing carrier, and the copper or bronze plated rotors are keyed to the rotating wheel. Hydraulic pressure applied to the piston causes the entire stack of stators and rotors to be compressed. This creates enormous friction and heat and slows the rotation of the wheel. *[Figure 13-84]*

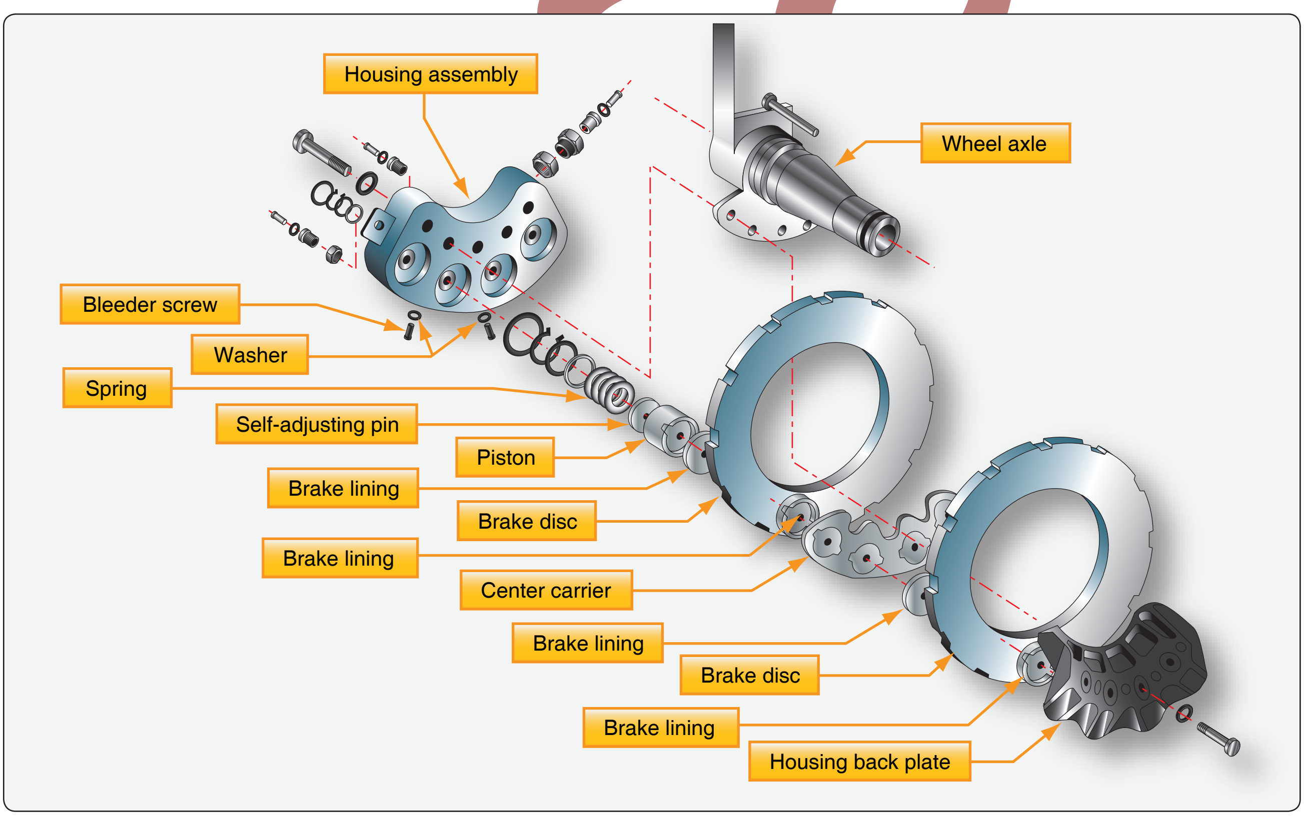


Figure 13-83. *A dual-disc brake is similar to a single-disc brake. It uses a center carrier to hold brake linings against each of the discs.*

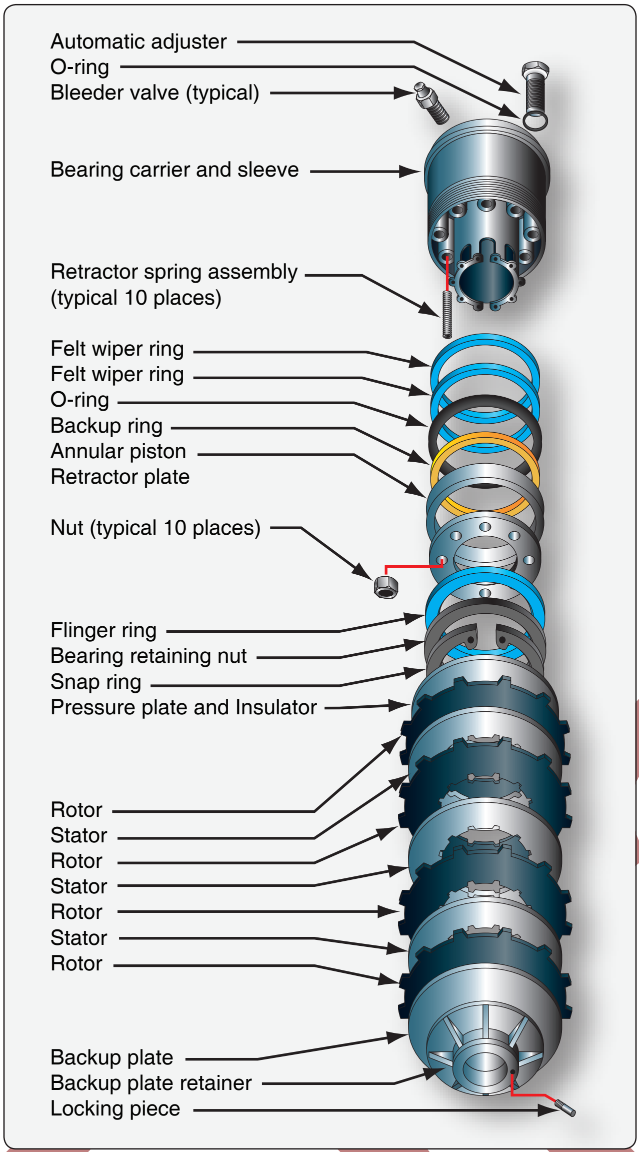


Figure 13-84. *A multiple disc brake with bearing carrier upon which the parts of the brake are assembled including an annular cylinder and piston assembly that apply pressure evenly to a stack of rotors and stators.*

As with the single and dual-disc brakes, retracting springs return the piston into the housing chamber of the bearing carrier when hydraulic pressure is relieved. The hydraulic fluid exits the brake to the return line through an automatic adjuster. The adjuster traps a predetermined amount of fluid in the brakes that is just sufficient to provide the correct clearances between the rotors and stators. *[Figure 13-85]* Brake wear is typically measured with a wear gauge that is not part of the brake assembly. These types of brake are typically found on older transport category aircraft. The rotors and stators are relatively thin, only about ⅛-inch thick. They do not dissipate heat very well and have a tendency to warp.

Segmented Rotor-Disc Brakes

The large amount of heat generated while slowing the rotation of the wheels on large and high-performance aircraft is problematic. To better dissipate this heat, segmented rotor-disc brakes have been developed. Segmented rotor-disc brakes are multiple-disc brakes but of more modern design than the type discussed earlier. There are many variations. Most feature numerous elements that aid in the control and dissipation of heat. Segmented rotor-disc brakes are heavy-duty brakes especially adapted for use with the high pressure hydraulic systems of power brake systems. Braking is accomplished by means of several sets of stationary, high friction type brake linings that make contact with rotating segments. The rotors are constructed with slots or in sections with space between them, which helps dissipate heat and give the brake its name. Segmented rotor multiple-disc brakes are the standard brake used on high performance and air carrier aircraft. An exploded view of one type of segmented rotor brake assembly is shown in *Figure 13-86*.

The description of a segmented rotor brake is very similar to the multiple-disc type brake previously described. The brake assembly consists of a carrier, a piston and piston cup seal, a pressure plate, an auxiliary stator plate, rotor segments, stator plates, automatic adjusters, and a backing plate.

The carrier assembly, or brake housing with torque tube, is the basic unit of the segmented rotor brake. It is the part that attaches to the landing gear shock strut flange upon which the other components of the brake are assembled. On some brakes, two grooves or cylinders are machined into the carrier to receive the piston cups and pistons. *[Figure 13-86]* Most segmented rotor-disc brakes have numerous individual cylinders machined into the brake housing into which fit the same number of actuating pistons. Often, these cylinders are supplied by two different hydraulic sources, alternating every other cylinder from a single source. If one source fails, the brake still operates sufficiently on the other. *[Figure 13-87]* External fittings in the carrier or brake housing admit the hydraulic fluid. A bleed port can also be found.

A pressure plate is a flat, circular, high-strength steel, non-rotating plate notched on the inside circumference to fit over the stator drive sleeves or torque tube spines. The brake actuating pistons contact the pressure plate. Typically, an insulator is used between the piston head and the pressure plate to impede heat conduction from the brake discs. The pressure plate transfers the motion of the pistons to the stack of rotors and stators that compress to slow the rotation of the wheels. On most designs, brake lining material attached directly to the pressure plate contacts the first rotor in the stack to transfer the motion of the piston(s). *[Figure 13-86]* An

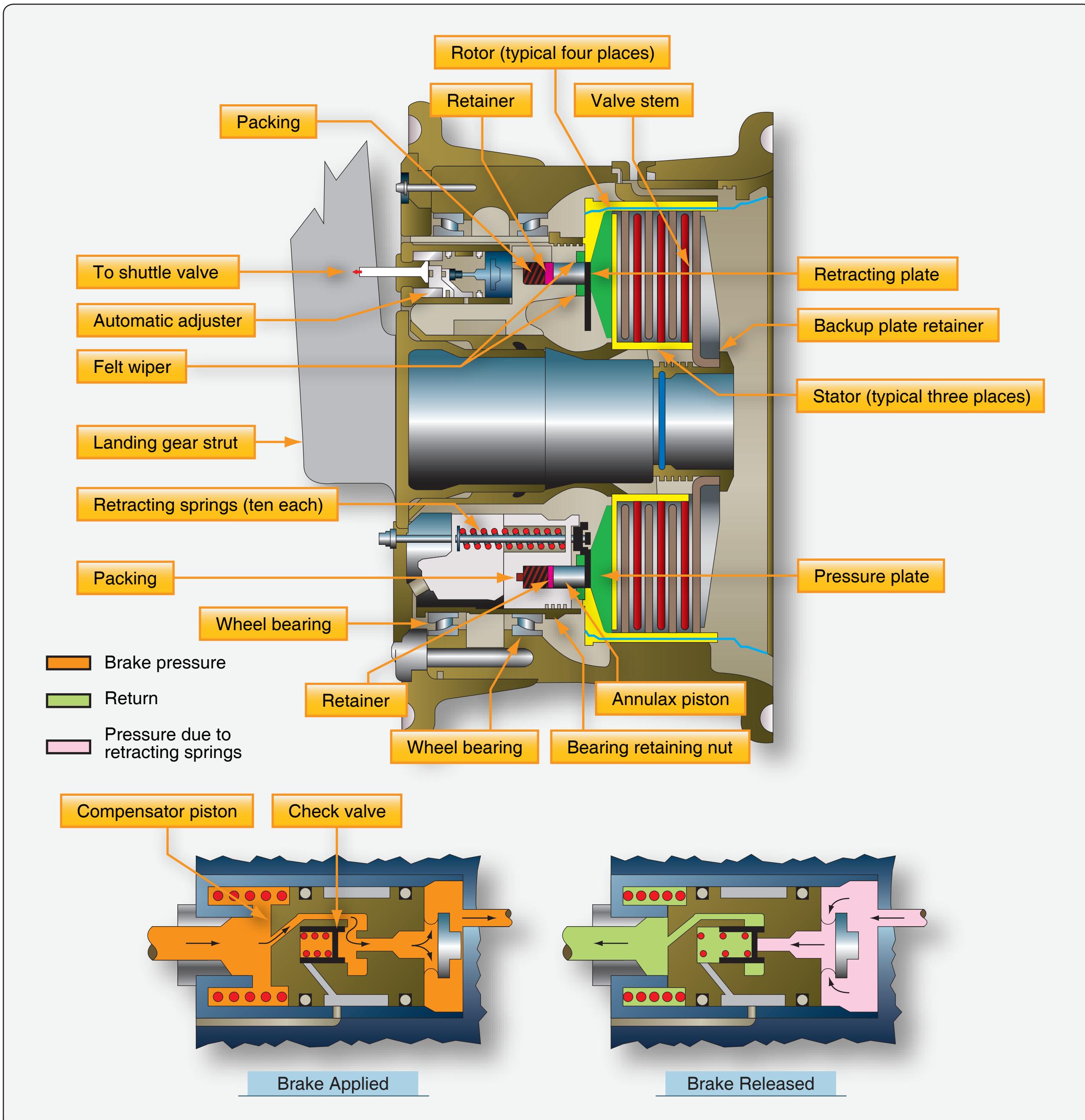


Figure 13-85. *A multiple-disc brake with details of the automatic adjuster.*

auxiliary stator plate with brake lining material on the side opposite the pressure plate can also be used.

Any number of alternating rotors and stators are sandwiched under hydraulic pressure against the backing plate of the brake assembly when the brakes are applied. The backing plate is a heavy steel plate bolted to the housing or torque tube at a fixed dimension from the carrier housing. In most cases, it has brake lining material attached to it and contacts the last rotor in the stack. *[Figure 13-86]*

Stators are flat plates notched on the internal circumference to be held stationary by the torque tube spines. They have wearable brake lining material riveted or adhered to each side to make contact with adjacent rotors. The liner is typically constructed of numerous isolated blocks. *[Figure 13-86]* The space between the liner blocks aids in the dissipation of heat. The composition of the lining materials vary. Steel is often used.

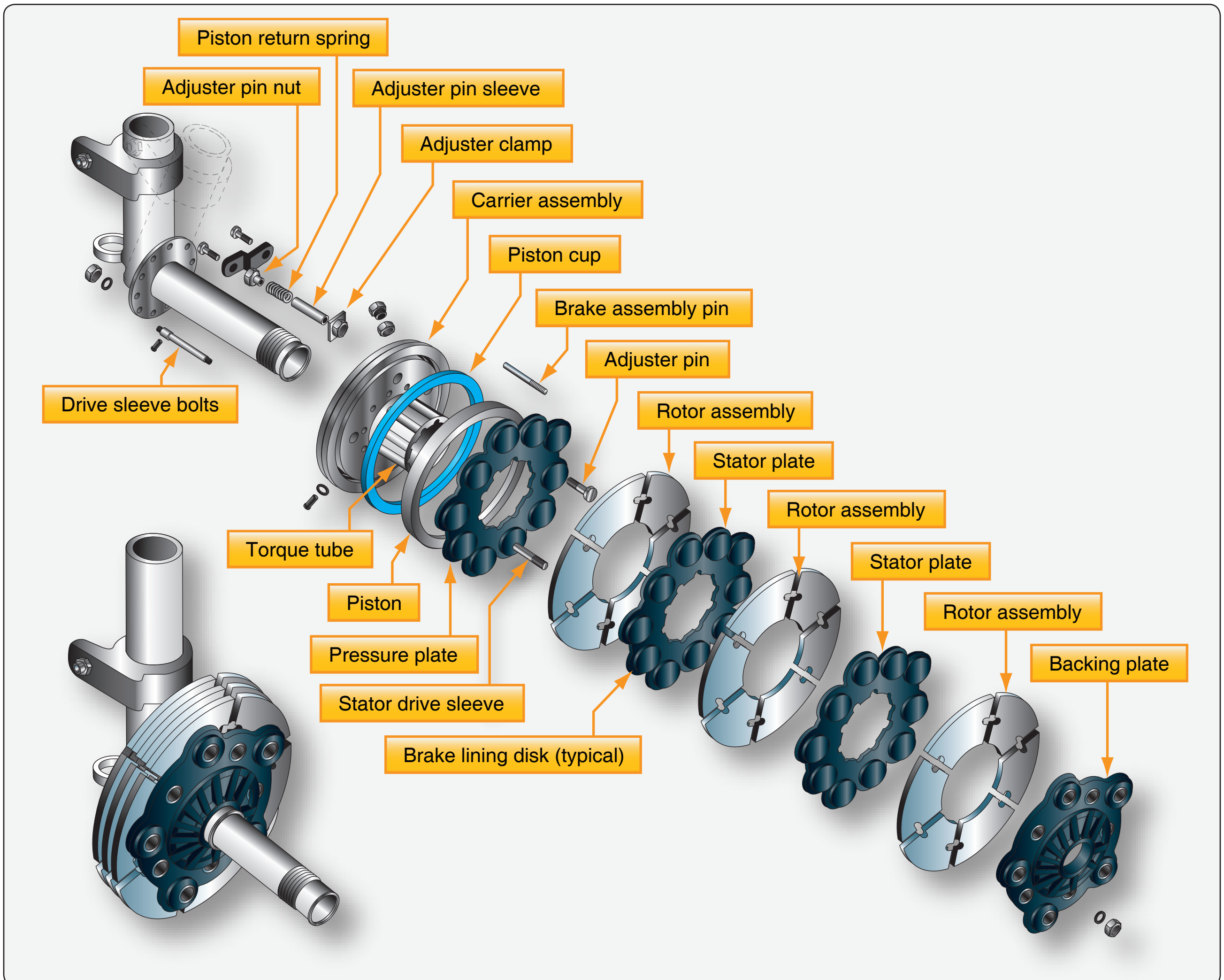


Figure 13-86. *Exploded and detail views of segmented rotor brakes.*

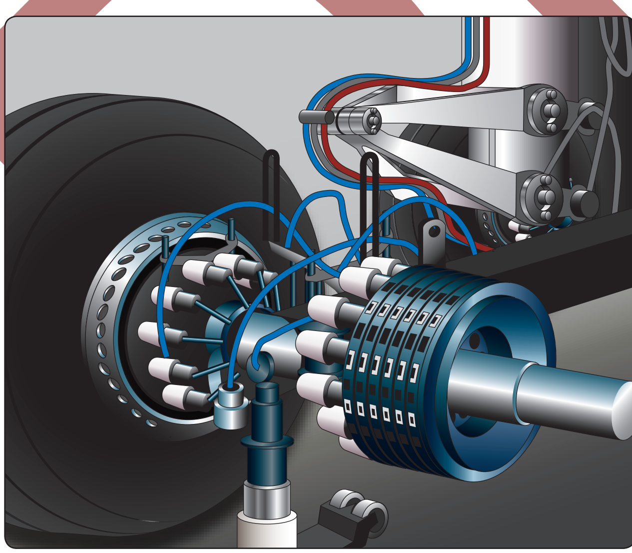


Figure 13-87. *Many modern segmented rotor disc brakes use a housing machined to fit numerous individual actuating pistons.*

Rotors are slit or segmented discs that have notches or tangs in the external circumference that key to the rotating wheel. Slots or spaces between sections of the rotor create segments that allow heat to dissipate faster than it would if the rotor was solid. They also allow for expansion and prevent warping. *[Figure 13- 86]* Rotors are usually steel to which a frictional surface is bonded to both sides. Typically, sintered metal is used in creating the rotor contact surface.

Segmented multiple-disc brakes use retraction spring assemblies with auto clearance adjusters to pull the backplate away from the rotor and stator stack when brake pressure is removed. This provides clearance so the wheel can turn unimpeded by contact friction between the brake parts but keeps the units in close proximity for rapid contact and braking when the brakes are applied. The number of retraction devices varies with brake design. *Figure 13-88* illustrates a brake assembly used on a Boeing 737 transport category aircraft. In the cutaway view, the number and locations of the

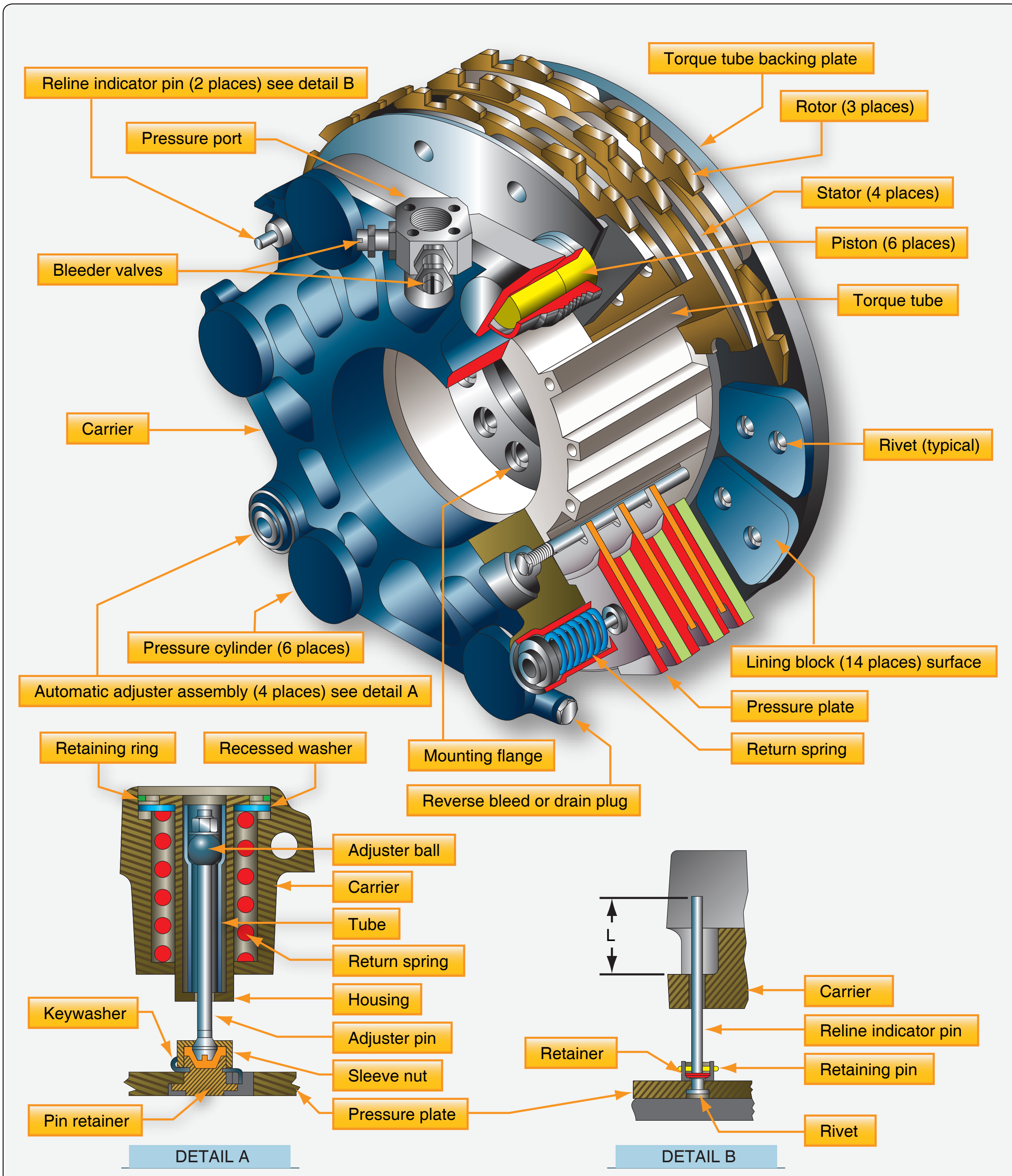


Figure 13-88. *The multiple-disk brake assembly and details from a Boeing 737.*

auto adjustment retraction mechanisms can be seen. Details of the mechanisms are also shown.

Instead of using a pin grip assembly for auto adjustment, an adjuster pin, ball, and tube operate in the same manner. They move out when brake pressure is applied, but the ball in the tube limits the amount of the return to that equal to the brake lining wear. Two independent wear indicators are used on the brake illustrated. An indicator pin attached to the backplate protrudes through the carrier. The amount that it protrudes with the brakes applied is measured to ascertain if new linings are required.

NOTE: Other segmented multiple-disc brakes may use slightly different techniques for pressure plate retraction and wear indication. Consult the manufacturer's maintenance information to ensure wear indicators are read correctly.

Carbon Brakes

The segmented multiple-disc brake has given many years of reliable service to the aviation industry. It has evolved through time in an effort to make it lightweight and to dissipate the frictional heat of braking in a quick, safe manner. The latest iteration of the multiple-disc brake is the carbon-disc brake. It is currently found on high performance and air carrier aircraft. Carbon brakes are so named because carbon fiber materials are used to construct the brake rotors. *[Figure 13-89]*

Carbon brakes are approximately forty percent lighter than conventional brakes. On a large transport category aircraft, this alone can save several hundred pounds in aircraft weight. The carbon fiber discs are noticeably thicker than sintered steel rotors but are extremely light. They are able to withstand temperatures fifty percent higher than steel component brakes. The maximum designed operating temperature is limited by the ability of adjacent components to withstand the high temperature. Carbon brakes have been shown to withstand two to three times the heat of a steel brake in non-aircraft applications. Carbon rotors also dissipate heat faster than steel rotors. A carbon rotor maintains its strength and dimensions at high temperatures. Moreover, carbon brakes last twenty to fifty percent longer than steel brakes, which results in reduced maintenance.

The only impediment to carbon brakes being used on all aircraft is the high cost of manufacturing. The price is expected to lower as technology improves and greater numbers of aircraft operators enter the market.

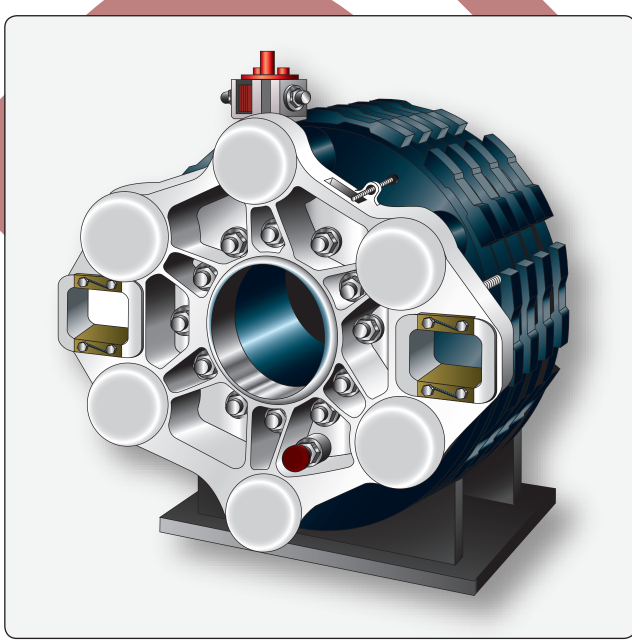


Figure 13-89. *A carbon brake for a Boeing 737.*

Expander Tube Brakes

An expander tube brake is a different approach to braking that is used on aircraft of all sizes produced in the 1930s–1950s. It is a lightweight, low pressure brake bolted to the axle flange that fits inside an iron brake drum. A flat, fabric-reinforced neoprene tube is fitted around the circumference of a wheel-like torque flange. The exposed flat surface of the expander tube is lined with brake blocks similar to brake lining material. Two flat frames bolt to the sides of the torque flange. Tabs on the frames contain the tube and allow evenly spaced torque bars to be bolted in place across the tube between each brake block. These prevent circumferential movement of the tube on the flange. *[Figure 13-90]*

The expander tube is fitted with a metal nozzle on the inner surface. Hydraulic fluid under pressure is directed through this fitting into the inside of the tube when the brakes are

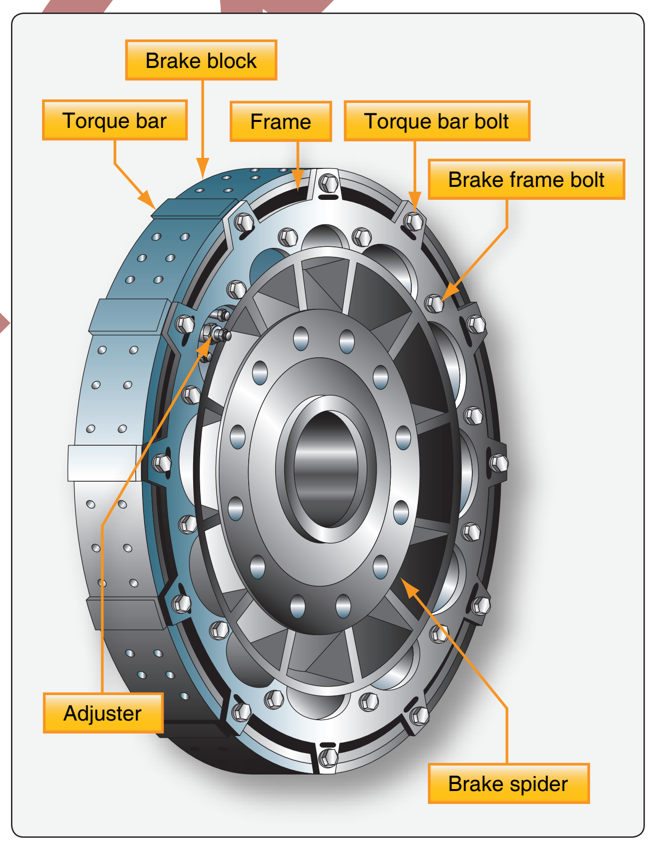


Figure 13-90. *An expander tube brake assembly.*

applied. The tube expands outward, and the brake blocks make contact with the wheel drum causing friction that slows the wheel. As hydraulic pressure is increased, greater friction develops. Semi-elliptical springs located under the torque bars return the expander tube to a flat position around the flange when hydraulic pressure is removed. The clearance between the expander tube and the brake drum is adjustable by rotating an adjuster on some expander tube brakes. Consult the manufacturer's maintenance manual for the correct clearance setting. *Figure 13-91* gives an exploded view of an expander tube brake, detailing its components.

Expander tube brakes work well but have some drawbacks. They tend to take a setback when cold. They also have a tendency to swell with temperature and leak. They may drag inside the drum if this occurs. Eventually, expander brakes were abandoned in favor of disc brake systems.

Brake Actuating Systems

The various brake assemblies, described in the previous section, all use hydraulic power to operate. Different means of delivering the required hydraulic fluid pressure to brake assemblies are discussed in this section. There are three basic actuating systems:

1. An independent system not part of the aircraft main hydraulic system;
2. A booster system that uses the aircraft hydraulic system intermittently when needed; and
3. A power brake system that only uses the aircraft main hydraulic system(s) as a source of pressure.

Systems on different aircraft vary, but the general operation is similar to those described.

Independent Master Cylinders

In general, small, light aircraft and aircraft without hydraulic systems use independent braking systems. An independent brake system is not connected in any way to the aircraft hydraulic system. Master cylinders are used to develop the necessary hydraulic pressure to operate the brakes. This is similar to the brake system of an automobile.

In most brake actuating systems, the pilot pushes on the tops of the rudder pedals to apply the brakes. A master cylinder for each brake is mechanically connected to the corresponding rudder pedal (i.e., right main brake to the right rudder pedal, left main brake to the left rudder pedal). *[Figure 13-92]* When the pedal is depressed, a piston inside a sealed fluid-filled chamber in the master cylinder forces hydraulic fluid through a line to the piston(s) in the brake assembly. The brake piston(s) push the brake linings against the brake rotor to create the friction that slows the wheel rotation. Pressure

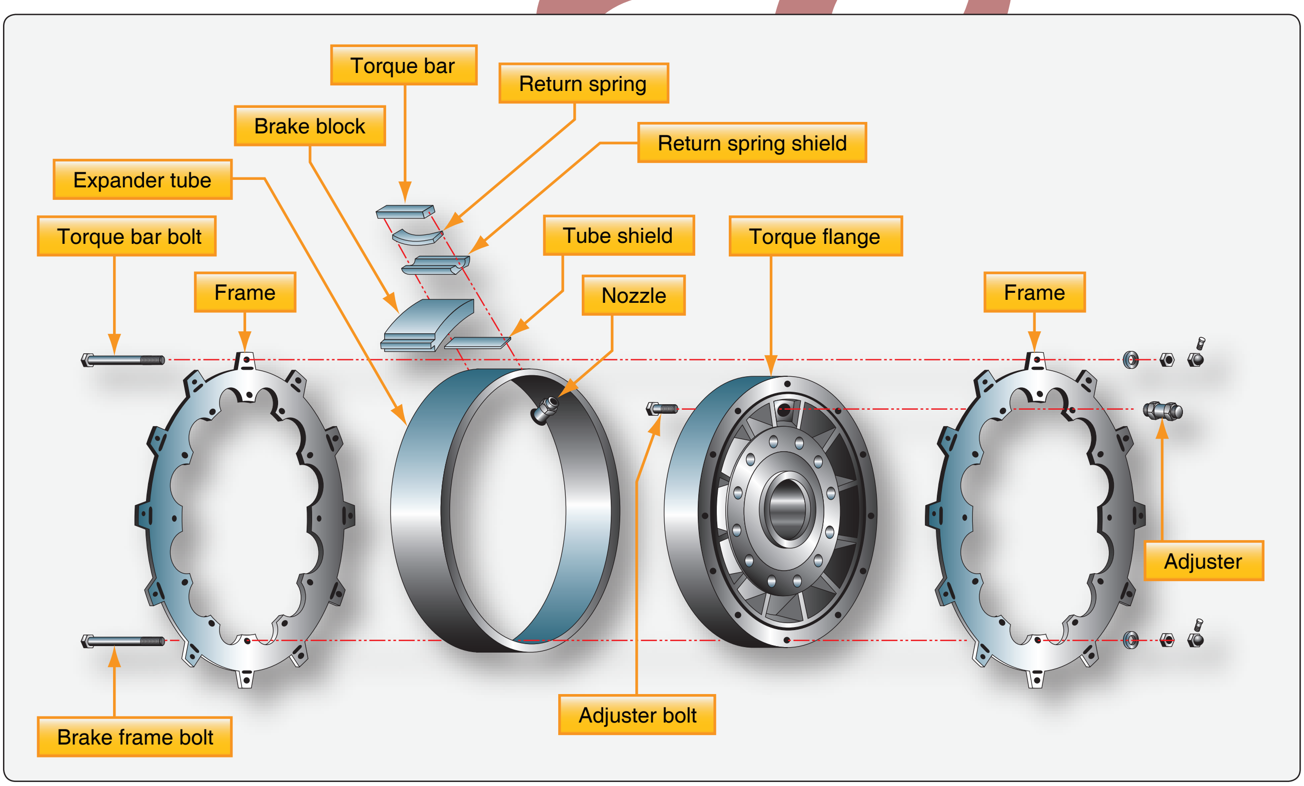


Figure 13-91. *An exploded view of an expander tube brake.*

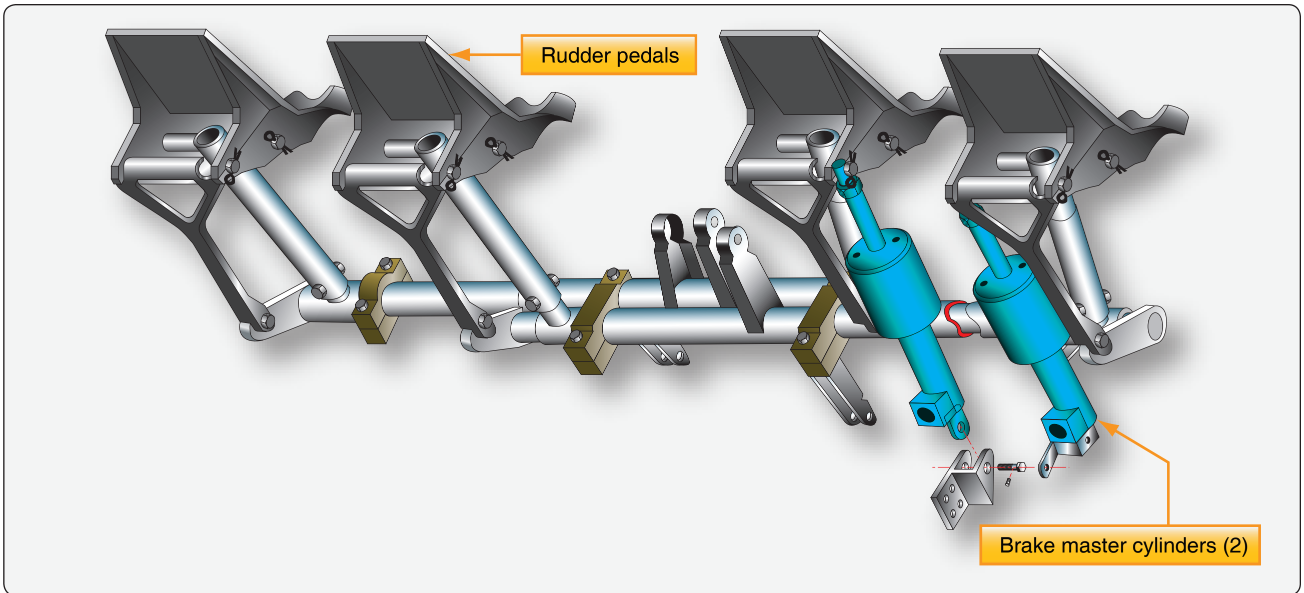


Figure 13-92. *Master cylinders on an independent brake system are directly connected to the rudder pedals or are connected through mechanical linkage.*

is increased throughout the entire brake systems and against the rotor as the pedal is pushed harder.

Many master cylinders have built-in reservoirs for the brake hydraulic fluid. Others have a single remote reservoir that services both of the aircraft's two master cylinders. *[Figure 13-93]* A few light aircraft with nose wheel steering have only one master cylinder that actuates both main wheel brakes. This is possible because steering the aircraft during taxi does not require differential braking. Regardless of the set-up, it is the master cylinder that builds up the pressure required for braking.

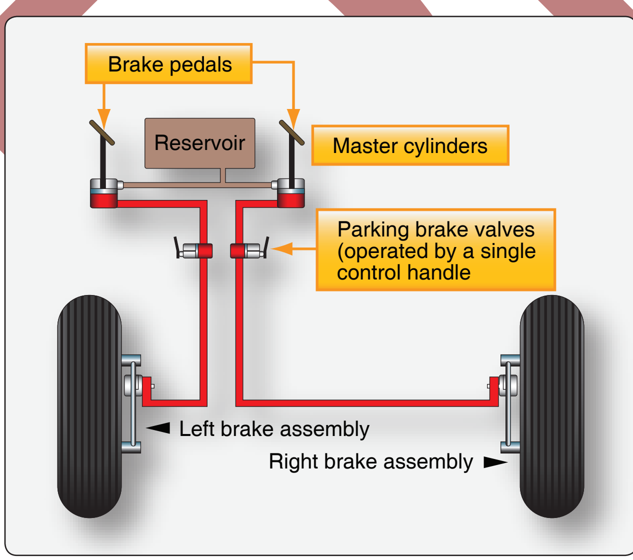


Figure 13-93. *A remote reservoir services both master cylinders on some independent braking systems.*

A master cylinder used with a remote reservoir is illustrated in *Figure 13-94*. This particular model is a Goodyear master cylinder. The cylinder is always filled with air-free, contaminant-free hydraulic fluid as is the reservoir and the line that connects the two together. When the top of the rudder pedal is depressed, the piston arm is mechanically moved forward into the master cylinder. It pushes the piston against the fluid, which is forced through the line to the brake. When pedal pressure is released, the return springs in the brake assembly retract the brake pistons back into the brake housing. The hydraulic fluid behind the pistons is displaced and must return to the master cylinder. As it does, a return spring in the master cylinder move the piston, piston rod and rudder pedal back to the original position (brake off, pedal not depressed). The fluid behind the master cylinder piston flows back into the reservoir. The brake is ready to be applied again.

Hydraulic fluid expands as temperature increases. Trapped fluid can cause a brake to drag against the rotor(s). Leaks may also result. When the brakes are not applied, fluid must be allowed to expand safely without causing these issues. A compensating port is included in most master cylinders to facilitate this. In the master cylinder in *Figure 13-94*, this port is opened when the piston is fully retracted. Fluid in the brake system is allowed to expand into the reservoir, which has the capacity to accept the extra fluid volume. The typical reservoir is also vented to the atmosphere to provide positive pressure on the fluid.

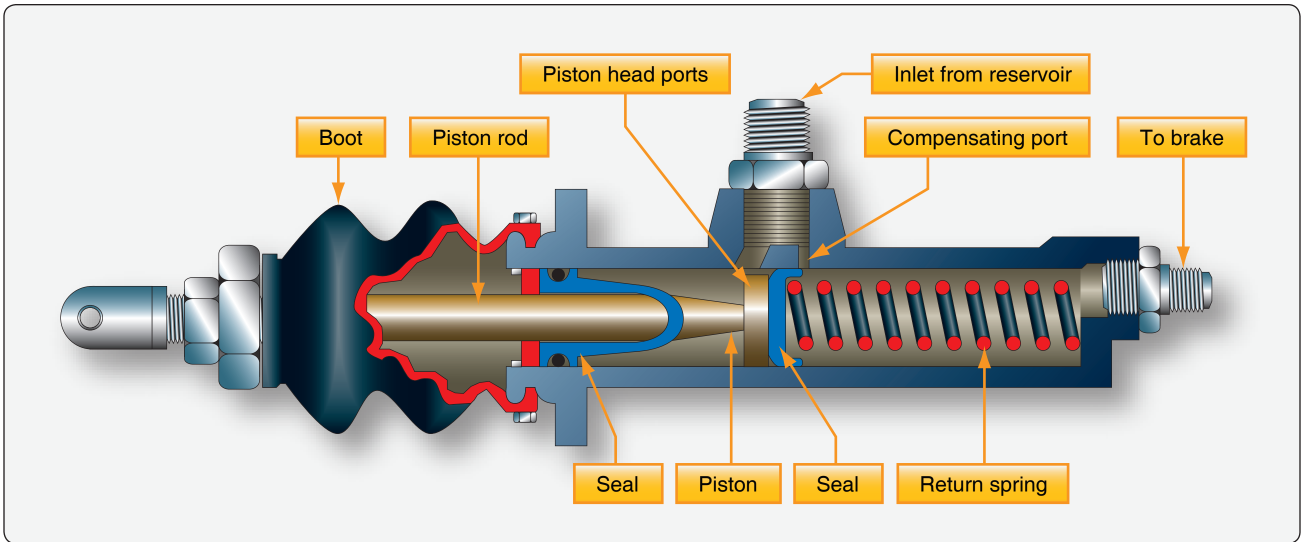


Figure 13-94. *A Goodyear brake master cylinder from an independent braking system with a remote reservoir.*

The forward side of the piston head contains a seal that closes off the compensating port when the brakes are applied so that pressure can build. The seal is only effective in the forward direction. When the piston is returning, or is fully retracted to the off position, fluid behind the piston is free to flow through piston head ports to replenish any fluid that may be lost downstream of the master cylinder. The aft end of the master cylinder contains a seal that prevents leakage at all times. A rubber boot fits over the piston rod and the aft end of the master cylinder to keep out dust.

A parking brake for this remote reservoir master cylinder brake system is a ratcheting mechanical device between the master cylinder and the rudder pedals. With the brakes applied, the ratchet is engaged by pulling the parking brake handle. To release the brakes, the rudder pedals are depressed further allowing the ratchet to disengage. With the parking brake set, any expansion of hydraulic fluid due to temperature is relieved by a spring in the mechanical linkage.

A common requirement of all braking systems is for there to be no air mixed in with the hydraulic fluid. Since air is compressible and hydraulic fluid essentially is not, any air under pressure when the brakes are applied causes spongy brakes. The pedals do not feel firm when pushed down due to the air compressing. Brake systems must be bled to remove all air from the system. Instructions for bleeding the brakes are in the manufacturer's maintenance information. Brake systems equipped with Goodyear master cylinders must be bled from the top down to ensure any air trapped behind the master cylinder piston is removed.

An alternative common arrangement of independent braking systems incorporates two master cylinders, each with its own integral fluid reservoir. Except for the reservoir location, the brake system is basically the same as just described. The master cylinders are mechanically linked to the rudder pedals as before. Depressing the top of a pedal causes the piston rod to push the piston into the cylinder forcing the fluid out to the brake assembly. The piston rod rides in a compensator sleeve and contains an O-ring that seals the rod to the piston when the rod is moved forward. This blocks the compensating ports. When released, a spring returns the piston to its original position which refills the reservoir as it returns. The rod end seal retracts away from the piston head allowing a free flow of fluid from the cylinder through the compensating ports in the piston to the reservoir. *[Figure 13-95]*

The parking brake mechanism is a ratcheting type that operates as described. A servicing port is supplied at the top of the master cylinder reservoir. Typically, a vented plug is installed in the port to provide positive pressure on the fluid.

Boosted Brakes

In an independent braking system, the pressure applied to the brakes is only as great as the foot pressure applied to the top of the rudder pedal. Boosted brake actuating systems augment the force developed by the pilot with hydraulic system pressure when needed. The boost is only during heavy braking. It results in greater pressure applied to the brakes than the pilot alone can provide. Boosted brakes are used on medium and larger aircraft that do not require a full power brake actuating system.

A boosted brake master cylinder for each brake is mechanically attached to the rudder pedals. However, the boosted brake master cylinder operates differently. *[Figure 13-96]*

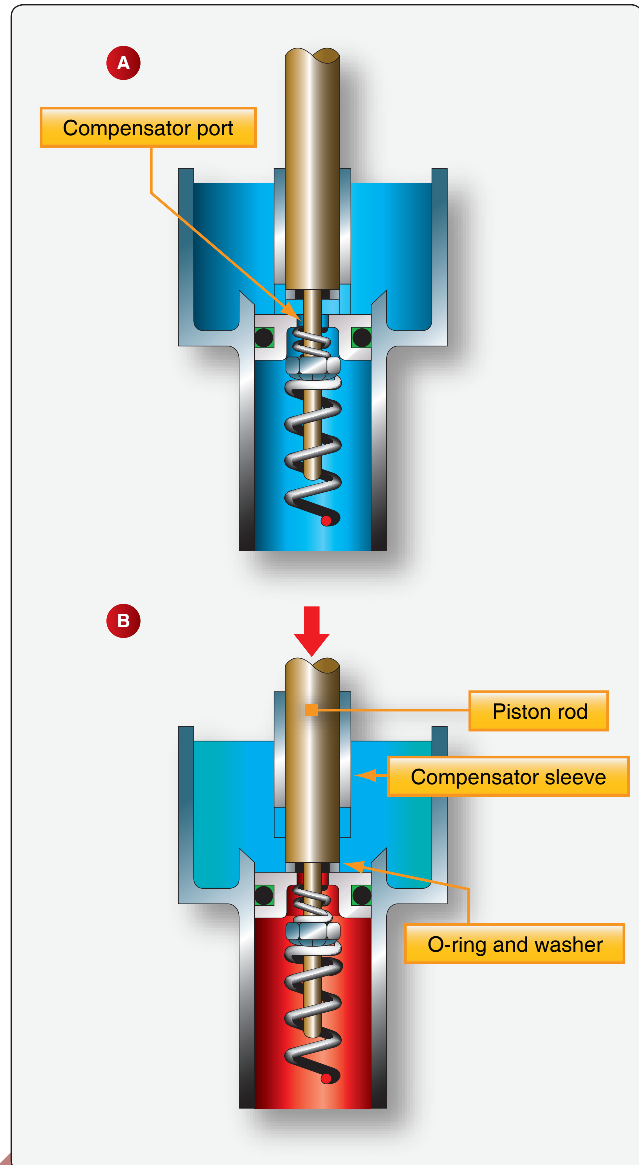


Figure 13-95. *A common master cylinder with built-in reservoir is shown. Illustration A depicts the master cylinder when the brakes are off. The compensating port is open to allow fluid to expand into the reservoir should temperature increase. In B, the brakes are applied. The piston rod-end seal covers the compensating port as it contacts the piston head.*

When the brakes are applied, the pressure from the pilot's foot through the mechanical linkage moves the master cylinder piston in the direction to force fluid to the brakes. The initial movement closes the compensator poppet used to provide thermal expansion relief when the brakes are not applied. As the pilot pushes harder on the pedal, a spring-loaded toggle moves a spool valve in the cylinder. Aircraft hydraulic system pressure flows through the valve to the back side of the piston. Pressure is increased, as is the force developed to apply the brakes.

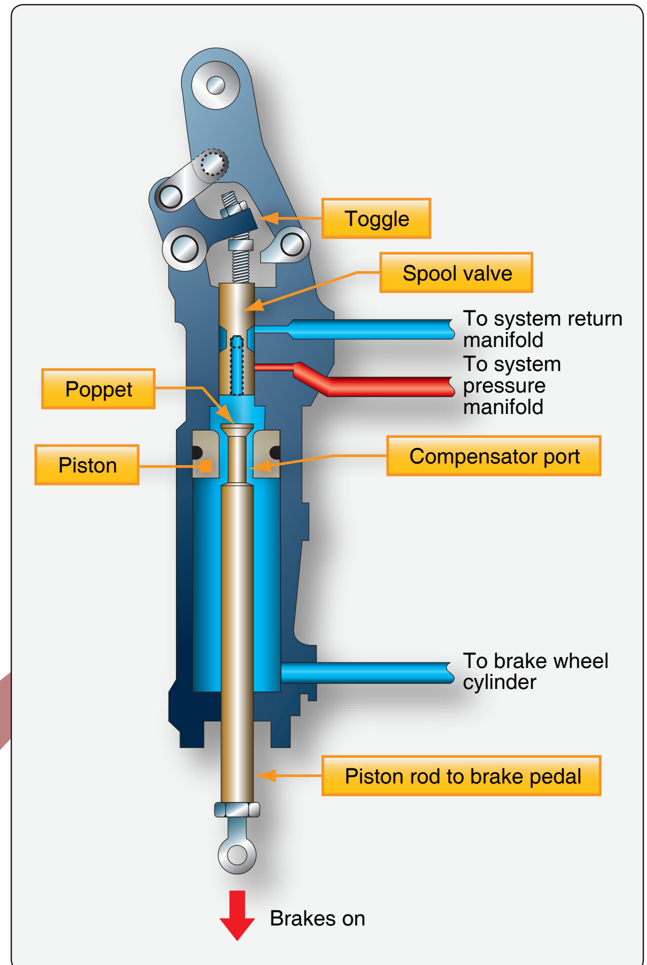


Figure 13-96. *A master cylinder for a boosted brake system augments foot pedal pressure with aircraft system hydraulic pressure during heavy braking.*

When the pedal is released, the piston rod travels in the opposite direction, and the piston returns to the piston stop. The compensating poppet reopens. The toggle is withdrawn from the spool via linkages, and fluid pushes the spool back to expose the system return manifold port. System hydraulic fluid used to boost brake pressure returns through the port.

Power Brakes

Large and high-performance aircraft are equipped with power brakes to slow, stop, and hold the aircraft. Power brake actuating systems use the aircraft hydraulic system as the source of power to apply the brakes. The pilot presses on the top of the rudder pedal for braking as with the other actuating systems. The volume and pressure of hydraulic fluid required cannot be produced by a master cylinder. Instead, a power brake control valve or brake metering valve receives the brake pedal input either directly or through linkages. The valve meters hydraulic fluid to the corresponding brake assembly in direct relation to the pressure applied to the pedal.

Many power brake system designs are in use. Most are similar to the simplified system illustrated in *Figure 13-97A*. Power brake systems are constructed to facilitate graduated brake pressure control, brake pedal feel, and the necessary redundancy required in case of hydraulic system failure. Large aircraft brake systems integrate anti-skid detection and correction devices. These are necessary because wheel skid is difficult to detect on the flight deck without sensors. However, a skid can be quickly controlled automatically through pressure control of the hydraulic fluid to the brakes. Hydraulic fuses are also commonly found in power brake systems. The hostile environment around the landing gear increases the potential for a line to break or sever, a fitting to fail, or other hydraulic system malfunctions to occur where hydraulic fluid is lost en route to the brake assemblies. A fuse stops any excessive flow of fluid when detected by closing to retain the remaining fluid in the hydraulic system. Shuttle valves are used to direct flow from optional sources of fluid, such as in redundant systems or during the use of an emergency brake power source. An airliner power brake system is illustrated in *Figure 13-97B*.

Brake Control Valve/Brake Metering Valve

The key element in a power brake system is the brake control valve, sometimes called a brake metering valve. It responds to brake pedal input by directing aircraft system hydraulic fluid to the brakes. As pressure is increased on the brake pedal, more fluid is directed to the brake causing a higher pressure and greater braking action.

A brake metering valve from a Boeing 737 is illustrated in *Figure 13-98*. The system in which it is installed is diagramed in *Figure 13-99*. Two sources of hydraulic pressure provide redundancy in this brake system. A brake input shaft, connected to the rudder/brake pedal through mechanical linkages, provides the position input to the metering valve. As in most brake control valves, the brake input shaft moves a tapered spool or slide in the valve so that it allows hydraulic system pressure to flow to the brakes. At the same time, the slide covers and uncovers access to the hydraulic system return port as required.

When the rudder/brake pedal is depressed, the slide in the metering valve moves to the left. *[Figure 13-98]* It covers the return port so pressure can build in the brake system. The hydraulic supply pressure chamber is connected to the brake system pressure chamber by the movement of the slide, which due to its taper, unblocks the passage between these two. As the pedal is depressed further, the valve slide moves farther to the left. This enables more fluid to flow to the brakes due to the narrowing shape of the slide. Brake pressure increases with the additional fluid. A passage in the slide directs brake pressure fluid into a compensating chamber at the end of the slide. This acts on the end of the slide creating a return force that counters the initial slide movement and gives feel to the brake pedal. As a result, the pressure and return ports are closed and pressure proportional to the foot pressure on the pedal is held on the brakes. When the pedal is released, a return spring and compensating chamber pressure drive the slide to the right into its original position (return port open, supply pressure chamber and brake pressure chambers blocked from each other).

The metering valve operates as described simultaneously for the inboard and the outboard brakes. *[Figure 13-98]* The design of the link assembly is such that a single side of the metering valve can operate even if the other fails. Most brake control valves and metering valves function in a similar manner, although many are single units that supply only one brake assembly.

The auto brake, referenced in the metering valve diagram, is connected into the landing gear retraction hydraulic line. Pressurized fluid enters this port and drives the slide slightly to the left to apply the brakes automatically after takeoff. This stops the wheels from rotating when retracted into the wheel wells. Auto brake pressure is withheld from this port when the landing gear is fully stowed since the retraction system is depressurized.

The majority of the rudder/brake pedal feel is supplied by the brake control or brake metering valve in a power brake system. Many aircraft refine the feel of the pedal with an additional feel unit. The brake valve feel augmentation unit, in the above system, uses a series of internal springs and pistons of various sizes to create a force on the brake input shaft movement. This provides feel back through the mechanical linkages consistent with the amount of rudder/brake pedal applied. The request for light braking with slight pedal depression results in a light feel to the pedal and a harder resistance feel when the pedals are pushed harder during heavy braking. *[Figure 13-100]*

Emergency Brake Systems

As can be seen in *Figure 13-99,* the brake metering valves not only receive hydraulic pressure from two separate hydraulic systems, they also feed two separate brake assemblies. Each main wheel assembly has two wheels. The inboard wheel brake and the outboard wheel brake, located in their respective wheel rims, are independent from each other. In case of hydraulic system failure or brake failure, each is independently supplied to adequately slow and stop the aircraft without the other. More complicated aircraft may involve another hydraulic system for back-up or use a similar alternation of sources and brake assemblies to maintain braking in case of hydraulic system or brake failure.

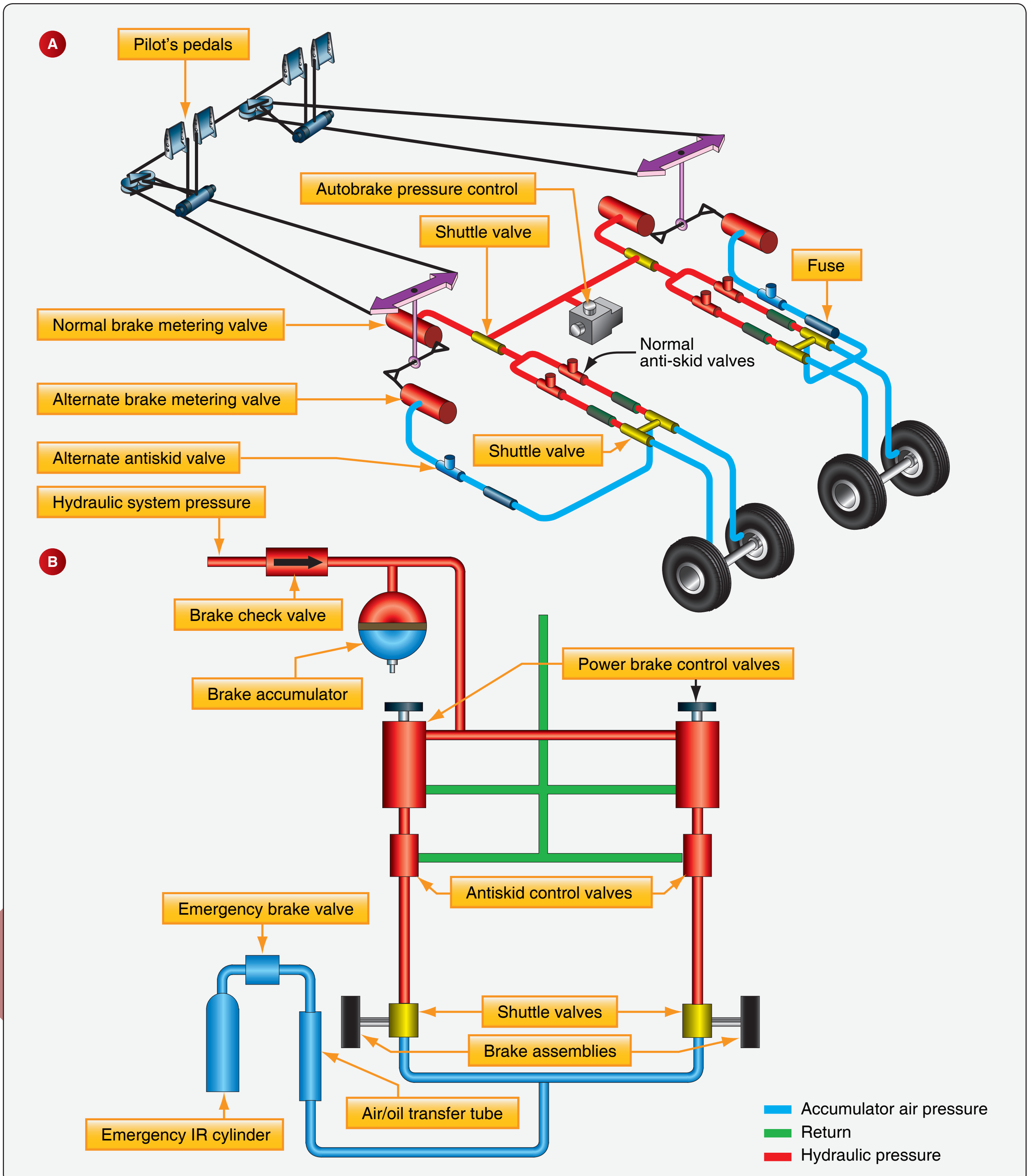


Figure 13-97. *The orientation of components in a basic power brake system is shown in A. The general layout of an airliner power brake system is shown in B.*

NOTE: In the segmented rotor brake section above, a brake assembly was described that had alternating pistons supplied by independent hydraulic sources. This is another method of redundancy particularly suitable on, but not limited to, single main wheel aircraft.

In addition to supply system redundancy, the brake accumulator is also an emergency source of power for the brakes in many power brake systems. The accumulator is pre-charged with air or nitrogen on one side of its internal diaphragm. Enough hydraulic fluid is contained on the other

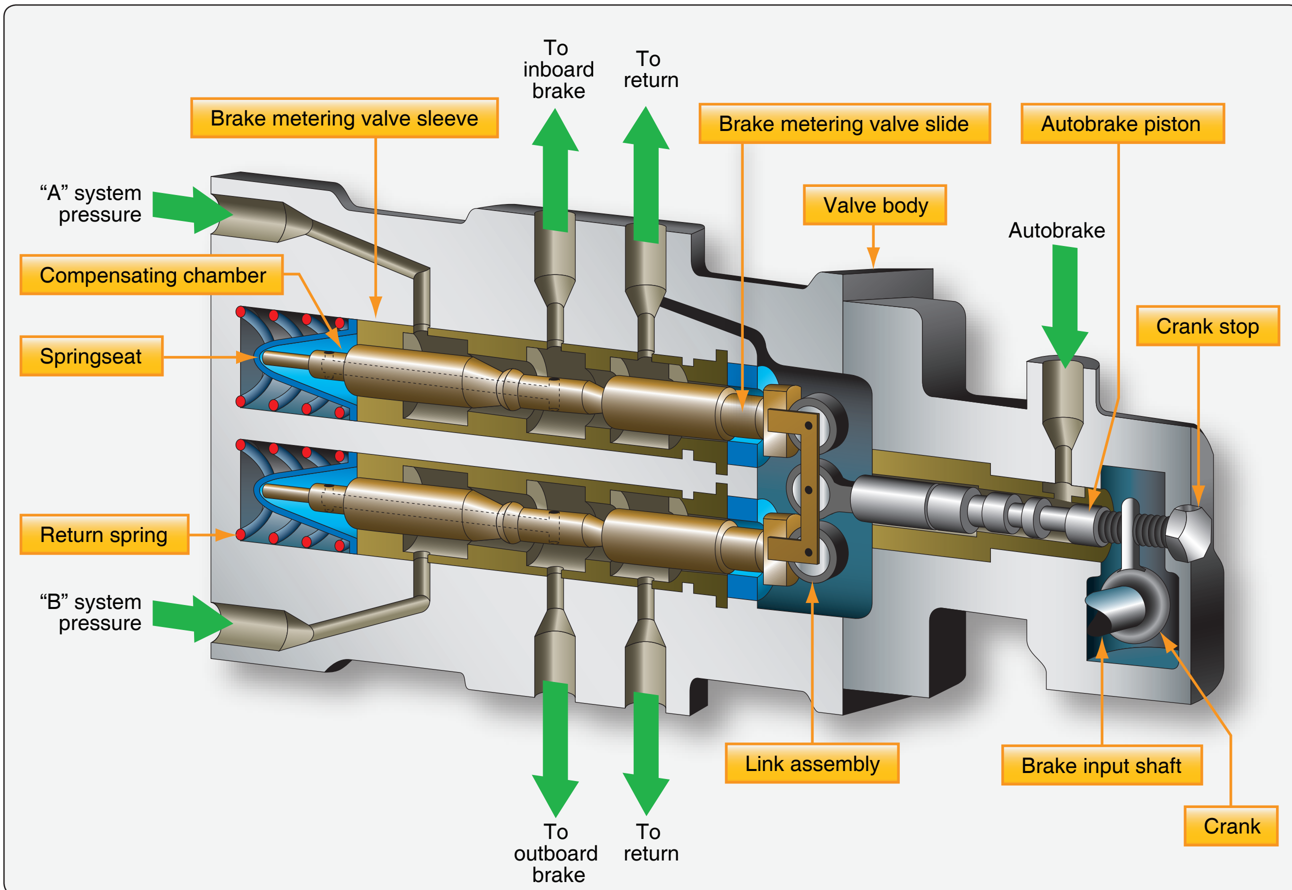


Figure 13-98. *A brake metering valve from a Boeing 737. A machined slide or spool moves laterally to admit the correct amount of hydraulic system fluid to the brakes. The pressure developed is in proportion to the amount the rudder/brake pedal is depressed and the amount the slide is displaced. The slide/spool also simultaneously controls the return of fluid to the hydraulic system return manifold when brake pressure is released.*

side of the diaphragm to operate the brakes in case of an emergency. It is forced out of the accumulator into the brakes through the system lines under enough stored pressure to slow the aircraft. Typically, the accumulator is located upstream of the brake control/metering valve to capitalize on the control given by the valve. *[Figure 13-101]*

Some simpler power brake systems may use an emergency source of brake power that is delivered directly to the brake assemblies and bypasses the remainder of the brake system completely. A shuttle valve immediately upstream of the brake units shifts to accept this source when pressure is lost from the primary supply sources. Compressed air or nitrogen is sometimes used. A pre-charged fluid source can also be used as an alternate hydraulic source.

Parking Brake

The parking brake system function is a combined operation. The brakes are applied with the rudder pedals and a ratcheting system holds them in place when the parking brake lever on the flight deck is pulled. *[Figure 13-102]* At the same time, a shut-off valve is closed in the common return line from the brakes to the hydraulic system. This traps the fluid in the brakes holding the rotors stationary. Depressing the pedals further releases the pedal ratchet and opens the return line valve.

Brake Deboosters

Some aircraft brake assemblies that operate on aircraft hydraulic system pressure are not designed for such high pressure. They provide effective braking through a power brake system but require less than maximum hydraulic system pressure. To supply the lower pressure, a brake debooster cylinder is installed downstream of the control valve and anti-skid valve. *[Figure 13-103]* The debooster reduces all pressure from the control valve to within the working range of the brake assembly.

Brake deboosters are simple devices that use the application of force over different sized pistons to reduce pressure. *[Figure 13-104]* Their operation can be understood through the application of the following equation:

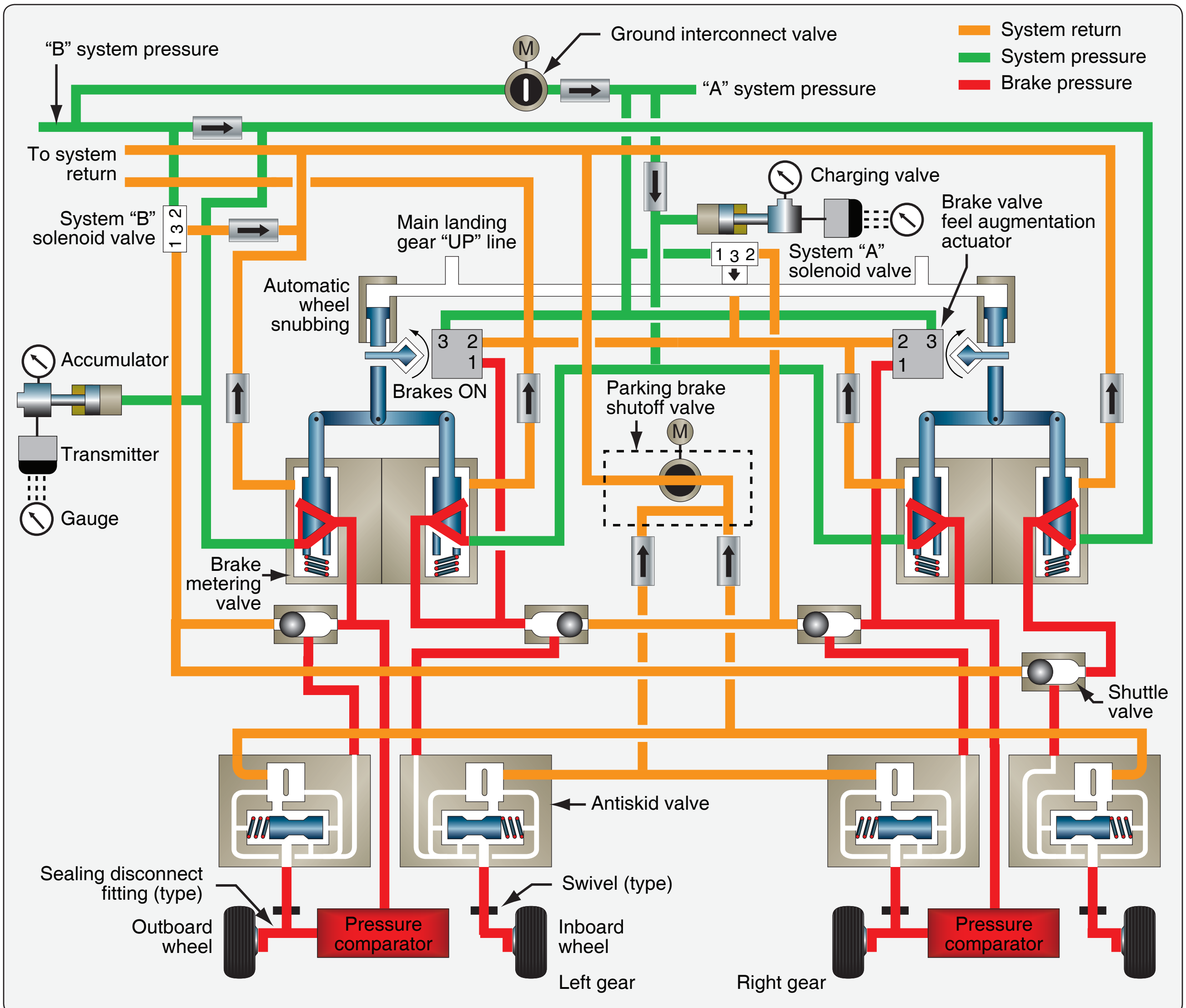


Figure 13-99. *The power brake system on a Boeing 737.*

Pressure = Force/Area

High-pressure hydraulic system input pressure acts on the small end of a piston. This develops a force proportional to the area of the piston head. The other end of the piston is larger and housed in a separate cylinder. The force from the smaller piston head is transferred to the larger area of the other end of the piston. The amount of pressure conveyed by the larger end of the piston is reduced due to the greater area over which the force is spread. The volume of output fluid increases since a larger piston and cylinder are used. The reduced pressure is delivered to the brake assembly. The spring in the debooster aids in returning the piston to the ready position. If fluid is lost downstream of the deboost cylinder, the piston travels further down into the cylinder when the brakes are applied. The pin unseats the ball and allows fluid into the lower cylinder to replace what was lost. Once replenished, the piston rises up in the cylinder due to pressure build-up. The ball reseats as the piston travels above the pin and normal braking resumes. This function is not meant to permit leaks in the brake assemblies. Any leak discovered must be repaired by the technician.

A lockout debooster functions as a debooster and a hydraulic fuse. If fluid is not encountered as the piston moves down in the cylinder, the flow of fluid to the brakes is stopped. This prevents the loss of all system hydraulic fluid should a rupture downstream of the debooster occur. Lockout deboosters have a handle to reset the device after it closes as a fuse. If not reset, no braking action is possible.

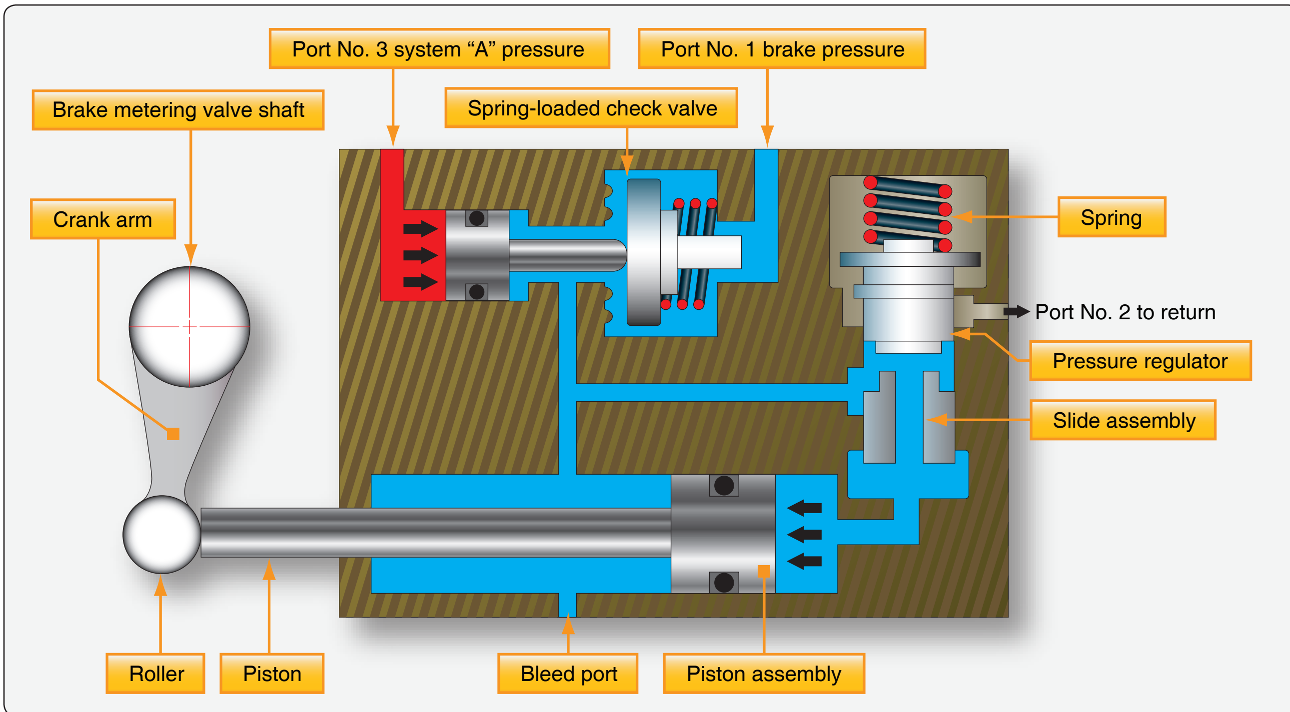


Figure 13-100. *The power brake system on a Boeing 737.*

Figure 13-101. *Emergency brake hydraulic fluid accumulators are precharged with nitrogen to deliver brake fluid to the brakes in the event normal and alternate hydraulic sources fail.*

Figure 13-102. *The parking brake lever on a Boeing 737 center pedestal throttle quadrant.*

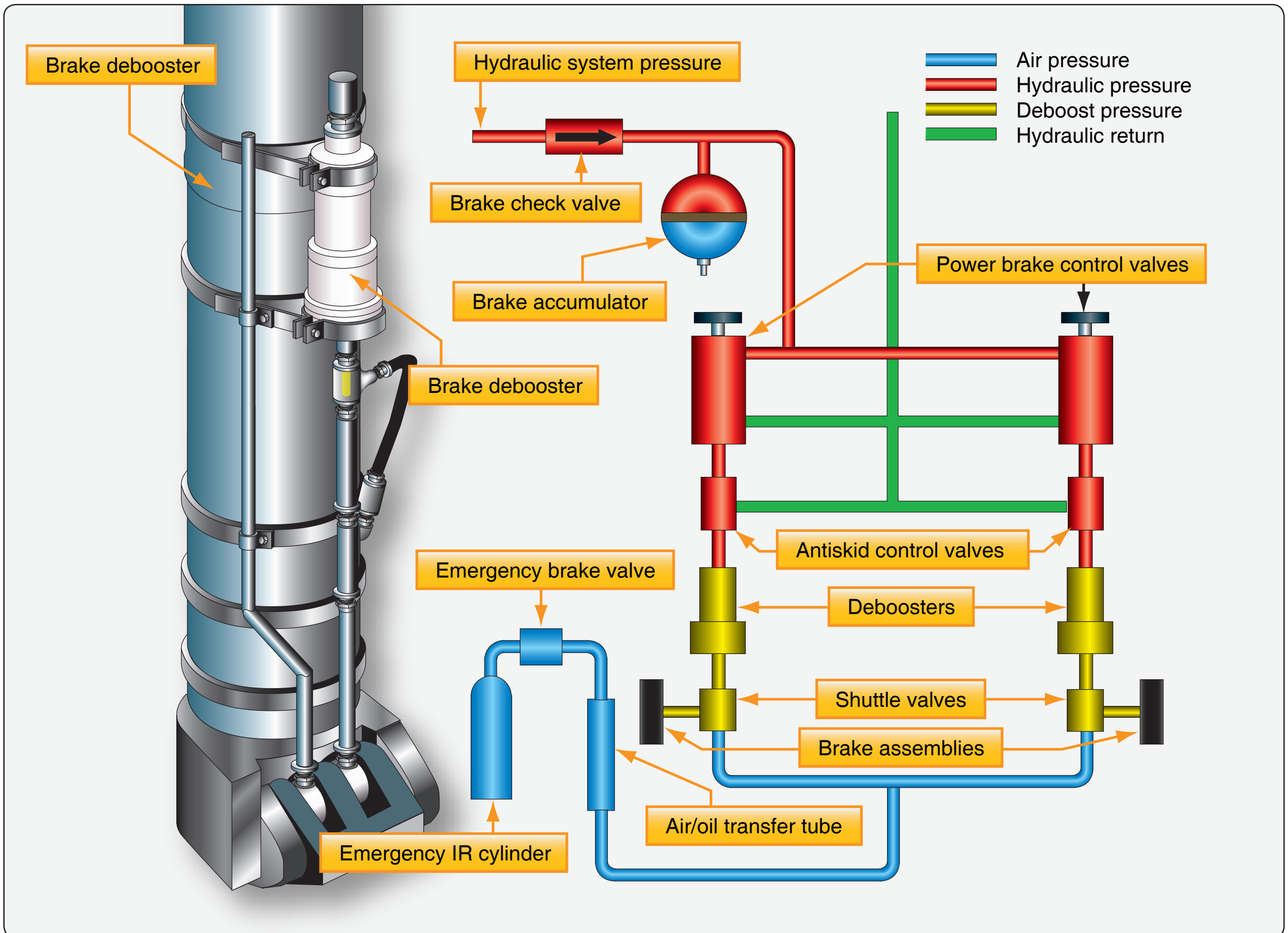


Figure 13-103. *The location of a brake debooster cylinder on a landing gear strut and the debooster's position in relation to other components of a power brake system.*

Anti-Skid

Large aircraft with power brakes require anti-skid systems. It is not possible to immediately ascertain in the flight deck when a wheel stops rotating and begins to skid, especially in aircraft with multiple-wheel main landing gear assemblies. A skid not corrected can quickly lead to a tire blowout, possible damage to the aircraft, and control of the aircraft may be lost.

System Operation

The anti-skid system not only detects wheel skid, it also detects when wheel skid is imminent. It automatically relieves pressure to the brake pistons of the wheel in question by momentarily connecting the pressurized brake fluid area to the hydraulic system return line. This allows the wheel to rotate and avoid a skid. Lower pressure is then maintained to the brake at a level that slows the wheel without causing it to skid.

Maximum braking efficiency exists when the wheels are decelerating at a maximum rate but are not skidding. If a wheel decelerates too fast, it is an indication that the brakes are about to lock and cause a skid. To ensure that this does not happen, each wheel is monitored for a deceleration rate faster than a preset rate. When excessive deceleration is detected, hydraulic pressure is reduced to the brake on that wheel. To operate the anti-skid system, flight deck switches must be placed in the ON position. *[Figure 13-105]* After the aircraft touches down, the pilot applies and holds full pressure to the rudder brake pedals. The anti-skid system then functions automatically until the speed of the aircraft has dropped to approximately 20 mph. The system returns to manual braking mode for slow taxi and ground maneuvering.

There are various designs of anti-skid systems. Most contain three main types of components: wheel speed sensors, anti-skid control valves, and a control unit. These units work together without human interference. Some anti-skid systems provide complete automatic braking. The pilot needs only to turn on the auto brake system, and the anti-skid components slow the aircraft without pedal input. *[Figure 13-105]* Ground safety switches are wired into the circuitry for anti-skid and auto brake systems. Wheel speed sensors are located on each wheel equipped with a brake assembly. Each brake also has

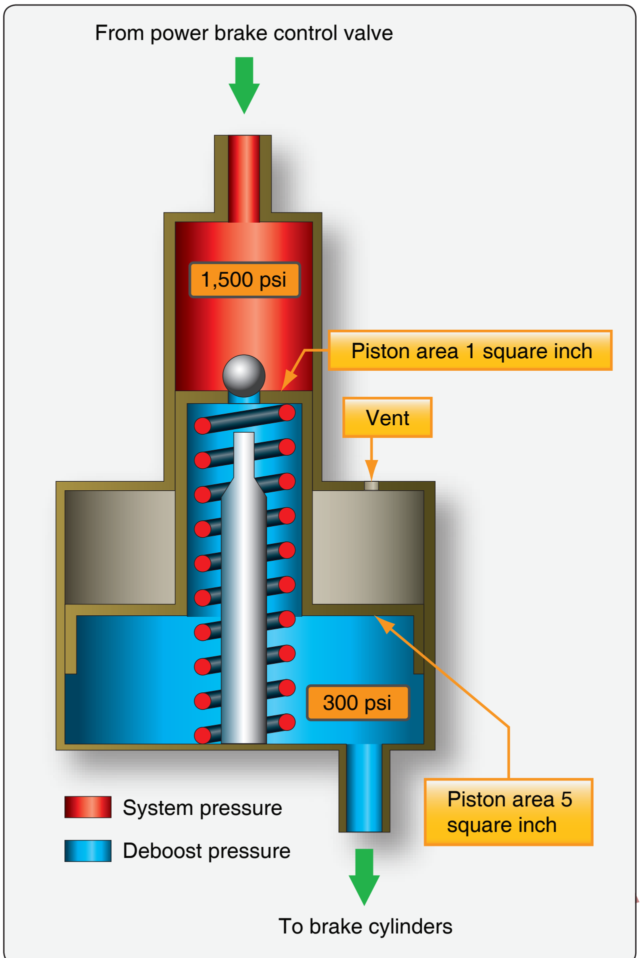


Figure 13-104. *Brake deboosters.*

Figure 13-105. *Antiskid switches in the cockpit.*

its own anti-skid control valve. Typically, a single control box contains the anti-skid comparative circuitry for all of the brakes on the aircraft. *[Figure 13-106]*

Wheel Speed Sensors

Wheel speed sensors are transducers. They may be alternating current (AC) or direct current (DC). The typical AC wheel speed sensor has a stator mounted in the wheel axle. A coil around it is connected to a controlled DC source so that when energized, the stator becomes an electromagnet. A rotor that turns inside the stator is connected to the rotating wheel hub assembly through a drive coupling so that it rotates at the speed of the wheel. Lobes on the rotor and stator cause the distance between the two components to constantly change during rotation. This alters the magnetic coupling or reluctance between the rotor and stator. As the electromagnetic field changes, a variable frequency AC is induced in the stator coil. The frequency is directly proportional to the speed of rotation of the wheel. The AC signal is fed to the control unit for processing. A DC wheel speed sensor is similar, except that a DC is produced the magnitude of which is directly proportional to wheel speed. *[Figure 13-107]*

Control Units

The control unit can be regarded as the brain of the anti-skid system. It receives signals from each of the wheel sensors. Comparative circuits are used to determine if any of the signals indicate a skid is imminent or occurring on a particular wheel. If so, a signal is sent to the control valve of the wheel to relieve hydraulic pressure to that brake which prevents or relieves the skid. The control unit may or may not have external test switches and status indicating lights. It is common for it to be located in the avionics bay of the aircraft. *[Figure 13-108]*

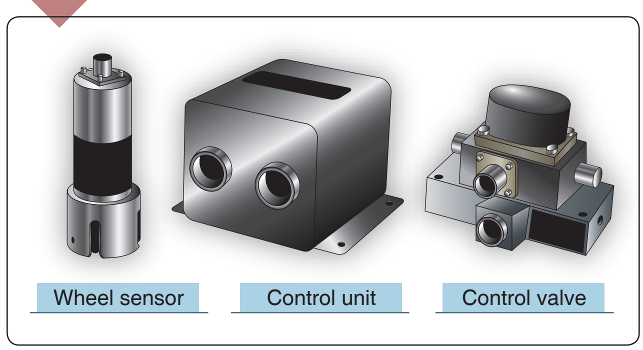


Figure 13-106. *A wheel sensor (left), a control unit (center), and a control valve (right) are components of an antiskid system. A sensor is located on each wheel equipped with a brake assembly. An antiskid control valve for each brake assembly is controlled from a single central control unit.*

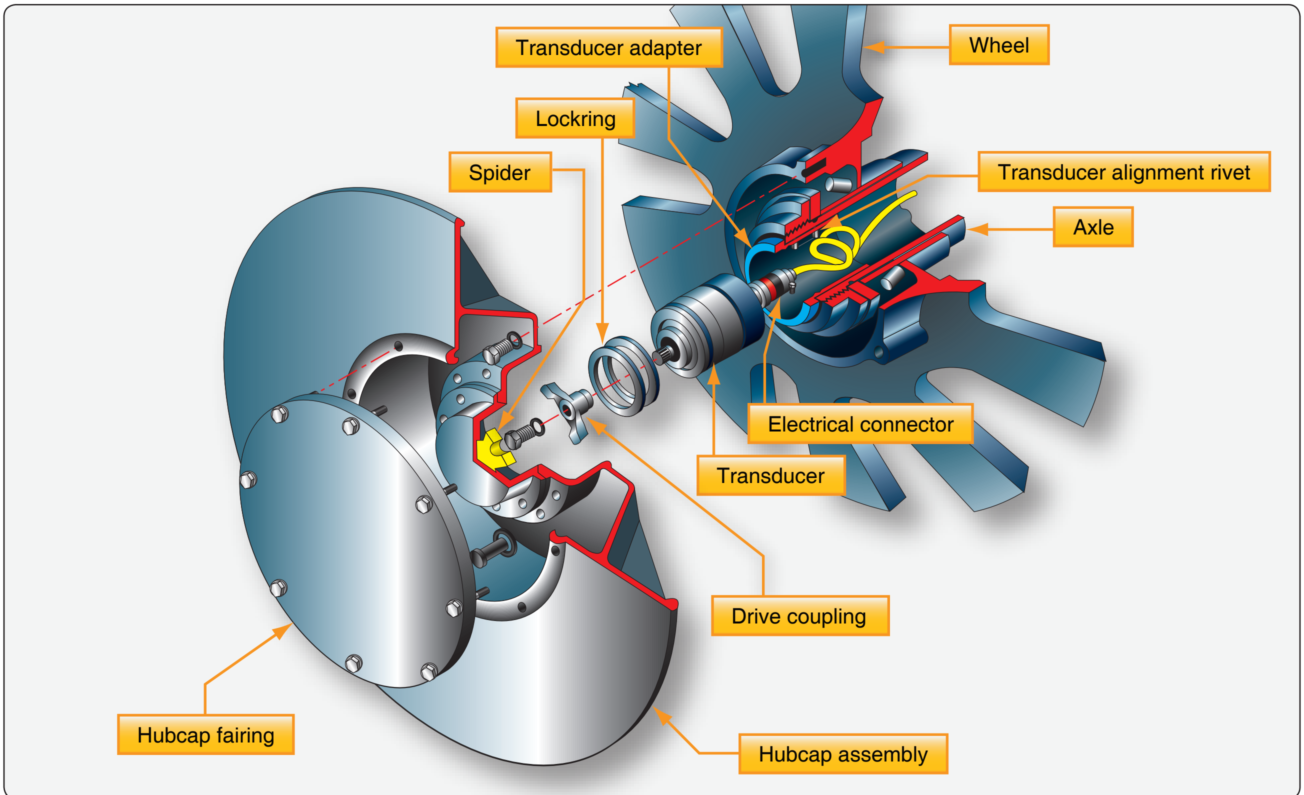


Figure 13-107. *The stator of an antiskid wheel sensor is mounted in the axle, and the rotor is coupled to the wheel hub spider that rotates with the wheel.*

The Boeing anti-skid control valve block diagram in *Figure 13-109* gives further detail on the functions of an anti-skid control unit. Other aircraft may have different logic to achieve similar end results. DC systems do not require an input converter since DC is received from the wheel sensors, and the control unit circuitry operates primarily with DC. Only the functions on one circuit card for one-wheel brake assembly are shown in *Figure 13-109*. Each wheel has its own identical circuitry card to facilitate simultaneous operation.

Figure 13-108. *A rack mounted antiskid control unit from an airliner.*

All cards are housed in a single control unit that Boeing calls a control shield.

The converter shown changes the AC frequency received from the wheel sensor into DC voltage that is proportional to wheel speed. The output is used in a velocity reference loop that contains deceleration and velocity reference circuits. The converter also supplies input for the spoiler system and the locked wheel system, which is discussed at the end of this section. A velocity reference loop output voltage is produced, which represents the instantaneous velocity of the aircraft. This is compared to converter output in the velocity comparator. This comparison of voltages is essentially the comparison of the aircraft speed to wheel speed. The output from the velocity comparator is a positive or negative error voltage corresponding to whether the wheel speed is too fast or too slow for optimum braking efficiency for a given aircraft speed.

The error output voltage from the comparator feeds the pressure bias modulator circuit. This is a memory circuit that establishes a threshold where the pressure to the brakes provides optimum braking. The error voltage causes the modulator to either increase or decrease the pressure to the brakes in attempt to hold the modulator threshold. It produces

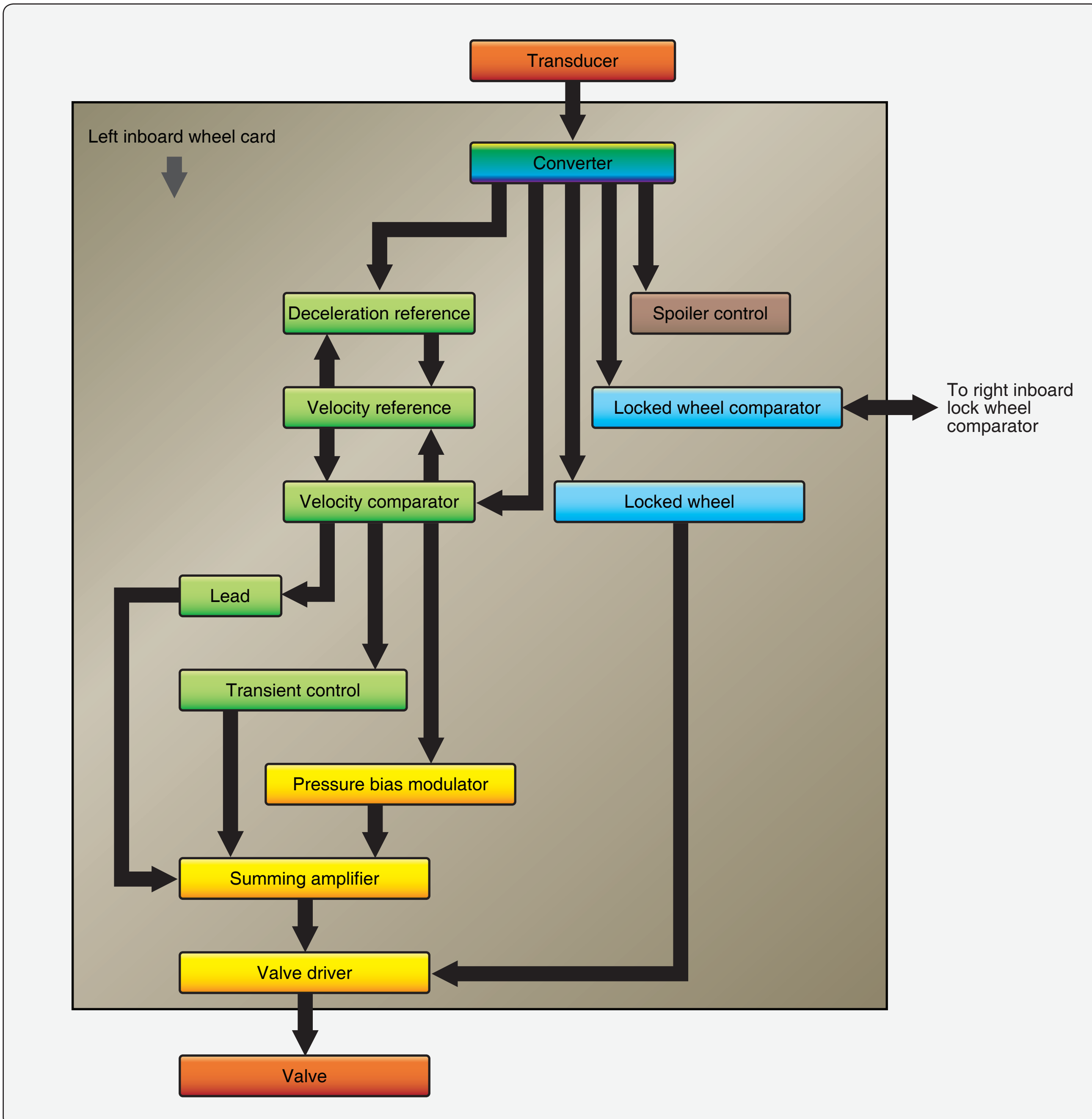


Figure 13-109. *A Boeing 737 antiskid control unit internal block diagram.*

a voltage output that is sent to the summing amplifier to do this. A lead output from the comparator anticipates when the tire is about to skid with a voltage that decreases the pressure to the brake. It sends this voltage to the summing amplifier as well. A transient control output from the comparator designed for rapid pressure dump when a sudden skid has occurred also sends voltage to the summing amp. As the name suggests, the input voltages to the amplifier are summed, and a composite voltage is sent to the valve driver. The driver prepares the current required to be sent to the control valve to adjust the position of the valve. Brake pressure increases, decreases, or holds steady depending on this value.

Anti-Skid Control Valves

Anti-skid control valves are fast-acting, electrically controlled hydraulic valves that respond to the input from the anti-skid control unit. There is one control valve for each brake assembly. A torque motor uses the input from the valve driver to adjust the position of a flapper between two nozzles. By moving the flapper closer to one nozzle or the other, pressures are developed in the second stage of the valve. These pressures act on a spool that is positioned to build or reduce pressure to the brake by opening and blocking fluid ports. *[Figure 13-110]*

As pressure is adjusted to the brakes, deceleration slows to within the range that provides the most effective braking without skidding. The wheel sensor signal adjusts to the wheel speed, and the control unit processes the change. Output is altered to the control valve. The control valve flapper position is adjusted and steady braking resumes without correction until needed. Anti-skid control valves are typically located in the main wheel for close access to hydraulic pressure and return manifolds, as well as the brake assemblies. *[Figure 13-111]* Systematically, they are positioned downstream of the power brake control valves but upstream of debooster cylinders if the aircraft is so equipped as was shown in *Figure 13-103*.

Touchdown and Lock Wheel Protection

It is essential that the brakes are not applied when the aircraft contacts the runway upon landing. This could cause immediate tire blowout. A touchdown protection mode is built into most aircraft anti-skid systems to prevent this. It typically functions in conjunction with the wheel speed sensor and the air/ground safety switch on the landing gear strut (squat switch). Until the aircraft has weight on wheels, the detector circuitry signals the anti-skid control valve to open the passage between the brakes and the hydraulic system return, thus preventing pressure build-up and application of the brakes. Once the squat switch is open, the anti-skid control unit sends a signal to the control valve to close and permit brake pressure build-up. As a back-up and when the aircraft is on the ground with the strut not compressed enough to open the squat switch, a minimum wheel speed sensor signal can override and allow braking. Wheels are often grouped with one relying on the squat switch and the other on wheel speed sensor output to ensure braking when the aircraft is on the ground, but not before then.

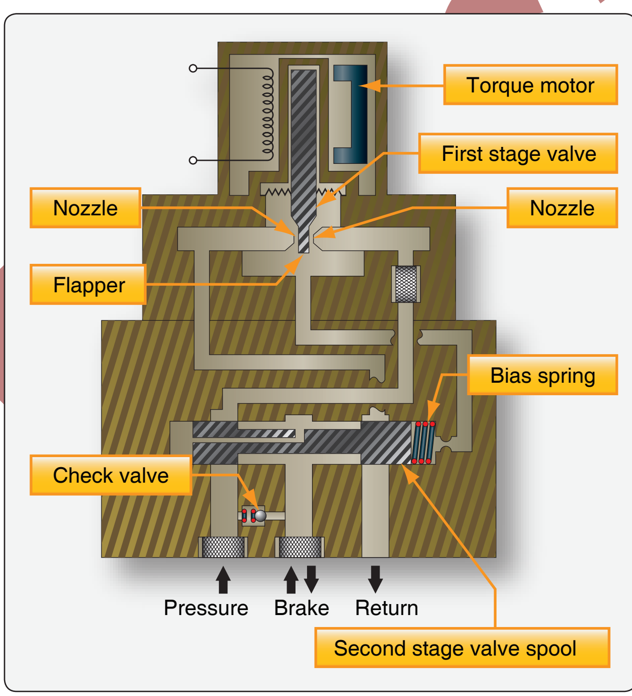


Figure 13-110. *An antiskid control valve uses a torque motor controlled flapper in the first stage of the valve to adjust pressure on a spool in the second stage of the valve to build or relieve pressure to the brake.*

Locked wheel protection recognizes if a wheel is not rotating. When this occurs, the anti-skid control valve is signaled to fully open. Some aircraft anti-skid control logic, such as the Boeing 737 shown in *Figure 13-110*, expands the locked wheel function. Comparator circuitry is used to relieve pressure when one wheel of a paired group of wheels rotates 25 percent slower than the other. Inboard and outboard pairs are used because if one of the pair is rotating at a certain speed, so should the other. If it is not, a skid is beginning or has occurred.

On takeoff, the anti-skid system receives input through a switch located on the gear selector that shuts off the anti-skid system. This allows the brakes to be applied as retraction occurs so that no wheel rotation exists while the gear is stowed.

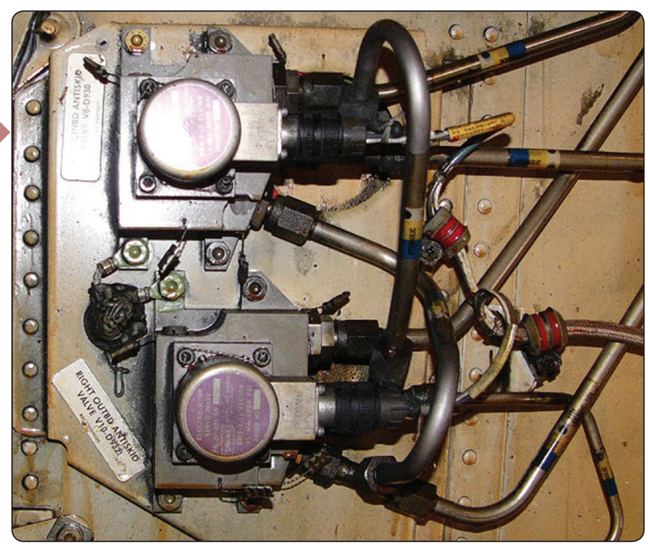


Figure 13-111. *Two antiskid control valves with associated plumbing and wiring.*

Auto Brakes

Aircraft equipped with auto brakes typically bypass the brake control valves or brake metering valves and use a separate auto brake control valve to provide this function. In addition to the redundancy provided, auto brakes rely on the anti-skid system to adjust pressure to the brakes if required due to an impending skid. *Figure 13-112* shows a simplified diagram of the Boeing 757 brake system with the auto brake valve in relation to the main metering valve and anti-skid valves in this eight-main wheel system.

Anti-Skid System Tests

It is important to know the status of the anti-skid system prior to attempting to use it during a landing or aborted takeoff. Ground tests and in-flight tests are used. Built-in test circuits and control features allow testing of the system components and provide warnings should a particular component or part of the system become inoperative. An inoperative anti-skid system can be shut off without affecting normal brake operation.

Ground Test

Ground tests vary slightly from aircraft to aircraft. Consult the manufacturer's maintenance manual for test procedures specific to the aircraft in question.

Much of the anti-skid system testing originates from testing circuits in the anti-skid control unit. Built-in test circuits continuously monitor the anti-skid system and provide warning if a failure occurs. An operational test can be performed before flight. The anti-skid control switch and/or test switch is used in conjunction with system indicator light(s) to determine system integrity. A test is first done with the aircraft at rest and then in an electrically simulated anti-skid braking condition. Some anti-skid control units contain system and component testing switches and lights for use by the technician. This accomplishes the same operational verification but allows an additional degree of troubleshooting. Test sets are available for anti-skid systems that produce electric signals that simulate speed outputs of the wheel transducer, deceleration rates, and flight/ground parameters.

In-Flight Test

In-flight testing of the anti-skid system is desirable and part of the pre-landing checklist so that the pilot is aware of system capability before landing. As with ground testing, a combination of switch positions and indicator lights are used according to information in the aircraft operations manual.

Anti-Skid System Maintenance

Anti-skid components require little maintenance. Troubleshooting anti-skid system faults is either performed via test circuitry or can be accomplished through isolation of the fault to one of the three main operating components of the system. Anti-skid components are normally not repaired in the field. They are sent to the manufacturer or a certified repair station when work is required. Reports of anti-skid system malfunction are sometimes malfunctions of the brake system or brake assemblies. Ensure brake assemblies are bled and functioning normally without leaks before attempting to isolate problems in the anti-skid system.

Wheel Speed Sensor

Wheel speed sensors must be securely and correctly mounted in the axle. The means of keeping contamination out of the sensor, such as sealant or a hub cap, should be in place and in good condition. The wiring to the sensor is subject to harsh conditions and should be inspected for integrity and security. It should be repaired or replaced if damaged in accordance with the manufacturer's instructions. Accessing the wheel speed sensor and spinning it by hand or other recommended device to ensure brakes apply and release via the anti-skid system is common practice.

Control Valve

Anti-skid control valve and hydraulic system filters should be cleaned or replaced at the prescribed intervals. Follow all manufacturer's instructions when performing this maintenance. Wiring to the valve must be secure, and there should be no fluid leaks.

Control Unit

Control units should be securely mounted. Test switches and indicators, if any, should be in place and functioning. It is essential that wiring to the control unit is secure. A wide variety of control units are in use. Follow the manufacturer's instructions at all times when inspecting or attempting to perform maintenance on these units.

Brake Inspection and Service

Brake inspection and service is important to keep these critical aircraft components fully functional at all times. There are many different brake systems on aircraft. Brake system maintenance is performed both while the brakes are installed on the aircraft and when the brakes are removed. The manufacturer's instructions must always be followed to ensure proper maintenance.

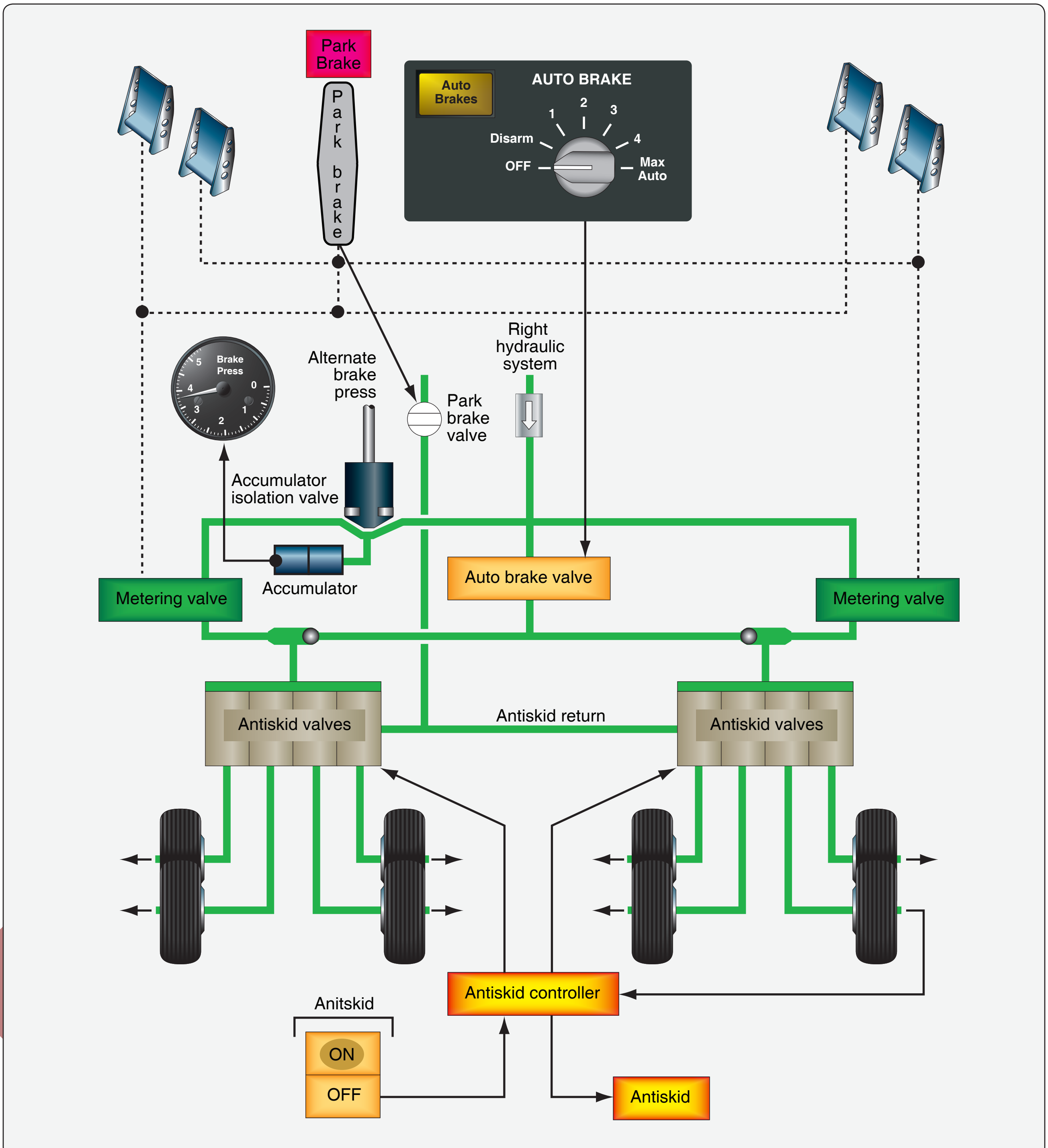


Figure 13-112. *The Boeing 757 normal brake system with auto brake and antiskid.*

On Aircraft Servicing

Inspection and servicing of aircraft brakes while installed on the aircraft is required. The entire brake system must be inspected in accordance with manufacturer's instructions. Some common inspection items include: brake lining wear, air in the brake system, fluid quantity level, leaks, and proper bolt torque.

Lining Wear

Brake lining material is made to wear as it causes friction during application of the brakes. This wear must be monitored to ensure it is not worn beyond limits and sufficient lining is available for effective braking. The aircraft manufacturer gives specifications for lining wear in its maintenance information. The amount of wear can be checked while the brakes are installed on the aircraft.

Many brake assemblies contain a built-in wear indicator pin. Typically, the exposed pin length decreases as the linings wear, and a minimum length is used to indicate the linings must be replaced. Caution must be used as different assemblies may vary in how the pin measured. On the Goodyear brake described above, the wear pin is measured where it protrudes through the nut of the automatic adjuster on the back side of the piston cylinder. *[Figure 13-113]* The Boeing brake illustrated in *Figure 13-88* measures the length of the pin from the back of the pressure plate when the brakes are applied (dimension L). The manufacturer's maintenance information must be consulted to ensure brake wear pin indicators on different aircraft are read correctly.

On many other brake assemblies, lining wear is not measured via a wear pin. The distance between the disc and a portion of the brake housing when the brakes are applied is sometimes used. As the linings wear, this distance increases. The manufacturer specified at what distance the linings should be changed. *[Figure 13-114]*

On Cleveland brakes, lining wear can be measured directly, since part of the lining is usually exposed. The diameter of a number 40 twist drill is approximately equal to the minimum lining thickness allowed. *[Figure 13-115]* Multiple disc brakes typically are checked for lining wear by applying the brakes and measuring the distance between the back of the pressure plate and the brake housing. *[Figure 13-116]* Regardless of the method particular to each brake, regular monitoring and measurement of brake wear ensures linings are replaced as they become unserviceable. Linings worn beyond limits usually require the brake assembly to be removed for replacement.

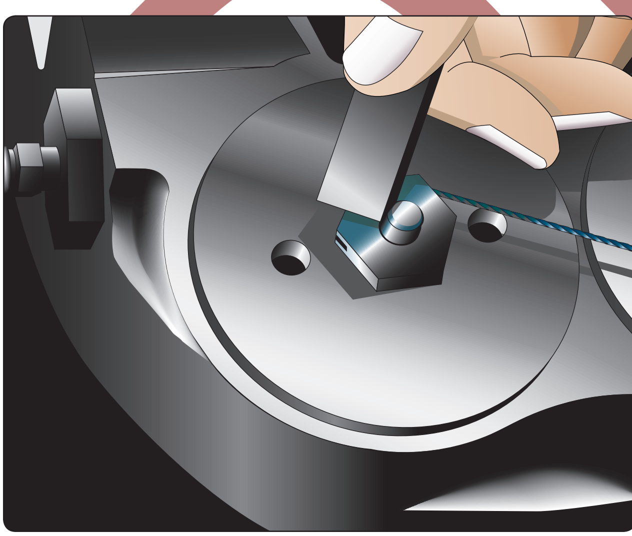


Figure 13-113. *Brake lining wear on a Goodyear brake is ascertained by measuring the wear pin of the automatic adjuster.*

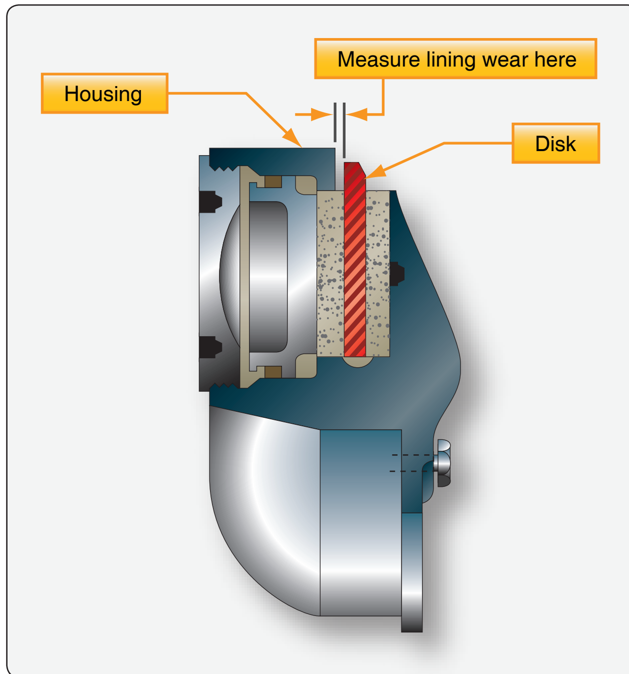


Figure 13-114. *The distance between the brake disc and the brake housing measured with the brakes applied is a means for determining brake lining wear on some brakes.*

Air in the Brake System

The presence of air in the brake system fluid causes the brake pedal to feel spongy. The air can be removed by bleeding to restore firm brake pedal feel. Brake systems must be bled according to manufacturers' instructions. The method used is matched to the type of brake system. Brakes are bled by one of two methods: top down, gravity bleeding or bottom up pressure bleeding. Brakes are bled when the pedals feel spongy or whenever the brake system has been opened.

Bleeding Master Cylinder Brake Systems

Brake systems with master cylinders may be bled by gravity or pressure bleeding methods. Follow the instructions in the aircraft maintenance manual. To pressure bleed a brake system from the bottom up, a pressure pot is used. *[Figure 13-117]* This is a portable tank that contains a supply

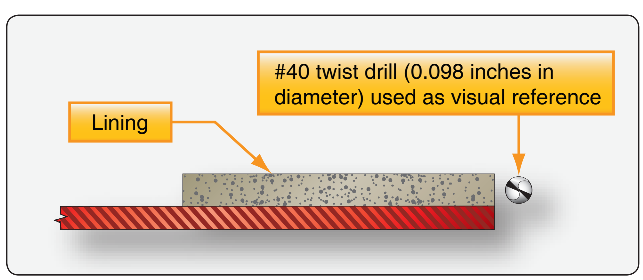


Figure 13-115. *A #40 twist drill laid next to the brake lining indicates when the lining needs to be changed on a Cleveland brake.*

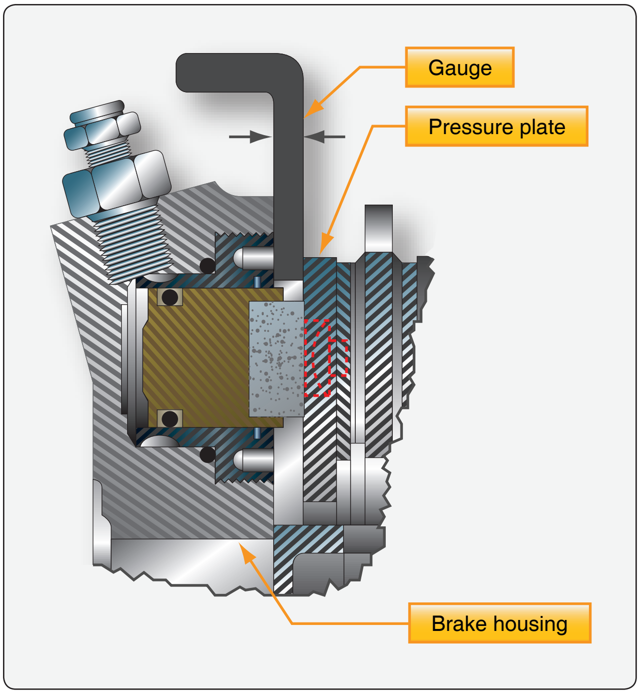


Figure 13-116. *The distance between the brake housing and the pressure plate indicates lining wear on some multiple disc brakes.*

of brake fluid under pressure. When dispersing fluid from the tank, pure air-free fluid is forced from near the bottom of the tank by the air pressure above it. The outlet hose that attaches the bleed port on the brake assembly contains a shut-off valve. Note that a similar source of pure, pressurized fluid can be substituted for a pressure tank, such as a hand-pump type unit found in some hangars.

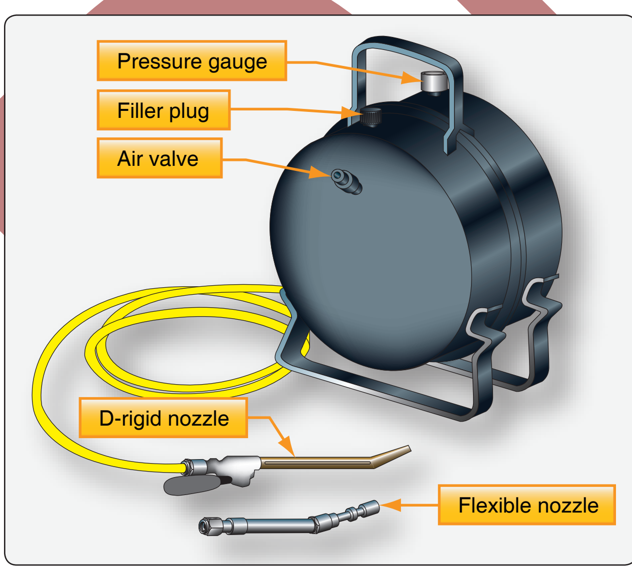


Figure 13-117. *A typical brake bleeder pot or tank contains pure brake fluid under pressure. It pushes the fluid through the brake system to displace any air that may be present.*

The typical pressure bleed is accomplished as illustrated in *Figure 13-118*. The hose from the pressure tank is attached to the bleed port on the brake assembly. A clear hose is attached to the vent port on the aircraft brake fluid reservoir or on the master cylinder if it incorporates the reservoir. The other end of this hose is placed in a collection container with a supply of clean brake fluid covering the end of the hose. The brake assembly bleed port is opened. The valve on the pressure tank hose is then opened allowing pure, air-free fluid to enter the brake system. Fluid containing trapped air is expelled through the hose attached to the vent port of the reservoir. The clear hose is monitored for air bubbles. When they cease to exist,

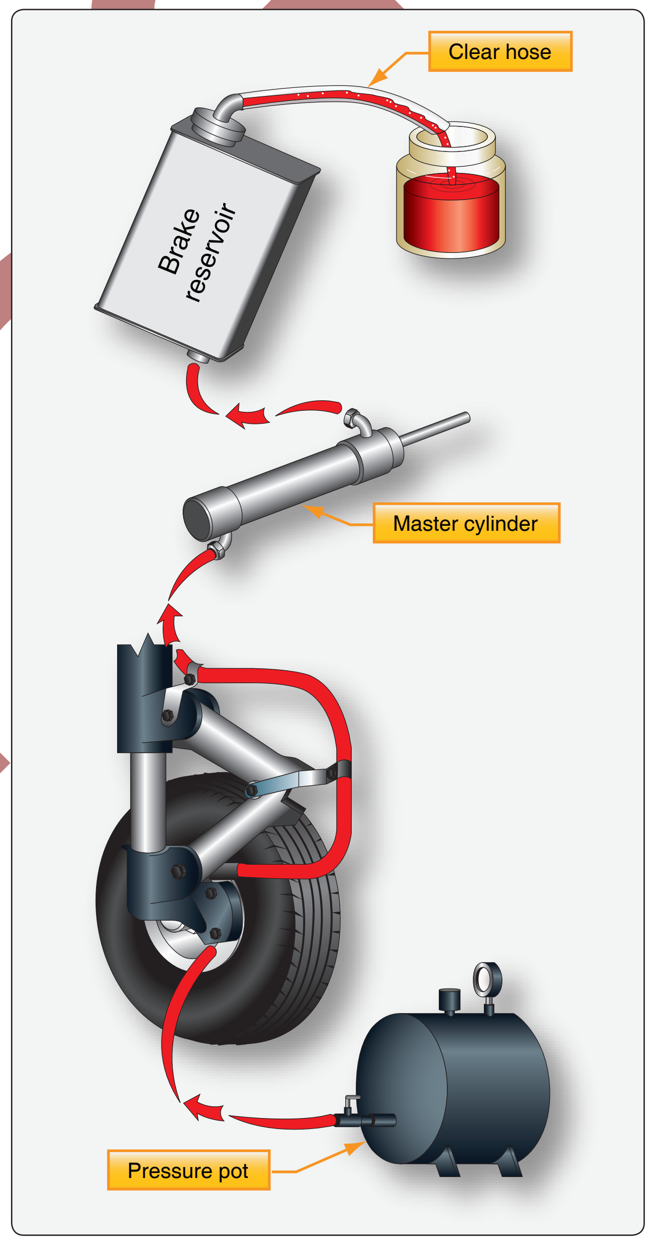


Figure 13-118. *Arrangement for bottom-up pressure bleeding of aircraft brakes. Fluid is pushed through the system until no air bubbles are visible in the hose at the top.*

the bleed port and pressure tank shutoff are closed, and the pressure tank hose is removed. The hose at the reservoir is also removed. Fluid quantity may need to be adjusted to assure the reservoir is not over filled. Note that it is absolutely necessary that the proper fluid be used to service any brake system including when bleeding air from the brake lines.

Brakes with master cylinders may also be gravity bled from the top down. This is a process similar to that used on automobiles. *[Figure 13-119]* Additional fluid is supplied to the aircraft brake reservoir so that the quantity does not exhaust while bleeding, which would cause the reintroduction of more air into the system. A clear hose is connected to the bleed port on the brake assembly. The other end is submersed in clean fluid in a container large enough to capture fluid expelled during the bleeding process. Depress the brake pedal and open the brake assembly bleed port. The piston in the master cylinder travels all the way to the end of the cylinder forcing air fluid mixture out of the bleed hose and into the container. With the pedal still depressed, close the bleed port. Pump the brake pedal to introduce more fluid from the reservoir ahead of the piston in the master cylinder. Hold the pedal down and open the bleed port on the brake assembly. More fluid and air is expelled through the hose into the container. Repeat this process until the fluid exiting the brake through the hose no longer contains any air. Tighten the bleed port fitting and ensure the reservoir is filled to the proper level.

Whenever bleeding the brakes, ensure that reservoirs and bleed tanks remain full during the process. Use only clean, specified fluid. Always check the brakes for proper operation, any leaks when bleeding is complete, and assure that the fluid quantity level is correct.

Bleeding Power Brake Systems

Top down brake bleeding is used in power brake systems. Power brakes are supplied with fluid from the aircraft hydraulic system. The hydraulic system should operate without air in the fluid as should the brake system. Therefore, bottom up pressure bleeding is not an option for power brakes. The trapped air in the brake system would be forced into the main hydraulic system, which is not acceptable.

Many aircraft with power brake systems accept the connection of an auxiliary hydraulic mule that can be used to establish pressure in the system for bleeding. Regardless, the aircraft system must be pressurized to bleed power brake systems. Attach a clear hose to the brake bleed port fitting on the brake assembly and immerse the other end of the hose in a container of clean hydraulic fluid. With the bleeder valve open, carefully apply the brake to allow aircraft hydraulic

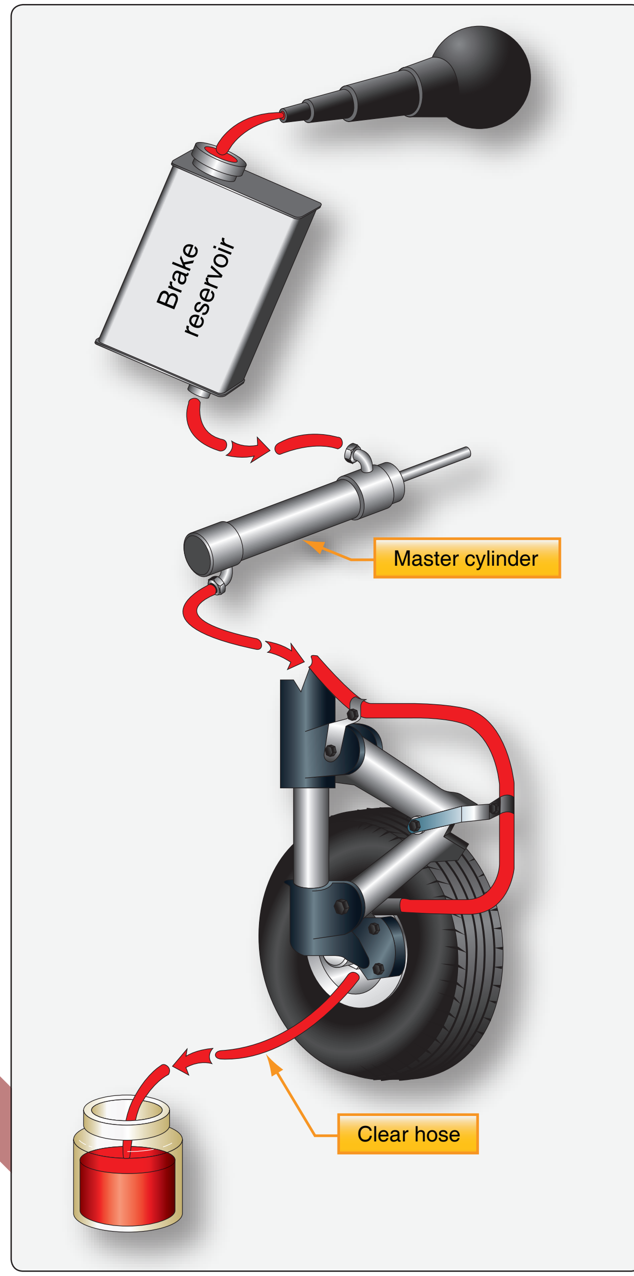


Figure 13-119. *Arrangement for top down or gravity bleeding of aircraft brakes.*

fluid to enter the brake system. The fluid expels the fluid contaminated with air out of the bleed hose into the container. When air is no longer visible in the hose, close the bleed valve and restore the hydraulic system to normal operation configuration.

Power brake systems on different aircraft contain many variations and a wide array of components that may affect the proper bleeding technique to be followed. Consult the manufacturer's maintenance information for the correct bleeding procedure for each aircraft. Be sure to bleed auxiliary and emergency brake systems when bleeding the normal brake system to ensure proper operation when needed.

Fluid Quantity and Type

As mentioned, it is imperative that the correct hydraulic fluid is used in each brake system. Seals in the brake system are designed for a particular hydraulic fluid. Deterioration and failure occurs when they are exposed to other fluids. Mineral-based fluid, such as MIL-H-5606 (red oil), should never be mixed with phosphate-ester based synthetic hydraulic fluid, such as Skydrol®. Contaminated brake/hydraulic systems must have all of the fluid evacuated and all seals replaced before the aircraft is released for flight.

Fluid quantity is also important. The technician is responsible for determining the method used to ascertain when the brake and hydraulic systems are fully serviced and for the maintenance of the fluid at this level. Consult the manufacturer's specifications for this information.

Inspection for Leaks

Aircraft brake systems should maintain all fluid inside lines and components and should not leak. Any evidence of a leak must be investigated for its cause. It is possible that the leak is a precursor to more significant damage that can be repaired, thus avoiding an incident or accident. *[Figure 13-120]*

Many leaks are found at brake system fittings. While this type of leak may be fixed by tightening an obviously loose connection, the technician is cautioned against over-tightening fittings. Removal of hydraulic pressure from the brake system followed by disconnection and inspection of the connectors is recommended. Over-tightening of fitting can cause damage and make the leak worse. MS flareless fitting are particularly sensitive to over-tightening. Replace all fittings suspected of damage. Once any leak is repaired, the brake system must be re-pressurized and tested for function as well as to ensure the leak no longer exists. Occasionally, a brake housing may seep fluid through the housing body. Consult the manufacturer's maintenance manual for limits and remove any brake assembly that seeps excessively.

Figure 13-120. *The cause of all aircraft brake leaks must be investigated, repaired, and tested before releasing the aircraft for flight.*

Proper Bolt Torque

The stress experience by the landing gear and brake system requires that all bolts are properly torqued. Bolts used to attach the brakes to the strut typically have the required torque specified in the manufacturer's maintenance manual. Check for torque specifications that may exist for any landing gear and brake bolts, and ensure they are properly tightened. Whenever applying torque to a bolt on an aircraft, use of a calibrated torque wrench is required.

Off Aircraft Brake Servicing and Maintenance

Certain servicing and maintenance of an aircraft brake assembly is performed while it has been removed from the aircraft. A close inspection of the assembly and its many parts should be performed at this time. Some of the inspection items on a typical assembly follow.

Bolt and Threaded Connections

All bolts and threaded connections are inspected. They should be in good condition without signs of wear. Self-locking nuts should still retain their locking feature. The hardware should be what is specified in the brake manufacturer's parts manual. Many aircraft brake bolts, for example, are not standard hardware and may be of closer tolerance or made of a different material. The demands of the high stress environment in which the brakes perform may cause brake failure if improper substitute hardware is used. Be sure to check the condition of all threads and O-ring seating areas machined into the housing. The fittings threaded into the housing must also be checked for condition.

Discs

Brake discs must be inspected for condition. Both rotating and stationary discs in a multiple disc brake can wear. Uneven wear can be an indication that the automatic adjusters may not be pulling the pressure plate back far enough to relieve all pressure on the disc stack.

Stationary discs are inspected for cracks. Cracks usually extend from the relief slots, if so equipped. On multiple disc brakes, the slots that key the disc to the torque tube must also be inspected for wear and widening. The discs should engage the torque tube without binding. The maximum width of the slots is given in the maintenance manual. Cracks or excessive key slot wear are grounds for rejection. Brake wear pads or linings must also be inspected for wear while the brake assembly is removed from the aircraft. Signs of uneven wear should be investigated, and the problem corrected. The pads may be replaced if worn beyond limits as long as the stationary disc upon which they mount passes inspection. Follow the manufacturer's procedures for inspections and for pad replacement.

Rotating discs must be similarly inspected. The general condition of the disc must be observed. Glazing can occur when a disc or part of a disc is overheated. It causes brake squeal and chatter. It is possible to resurface a glazed disc if the manufacturer allows it. Rotating discs must also be inspected in the drive key slot or drive tang area for wear and deformation. Little damage is allowed before replacement is required.

The pressure plate and back plate on multiple disc brakes must be inspected for freedom of movement, cracks, general condition, and warping. New linings may be riveted to the plates if the old linings are worn and the condition of the plate is good. Note that replacing brake pads and linings by riveting may require specific tools and technique as described in the maintenance manual to ensure secure attachment. Minor warping can be straightened on some brake assemblies.

Automatic Adjuster Pins

A malfunctioning automatic adjuster assembly can cause the brakes to drag on the rotating disc(s) by not fully releasing and pulling the lining away from the disc. This can lead to excessive, uneven lining wear and disc glazing. The return pin must be straight with no surface damage so it can pass through the grip without binding. Damage under the head can weaken the pin and cause failure. Magnetic inspection is sometimes used to inspect for cracks.

The components of the grip and tube assembly must be in good condition. Clean and inspect in accordance with the manufacturer's maintenance instructions. The grip must move with the force specified and must move through its full range of travel.

Torque Tube

A sound torque tube is necessary to hold the brake assembly stable on the landing gear. General visual inspection should be made for wear, burrs, and scratches. Magnetic particle inspection is used to check for cracks. The key areas should be checked for dimension and wear. All limits of damage are referenced in the manufacturer's maintenance data. The torque tube should be replaced if a limit is exceeded.

Brake Housing and Piston Condition

The brake housing must be inspected thoroughly. Scratches, gouges, corrosion, or other blemishes may be dressed out and the surface treated to prevent corrosion. Minimal material should be removed when doing so. Most important is that there are no cracks in the housing. Fluorescent dye penetrant is typically used to inspect for cracks. If a crack is found, the housing must be replaced. The cylinder area(s) of the housing must be dimensionally checked for wear. Limits are specified in the manufacturer's maintenance manual.

The brake pistons that fit into the cylinders in the housing must also be checked for corrosion, scratches, burrs, etc. Pistons are also dimensionally checked for wear limits specified in the maintenance data. Some pistons have insulators on the bottom. They should not be cracked and should be of a minimal thickness. A file can be used to smooth out minor irregularities.

Seal Condition

Brake seals are very important. Without properly functioning seals, brake operation will be compromised, or the brakes will fail. Over time, heat and pressure mold a seal into the seal groove and harden the material. Eventually, resilience is reduced and the seal leaks. New seals should be used to replace all seals in the brake assembly. Acquire seals by part number in a sealed package from a reputable supplier to avoid bogus seals and ensure the correct seals for the brake assembly in question. Check to ensure the new seals have not exceeded their shelf life, which is typically three years from the cure date.

Many brakes use back-up rings in the seal groove to support the O-ring seals and reduce the tendency of the seal to extrude into the space which it is meant to seal. These are often made of Teflon® or similar material. Back-up seals are installed on the side of the O-ring away from the fluid pressure. *[Figure 13-121]* They are often reusable.

Replacement of Brake Linings

In general aviation, replacement of brake linings is commonly done in the hangar. The general procedure used on two common brake assemblies is given. Follow the actual manufacturer's instruction when replacing brake linings on any aircraft brake assembly.

Goodyear Brakes

To replace the linings on a Goodyear single disc brake assembly, the aircraft must be jacked and supported. Detach the anti-rattle clips that help center the disc in the wheel before removing the wheel from the axle. The disc

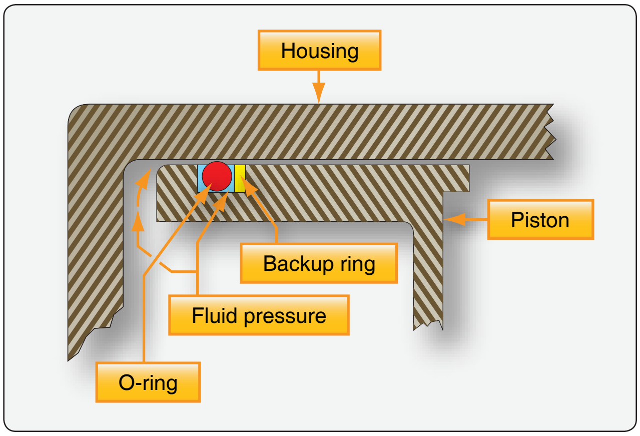


Figure 13-121. *Back-up rings are used to keep O-rings from extruding into the space between the piston and the cylinder. They are positioned on the side of the O-ring away from the fluid pressure.*

remains between the inner and outer lining when the wheel is removed. Extract the disc to provide access to the old lining pucks. These can be removed from the cavities in the housing and replaced with new pucks. Ensure the smooth braking surface of the puck contacts the disc. Reinsert the disc between the linings. Reinstall the wheel and anti-rattle clips. Tighten the axle nut in accordance with the manufacturer's instructions. Secure it with a cotter pin and lower the aircraft from the jack. *[Figure 13-122]*

Cleveland Brakes

The popular Cleveland brake uniquely features the ability to change the brake linings without jacking the aircraft or removing the wheel. On these assemblies, the torque plate is bolted to the strut while the remainder of the brake is assembled on the anchor bolts. The disc rides between the pressure plate and back plate. Linings are riveted to both plates. By unbolting the cylinder housing from the backplate, the backplate is freed to drop away from the torque plate. The remainder of the assembly is pulled away, and the pressure plate slides off of the torque bolts. *[Figure 13-123]*

The rivets that hold the linings on the pressure plate and back plate are removed with a knockout punch. After a thorough inspection, new linings are riveted to the pressure plate and backplate using a rivet clinching tool *[Figure 13-124]* Kits are sold that supply everything needed to perform the operation. The brake is reassembled in the reverse order. Be certain to include any shims if required. The bolts holding the backplate to the cylinder assembly must be torqued according to manufacturer specifications and safetied. The manufacturer's data also provides a burn in procedure. The aircraft is taxied at a specified speed, and the brakes are smoothly applied. After a cooling period, the process is repeated, thus preparing the linings for service.

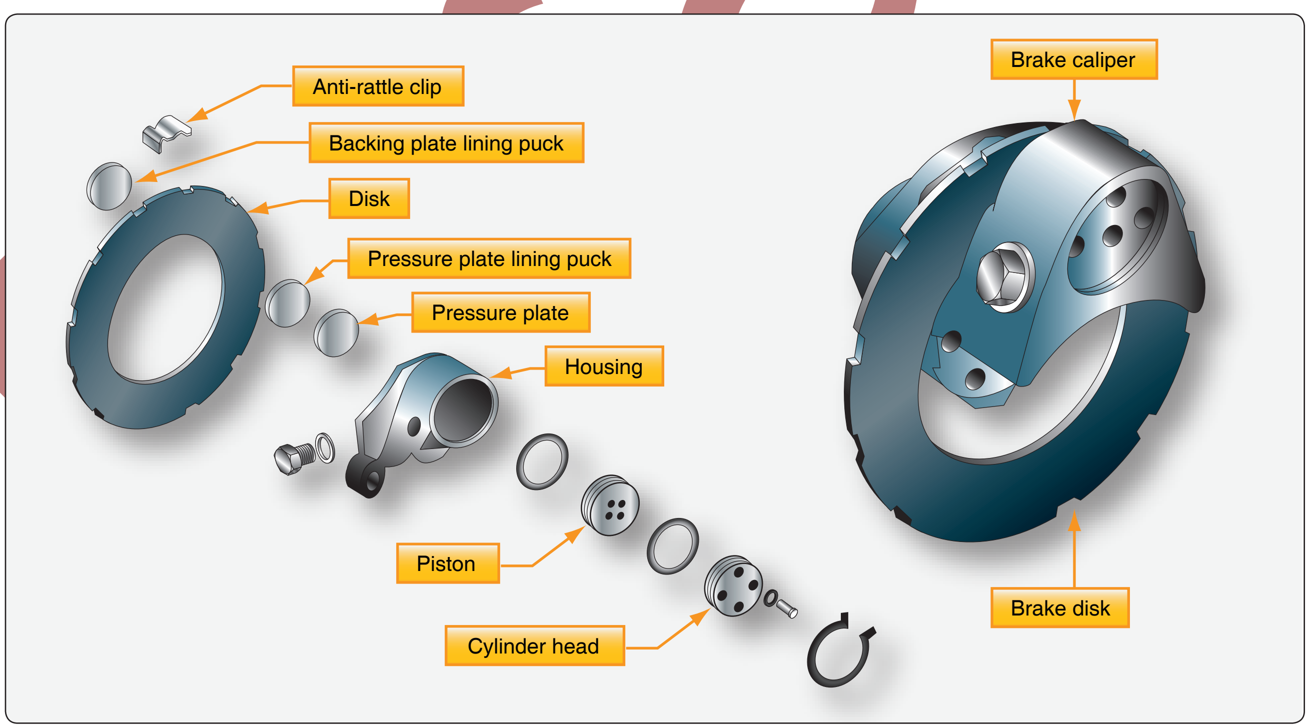


Figure 13-122. *Goodyear brake lining replacement requires that the wheel be removed from the axle to access the brake assembly. The lining pucks slip into recesses in the brake housing.*

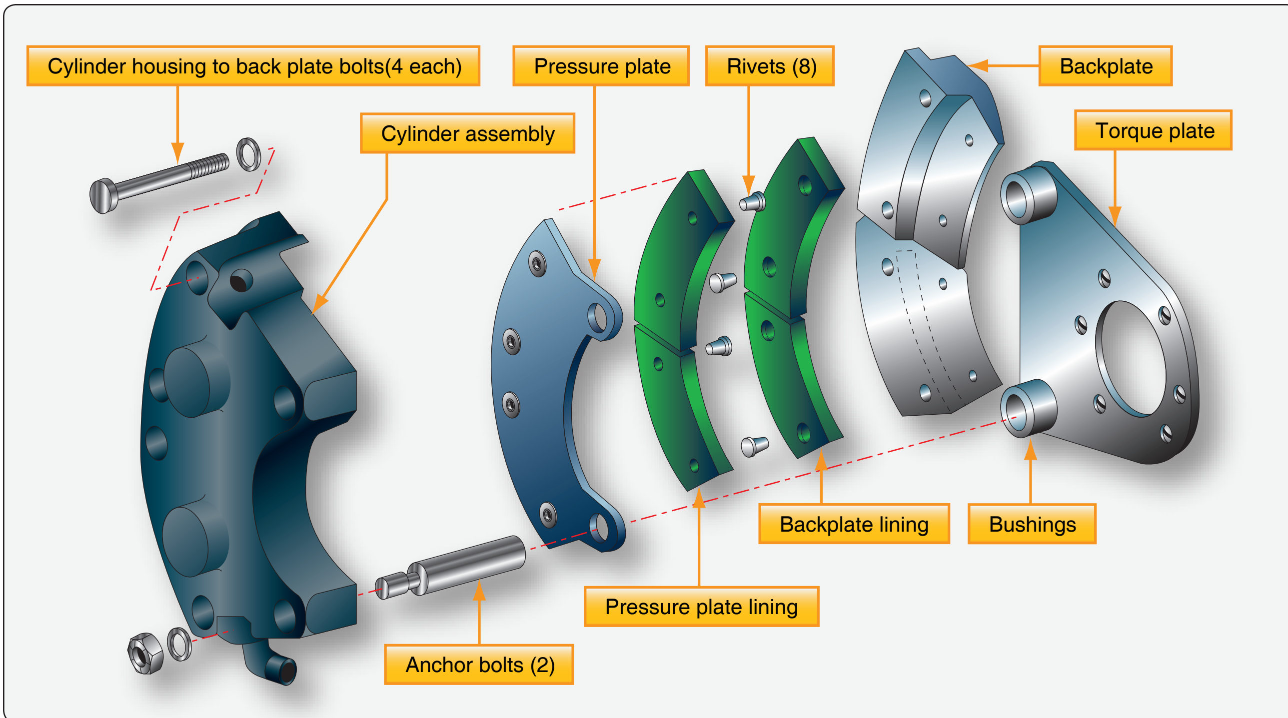


Figure 13-123. *A Cleveland brake disassembles once the four bolts holding the cylinder to the backplate are removed while the aircraft wheel remains in place. The pressure plate slides off the anchor bolts and linings can be replaced by riveting on the pressure plate and back plate.*

Brake Malfunctions and Damage

Aircraft brakes operate under extreme stress and varied conditions. They are susceptible to malfunction and damage. A few common brake problems are discussed in this section.

Overheating

While aircraft brakes slow the aircraft by changing kinetic energy into heat energy, overheating of the brakes is not desirable. Excessive heat can damage and distort brake parts weakening them to the point of failure. Protocol for brake usage is designed to prevent overheating. When a brake shows signs of overheating, it must be removed from the aircraft and inspected for damage. When an aircraft is involved in an aborted takeoff, the brakes must be removed and inspected to ensure they withstood this high level of use.

The typical post-overheat brake inspection involves removal of the brake from the aircraft and disassembly of the brakes. All of the seals must be replaced. The brake housing must be checked for cracks, warping, and hardness per the maintenance manual. Any weakness or loss of heat treatment could cause the brake to fail under high-pressure braking. The brake discs must also be inspected. They must not be warped, and the surface treatment must not be damaged or transferred to an adjacent disc. Once reassembled, the brake should be bench tested for leaks and pressure tested for operation before being installed on the aircraft.

Figure 13-124. *Rivet setting tool is used to install brake linings on Cleveland brake pressure plates and back plates.*

Dragging

Brake drag is a condition caused by the linings not retracting from the brake disc when the brakes are no longer being applied. It can be caused by several different factors. Brakes that drag are essentially partially on at all times. This can cause excessive lining wear and overheating leading to damage to the disc(s).

A brake may drag when the return mechanism is not functioning properly. This could be due to a weak return spring, the return pin slipping in the auto adjuster pin grip, or similar malfunction. Inspect the auto adjuster(s) and return units on the brake when dragging is reported. An overheated brake that has warped the disc also causes brake drag. Remove the brake and perform a complete inspection as discussed in the previous section. Air in the brake fluid line can also cause brake drag. Heat causes the air to expand, which pushes the brake linings against the disc prematurely. If no damage has been caused when reported, bleed the brakes to remove the air from the system to eliminate the drag.

At all times, the technician should perform inspections to ensure the proper parts are used in the brake assembly. Improper parts, especially in the retraction/adjuster assemblies, can cause the brakes to drag.

Chattering or Squealing

Brakes may chatter or squeal when the linings do not ride smoothly and evenly along the disc. A warped disc(s) in a multiple brake disc stack produces a condition wherein the brake is actually applied and removed many times per minute. This causes chattering and, at high frequency, it causes squealing. Any misalignment of the disc stack out of parallel causes the same phenomenon. Discs that have been overheated may have damage to the surface layer of the disc. Some of this mix may be transferred to the adjacent disc resulting in uneven disc surfaces that also leads to chatter or squeal. In addition to the noise produced by brake chattering and squealing, vibration is caused that may lead to further damage of the brake and the landing gear system. The technician must investigate all reports of brake chattering and squealing.

Aircraft Tires and Tubes

Aircraft tires may be tube-type or tubeless. They support the weight of the aircraft while it is on the ground and provide the necessary traction for braking and stopping. The tires also help absorb the shock of landing and cushion the roughness of takeoff, rollout, and taxi operations. Aircraft tires must be carefully maintained to perform as required. They accept a variety of static and dynamic stresses and must do so dependably in a wide range of operating conditions.

Tire Classification

Aircraft tires are classified in various ways including by: type, ply rating, whether they are tube-type or tubeless, and whether they are bias ply tires or radials. Identifying a tire by its dimensions is also used. Each of these classifications is discussed as follows.

Types

A common classification of aircraft tires is by type as classified by the United States Tire and Rim Association. While there are nine types of tires, only Types I, III, VII, and VIII, also known as a Three-Part Nomenclature tires, are still in production.

Type I tires are manufactured, but their design is no longer active. They are used on fixed gear aircraft and are designated only by their nominal overall diameter in inches. These are smooth profile tires that are obsolete for use in the modern aviation fleet. They may be found on older aircraft.

Type III tires are common general aviation tires. They are typically used on light aircraft with landing speeds of 160 miles per hour (mph) or less. Type III tires are relatively low-pressure tires that have small rim diameters when compared to the overall width of the tire. They are designed to cushion and provide flotation from a relatively large footprint. Type III tires are designated with a two-number system. The first number is the nominal section width of the tire, and the second number is the diameter of the rim the tire is designed to mount upon. *[Figure 13-125]*

Type VII tires are high performance tires found on jet aircraft. They are inflated to high-pressure and have exceptional high load carrying capability. The section width of Type VII tires is typically narrower than Type III tires. Identification of Type VII aircraft tires involves a two-number system. An X is used between the two numbers. The first number designates the nominal overall diameter of the tire. The second number designates the section width. *[Figure 13-126]*

Type VIII aircraft tires are also known as three-part nomenclature tires. *[Figure 13-127]* They are inflated to very high-pressure and are used on high-performance jet aircraft. The typical Type VIII tire has relatively low profile and is capable of operating at very high speeds and very high loads. It is the most modern design of all tire types. The three-part nomenclature is a combination of Type III and Type VII nomenclature where the overall tire diameter, section width, and rim diameter are used to identify the tire. The X and "–" symbols are used in the same respective positions in the designator.

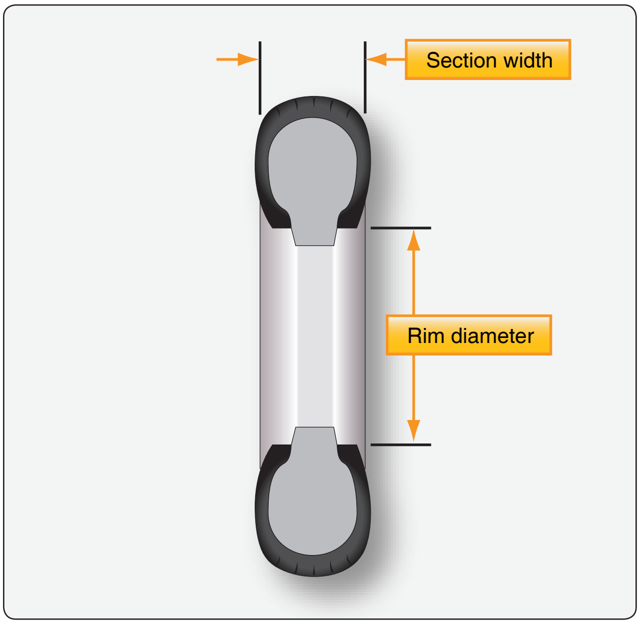


Figure 13-125. *Type III aircraft tires are identified via a two-number system with a (-) separating the numbers. The first number is the tire section width in inches. The second number is the rim diameter in inches. For example: 6.00 – 6 is a Cessna 172 tire that is 6.00 inches wide and fits on a rim that has a diameter of 6 inches.*

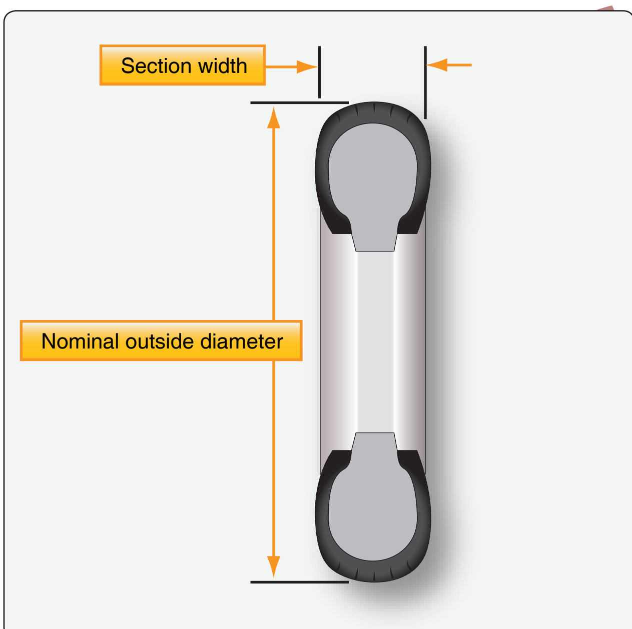


Figure 13-126. *A Type VII aircraft tire is identified by its two-number designation. The first number represents the tire's overall diameter in inches and the second number represents the section width in inches. Type VII designators separate the first and second number an "X." For example: 26 X 6.6 identifies a tire that is 26 inches in diameter with a 6.6-inch nominal width.*

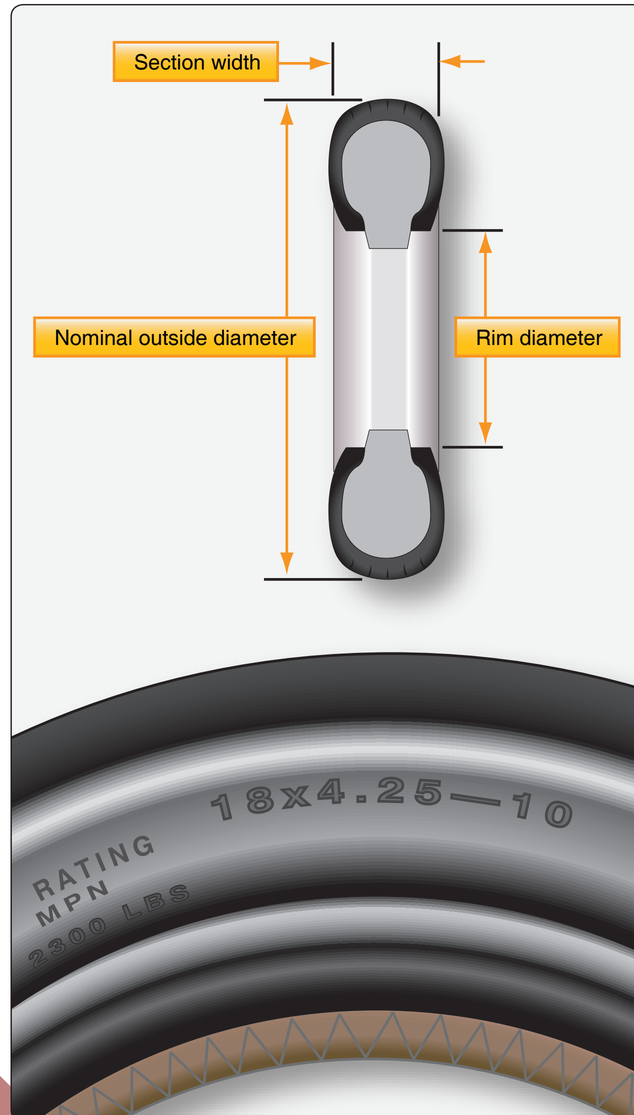


Figure 13-127. *A Type VIII or three-part nomenclature tire is identified by 3 parameters: overall diameter, section width, and rim diameter. They are arranged in that order with the first two separated by an "X" and the second two separated by a "–." For example: 18 X 4.25—10 designates a tire that is 18 inches in diameter with a 4.25-inch section width to be mounted on a 10-inch wheel rim.*

When three-part nomenclature is used on a Type VIII tire, dimensions may be represented in inches or in millimeters. Bias tires follow the designation nomenclature and radial tires replace the "–" with the letter R. For example, 30 X 8.8 R 15 designates a Type VIII radial aircraft tire with a 30-inch tire diameter, an 8.8-inch section width to be mounted on a 15-inch wheel rim.

A few special designators may also be found for aircraft tires. When a B appears before the identifier, the tire has a wheel rim to section width ratio of 60 to 70 percent with a bead taper of 15 degrees. When an H appears before the identifier, the tire has a 60 to 70 percent wheel rim to section width ratio but a bead taper of only 5 degrees.

Ply Rating

Tire plies are reinforcing layers of fabric encased in rubber that are laid into the tire to provide strength. In early tires, the number of plies used was directly related to the load the tire could carry. Nowadays, refinements to tire construction techniques and the use of modern materials to build up aircraft tires makes the exact number of plies somewhat irrelevant when determining the strength of a tire. However, a ply rating is used to convey the relative strength of an aircraft tire. A tire with a high ply rating is a tire with high strength able to carry heavy loads regardless of the actual number of plies used in its construction.

Tube-Type or Tubeless

As stated, aircraft tires can be tube-type or tubeless. This is often used as a means of tire classification. Tires that are made to be used without a tube inserted inside have an inner liner specifically designed to hold air. Tube-type tires do not contain this inner liner since the tube holds the air from leaking out of the tire. Tires that are meant to be used without a tube have the word tubeless on the sidewall. If this designation is absent, the tire requires a tube. Consult the aircraft manufacturer's maintenance information for any allowable tire damage and the use of a tube in a tubeless tire.

Bias Ply or Radial

Another means of classifying an aircraft tire is by the direction of the plies used in construction of the tire, either bias or radial. Traditional aircraft tires are bias ply tires. The plies are wrapped to form the tire and give it strength. The angle of the plies in relation to the direction of rotation of the tire varies between 30° and 60°. In this manner, the plies have the bias of the fabric from which they are constructed facing the direction of rotation and across the tire. Hence, they are called bias tires. The result is flexibility as the sidewall can flex with the fabric plies laid on the bias. *[Figure 13-128]*

Some modern aircraft tires are radial tires. The plies in radial tires are laid at a 90° angle to the direction of rotation of the tire. This configuration puts the non-stretchable fiber of the plies perpendicular to the sidewall and direction of rotation. This creates strength in the tire allowing it to carry high loads with less deformation. *[Figure 13-129]*

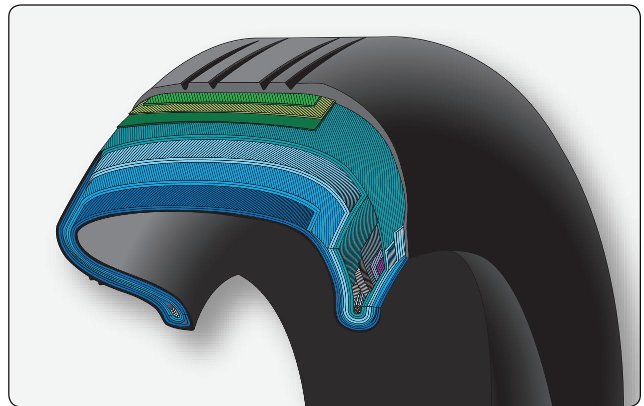


Figure 13-128. *A bias ply tire has the fabric bias oriented with and across the direction of rotation and the sidewall. Since fabric can stretch on the bias, the tire is flexible, and can absorb loads. Strength is obtained by adding plies.*

Tire Construction

An aircraft tire is constructed for the purpose it serves. Unlike an automobile or truck tire, it does not have to carry a load for a long period of continuous operation. However, an aircraft tire must absorb the high impact loads of landing and be able to operate at high speeds even if only for a short time. The deflection built into an aircraft tire is more than twice that of an automobile tire. This enables it to handle the forces during landings without being damaged. Only tires designed for an aircraft as specified by the manufacturer should be used.

It is useful to the understanding of tire construction to identify the various components of a tire and the functions contributed to the overall characteristics of a tire. Refer to *Figure 13-130* for tire nomenclature used in this discussion.

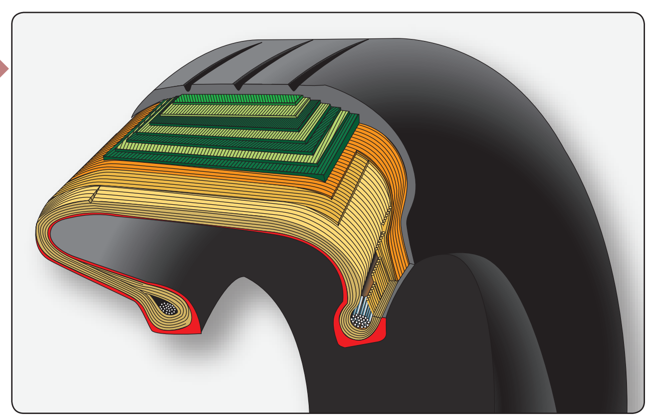


Figure 13-129. *A radial tire has the fiber strands of the ply fabric oriented with and at 90° to the direction of rotation and the tire sidewall. This restricts flexibility directionally and the flexibility of the sidewall while it strengthens the tire to carry heavy loads.*

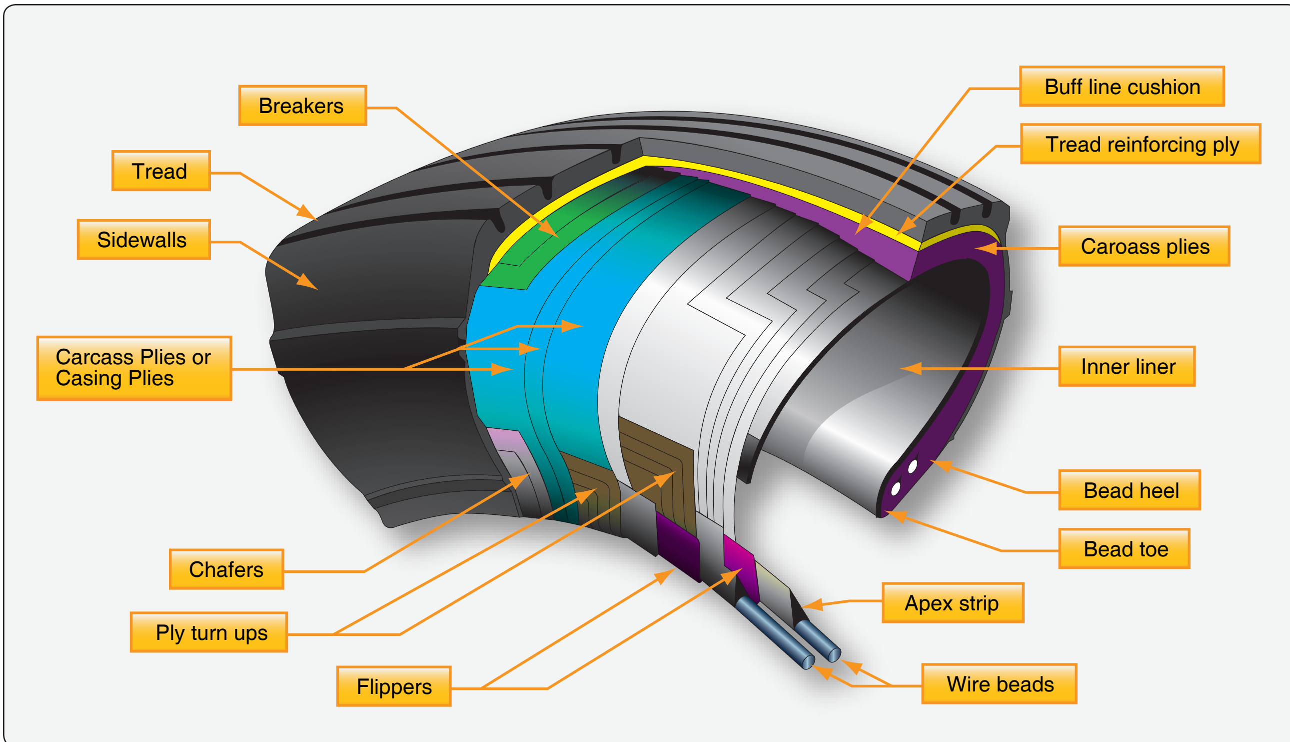


Figure 13-130. *Construction nomenclature of an aircraft tire.*

Bead

The tire bead is an important part of an aircraft tire. It anchors the tire carcass and provides a dimensioned, firm mounting surface for the tire on the wheel rim. Tire beads are strong. They are typically made from high-strength carbon steel wire bundles encased in rubber. One, two, or three bead bundles may be found on each side of the tire depending on its size and the load it is designed to handle. Radial tires have a single bead bundle on each side of the tire. The bead transfers the impact loads and deflection forces to the wheel rim. The bead toe is closest to the tire centerline and the bead heel fit against the flange of the wheel rim.

An apex strip is additional rubber formed around the bead to give a contour for anchoring the ply turn-ups. Layers of fabric and rubber called flippers are placed around the beads to insulate the carcass from the beads and improve tire durability. Chafers are also used in this area. Chafer strips made of fabric or rubber are laid over the outer carcass plies after the plies are wrapped around the beads. The chafers protect the carcass from damage during mounting and demounting of the tire. They also help reduce the effects of wear and chafing between the wheel rim and the tire bead especially during dynamic operations.

Carcass Plies

Carcass plies, or casing plies as they are sometimes called, are used to form the tire. Each ply consists of fabric, usually nylon, sandwiched between two layers of rubber. The plies are applied in layers to give the tire strength and form the carcass body of the tire. The ends of each ply are anchored by wrapping them around the bead on both sides of the tire to form the ply turn-ups. As mentioned, the angle of the fiber in the ply is manipulated to create a bias tire or radial tire as desired. Typically, radial tires require fewer plies than bias tires.

Once the plies are in place, bias tires and radial tires each have their own type of protective layers on top of the plies but under the tread of the running surface of the tire. On bias tires, these single or multiple layers of nylon and rubbers are called tread reinforcing plies. On radial tires, an undertread and a protector ply do the same job. These additional plies stabilize and strengthen the crown area of the tire. They reduce tread distortion under load and increase stability of the tire at high speeds. The reinforcing plies and protector plies also help resist puncture and cutting while protecting the carcass body of the tire.

Tread

The tread is the crown area of the tire designed to come in contact with the ground. It is a rubber compound formulated to resist wear, abrasion, cutting, and cracking. It also is made to resist heat build-up. Most modern aircraft tire tread is formed with circumferential grooves that create tire ribs. The grooves provide cooling and help channel water from under the tire in wet conditions to increase adhesion to the ground surface. Tires designed for aircraft frequently operated from unpaved surfaces may have some type of cross-tread pattern. Older aircraft without brakes or brakes designed only to aid in taxi may not have any grooves in the tread. An all-weather tread may be found on some aircraft tires. This tread has typical circumferential ribs in the center of the tire with a diamond patterned cross tread at the edge of the tire. [*Figure 13-131]*

The tread is designed to stabilize the aircraft on the operating surface and wears with use. Many aircraft tires are designed with protective undertread layers as described above. Extra tread reinforcement is sometimes accomplished with breakers. These are layers of nylon cord fabric under the tread that strengthen the tread while protecting the carcass plies. Tires with reinforced tread are often designed to be re-treaded and used again once the tread has worn beyond limits. Consult the tire manufacturer's data for acceptable tread wear and re-tread capability for a particular tire.

Sidewall

The sidewall of an aircraft tire is a layer of rubber designed to protect the carcass plies. It may contain compounds designed to resist the negative effects of ozone on the tire. It also is the area where information about the tire is contained. The tire sidewall imparts little strength to the cord body. Its main function is protection.

The inner sidewall of a tire is covered by the tire inner liner. A tube-type tire has a thin rubber liner adhered to the inner surface to prevent the tube from chafing on the carcass plies. Tubeless tires are lined with a thicker, less permeable rubber. This replaces the tube and contains the nitrogen or inflation air within the tire and keeps from seeping through the carcass plies.

The inner liner does not contain 100 percent of the inflation gas. Small amounts of nitrogen or air seep through the liner into the carcass plies. This seepage is released through vent holes in the lower outer sidewall of the tires. These are typically marked with a green or white dot of paint and must be kept unobstructed. Gas trapped in the plies could expand with temperature changes and cause separation of the plies, thus weakening the tire leading to tire failure. Tube-type tires also have seepage holes in the sidewall to allow air trapped between the tube and the tire to escape. *[Figure 13-132]*

Chine

Some tire sidewalls are mounded to form a chine. A chine is a special built-in deflector used on nose wheels of certain aircraft, usually those with fuselage mounted engines. The chine diverts runway water to the side and away from the intake of the engines. *[Figure 13-131E]* Tires with a chine on both sidewalls are produced for aircraft with a single nose wheel.

Tire Inspection on the Aircraft

Tire condition is inspected while mounted on the aircraft on a regular basis. Inflation pressure, tread wear and condition, and sidewall condition are continuously monitored to ensure proper tire performance.

Inflation

To perform as designed, an aircraft tire must be properly inflated. The aircraft manufacturer's maintenance data

Figure 13-131. *Aircraft tire treads are designed for different uses. A is a rib tread designed for use on paved surfaces. It is the most common aircraft tire tread design. B is a diamond tread designed for unpaved runways. C is an all weather tread that combines a ribbed center tread with a diamond tread pattern of the edges. D is a smooth tread tire found on older, slow aircraft without brakes designed for stopping. E is a chine tire used on the nose gear of aircraft with fuselage mounted jet engines to deflect runway water away from the engine intake(s).*

Figure 13-132. *A sidewall vent marked by a colored dot must be kept free from obstruction to allow trapped air or nitrogen to escape from the carcass plies of the tire.*

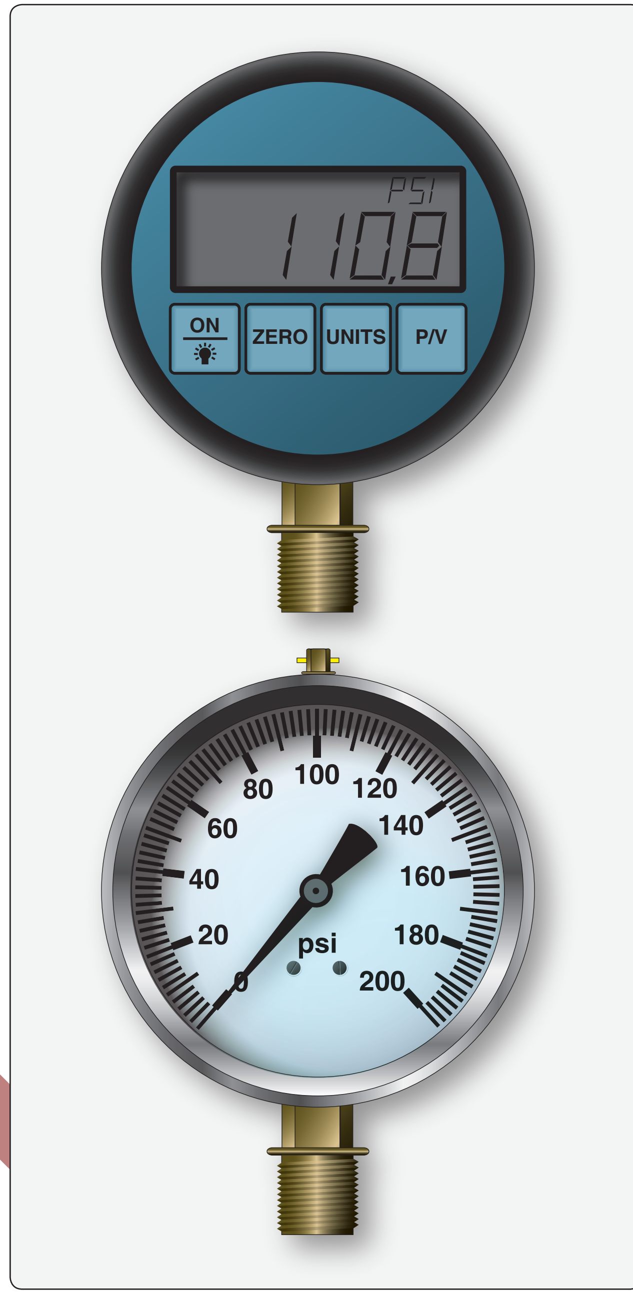


Figure 13-133. *A calibrated bourdon tube dial-type pressure gauge or a digital pressure gauge is recommended for checking tire pressure.*

must be used to ascertain the correct inflation pressure for a tire on a particular aircraft. Do not inflate to a pressure displayed on the sidewall of the tire or by how the tire looks. Tire pressure is checked while under load and is measured with the weight of the aircraft on the wheels. Loaded versus unloaded pressure readings can vary as much as 4 percent. Tire pressure measured with the aircraft on jacks or when the tire is not installed is lower due to the larger volume of the inflation gas space inside of the tire. On a tire designed to be inflated to 160 psi, this can result in a 6.4 psi error. A calibrated pressure gauge should always be used to measure inflation pressure. Digital and dial-type pressure gauges are more consistently accurate and preferred. *[Figure 13-133]*

Aircraft tires disperse the energy from landing, rollout, taxi, and takeoff in the form of heat. As the tire flexes, heat builds and is transferred to the atmosphere, as well as to the wheel rim through the tire bead. Heat from braking also heats the tire externally. A limited amount of heat is able to be handled by any tire beyond which structural damage occurs.

An improperly inflated aircraft tire can sustain internal damage that is not readily visible and that can lead to tire failure. Tire failure upon landing is always dangerous. An aircraft tire is designed to flex and absorb the shock of landing. Temperature rises as a result. However, an underinflated tire may flex beyond design limits of the tire. This causes excessive heat build-up that weakens the carcass construction. To ensure tire temperature is maintained within limits, tire pressure must be checked and maintained within the proper range on a daily basis or before each flight if the aircraft is only flown periodically.

Tire pressure should be measured at ambient temperature. Fluctuations of ambient temperature greatly affect tire pressure and complicate maintenance of pressure within the allowable range for safe operation. Tire pressure typically changes 1 percent for every 5 °F of temperature change. When aircraft are flown from one environment to another, ambient temperature differences can be vast. Maintenance personnel must ensure that tire pressure is adjusted accordingly. For example, an aircraft with the correct tire pressure departing Phoenix, Arizona where the ambient temperature is 100 °F arrives in Vail, Colorado where the temperature is 50 °F. The 50° difference in ambient temperature results in a 10 percent reduction in tire pressure. Therefore, the aircraft could land with underinflated tires that may be damaged due to over-temperature from flexing beyond design limits as described above. An increase in tire pressure before takeoff in Phoenix, Arizona prevents this problem as long as the tires are not inflated beyond the allowable limit provided in the maintenance data.

When checking tire pressure, allow 3 hours to elapse after a typical landing to ensure the tire has cooled to ambient temperature. The correct tire pressure for each ambient temperature is typically provided by the manufacturer on a table or graph.

In addition to overheating, under inflated aircraft tires wear unevenly, which leads to premature tire replacement. They may also creep or slip on the wheel rim when under stress or when the brakes are applied. Severely under inflated tires can pinch the sidewall between the rim and the runway causing sidewall and rim damage. Damage to the bead and lower sidewall area are also likely. This type of abuse like any over flexing damages the integrity of the tire and it must be replaced. In dual-wheel setups, a severely underinflated tire affects both tires and both should be replaced.

Over inflation of aircraft tires is another undesirable condition. While carcass damage due to overheating does not result, adherence to the landing surface is reduced. Over a long period of time, over inflation leads to premature tread wear. Therefore, over inflation reduces the number of cycles in service before the tire must be replaced. It makes the tire more susceptible to bruises, cutting, shock damage, and blowout. *[Figure 13-134]*

Tread Condition

Condition of an aircraft tire tread is able to be determined while the tire is inflated and mounted on the aircraft. The following is a discussion of some of the tread conditions and damage that the technician may encounter while inspecting tires.

Tread Depth and Wear Pattern

Evenly worn tread is a sign of proper tire maintenance. Uneven tread wear has a cause that should be investigated and corrected. Follow all manufacturer instructions specific to the aircraft when determining the extent and serviceability of a worn tire. In the absence of this information, remove any tire that has been worn to the bottom of a tread groove along more than ⅛ of the circumference of the tire. If either the protector ply on a radial tire or the reinforcing ply on a bias tire is exposed for more than ⅛ of the tire circumference, the tire should also be removed. A properly maintained evenly worn tire usually reaches its wear limits at the centerline of the tire. *[Figure 13-135]*

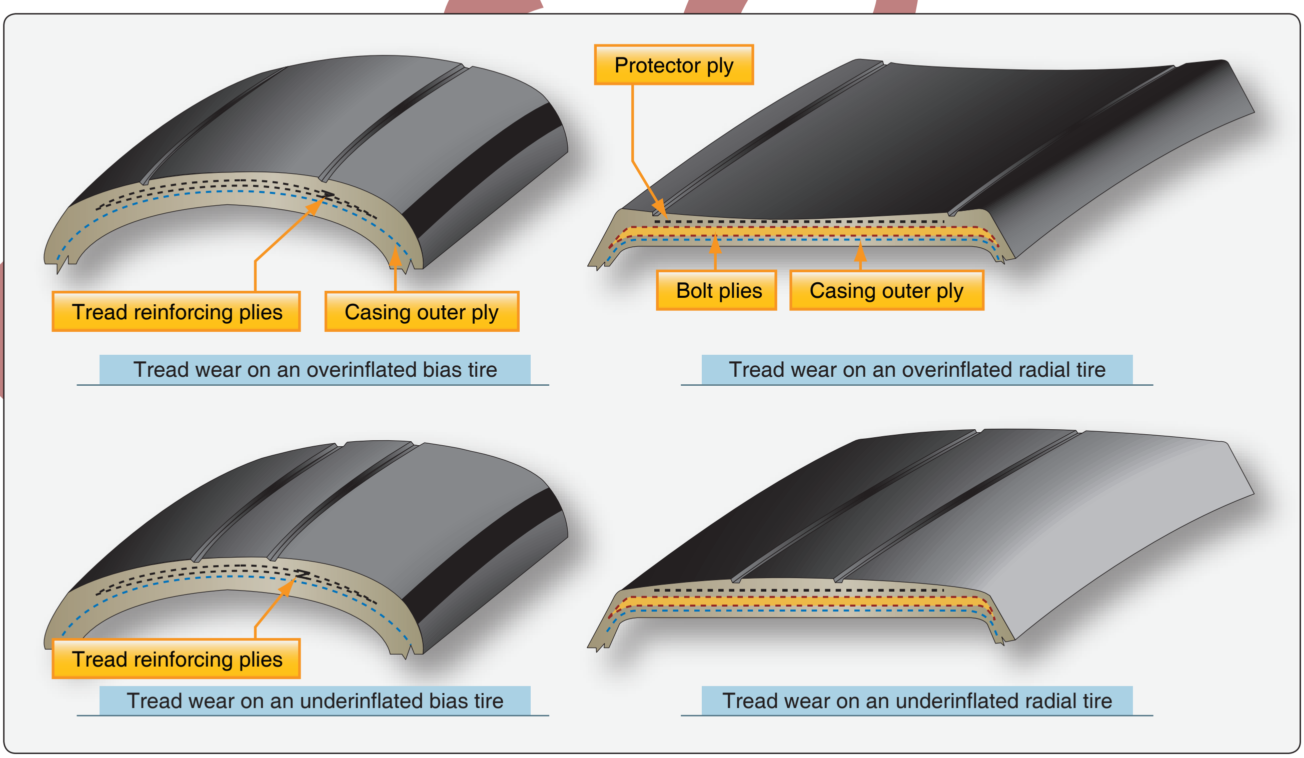


Figure 13-134. *Tires that are overinflated lack adherence to the runway and develop excess tread wear in the center of the tread. Tires that are underinflated develop excess tread wear on the tire shoulders. Overheating resulting in internal carcass damage and potential failure are possible from flexing the tire beyond design limits.*

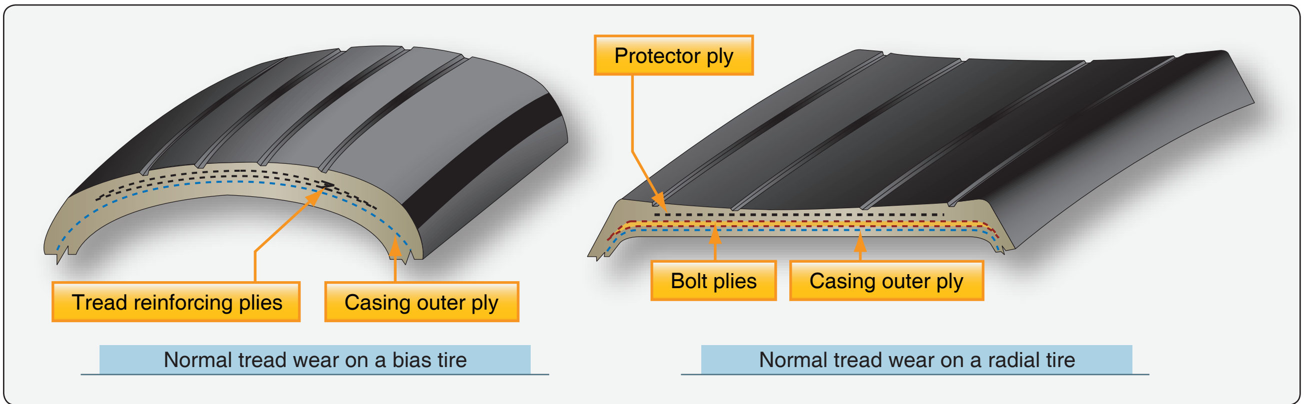


Figure 13-135. *Normal tire wear.*

Asymmetrical tread wear may be caused by the wheels being out of alignment. Follow the manufacturer's instructions while checking caster, camber, tow-in, and tow-out to correct this situation. Occasionally, asymmetrical tire wear is a result of landing gear geometry that cannot, or is not, required to be corrected. It may also be caused by regular taxiing on a single engine or high-speed cornering while taxiing. It is acceptable to remove the tire from the wheel rim, turn it around, and remount it to even up tread wear if the tire passes all other criterion of inspection for serviceability.

Removal of a tire before it is worn beyond limits to be eligible for retreading is cost effective and good maintenance practice. Considerable traction is lost when tire tread is severely worn and must also be considered when inspecting a tire for condition. *[Figure 13-136]* Consult airframe manufacturer and tire manufacturer specifications for wear and retread limitations.

Tread Damage

In addition to tread wear, an aircraft tire should be inspected for damage. Cuts, bruises, bulges, imbedded foreign objects, chipping, and other damage must be within limits to continue the tire in service. Some acceptable methods of dealing with this type of damage are described below. All damage, suspected damage, and areas with leaks should be marked with chalk, a wax marker, paint stick, or other device before the tire is deflated or removed. Often, it is impossible to relocate these areas once the tire is deflated. Tires removed for retread should be marked in damaged areas to enable closer inspection of the extent of the damage before the new tread is installed. *[Figure 13-137]*

Foreign objects imbedded in a tire's tread are of concern and should be removed when not imbedded beyond the tread. Objects of questionable depth should only be removed after the tire has been deflated. A blunt awl or appropriately sized screwdriver can be used to pry the object from the tread. Care must be exercised to not enlarge the damaged area with the removal tool. *[Figure 13-138]* Once removed, assess the remaining damage to determine if the tire is serviceable. A round hole caused by a foreign object is acceptable only if it is $\frac{3}{8}$-inch or less in diameter. Embedded objects that penetrate or expose the casing cord body of a bias ply tire or the tread belt layer of a radial tire cause the tire to become unairworthy and it must be removed from service.

Cuts and tread undercutting can also render a tire unairworthy. A cut that extends across a tread rib is cause for tire removal. These can sometimes lead to a section of the rib to peel off

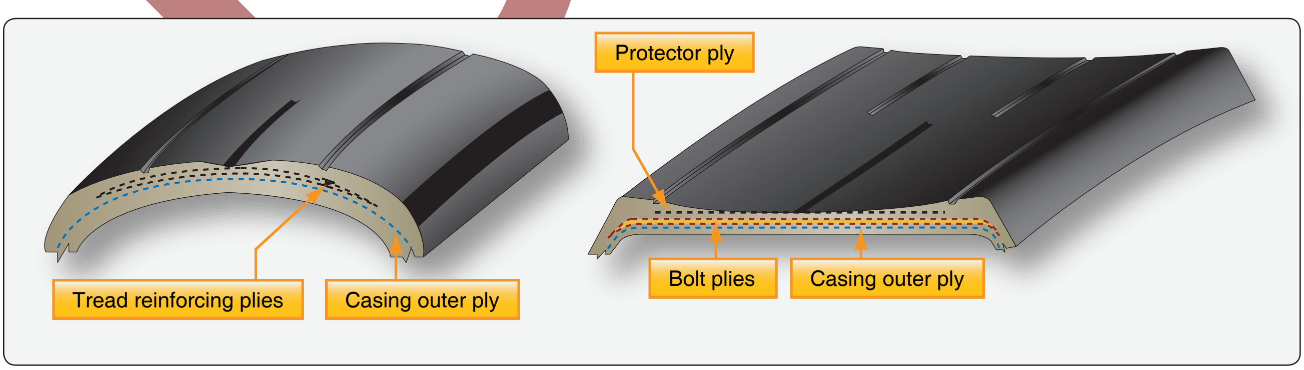


Figure 13-136. *Tread wear on a bias ply tire (left) and a radial tire (right) show wear beyond limits of serviceability but still eligible to be retreaded.*

Figure 13-137. *Marking of damaged area to enable closer inspection.*

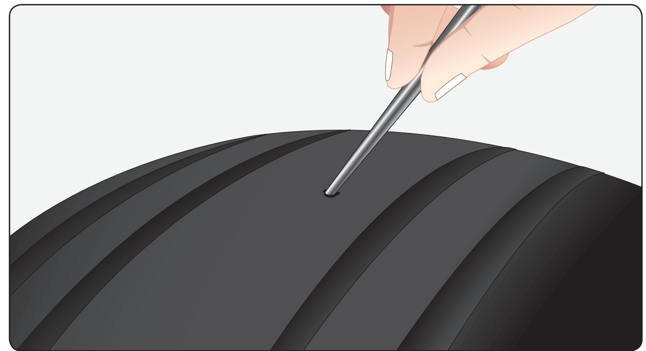


Figure 13-138. *Deflate a tire before removing or probing any area where a foreign object is lodged.*

the tire. *[Figure 13-139]* Consult the aircraft maintenance manual, airline operations manual, or other technical documents applicable to the aircraft tire in question.

A flat spot on a tire is the result of the tire skidding on the runway surface while not rotating. This typically occurs when the brakes lock on while the aircraft is moving. If the flat spot damage does not expose the reinforcing ply of a bias tire or the protector ply of a radial tire, it may remain in service. However, if the flat spot causes vibration, the tire must be removed. Landing with a brake applied can often cause a severe flat spot that exposes the tire under tread. It can also cause a blowout. The tire must be replaced in either case. *[Figure 13-140]*

A bulge or separation of the tread from the tire carcass is cause for immediate removal and replacement of the tire.

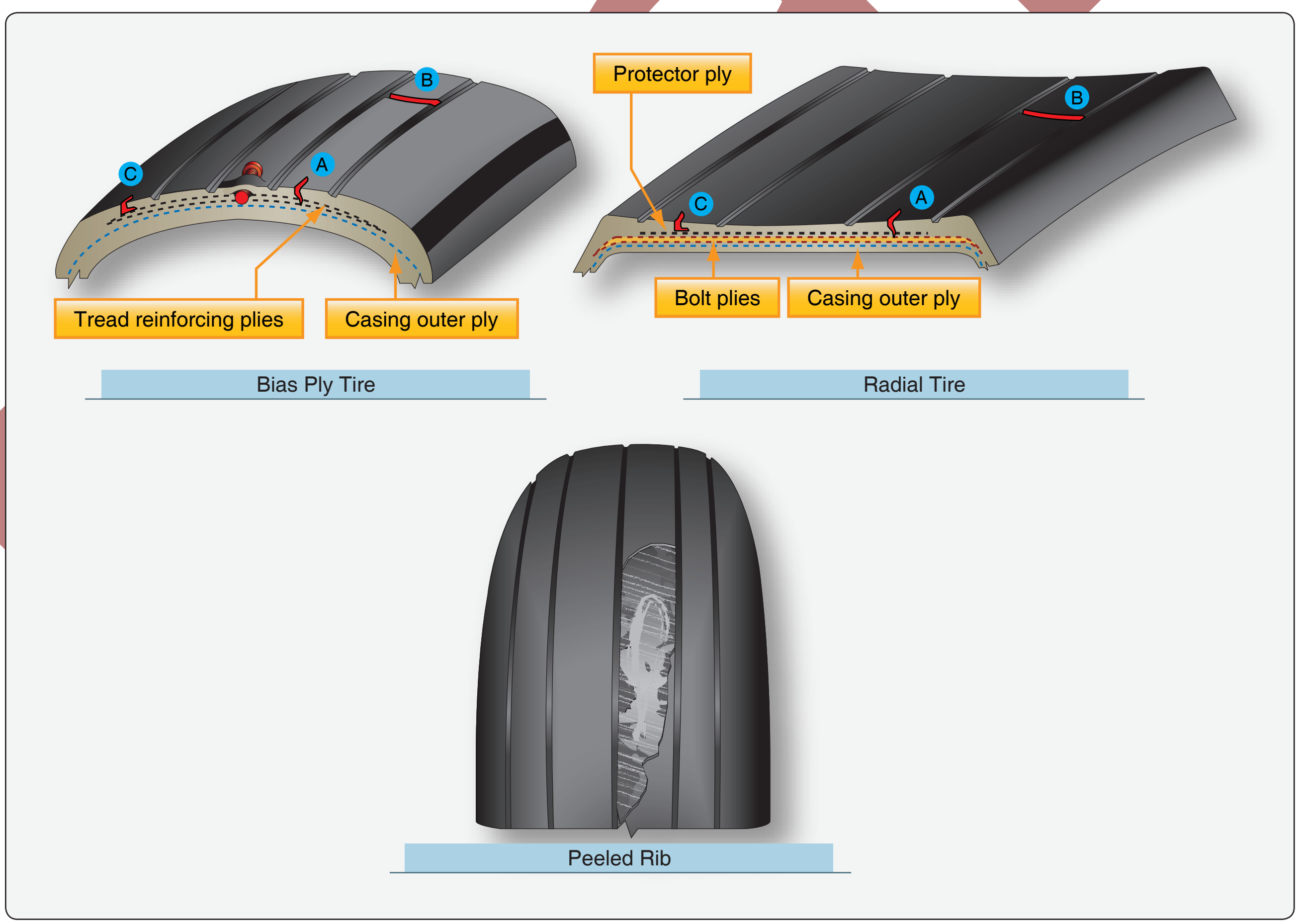


Figure 13-139. *Remove an aircraft tire from service when the depth of a cut exposes the casing outer plies of a bias ply tire or the outer belt layer of a radial tire (A); a tread rib has been severed across the entire width (B); or, when undercutting occurs at the base of any cut (C). These conditions may lead to a peeled rib.*

Figure 13-140. *Landing with the brake on causes a tire flat spot that exposes the under tread and requires replacement of the tire.*

Mark the area before deflation as it could easily become undetectable without air in the tire. *[Figure 13-141]*

Operation on a grooved runway can cause an aircraft tire tread to develop shallow chevron shaped cuts. These cuts are allowed for continued service, unless chunks or cuts into the fabric of the tire result. Deep chevrons that cause a chunk of the tread to be removed should not expose more than 1 square inch of the reinforcing or protector ply. Consult the applicable inspection parameters to determine the allowable extent of chevron cutting. *[Figure 13-142]*

Tread chipping and chunking sometimes occurs at the edge of the tread rib. Small amounts of rubber lost in this way are permissible. Exposure of more than 1 square inch of the reinforcing or protector ply is cause for removal of the tire. *[Figure 13-143]*

Figure 13-142. *Chevron cuts in a tire are caused by operation on grooved runway surfaces. Shallow chevron cuts are permitted on aircraft tires.*

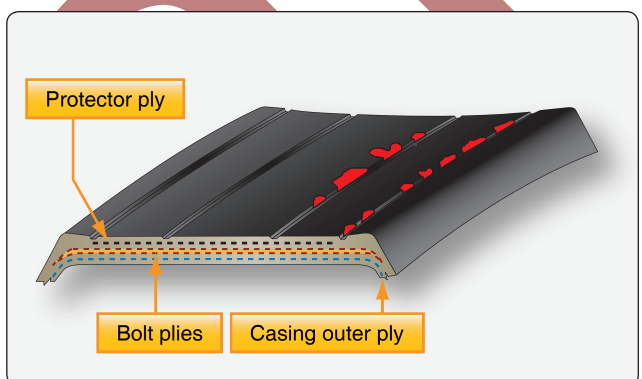


Figure 13-143. *Tread chipping and chunking of a tire requires that the tire be removed from service if more than 1 square inch of the reinforcing ply or protector ply is exposed.*

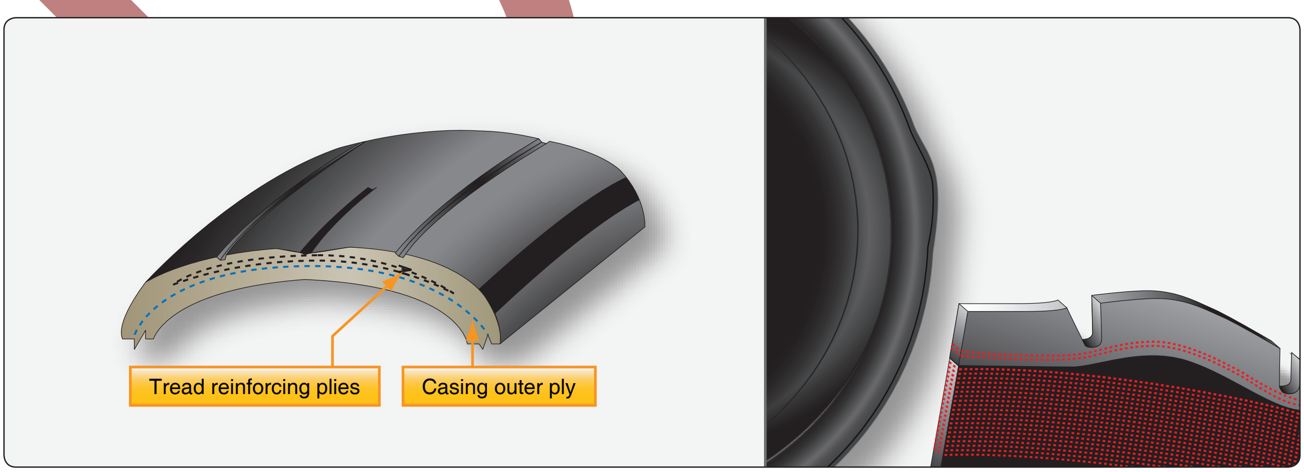


Figure 13-141. *Bulges and tread separation are cause for removal of a tire from service.*

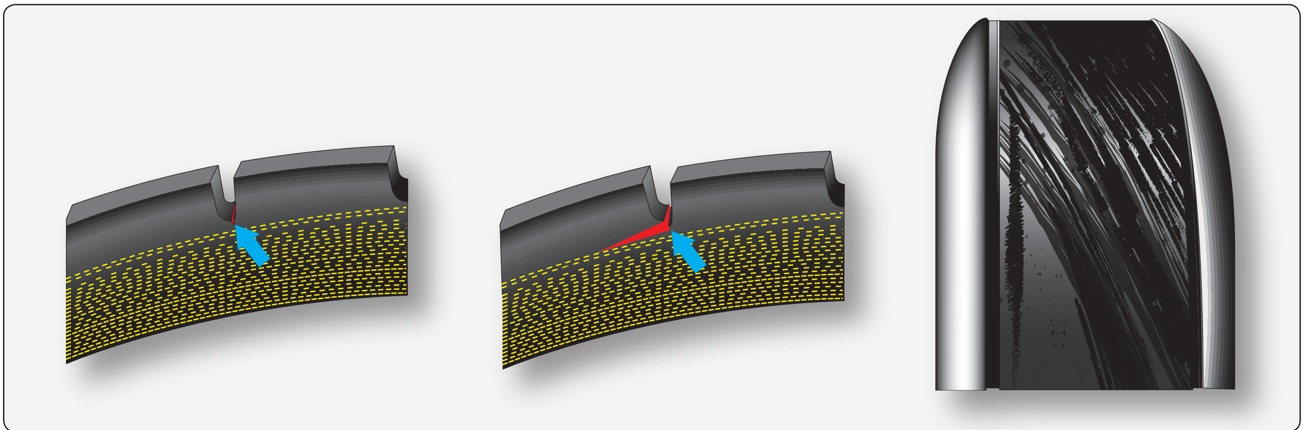


Figure 13-144. *A thrown tread can result from a groove crack or tread undercutting and must be removed from service.*

Cracking in a tread groove of an aircraft tire is generally not acceptable if more than ¼-inch of the reinforcing or protector ply is exposed. Groove cracks can lead to undercutting of the tread, which eventually can cause the entire tread to be thrown from the tire. *[Figure 13-144]*

Oil, hydraulic fluid, solvents, and other hydrocarbon substances contaminate tire rubber, soften it, and make it spongy. A contaminated tire must be removed from service. If any volatile fluids come in contact with the tire, it is best to wash the tire or area of the tire with denatured alcohol followed by soap and water. Protect tires from contact with potentially harmful fluids by covering tires during maintenance in the landing gear area.

Tires are also subject to degradation from ozone and weather. Tires on aircraft parked outside for long periods of times can be covered for protection from the elements. *[Figure 13-145]*

Figure 13-145. *Cover tires to protect from harmful chemicals and from the elements when parked outside for long periods of time.*

Sidewall Condition

The primary function of the sidewall of an aircraft tire is protection of the tire carcass. If the sidewall cords are exposed due to a cut, gouge, snag, or other injury, the tire must be replaced. Mark the area of concern before removal of the tire. Damage to the sidewall that does not reach the cords is typically acceptable for service. Circumferential cracks or slits in the sidewall are unacceptable. A bulge in a tire sidewall indicates possible delamination of the sidewall carcass plies. The tire must immediately be removed from service.

Weather and ozone can cause cracking and checking of the sidewall. If this extends to the sidewall cords, the tire must be removed from service. Otherwise, sidewall checking as show in *Figure 13-146* does not affect the performance of the tire and it may remain in service.

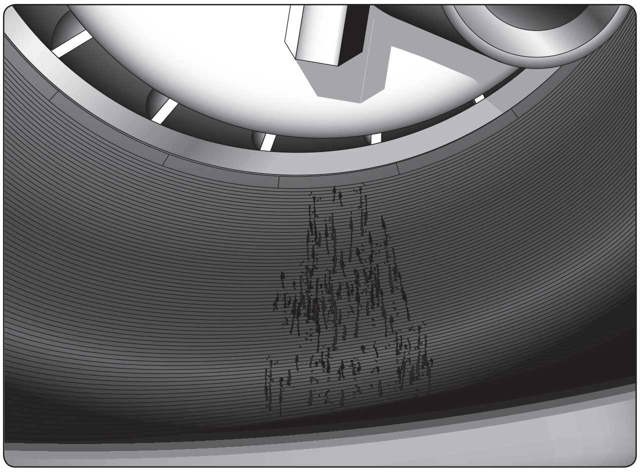


Figure 13-146. *Cracking and checking in the sidewall of a tire is acceptable for service as long as it does not extend to or expose the sidewall carcass plies.*

Tire Removal

Removal of any tire and wheel assembly should be accomplished following all aircraft manufacturer's instructions for the procedure. Safety procedures are designed for the protection of the technician and the maintenance of aircraft parts in serviceable condition. Follow all safety procedures to prevent personal injury and damage to aircraft parts and assemblies.

An aircraft tire and wheel assembly, especially a high-pressure assembly that has been damaged or overheated, should be treated as though it may explode. Never approach such a tire while its temperature is still elevated above ambient temperature. Once cooled, approach a damage tire and wheel assembly from an oblique angle advancing toward the shoulder of the tire. *[Figure 13-147]*

Deflate all unserviceable and damaged tires before removal from the aircraft. Use a valve core/deflation tool to deflate the tire. Stand to the side—away from the projectile path of the valve core. A dislodged valve core propelled by internal tire pressure can cause serious human injury. When completely deflated, remove the valve core. *[Figure 13-148]* A tire and wheel assembly in airworthy condition may be removed to access other components for maintenance without deflating the tire. This is common practice, such as when accessing the brake when the wheel assembly is immediately reinstalled. For tracking purposes, ensure damaged areas of a tire are marked before deflation. Record all known information about an unserviceable tire and attach it to the tire for use by the retread repair station.

Once removed from the aircraft, a tire must be separated from the wheel rim upon which is mounted. Proper equipment and technique should be followed to avoid damage to the tire and wheel. The wheel manufacturer's maintenance information is the primary source for dismounting guidelines.

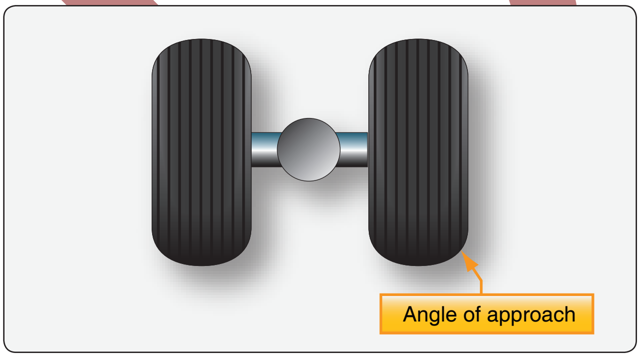


Figure 13-147. *To avoid potential injury, approach a tire/wheel assembly that has damage or has been overheated at an angle toward the tire shoulder only after it has cooled to ambient temperature.*

Figure 13-148. *The tire valve core should be removed after the tire is completely deflated and before the tire and wheel assembly is removed from the aircraft.*

The bead area of the tire sits firmly against the rim shoulder and must be broken free. Always use proper bead breaking equipment for this purpose. Never pry a tire from a wheel rim as damage to the wheel is inevitable. The wheel tie bolts must remain installed and fully tightened when the bead is broken from the rim to prevent damage to the wheel half mating surfaces.

When the bead breaking press contact surface is applied to the tire, it should be as close to the wheel as possible without touching it during the entire application of pressure. Tires and rims of different sizes require contact pads suitable for the tire. Hand presses and hydraulic presses are available. Apply the pressure and hold it to allow the bead to move on the rim. Gradually progress around the rim until the tire bead is broken free. Ring-type bead breakers apply pressure around the circumference of the entire sidewall so rotation is not required. *[Figure 13-149]* Once the bead is broken

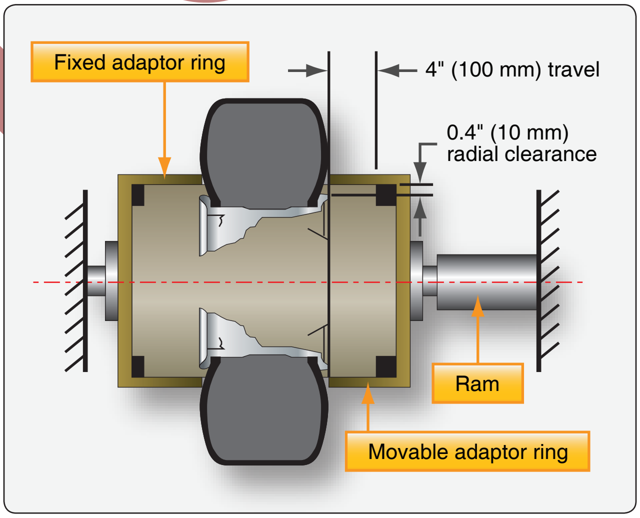


Figure 13-149. *A ring adapter applies pressure around the entire circumference of the lower sidewall of the tire to break the bead free from the wheel rim. The diameter of the adapter must be correct for the tire and the travel limited so as to not injure the tire.*

free, the wheel halves may be disassembled. *[Figure 13-150]* Radial tires have only one bead bundle on each side of the tire. The sidewall is more flexible in this area than a bias ply tire. The proper tooling should be used, and pressure should be applied slowly to avoid heavy distortion of the sidewall. Lubrication may be applied and allowed to soak into the tire-wheel interface. Only soapy tire solutions should be used. Never apply a hydrocarbon-based lubricant to an aircraft tire as this contaminates the rubber compound used to construct the tire. Beads on tube-type and tubeless tires are broken free in a similar manner.

Tire Inspection Off of the Aircraft

Once a tire has been removed from the wheel rim, it should be inspected for condition. It may be possible to retread the tire at an approved repair station and return it to service. A sequential inspection procedure helps ensure no parts of the tire are overlooked. Mark and record the extent of all damage. Advisory Circular (AC) 43-13-1 gives general guidelines for tire inspection and repair. Tires must only be repaired by those with the experience and equipment to do so. Most tire repairs are accomplished at a certified tire repair facility.

When inspecting a tire removed from the aircraft, pay special attention to the bead area since it must provide an air tight seal to the wheel rim and transfer forces from the tire to the rim. Inspect the bead area closely as it is where the heat is concentrated during tire operation. Surface damage to the chafer is acceptable and can be repaired when the tire is retreaded. Other damage in the bead area is usually cause for rejection. Damage to the turn-ups, ply separation at the bead, or a kinked bead are examples of bead area damage that warrant the tire be discarded. The bead area of the tire may sustain damage or have an altered appearance or texture on a tire that has been overheated. Consult a certified tire repair station or re-tread facility when in doubt about the condition observed. The wheel rim must also be inspected for damage. An effective seal without slippage, especially on tubeless tires, is dependent on the condition and integrity of the wheel in the bead seat area.

Overheating of a tire weakens it even though the damage might not be obvious. Any time a tire is involved in an aborted takeoff, severe braking, or the thermal plug in the wheel has melted to deflate the tire before explosion, the tire must be removed. On a dual installation, both tires must be removed. Even if only one tire shows obvious damage or deflates, the loads experienced by the mate are excessive. Internal damage such as ply separation, is likely. The history of having been through an overheat event is all that is required for the tire to be discarded.

Damaged or suspected damaged areas of the tire should be re-inspected while the tire is off the aircraft. Cuts can be probed to check for depth and extent of damage below the tread. In general, damage that does not exceed 40 percent of the tire plies can be repaired when the tire is retreaded. Small punctures with a diameter on the tire inner surface of less than ⅛-inch and a diameter on the outer surface of less than ¼-inch can also be repaired and retreaded. A bulge caused by ply separation is reason to discard a tire. However, a bulge caused by tread separation from the tire carcass may be repairable during retread. Exposed sidewall cord or sidewall cord damage is unacceptable, and the tire cannot be repaired or retreaded. Consult the tire manufacturer or certified retreader for clarification on damage to a tire.

Tire Repair and Retreading

The technician should follow airframe and tire manufacturer instructions to determine if a tire is repairable. Many example guidelines have also been given in this section. Nearly all tire repairs must be made at a certified tire repair facility equipped to perform the approved repair. Bead damage, ply separation, and sidewall cord exposure all require that the

Figure 13-150. *An electrohydraulic tire bead breaker (left) used on large tires and a manual tire bead breaker (right) used on small tires.*

tire be scrapped. Inner liner condition on tubeless tires is also critical. Replacing the tube in a tube-type tire is performed by the technician as are mounting and balancing all types of aircraft tires.

Aircraft tires are very expensive. They are also extremely durable. The effective cost of a tire over its life can be reduced by having the tread replaced while the carcass is still sound, and injuries are within repairable limits. Federal Aviation Administration (FAA) certified tire retread repair stations, often the original equipment manufacturer (OEM), do this work. The technician inspects a tire to pre-qualify it for retread so that the cost of shipping it to the retread repair facility is not incurred if there is no chance to retread the tire. The tire retreader inspects and tests every tire to a level beyond the capability of the hangar or line technician. Shearography, an optical nondestructive testing method that provides detailed information about the internal integrity of the tire, is used by tire retread repair facilities to ensure a tire carcass is suitable for continued service.

Tires that are retreaded are marked as such. They are not compromised in strength and give the performance of a new tire. No limits are established for the number of times a tire can be retreaded. This is based on the structural integrity of the tire carcass. A well maintained main gear tire may be able to be retreaded a handful of times before fatigue renders the carcass un-airworthy. Some nose tires can be retread nearly a dozen times.

Tire Storage

An aircraft tire can be damaged if stored improperly. A tire should always be stored vertically so that it is resting on its treaded surface. Horizontal stacking of tires is not recommended. Storage of tires on a tire rack with a minimum 3–4-inch flat resting surface for the tread is ideal and avoids tire distortion.

If horizontal stacking of tires is necessary, it should only be done for a short time. The weight of the upper tires on the lower tires cause distortion possibly making it difficult for the bead to seat when mounting tubeless tires. A bulging tread also stresses rib grooves and opens the rubber to ozone attack in this area. *[Figure 13-151]* Never stack aircraft tires horizontally for more than 6 months. Stack no higher than four tires if the tire is less than 40-inches in diameter and no higher than three tires if greater than 40-inches in diameter. The environment in which an aircraft tire is stored is critical. The ideal location in which to store an aircraft tire is cool, dry, and dark, free from air currents and dirt.

An aircraft tire contains natural rubber compounds that are prone to degradation from chemicals and sunlight. Ozone

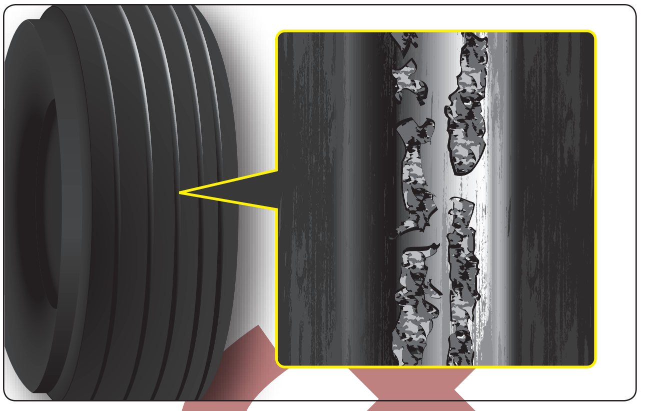


Figure 13-151. *Ozone cracking in a tire tread groove is facilitated by horizontal stacking.*

(O_3) and oxygen (O_2) cause degradation of tire compounds. Tires should be stored away from strong air currents that continually present a supply of one or both of these gases. Fluorescent lights, mercury vapor lights, electric motors, battery chargers, electric welding equipment, electric generators, and similar shop equipment produce ozone and should not be operated near aircraft tires. Mounted inflated tires can be stored with up to 25 percent less pressure than operating pressure to reduce vulnerability from ozone attacks. Sodium vapor lighting is acceptable. Storage of an aircraft tire in the dark is preferred to minimize degradation from ultraviolet (UV) light. If this is not possible, wrap the tire in dark polyethylene or paper to form an ozone barrier and to minimize exposure to UV light.

Common hydrocarbon chemicals, such as fuels, oils, and solvents, should not contact a tire. Avoid rolling tires through spills on the hangar or shop floor and be sure to clean any tire immediately if contaminated. Dry the tire and store all tires in a dry place away from any moisture, which has a deteriorating effect on the rubber compounds. Moisture with foreign elements may further damage the rubber and fabric of a tire. Dirty areas must be avoided.

Tires are made to operate in a wide range of temperatures. However, storage should be at cool temperatures to minimize degradation. A general range for safe aircraft tire storage is between 32 °F and 104 °F. Temperatures below this are acceptable but higher temperatures must be avoided.

Aircraft Tubes

Many aircraft tires accept a tube inside to contain the inflation air. Tube-type tires are handled and stored in similar fashion as tubeless tires. A number of issues concerning the tubes themselves must be addressed.

Tube Construction and Selection

Aircraft tire tubes are made of a natural rubber compound. They contain the inflation air with minimal leakage. Unreinforced and special reinforced heavy-duty tubes are available. The heavy-duty tubes have nylon reinforcing fabric layered into the rubber to provide strength to resist chafing and to protect against heat such as during braking.

Tubes come in a wide range of sizes. Only the tube specified for the applicable tire size must be used. Tubes that are too small stress the tube construction.

Tube Storage and Inspection

An aircraft tire tube should be kept in the original carton until put into service to avoid deterioration through exposure to environmental elements. If the original carton is not available, the tube can be wrapped in several layers of paper to protect it. Alternately, for short time periods only, a tube may be stored in the correct size tire it is made for while inflated just enough to round out the tube. Application of talc to the inside of the tire and outside of the tube prevents sticking. Remove the tube and inspect it and the tire before permanently mounting the assembly. Regardless of storage method, always store aircraft tubes in a cool, dry, dark place away from ozone producing equipment and moving air.

When handling and storing aircraft tire tubes, creases are to be avoided. These weaken the rubber and eventually cause tube failure. Creases and wrinkles also tend to be chafe points for the tube when mounted inside the tire. Never hang a tube over a nail or peg for storage.

An aircraft tube must be inspected for leaks and damage that may eventually cause a leak or failure. To check for leaks, remove the tube from the tire. Inflate the tube just enough to have it take shape but not stretch. Immerse a small tube in a container of water and look for the source of air bubbles. A large tube may require that water be applied over the tube. Again, look for the source of bubbles. The valve core should also be wetted to inspect it for leaks.

There is no mandatory age limit for an aircraft tire tube. It should be elastic without cracks or creases in order to be consider serviceable. The valve area is prone to damage and should be inspected thoroughly. Bend the valve to ensure there are no cracks at the base where it is bonded to the tire or in the area where it passes through the hole in the wheel rim. Inspect the valve core to ensure it is tight and that it does not leak.

If an area of a tube experiences chafing to the point where the rubber is thinned, the tube should be discarded. The inside diameter of the tube should be inspected to ensure it has not been worn by contact with the toe of the tire bead. Tubes that have taken an unnatural set should be discarded. *[Figure 13-152]*

Tire Inspection

It is important to inspect the inside of a tube-type tire before installing a tube for service. Any protrusions or rough areas should be cause for concern, as these tend to abrade the tube and may cause early failure. Follow the tire, tube, and aircraft manufacturer's inspection criterion when inspecting aircraft tires and tubes.

Tire Mounting

A licensed technician is often called upon to mount an aircraft tire onto the wheel rim in preparation for service. In the case of a tube-type tire, the tube must also be mounted. The following section presents general procedures for these operations using tube-type and tubeless tires. Be sure to have the proper equipment and training to perform the work according to manufacturer's instructions.

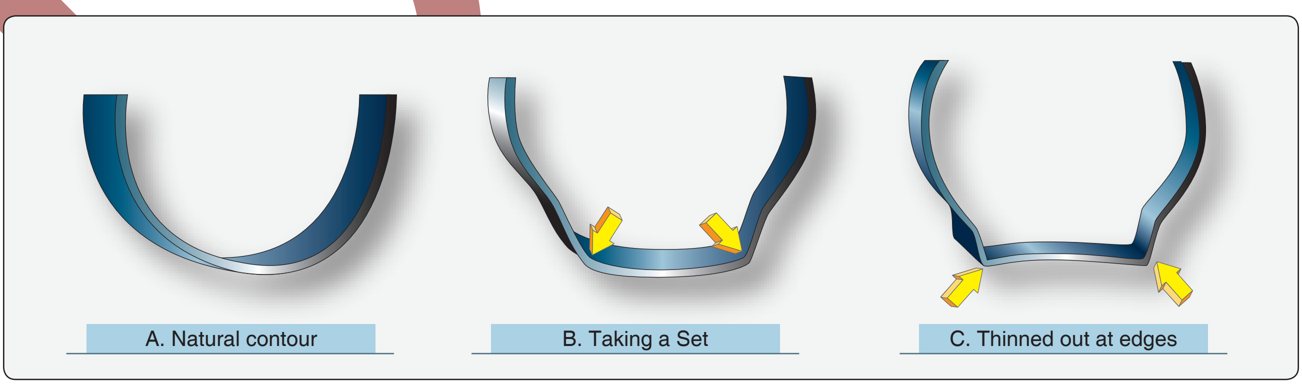


Figure 13-152. *During inspection, an aircraft tire tube should retain its natural contour. Tubes with thinned areas or that have taken a set should be discarded and replaced.*

Tubeless Tires

Aircraft tire and wheel assemblies are subject to enormous stress while in service. Proper mounting ensures tires perform to the limits of their design. Consult and follow all manufacturer's service information including bolt torques, lubrication and balancing requirements, and inflation procedures.

As mentioned, a wheel assembly that is to have a tire mounted upon it must be thoroughly inspected to ensure it is serviceable. Pay close attention to the bead seat area, which should be smooth and free from defects. The wheel half mating surface should be in good condition. The O-ring should be lubricated and in good condition to ensure it seals the wheel for the entire life of the tire. Follow the manufacturer's instructions when inspecting wheels and the tips provided earlier in this chapter. *[Figure 13-153]*

A final inspection of the tire to be mounted should be made. Most important is to check that the tire is specified for the aircraft application. It should say tubeless on the sidewall. The part number, size, ply rating, speed rating, and technical standard order (TSO) number should also be on the sidewall and be approved for the aircraft installation. Visually check the tire for damage from shipping and handling. There should be no permanent deformation of the tire. It should pass all inspections for cuts and other damage discussed in the previous sections of this chapter. Clean the tire bead area with a clean shop towel and soap and water or denatured alcohol. Inspect the inside of the tire for condition. There should be no debris inside the tire.

Tire beads are sometimes lubricated when mounted on aluminum wheels. Follow the manufacturer's instructions and use only the non-hydrocarbon lubricant specified. Never lubricate any tire bead with grease. Do not use lubricants with magnesium alloy wheels. Most radial tires are mounted without lubricant. The airframe manufacturer may specify lubrication for a radial tire in a few cases.

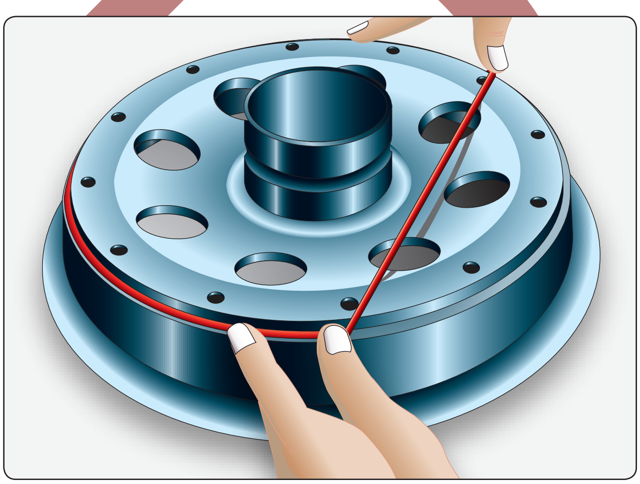


Figure 13-153. *The wheel half O-ring for a tubeless tire wheel assembly must be in good condition and lubricated to seal for the entire life of the tire. The mating surfaces of the wheel halves must also be in good condition.*

When the wheel halves and tires are ready to be mounted, thought must be given to tire orientation and the balance marks on the wheel halves and tire. Typically, the tire serial number is mounted to the outboard side of the assembly. The marks indicating the light portion of each wheel half should be opposite each other. The mark indicating the heavy spot of the wheel assembly should be mounted aligned with the light spot on the tire, which is indicated by a red mark. If the wheel lacks a mark indicating the heavy spot, align the red spot on the tire (the light point) with the valve fitting location on the wheel. A properly balanced tire and wheel assembly improves the overall performance of the tire. It promotes smooth operation free from vibration, which results in uniform tread wear and extended tire life.

When assembling the wheel halves, follow manufacturer's instructions for tie bolt tightening sequences and torque specification. Anti-seize lubricants and wet-torque values are common on wheel assemblies. Use a calibrated hand torque wrench. Never use an impact wrench on an aircraft tire assembly.

For the initial inflation of an aircraft tire and wheel assembly, the tire must be placed in a tire inflation safety cage and treated as though it may explode due to wheel or tire failure. The inflation hose should be attached to the tire valve stem, and inflation pressure should be regulated from a safe distance away. A minimum of 30 feet is recommended. Air or nitrogen should be introduced gradually as specified. Dry nitrogen keeps the introduction of water into the tire to a minimum, which helps prevent corrosion. Observe the tire seating progress on the wheel rim while it inflates. Depressurize the tire before approaching it to investigate any observed issue. *[Figure 13-154]*

Aircraft tires are typically inflated to their full specified operating pressure. Then, they are allowed to remain with no load applied for 12-hours. During this time, the tire stretches, and tire pressure decreases. A 5-10 percent reduction is normal. Upon bringing the tire up to full pressure again, less than 5 percent loss per day of pressure is allowable. More should be investigated.

Tube-Type Tires

Wheel and tire inspection should precede the mounting of any tire, including tube-type tires. The tube to be installed must also pass inspection and must be the correct size for the tire and tire must be specified for the aircraft. Tire talc

Figure 13-154. *Modern tire inflation cages have been tested to withstand catastrophic failure of a tire and wheel assembly during inflation. All newly mounted tires should be inflated in such a cage.*

is commonly used when installing tube-type tires to ensure easy mounting and free movement between the tube and tire as they inflate. *[Figure 13-155]* The technician should lightly talc the inside of the tire and the outside of the tube. Some tubes come from the factory with a light talc coating over the outside of the tube. Inflate the tube so that it just takes shape with minimal pressure. Install the tube inside the tire. Tubes are typically produced with a mark at the heavy spot of the tube. In the absence of this balance mark, it is assumed that the valve is located at the heaviest part of the tube. For proper balance, align the heavy part of the tube with the red mark on the tire (the light spot on the tire). *[Figure 13-156]* Once wheel balance is marked and the tube balance mark and the tire balance mark are all positioned correctly, install the outboard wheel half so the valve stem of the tube passes through the valve stem opening. *[Figure 13-157]* Mate the inboard wheel half to it, being careful not to pinch the tube between the wheel rims. Install the tie bolts, tighten, and torque as specified. Inflate the assembly in a tire inflation cage. The inflation procedure for a tube-type tire differs slightly from that of a tubeless tire. The assembly is slowly brought

Figure 13-155. *Tire talc is used on the inside of tube-type tires and the outside of aircraft tubes. This prevents binding and allows the tube to expand without stress into place within the tire.*

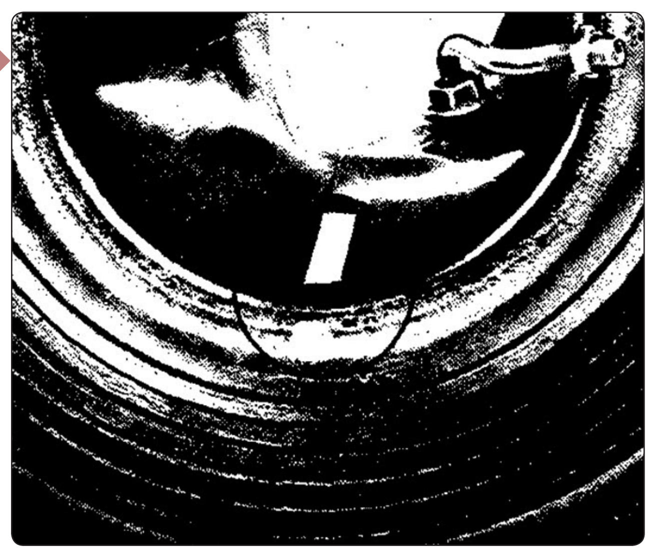


Figure 13-156. *When assembling a tube into a tire, the heavy balance mark on the tube is aligned with the light balance mark on the tire*

Figure 13-157. *Mounting a tube type tire with the tube valve stem positioned to pass through the outboard wheel half.*

up.to full operating pressure. Then, it is completely deflated. Re-inflate the tire/tube assembly a second time to the specified operating pressure and allow it to remain with no load for 12-hours. This allows any wrinkles in the tube to smooth out, helps prevent the tube from being trapped under a bead, and generally evens how the tube lays within the tire to avoid any stretched areas and thinning of the tube. The holding time allows air trapped between the tube and the tire to work its way out of the assembly, typically through the tire sidewall or around the valves stem.

Tire Balancing

Once an aircraft tire is mounted, inflated, and accepted for service, it can be balanced to improve performance. Vibration is the main result of an imbalanced tire and wheel assembly. Nose wheels tend to create the greatest disturbance in the cabin when imbalanced.

Static balance is all that is required for most aircraft tires and wheels. A balance stand typically accepts the assembly on

Figure 13-158. *A typical aircraft tire and wheel balancing stand.*

cones. The wheel is free to rotate. The heavy side moves to the bottom. *[Figure 13-158]* Temporary weights are added to eliminate the wheel from rotating and dropping the heavy side down. Once balanced, permanent weights are installed. Many aircraft wheels have provisions for securing the permanent weight to the wheel. Weights with adhesive designed to be glued to the wheel rim are also in use. Occasionally, a weight in the form of a patch glued to the inside of the tire is required. Follow all manufacturer's instructions and use only the weights specified for the wheel assembly. *[Figure 13-159]*

Some aviation facilities offer dynamic balancing of aircraft tire and wheel assemblies. While this is rarely specified by manufacturers, a well-balanced tire and wheel assembly helps provide shimmy free operation and reduces wear on brake and landing gear components, such as torque links.

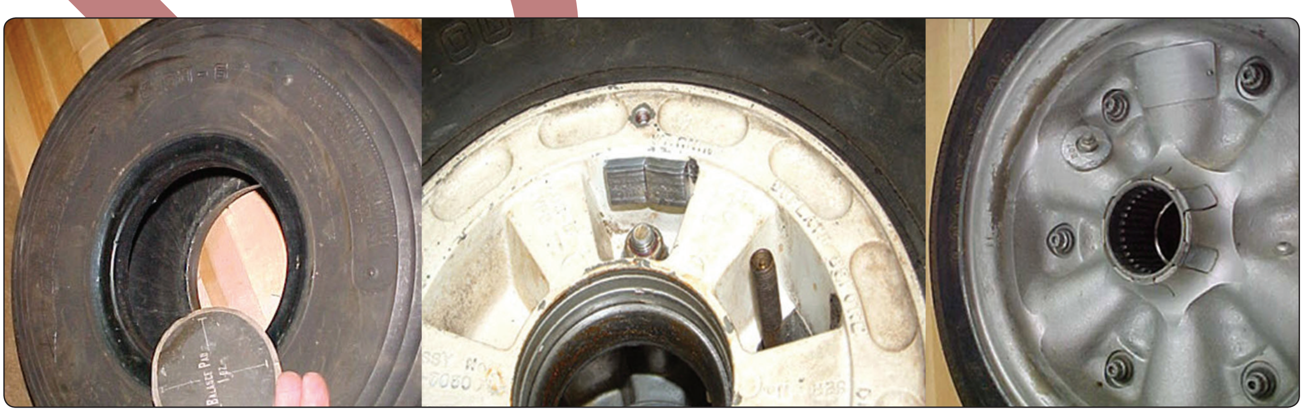


Figure 13-159. *A tire balancing patch (left), adhesive wheel weights (center), and a bolted wheel weight (right) are all used to balance aircraft tire and wheel assemblies per the manufacturer's instructions.*

Operation and Handling Tips

Aircraft tires experience longer life if operated in a manner to conserve wear and minimize damage. The most important factor impinging on tire performance and wear, as well as resistance to damage is proper inflation. Always inflate tires to the specified level before flight for maximum performance and minimal damage. An improperly inflated tire has increased potential to fail upon landing due to the high impact loads experienced. The following sections include other suggestions that can extend the life and the investment made in aircraft tires.

Taxiing

Needless tire damage and excessive wear can be prevented by proper handling of the aircraft during taxi. Most of the gross weight of an aircraft is on the main landing gear wheels. Aircraft tires are designed and inflated to absorb the shock of landing by deflection of the sidewalls two to three times as much as that found on an automobile tire. While this enables the tire to handle heavy loads, it also causes more working of the tread and produces scuffing action along the outer edges of the tread that results in more rapid wear. It also leaves the tire more prone to damage as the tread compound opens during this flexing.

An aircraft tire that strikes a chuck hole, a stone, or some other foreign object is more likely to sustain a cut, snag, or bruise than an automobile tire due to its more flexible nature. There is also increased risk for internal tire injury when a tire leaves the paved surface of the taxi way. These incidents should be avoided. Dual or multiple wheel main gear should be operated so that all tires remain on the paved surface so the weight of the aircraft is evenly distributed between the tires. When backing an aircraft on a ramp for parking, care should be taken to stop the aircraft before the main wheels roll off of the paved surface.

Taxiing for long distances or at high speeds increase the temperature of aircraft tires. This makes them more susceptible to wear and damage. Short taxi distances at moderate speeds are recommended. Caution should also be used to prevent riding the brakes while taxiing, which adds unnecessary heat to the tires.

Braking and Pivoting

Heavy use of aircraft brakes introduces heat into the tires. Sharp radius turns do the same and increase tread abrasion and side loads on the tire. Plan ahead to allow the aircraft to slow without heavy braking and make large radius turns to avoid these conditions. Objects under a tire are ground into the tread during a pivot. Since many aircraft are primarily maneuvered on the ground via differential braking, efforts should be made to always keep the inside wheel moving during a turn rather than pivoting the aircraft with a locked brake around a fixed main wheel tire.

Landing Field and Hangar Floor Condition

One of the main contributions made to the welfare of aircraft tires is good upkeep of airport runway and taxiway surfaces, as well as all ramp areas and hangar floors. While the technician has little input into runway and taxiway surface upkeep, known defects in the paved surfaces can be avoided and rough surfaces can be negotiated at slower than normal speeds to minimize tire damage. Ramps and hangar floors should be kept free of all foreign objects that may cause tire damage. This requires continuous diligence on the part of all aviation personnel. Do not ignore foreign object damage (FOD). When discovered, action must be taken to remove it. While FOD to engines and propellers gains significant attention, much damage to tires is avoidable if ramp areas and hangar floors are kept clean.

Takeoffs and Landings

Aircraft tires are under severe strain during takeoff and landing. Under normal conditions, with proper control and maintenance of the tires, they are able to withstand these stresses and perform as designed.

Most tire failures occur during takeoff which can be extremely dangerous. Tire damage on takeoff is often the result of running over some foreign object. Thorough preflight inspection of the tires and wheels, as well as maintenance of hangar and ramp surfaces free of foreign objects, are keys to prevention of takeoff tire failure. A flat spot caused on the way to the runway may lead to tire failure during takeoff. Heavy braking during aborted takeoffs is also a common cause of takeoff tire failure. *[Figure 13-160]*

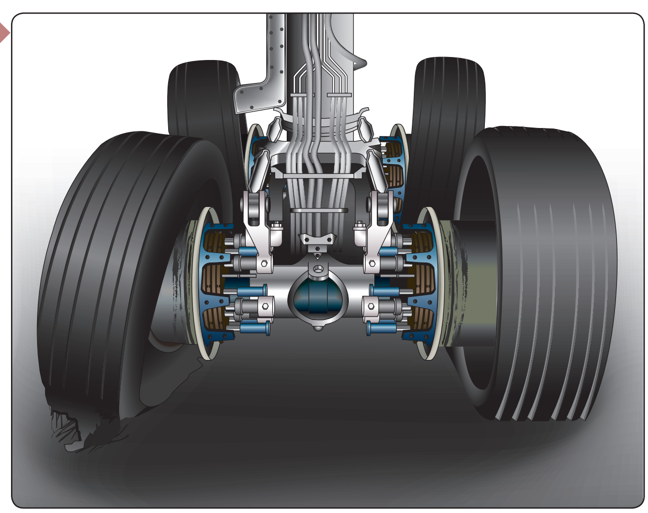


Figure 13-160. *Heavy braking during an aborted takeoff caused these tires to fail.*

Tire failure upon landing can have several causes. Landing with the brakes on is one. This is mitigated on aircraft with anti-skid systems but can occur on other aircraft. Other errors in judgment, such as landing too far down the runway and having to apply the brakes heavily, can cause overheating or skidding. This can lead to flat-spotting the tires or blow out.

Hydroplaning

Skidding on a wet, icy, or dry runway is accompanied by the threat of tire failure due to heat build-up and rapid tire wear damage. Hydroplaning on a wet runway may be overlooked as a damaging condition for a tire. Water building up in front of the tire provides a surface for the tire to run on and contact with the runway surface is lost. This is known as dynamic hydroplaning. Steering ability and braking action is also lost. A skid results if the brakes are applied and held.

Viscous hydroplaning occurs on runways with a thin film of water that mixes with contaminants to cause an extremely slick condition. This can also happen on a very smooth runway surface. A tire with a locked brake during viscous hydroplaning can form an area of reverted rubber or skid burn in the tread. While the tire may continue in service if the damage is not too severe, it can be cause for removal if the reinforcing tread or protector ply is penetrated. The same damage can occur while skidding on ice.

Modern runways are designed to drain water rapidly and provide good traction for tires in wet conditions. A compromise exists in that crosscut runways and textured runway surfaces cause tires to wear at a greater rate than a smooth runway. *[Figure 13-161]* A smooth landing is of great benefit to any tire. Much aircraft tire handling and care is the responsibility of the pilot. However, the technician benefits from knowing the causes of tire failure and communicating this knowledge to the flight crew so that operating procedures can be modified to avoid those causes.

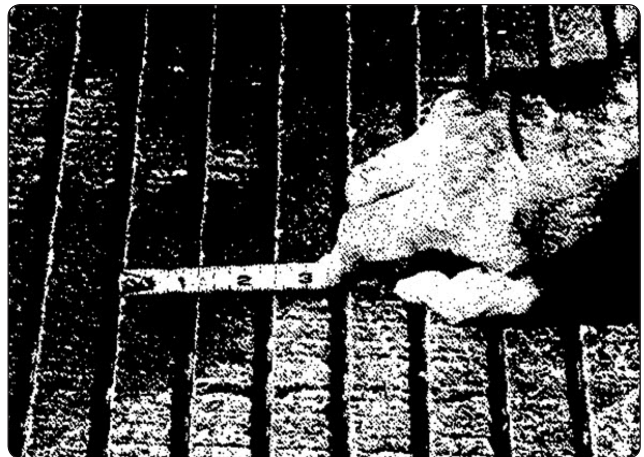


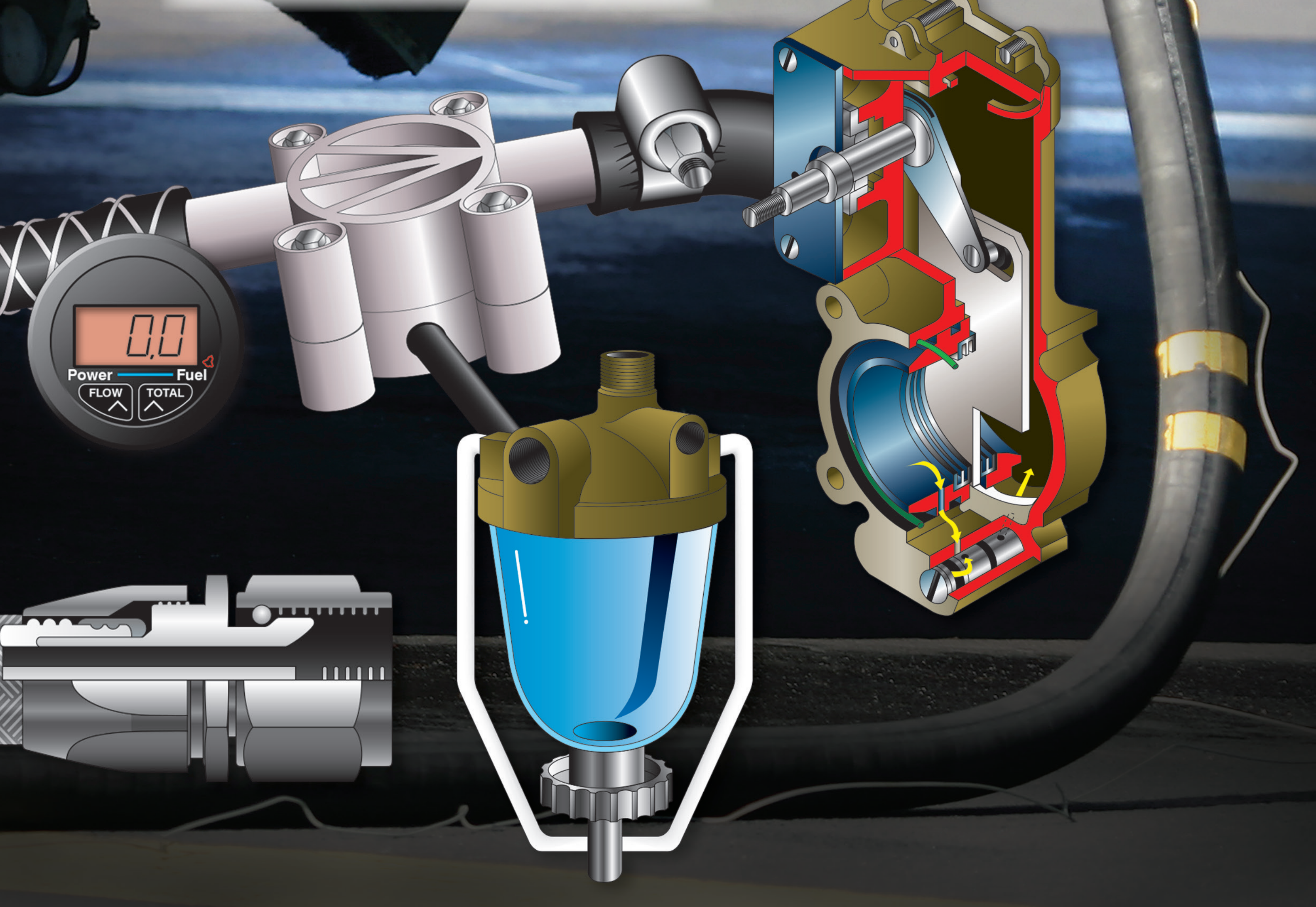
Figure 13-161. *Crosscut runway surfaces drain water rapidly but increase tire wear.*

Chapter 14

Aircraft Fuel System

Basic Fuel System Requirements

All powered aircraft require fuel on board to operate the engine(s). A fuel system consisting of storage tanks, pumps, filters, valves, fuel lines, metering devices, and monitoring devices is designed and certified under strict Title 14 of the Code of Federal Regulations (14 CFR) guidelines. Each system must provide an uninterrupted flow of contaminant-free fuel regardless of the aircraft's attitude. Since fuel load can be a significant portion of the aircraft's weight, a sufficiently strong airframe must be designed. Varying fuel loads and shifts in weight during maneuvers must not negatively affect control of the aircraft in flight.



Each Federal Aviation Administration (FAA) certified aircraft is designed and constructed under regulations applicable to that type of aircraft. The certification airworthiness standards are found in 14 CFR as follows:

- 14 Part 23—Normal, Utility, Acrobatic, and Commuter Category Airplanes
- 14 Part 25—Transport Category Airplanes
- 14 Part 27—Normal Category Rotorcraft
- 14 Part 29—Transport Category Rotorcraft
- 14 Part 31—Manned Free Balloons

Additional information is found in 14 CFR part 33. It addresses airworthiness standards for engines and pertains mainly to engine fuel filter and intake requirements.

Title 14 of the CFR, part 23, Normal, Utility, Acrobatic, and Commuter Category Airplanes, section 23.2430, Fuel Systems, is summarized below. Airworthiness standards specified for air carrier and helicopter certification are similar. Although the technician is rarely involved with designing fuel systems, a review of these criteria gives insight into how an aircraft fuel system operates.

Each fuel system must be constructed and arranged to ensure fuel flow at a rate and pressure established for proper engine and auxiliary power unit (APU) functioning under each likely operating condition. This includes any maneuver for which certification is requested and during which the engine or APU may be in operation. *[Figure 14-1]* Each fuel system must be arranged so that no fuel pump can draw fuel from more than one tank at a time. There must also be a means to prevent the introduction of air into the system.

Each fuel system for a turbine engine powered airplane must meet applicable fuel venting requirements. 14 CFR part 34 outlines requirements that fall under the jurisdiction of the Environmental Protection Agency (EPA). A turbine engine fuel system must be capable of sustained operation throughout its flow and pressure range even though the fuel has some water in it. The standard is that the engine continues to run using fuel initially saturated with water at 80 °F having 0.75 cubic centimeters (cm) of free water per gallon added to it and then cooled to the most critical condition for icing likely to be encountered in operation.

Figure 14-1. *Aircraft fuel systems must deliver fuel during any maneuver for which the aircraft is certified.*

Fuel System Independence

Each fuel system must be designed and arranged to provide independence between multiple fuel storage and supply systems so that failure of any one component in one system will not result in loss of fuel storage or supply of another system.

Fuel System Lightning Protection

The fuel system must be designed and arranged to prevent the ignition of the fuel within the system by direct lightning strikes or swept lightning strokes to areas where such occurrences are highly probable, or by corona or streamering at fuel vent outlets. A corona is a luminous discharge that occurs as a result of an electrical potential difference between the aircraft and the surrounding area. Streamering is a branch-like ionized path that occurs in the presence of a direct stroke or under conditions when lightning strikes are imminent. *[Figure 14-2]*

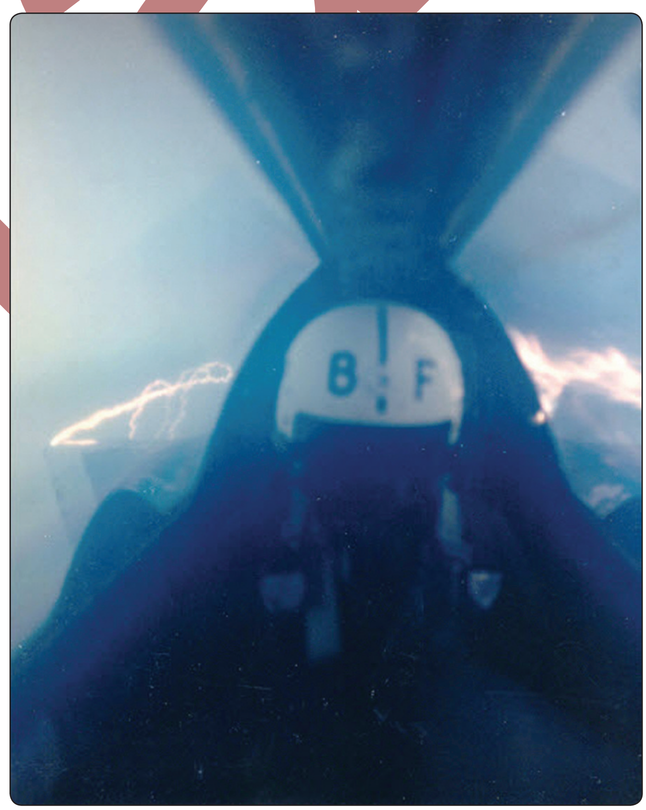


Figure 14-2. *Lightning streamering at the wingtips of a jet fighter.*

Fuel Flow

The ability of the fuel system to provide the fuel necessary to ensure each powerplant and auxiliary power unit functions properly in all likely operating conditions. It must also prevent hazardous contamination of the fuel supplied to each powerplant and auxiliary power unit.

The fuel system must provide the flightcrew with a means to determine the total useable fuel available and provide uninterrupted supply of that fuel when the system is correctly operated, accounting for likely fuel fluctuations. It should also provide a means to safely remove or isolate the fuel stored in the system from the airplane and be designed to retain fuel under all likely operating conditions and minimize hazards to the occupants during any survivable emergency landing. For level 4 airplanes, failure due to overload of the landing system must be taken into account

Fuel Storage System

Each fuel tank must be able to withstand, without failure, the loads the loads under likely operating conditions. Each tank must be isolated from personnel personnel compartments and protected from hazards due to unintended temperature influences. The fuel storage system must provide fuel for at least one-half hour of operation at maximum continuous power or thrust and be capable of jettisoning fuel safely if required for landing. *[Figure 14-3]* Fuel jettisoning systems are also referred to as fuel dump systems. *[Figure 14-4]*

Aircraft fuel tanks must be designed to prevent significant loss of stored fuel from any vent system due to fuel transfer between fuel storage or supply systems, or under likely operating conditions.

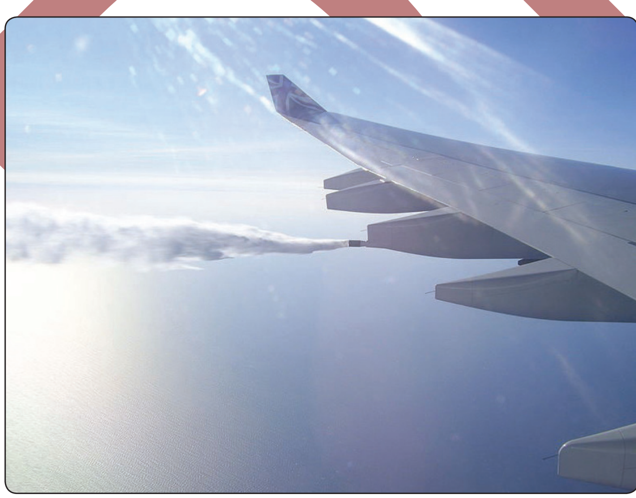


Figure 14-3. *Fuel being jettisoned free of the airframe on a transport category aircraft.*

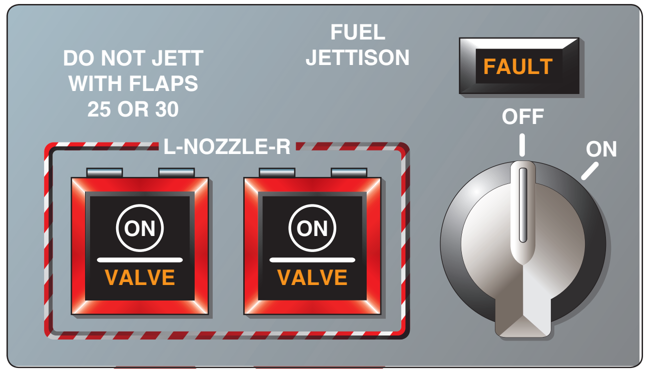


Figure 14-4. *The fuel jettison panel on a Boeing 767.*

Fuel Storage Refilling or Recharging System

Each fuel storage refilling or recharging system must be designed to prevent improper refilling or recharging; prevent contamination of the fuel stored during likely operating conditions; and prevent the occurrence of any hazard to the airplane or to persons during refilling or recharging.

Types of Aviation Fuel

Each aircraft engine is designed to burn a certain fuel. Use only the fuel specified by the manufacturer. Mixing fuels is not permitted. There are two basic types of fuel discussed in this section: reciprocating-engine fuel (also known as gasoline or AVGAS) and turbine-engine fuel (also known as jet fuel or kerosene).

Reciprocating Engine Fuel—AVGAS

Reciprocating engines burn gasoline, also known as AVGAS. It is specially formulated for use in aircraft engines. Combustion releases energy in the fuel, which is converted into the mechanical motion of the engine. AVGAS of any variety is primarily a hydrocarbon compound refined from crude oil by fractional distillation. Aviation gasoline is different from the fuel refined for use in turbine-powered aircraft. AVGAS is very volatile and extremely flammable, with a low flash point. Turbine fuel is a kerosene-type fuel with a much higher flash point, so it is less flammable.

Aircraft engines must perform throughout a wide range of demanding conditions. They must be lightweight and produce significant power in a wide range of atmospheric and engine operating temperatures. The gasoline used must support uninterrupted combustion throughout this range and must truly burn rather than explode or detonate. This ensures maximum power derivation and minimal engine wear. Over the years, AVGAS has been available in different formulas. These mostly correlate to how much energy can be produced without the fuel detonating. Larger, high-compression engines require fuel with a greater amount of potential power production without detonation than smaller low-compression engines.

Volatility

One of the most important characteristics of an aircraft fuel is its volatility. Volatility is a term used to describe how readily a substance changes from liquid into a vapor. For reciprocating engines, highly volatile fuel is desired. Liquid gasoline delivered to the engine induction system carburetor must vaporize in the carburetor to burn in the engine. Fuel with low volatility vaporizes slowly. This can cause hard engine starting, slow warm-up, and poor acceleration. It can also cause uneven fuel distribution to the cylinders and excessive dilution of the oil in the crankcase in engines equipped with oil dilution systems. However, fuel can also be too volatile, causing detonation and vapor lock.

AVGAS is a blend of numerous hydrocarbon compounds, each with different boiling points and volatility. A straight chain of volatile compounds creates a fuel that vaporizes easily for starting, but also delivers power through the acceleration and power ranges of the engine.

Vapor Lock

Vapor lock is a condition in which AVGAS vaporizes in the fuel line or other components between the fuel tank and the carburetor. This typically occurs on warm days on aircraft with engine-driven fuel pumps that suck fuel from the tank(s). Vapor lock can be caused by excessively hot fuel, low pressure, or excessive turbulence of the fuel traveling through the fuel system. In each case, liquid fuel vaporizes prematurely and blocks the flow of liquid fuel to the carburetor.

Aircraft gasoline is refined to have a vapor pressure be between 5.5 pounds per square inch (psi) and 7.0 psi at 100 °F. At this pressure, an aircraft fuel system is designed to deliver liquid fuel to the carburetor when drawn out of the tank by an engine-driven fuel pump. But temperatures in the fuel system can exceed 100 °F under the engine cowl on a hot day. Fuel may vaporize before it reaches the carburetor, especially if it is drawn up a line under a low pressure, or if it swirls while navigating a sharp bend in the tubing. To make matters worse, when an aircraft climbs rapidly, the pressure on the fuel in the tank decreases while the fuel is still warm. This causes an increase in fuel vaporization that can also lead to vapor lock.

Various steps can be taken to prevent vapor lock. The use of boost pumps located in the fuel tank that force pressurized liquid fuel to the engine is most common.

Carburetor Icing

As fuel vaporizes, it draws energy from its surroundings to change state from a liquid to a vapor. This can be a problem if water is present. When fuel vaporizes in the carburetor, water in the fuel-air mixture can freeze and deposit inside the carburetor and fuel induction system. The fuel discharge nozzle, throttle valve, venturi, or simply the walls of the induction system all can develop ice. As the ice builds, it restricts the fuel-air flow and causes loss of engine power. In severe cases, the engine stops running. *[Figure 14-5]*

Carburetor icing is most common at ambient temperatures of 30–40 °F but can occur at much higher temperatures, especially in humid conditions. Most aircraft are equipped with carburetor heating to help eliminate this threat caused by the high volatility of the fuel and the presence of moisture. *[Figure 14-6]*

Aromatic Fuels

The aviation gasoline market is a relatively small part of the overall gasoline market. AVGAS producers are few. In years past, when this was less the case, considerable quantities of aromatic hydrocarbons were sometimes added to increase the rich mixture performance of AVGAS. It was used mainly in high horsepower reciprocating engines, such as military

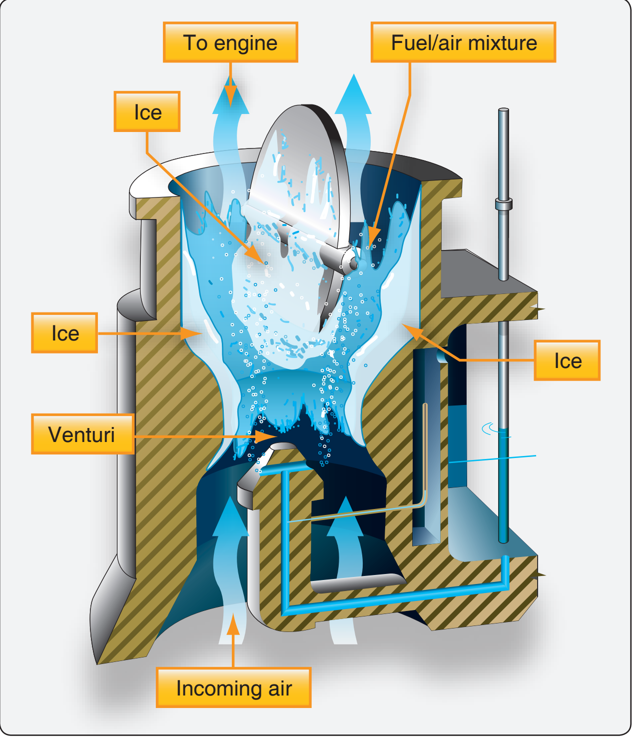


Figure 14-5. *An example of common areas where ice can form on a carburetor. The evaporation of volatile fuel takes energy from its surroundings to change state. As it does, water in the fuel-air mixture condenses and freezes.*

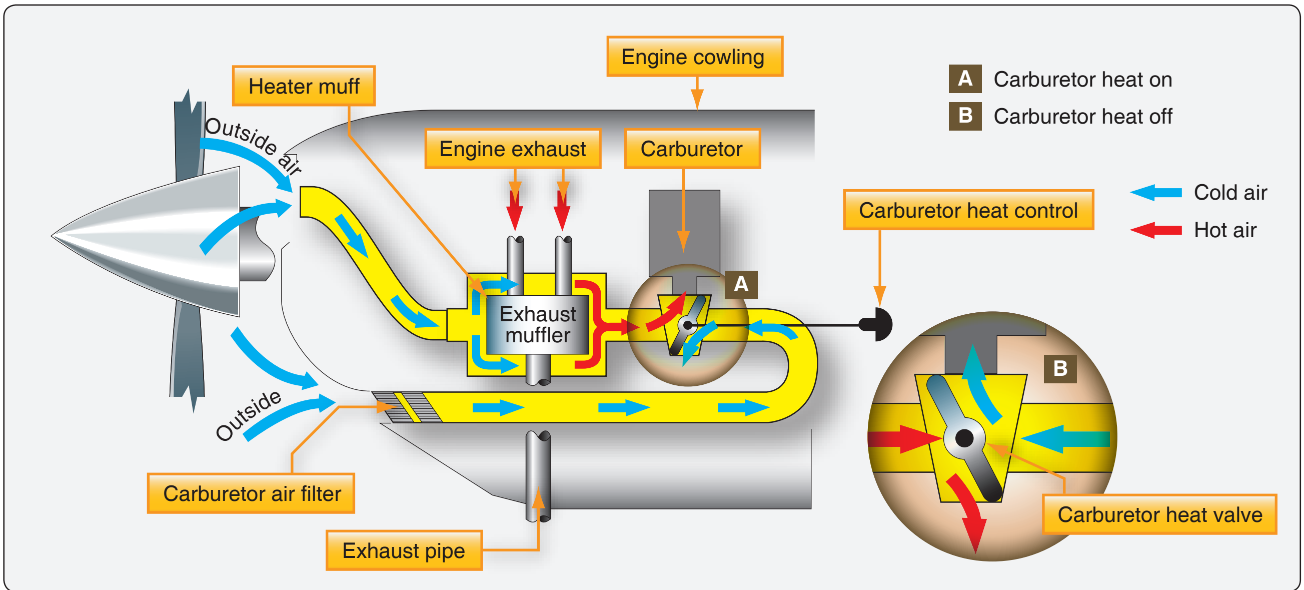


Figure 14-6. *To combat carburetor icing, air preheated by the exhaust manifold is directed into the carburetor via a push/pull control in the cockpit. The control changes the position of the air diverter butterfly in the carburetor heat valve box.*

and transport category aircraft. Special hoses and seals were required for use of aromatic fuels. These additives are no longer available.

Detonation

Detonation is the rapid, uncontrolled explosion of fuel due to high pressure and temperature in the combustion chamber. The fuel-air charge ignites and explodes before the ignition system spark lights it. Occasionally, detonation occurs when the fuel is ignited via the spark plug but explodes before it is finished burning.

The engine is not designed to withstand the forces caused by detonation. It is made to turn smoothly by having the fuel-air mixture burn in the combustion chamber and propagate directionally across the top of the piston. When it does so, a smooth transfer of the force developed by the burning fuel pushes the piston down. Detonation of fuel instead sends a shock wave of force against the top of the piston, which in turn is transferred through the piston to the piston pin, to the connecting rod, and to the crankshaft. Valve operation is also affected by this shock wave. In short, the explosion of fuel detonating in the combustion chamber transfers the energy contained in the fuel harshly throughout the entire engine, causing damage.

Aviation fuels are refined and blended to avoid detonation. Each has an ignition point and burn speed at specific fuel-air mixture ratios that manufacturers rely on to design engines that can operate without detonation. An engine experiencing detonation in the field should be investigated. A pinging or knocking sound is a sign of detonation. This is often more difficult to detect in an aircraft than in an automobile due to propeller tip noise. Detonation causes an increase in cylinder head temperature.

If ignored or allowed to continue, detonation can eventually lead to engine failure. Causes of detonation include incorrect fuel, already high engine temperature at high power settings, such as takeoff, preignition of the fuel, extended operations with an extremely lean mixture, and operation at high revolutions per minute (rpm) with low airspeed.

Surface Ignition and Preignition

A sharp deposit or incandescent hot spot in the combustion chamber can cause fuel to ignite before the spark plug lights it. Detonation can cause such an area to form as can a cracked spark plug insulator or a sharp valve edge. The result could be ignition of the fuel before the piston is at the proper place during its movement toward top dead center of the compression stroke. The extended burn period of the fuel can increase temperatures and pressure in the combustion chamber to the point at which the fuel detonates. The repeated incorrect flame propagation and detonation can cause serious engine damage and eventual engine failure. *[Figure 14-7]*

Maintenance personnel should ensure that the correct fuel is being used, and that the engine is being operated correctly. Spark plugs and valves should be checked for wear. Signs of deposits and detonation must also be investigated and addressed.

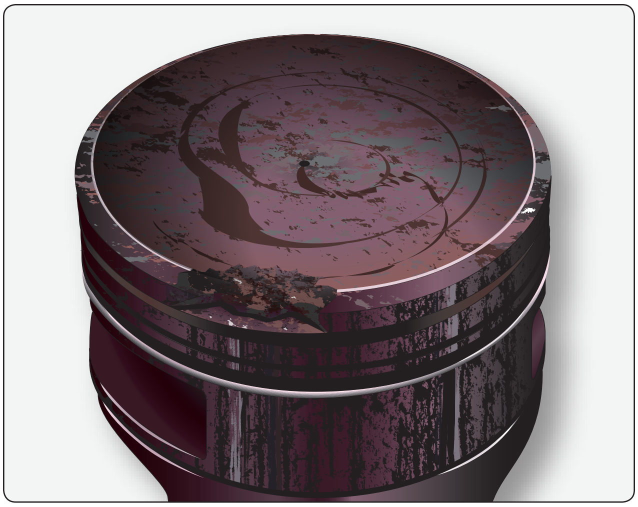


Figure 14-7. *Preignition can cause detonation and damage to the engine.*

Octane and Performance Number Rating

Octane ratings and performance numbers are given to fuels to describe their resistance to detonation. Fuels with high critical pressure and high octane or performance numbers have the greatest resistance. A referencing system is used to rate the fuel. A mixture of two hydrocarbons, iso-octane (C_8H_{18}) and heptane (C_7H_{16}), is used. Various ratios of the two hydrocarbons in a mixture result in proportional antidetonation properties. The more iso-octane there is in the mixture, the higher its resistance is to detonation.

When a fuel has the same critical pressure as a reference mixture of these two hydrocarbons, it is said to have an octane rating that is the same as the percentage of the iso-octane is this reference mixture. An 80-octane fuel has the same resistance to detonation as an 80 percent iso-octane, 20 percent heptane mixture; a 90-octane fuel has the same resistance to detonation as a 90 percent iso-octane, 10 percent heptane mixture; and a 100-octane fuel has the same resistance to detonation as 100 percent pure iso-octane. So, by comparing a fuel's tendency to detonate to reference mixtures of iso-octane and heptane, octane ratings from 80 to 100 can be established. The highest-octane fuel possible with this system of measurement is 100-octane fuel.

To increase antidetonation characteristics of fuel, substances can be added. Tetraethyl lead (TEL) is the most common additive that increases the critical pressure and temperature of a fuel. However, additional additives, such as ethylene dibromide and tricresyl phosphate, must be also be added so that the TEL does not leave solid deposits in the combustion chamber.

The amount of TEL added to a fuel can be increased to raise the antidetonation characteristics from 80 to the 100-octane level and higher. References to octane characteristics above 100 percent iso-octane are made by referencing the antidetonation properties of the fuel to a mixture of pure iso-octane and specific quantities of TEL. The specific mixtures of iso-octane and TEL are assigned arbitrary octane numbers above 100. In addition to increasing the antidetonation characteristics of a fuel, TEL also lubricates the engine valves.

Performance numbers are also used to characterize the antidetonation characteristics of fuel. A performance number consists of two numbers (e.g., 80/87, 100/130, 115/145) in which higher numbers indicate a higher resistance to detonation. The first number indicates the octane rating of the fuel in a lean fuel-air mixture, and the second number indicates the octane rating of the fuel in a rich mixture.

Due to the small size of the worldwide aviation gasoline market, a single 100 octane low-lead fuel (100LL) is desired as the only AVGAS for all aircraft with reciprocating engines. This presents problems in engines originally designed to run on 80/87 fuel; the low lead 100-octane fuel still contains more lead than the 80-octane fuel. Spark plug fouling has been common and lower times between overhaul have occurred. Other engines designed for 91/96 fuel or 100/130 fuel operate satisfactorily on 100LL, which contains 2 milliliters of TEL per gallon (enough to lubricate the valves and control detonation). For environmental purposes, AVGAS with no TEL is sought for the aviation fleet of the future.

Fuel Identification

Aircraft and engine manufacturers designate approved fuels for each aircraft and engine. Consult manufacturer data and use only those fuel specified therein.

The existence of more than one fuel makes it imperative that fuel be positively identified and never introduced into a fuel system that is not designed for it. The use of dyes in fuel helps aviators monitor fuel type. 100LL AVGAS is the AVGAS most readily available and used in the United States. It is dyed blue. Some 100 octane or 100/130 fuel may still be available, but it is dyed green.

80/87 AVGAS is no longer available. It was dyed red. Many supplemental type certificates have been issued to engine and engine/airframe combinations that permit the use of automobile gasoline in engines originally designed for red AVGAS. A relatively new AVGAS fuel, 82UL (unleaded), has been introduced for use by this group of relatively low compression engines. It is dyed purple.

115/145 AVGAS is a fuel designed for large, high performance reciprocating engines from the World War II era. It is available only by special order from refineries and is also dyed purple in color.

The color of fuel may be referred to in older maintenance manuals. All grades of jet fuel are colorless or straw colored. This distinguishes them from AVGAS of any kind that contains dye of some color. Should AVGAS fuel not be of a recognizable color, the cause should be investigated. Some color change may not affect the fuel. Other times, a color change may be a signal that fuels have been mixed or contaminated in some way. Do not release an aircraft for flight with unknown fuel onboard.

Identifying fuel and ensuring the correct fuel is delivered into storage tanks, fuel trucks, and aircraft fuel tanks is a process aided by labeling. Decals and markings using the same colors as the AVGAS colors are used. Delivery trucks and hoses are marked as are aircraft tank fuel caps and fill areas. Jet fuel fill hose nozzles are sized too large to fit into an AVGAS tank fill opening. *Figure 14-8* shows examples of color-coded fuel labeling.

Purity

The use of filters in the various stages of transfer and storage of AVGAS removes most foreign sediment from the fuel. Once in the aircraft fuel tanks, debris should settle into the fuel tank drain sumps to be removed before flight. Filters and strainers in the aircraft fuel system can successfully capture any remaining sediment.

The purity of aviation gasoline is compromised most often by water. Water also settles into the sumps given enough time. However, water is not removed by the aircraft's filters and strainers as easily as solid particles. It can enter the fuel even when the aircraft is parked on the ramp with the fuel caps in place. Air in the tank vapor space above the liquid fuel contains water vapor. Temperature fluctuations cause the water vapor to condense on the inner surface of the tanks and settle into the liquid fuel. Eventually, this settles to the sump, but some can remain in the fuel when the aircraft is to be flown.

Proper procedure for minimizing water entering aircraft fuel is to fill the aircraft fuel tanks immediately after each

Fuel Type and Grade	Color of Fuel	Equipment Control Color	Pipe Banding and Marking	Refueler Decal
AVGAS 82UL	Purple	82UL AVGAS	AVGAS 82UL	82UL AVGAS
AVGAS 100	Green	100 AVGAS	AVGAS 100	100 AVGAS
AVGAS 100LL	Blue	100LL AVGAS	AVGAS 100LL	100LL AVGAS
JET A	Colorless or straw	JET A	JET A	JET A
JET A-1	Colorless or straw	JET A-1	JET A-1	JET A-1
JET B	Colorless or straw	JET B	JET B	JET B

Figure 14-8. *Color coded labeling and markings used on fueling equipment.*

flight. This minimizes the size of the vapor space above the liquid fuel and the amount of air and associated water vapor present in the tank. When excessive water is drawn into the fuel system, it passes through carburetor jets where it can interrupt the smooth operation of the engine(s).

If water is entrained or dissolved in the fuel, it cannot be removed by draining the sump(s) and filter bowls before flight. However, there may be enough water for icing to be a concern. As the aircraft climbs and fuel is drawn out of the tanks, the fuel supply cools. Entrained and dissolved water in the fuel is forced out of solution and becomes free water. If cool enough, ice crystals form rather than liquid water. These can clog filters and disrupt fuel flow to the engines. Both AVGAS and jet fuel have this type of water impurity issue leading to icing that must be monitored and treated.

Fuel anti-ice additives can be added to the bulk fuel and also directly into the aircraft fuel tank, usually during refueling. These are basically diethylene glycol solutions that work as antifreeze. They dissolve in free water as it comes out of the fuel and lower its freezing point. *[Figure 14-9]*

Turbine Engine Fuels

Aircraft with turbine engines use a type of fuel different from that of reciprocating aircraft engines. Commonly known as jet fuel, turbine engine fuel is designed for use in turbine engines and should never be mixed with aviation gasoline or introduced into the fuel system of a reciprocating aircraft engine fuel system.

Figure 14-9. *Fuel anti-icing products, such as Prist®, act as antifreeze for any free water in aircraft fuel. They dissolve in the water and lower its freezing point to prevent ice crystals from disrupting fuel flow.*

The characteristics of turbine engine fuels are significantly different from those of AVGAS. Turbine engine fuels are hydrocarbon compounds of higher viscosity with much lower volatility and higher boiling points than gasoline. In the distillation process from crude oil, the kerosene cut from which jet fuel is made condenses at a higher temperature than the naphtha or gasoline cuts. The hydrocarbon molecules of turbine engine fuels are composed of more carbon than are in AVGAS. *[Figure 14-10]*

Turbine engine fuels sustain a continuous flame inside the engine. They typically have a higher sulfur content than gasoline, and various inhibitors are commonly added to them. Used to control corrosion, oxidation, ice, and microbial and bacterial growth, these additives often are already in the fuel when it arrives at the airport for use.

Turbine Fuel Volatility

The choice of turbine engine fuel reflects consideration of conflicting factors. While it is desirable to use a fuel that is low in volatility to resist vapor lock and evaporation while in the aircraft's fuel tanks, turbine engine aircraft operate in cold environments. Turbine engines must start readily and be able to restart while in flight. Fuel with high volatility makes this easier.

AVGAS has a relatively low maximum vapor pressure compared to automotive gasoline—only 7 psi. But the vapor pressure of Jet A is only 0.125 psi at standard atmospheric conditions. Jet B, a blend of Jet A and gasoline, has higher volatility with a vapor pressure between 2 and 3 psi.

Turbine Engine Fuel Types

Three basic turbine engine fuel types are available worldwide, although some countries have their own unique fuels. The first is Jet A. It is the most common turbine engine fuel available in the continental United States. Globally, Jet A-1 is the most popular. Both Jet A and Jet A-1 are fractionally distilled in the kerosene range. They have low volatility and low vapor pressure. Flashpoints range between 110 °F and 150 °F. Jet A freezes at –40 °F and Jet A-1 freezes at –52.6 °F. Most engine operations manuals permit the use of either Jet A or Jet A-1.

The third basic type of turbine engine fuel available is Jet B. It is a wide-cut fuel that is basically a blend of kerosene and gasoline. Its volatility and vapor pressure reflect this and fall between Jet A and AVGAS. Jet B is primarily available in Alaska and Canada due to its low freezing point of approximately –58 °F, and its higher volatility yields better cold weather performance.

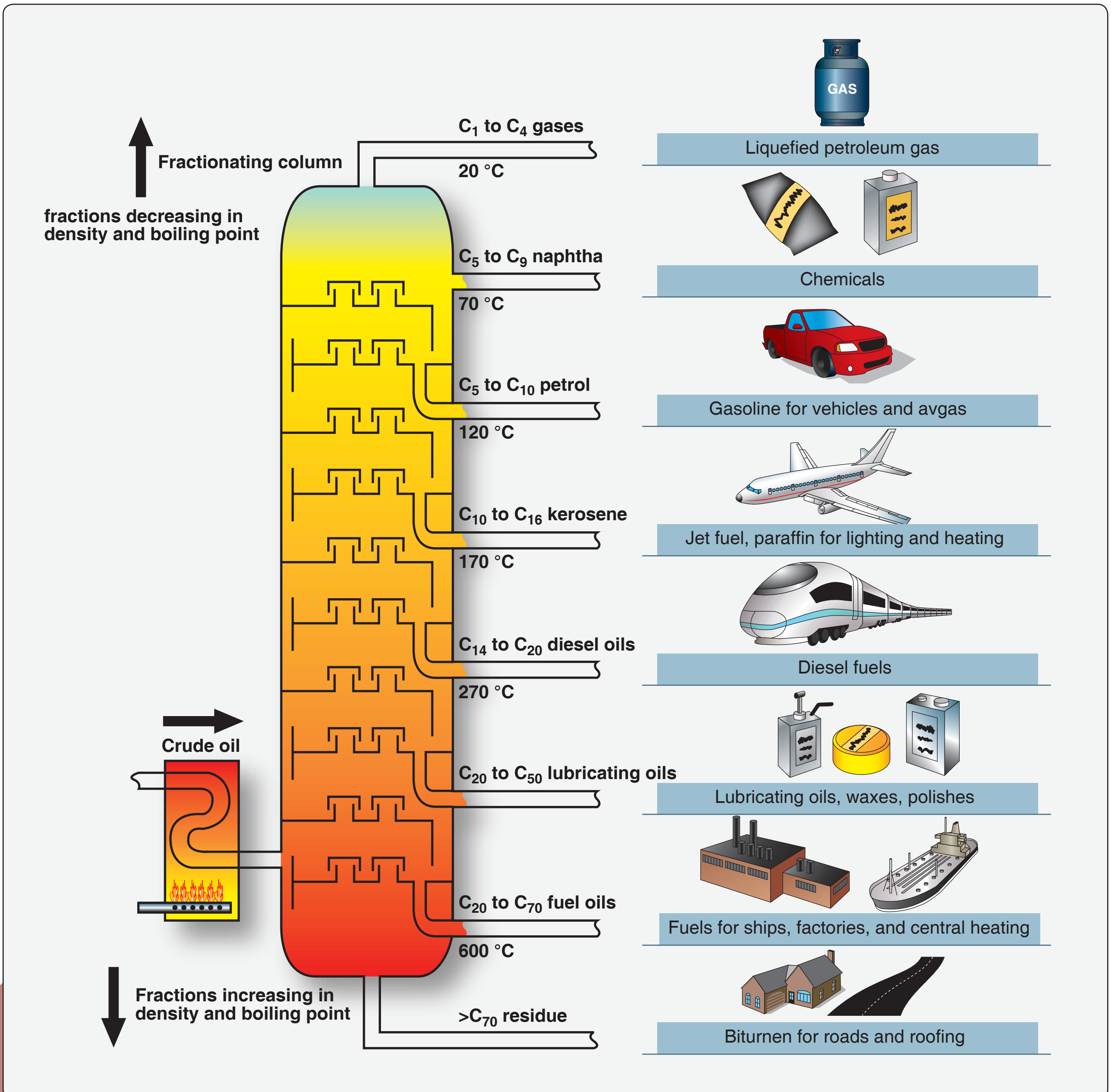


Figure 14-10. *Petroleum products are produced by distillation. Various fractions condense and are collected at different temperatures that correspond to the height of collection in the distillation tower. As can be seen, there are significant differences between turbine engine fuel and ordinary AVGAS.*

Turbine Engine Fuel Issues

Purity issues related to turbine engine fuels are unique. While AVGAS experiences similar issues of solid particle contamination and icing concerns, the presence of water and fuel-consuming microbes is more prominent in jet fuel, which has different molecular structure and retains water in two principal ways. Some water is dissolved into the fuel. Other water also is entrained in the fuel, which is more viscous than AVGAS. The greater presence of water in jet fuel allows microbes to assemble, grow, and live on the fuel.

Since turbine engine fuels always contain water, microbial contamination is always a threat. The large tanks of many turbine engine aircraft have numerous areas where water can settle, and microbes can flourish. Areas between the fuel tank and any water that may come to rest in the bottom of the tanks is where the microbes thrive. These microorganisms form a bio-film that can clog filters, corrode tank coatings, and degrade the fuel. They can be controlled somewhat with the addition of biocides to the fuel. *[Figure 14-11]* Anti-ice additives are also known to inhibit bacterial growth.

Figure 14-11. *Biocides, such as these, are often added to jet fuel to kill microbes that live on hydrocarbons.*

Since the microbes are sustained by fuel and water, best practices must be followed to keep the water in fuel to a minimum. Avoid having fuel in a storage tank for a prolonged period of time on or off the aircraft. Drain sumps and monitor the fuel for settled water. Investigate all incidents of water discovered in the fuel. In addition to water in jet fuel supporting the growth of microorganisms, it also poses a threat of icing. Follow the manufacturer's instructions for fuel handling procedures and fuel system maintenance.

Aircraft Fuel Systems

While each manufacturer designs its own fuel system, the basic fuel system requirements referenced at the beginning of this chapter yield fuel systems of similar design and function in the field. In the following sections are representative examples of various fuel systems in each class of aircraft discussed. Others are similar but not identical. Each aircraft fuel system must store and deliver clean fuel to the engine(s) at a pressure and flow rate able to sustain operations regardless of the operating conditions of the aircraft.

Small Single-Engine Aircraft Fuel Systems

Small single-engine aircraft fuel systems vary depending on factors, such as tank location and method of metering fuel to the engine. A high-wing aircraft fuel system can be designed differently from one on a low-wing aircraft. An aircraft engine with a carburetor has a different fuel system than one with fuel injection.

Gravity Feed Systems

High-wing aircraft with a fuel tank in each wing are common. With the tanks above the engine, gravity is used to deliver the fuel. A simple gravity feed fuel system is shown in *Figure 14-12*. The space above the liquid fuel is vented to maintain atmospheric pressure on the fuel as

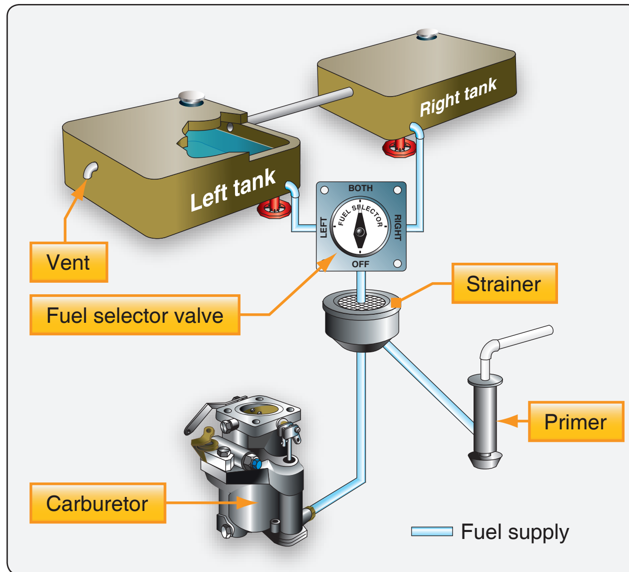


Figure 14-12. *The gravity-feed fuel system in a single-engine high-wing aircraft is the simplest aircraft fuel system.*

the tank empties. The two tanks are also vented to each other to ensure equal pressure when both tanks feed the engine. A single screened outlet on each tank feeds lines that connect to either a fuel shutoff valve or multiposition selector valve. The shutoff valve has two positions: fuel ON and fuel OFF. If installed, the selector valve provides four options: fuel shutoff to the engine; fuel feed from the right-wing tank only; fuel feed from the left fuel tank only; fuel feed to the engine from both tanks simultaneously.

Downstream of the shutoff valve or selector valve, the fuel passes through a main system strainer. This often has a drain function to remove sediment and water. From there, it flows to the carburetor or to the primer pump for engine starting. Having no fuel pump, the gravity feed system is the simplest aircraft fuel system.

Pump Feed Systems

Low- and mid-wing single reciprocating engine aircraft cannot utilize gravity-feed fuel systems because the fuel tanks are not located above the engine. Instead, one or more pumps are used to move the fuel from the tanks to the engine. A common fuel system of this type is shown in *Figure 14-13*. Each tank has a line from the screened outlet to a selector valve. However, fuel cannot be drawn from both tanks simultaneously; if the fuel is depleted in one tank, the pump would draw air from that tank instead of fuel from the full tank. Since fuel is not drawn from both tanks at the same time, there is no need to connect the tank vent spaces together.

From the selector valve (LEFT, RIGHT, or OFF), fuel flows through the main strainer where it can supply the

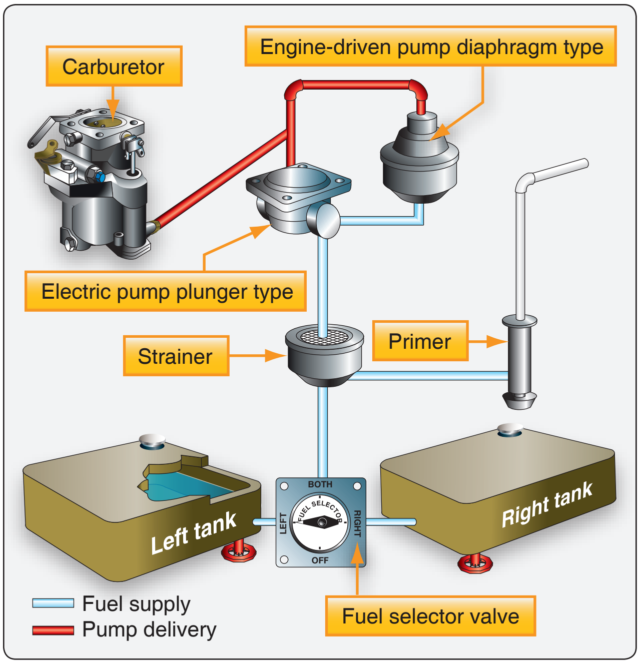


Figure 14-13. *A single reciprocating engine aircraft with fuel tanks located in wings below the engine uses pumps to draw fuel from the tanks and deliver it to the engine.*

engine primer. Then, it flows downstream to the fuel pumps. Typically, one electric and one engine-driven fuel pump are arranged in parallel. They draw the fuel from the tank(s) and deliver it to the carburetor. The two pumps provide redundancy. The engine-driven fuel pump acts as the primary pump. The electric pump can supply fuel should the other fail.

The electric pump also supplies fuel pressure while starting and is used to prevent vapor lock during flight at high altitude.

High-Wing Aircraft with Fuel Injection System

Some high-wing, high-performance, single-engine general aviation aircraft are equipped with a fuel system that features fuel injection rather than a carburetor. It combines gravity flow with the use of a fuel pump(s). The Teledyne-Continental system is an example. *[Figure 14-14]*

NOTE: Fuel injection systems spray pressurized fuel into the engine intake or directly into the cylinders. Fuel without any air mixed in is required to provide a measured, continuous spray and smooth engine operation.

Fuel pressurized by an engine-driven pump is metered as a function of engine rpm on the Teledyne-Continental system. It is first delivered from the fuel tanks by gravity to two smaller accumulator or reservoir tanks. These tanks, one for each wing tank, consolidate the liquid fuel and have a relatively small airspace. They deliver fuel through a three-

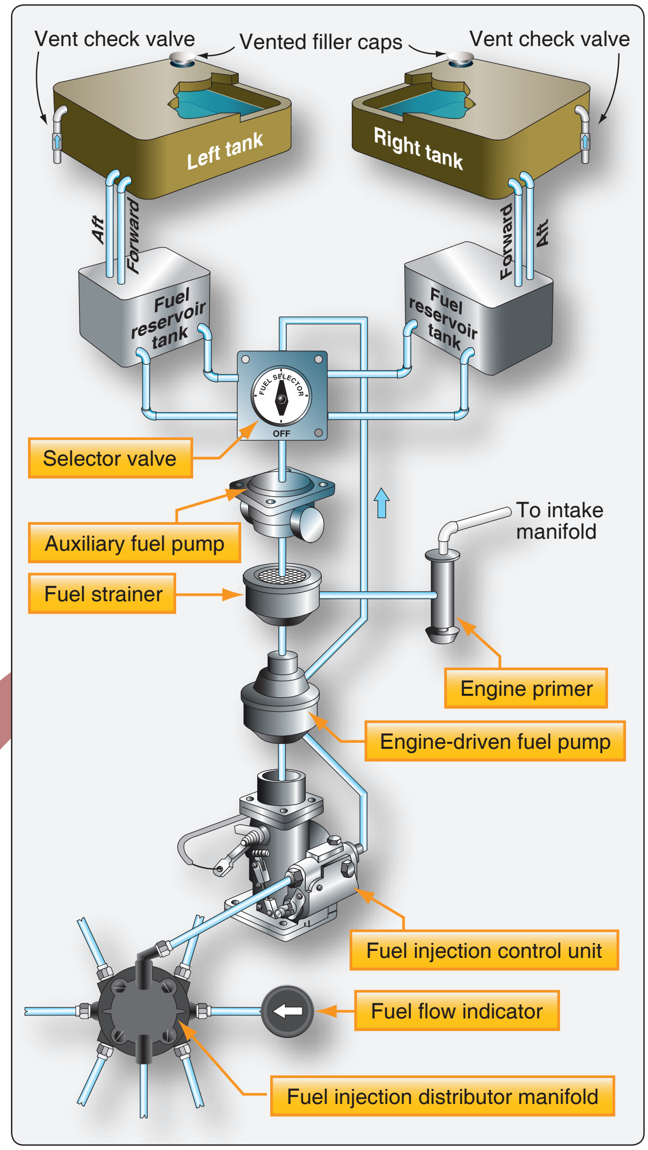


Figure 14-14. *A Teledyne-Continental fuel system featuring fuel injection used on high-wing, high-performance single-engine aircraft.*

way selector valve (LEFT, RIGHT, or OFF). The selector valve also acts simultaneously as a diverter of air that has been separated out of the fuel in the engine-driven fuel pump and returned to the valve. It routes the air to the vent space above the fuel in the selected reservoir tank.

An electric auxiliary fuel pump draws fuel through the selector valve. It forces the fuel through the strainer, making it available for the primer pump and the engine-driven fuel pump. This pump is typically used for starting and as a backup should the engine-driven pump fail. It is controlled by a switch in the cockpit and does not need to be operating to allow the engine-driven fuel pump access to the fuel.

The engine-driven fuel pump intakes the pressurized fuel from the electrically driven pump or from the reservoir tanks if the electric pump is not operating. It supplies a higher-than-needed volume of fuel under pressure to the fuel control. Excess fuel is returned to the pump, which pumps it through the selector valve into the appropriate reservoir tank. Fuel vapor is also returned to tanks by the pump. The fuel control unit meters the fuel according to engine rpm and mixture control inputs from the cockpit.

The fuel control delivers the fuel to the distribution manifold, which divides it and provides equal, consistent fuel flow for individual fuel injector in each cylinder. *[Figure 14-15]* A fuel flow indicator tapped off of the distribution manifold provides feedback in cockpit. It senses fuel pressure but is displayed on a dial calibrated in gallons per hour.

Small Multiengine (Reciprocating) Aircraft Fuel Systems

Low-Wing Twin

The fuel system on a small, multiengine aircraft is more complicated than a single-engine aircraft but contains many of the same elements. An example system used on a low-wing aircraft is illustrated in *Figure 14-16*. It features the main fuel tanks in the wing tips and auxiliary tanks in the wing structure. A boost pump is located at the outlet of each main tank. This pressurizes the entire fuel system from the tank to the injectors eliminating the possibility of vapor lock. An engine can operate with just its boost pump running in the event the engine-driven injection pump fails. Typically, the boost pumps are used to prime and start the engine.

Two selector valves are required on twin-engine aircraft, one for each engine. The right selector valve receives fuel from a main tank on either side of the aircraft and directs it to the right engine. The left selector valve also receives fuel from either main tank and directs it to the left engine. This allows fuel to crossfeed from one side of the aircraft to the opposite engine if desired. The selector valves can also direct fuel from the auxiliary tank to the engine on the same side. Crossfeed of fuel from auxiliary tanks is not possible. From the outlet of the selector valve, fuel flows to the strainer. On some aircraft, the strainer is built into the selector valve unit. From the strainer, fuel flows to the engine-driven fuel pump.

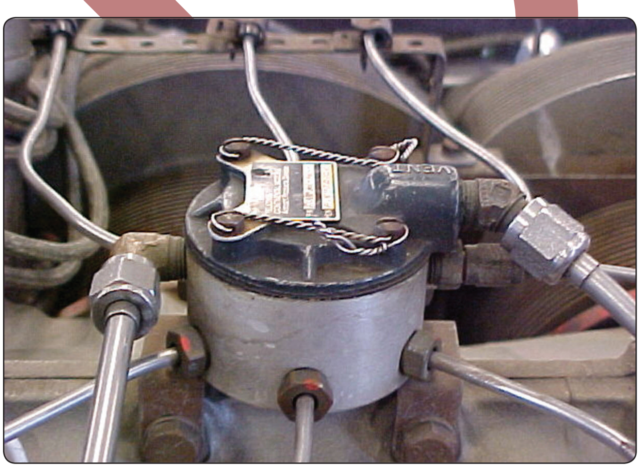


Figure 14-15. *A fuel distribution manifold for a fuel-injected engine.*

The engine-driven fuel pump is an assembly that also contains a vapor separator and a pressure regulating valve with an adjustment screw. The vapor separator helps eliminate air from the fuel. It returns a small amount of fuel and any vapor present back to the main fuel tank. The pump supplies pressurized fuel to the fuel control. The fuel control, one for each engine, responds to throttle and mixture control settings from the cockpit and supplies the proper amount of fuel to the fuel manifold. The manifold divides the fuel and sends it to an injector in each cylinder. A fuel pressure gauge is placed between the fuel control unit outlet and the manifold to monitor the injector-applied pressure that indicates engine power.

High-Wing Twin

A simplified system on a high-wing, twin-engine aircraft that combines gravity feed with an electric fuel pump is illustrated in *Figure 14-17*. Directly downstream of the selector valves are the fuel strainers and then an electric fuel pump for each engine. This pump draws fuel from the selected tank and sends it under pressure to the inlet side of the fuel injection metering unit. The metering unit for each engine provides the proper flow of fuel to the distribution manifold which feeds the injectors.

Large Reciprocating-Engine Aircraft Fuel Systems

Large, multiengine transport aircraft powered by reciprocating radial engines are no longer produced. However, many are still in operation. They are mostly carbureted and share many features with the light aircraft systems previously discussed.

Figure 14-18 shows the fuel system of a DC-3. A selector valve for each engine allows an engine-driven pump to pull fuel from the main tank or an auxiliary tank. The fuel passes through a strainer before reaching the pump where it is delivered to the engine. The outlet of the pump can feed either engine through the use of a crossfeed line with valves controlled in the cockpit. A hand-operated wobble pump located upstream of the strainer is used to prime the system for starting. Fuel vapor lines run from the pressure carburetor to the vent space in the main and auxiliary tanks. Fuel pressure gauges are tapped off of the carburetor for power indication.

The hand-operated wobble pumps were replaced by electric pumps on later model aircraft. A fuel pressure warning light

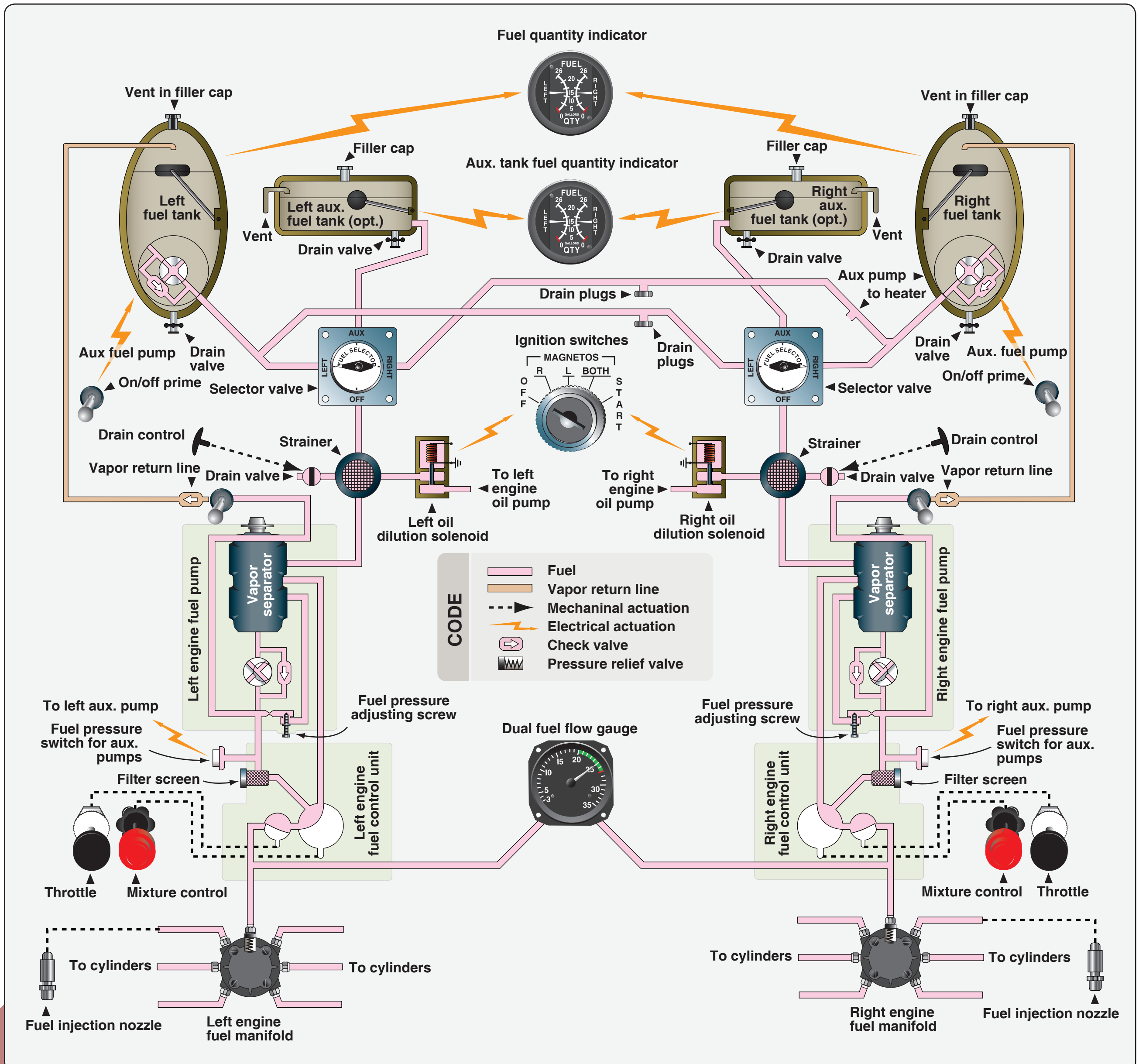


Figure 14-16. *A low-wing, twin-engine, light aircraft fuel system.*

tapped in downstream of the engine-driven fuel pump alerts the crew should fuel pressure decline.

Not all large, old aircraft have this fuel system. This is merely an example. Other aircraft share similar features and possess unique features of their own. The same is true for small reciprocating-engine aircraft. There are many systems that share features with those described above, but they also differ in some ways. Always consult the manufacturer's data when working on aircraft fuel systems and follow all instructions for service and repair. The fuel system of an aircraft provides the life blood for engine operation and must be maintained with the highest discretion.

Jet Transport Aircraft Fuel Systems

Fuel systems on large transport category jet aircraft are complex with some features and components not found in reciprocating-engine aircraft fuel systems. They typically contain more redundancy and facilitate numerous options from which the crew can choose while managing the aircraft's fuel load. Features like an onboard APU, single point pressure refueling, and fuel jettison systems, which are not needed on smaller aircraft, add to the complexity of an airliner fuel system.

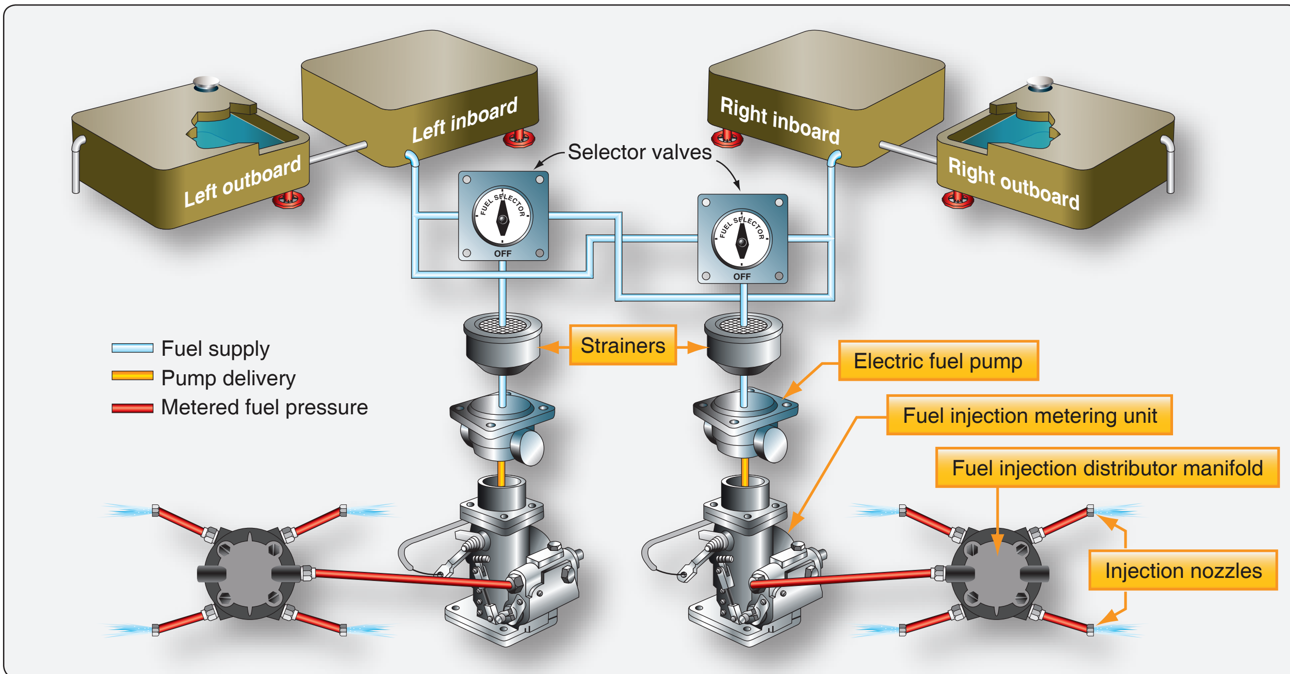


Figure 14-17. *A simple high-wing fuel injection fuel system for a light twin reciprocating-engine aircraft.*

Jet transport fuel systems can be regarded as a handful of fuel subsystems as follows:

1. Storage
2. Vent
3. Distribution
4. Feed
5. Indicating

Most transport category aircraft fuel systems are very much alike. Integral fuel tanks are the norm with much of each wing's structure sealed to enable its use as a fuel tank. Center wing section or fuselage tanks are also common. These may be sealed structure or bladder type. Jet transport aircraft carry tens of thousands of pounds of fuel on board. *Figure 14-19* shows a diagram of a Boeing 777 fuel tank configuration with tank capacities.

Note that there are optional fuel storage configurations available on the same model airliner. For example, airlines expecting to use an aircraft on transoceanic flights may order the aircraft with long-range auxiliary tanks. These additional tanks, usually located in the fuselage section of the aircraft, can alter fuel management logistics in addition to complicating the fuel system.

In addition to main and auxiliary fuel tanks, surge tanks may also be found on jet transports. These normally empty tanks located in the wing structure outboard of the main wing tanks are used for fuel overflow. A check valve allows the one-way drainage of fuel back into the main tanks. Surge tanks are also use for fuel system venting.

Transport category fuel systems require venting similar to reciprocating engine aircraft fuel systems. A series of vent tubing and channels exists that connects all tanks to vent space in the surge tanks (if present) or vent overboard. Venting must be configured to ensure the fuel is vented regardless of the attitude of the aircraft or the quantity of fuel on board. This sometimes requires the installation of various check valves, float valves, and multiple vent locations in the same tank. *Figure 14-20* shows the fuel vent system of a Boeing 737.

A transport category aircraft fuel distribution subsystem consists of the pressure fueling components, defueling components, transfer system, and fuel jettison or dump system. Single-point pressure fueling at a fueling station accessible by ramp refueling trucks allows all aircraft fuel tanks to be filled with one connection of the fuel hose. Leading and trailing edge wing locations are common for these stations. *Figure 14-21* shows an airliner fueling station with the fueling rig attached.

To fuel with pressure refueling, a hose nozzle is attached at the fueling station and valves to the tanks required to be filled are opened. These valves are called fueling valves or refueling valves depending upon the manufacturer's preference. Various automatic shutoff systems have been designed to close tank fueling valves before the tanks overfill or are damaged. Gauges on the refueling panel allow refueling personnel to monitor progress.

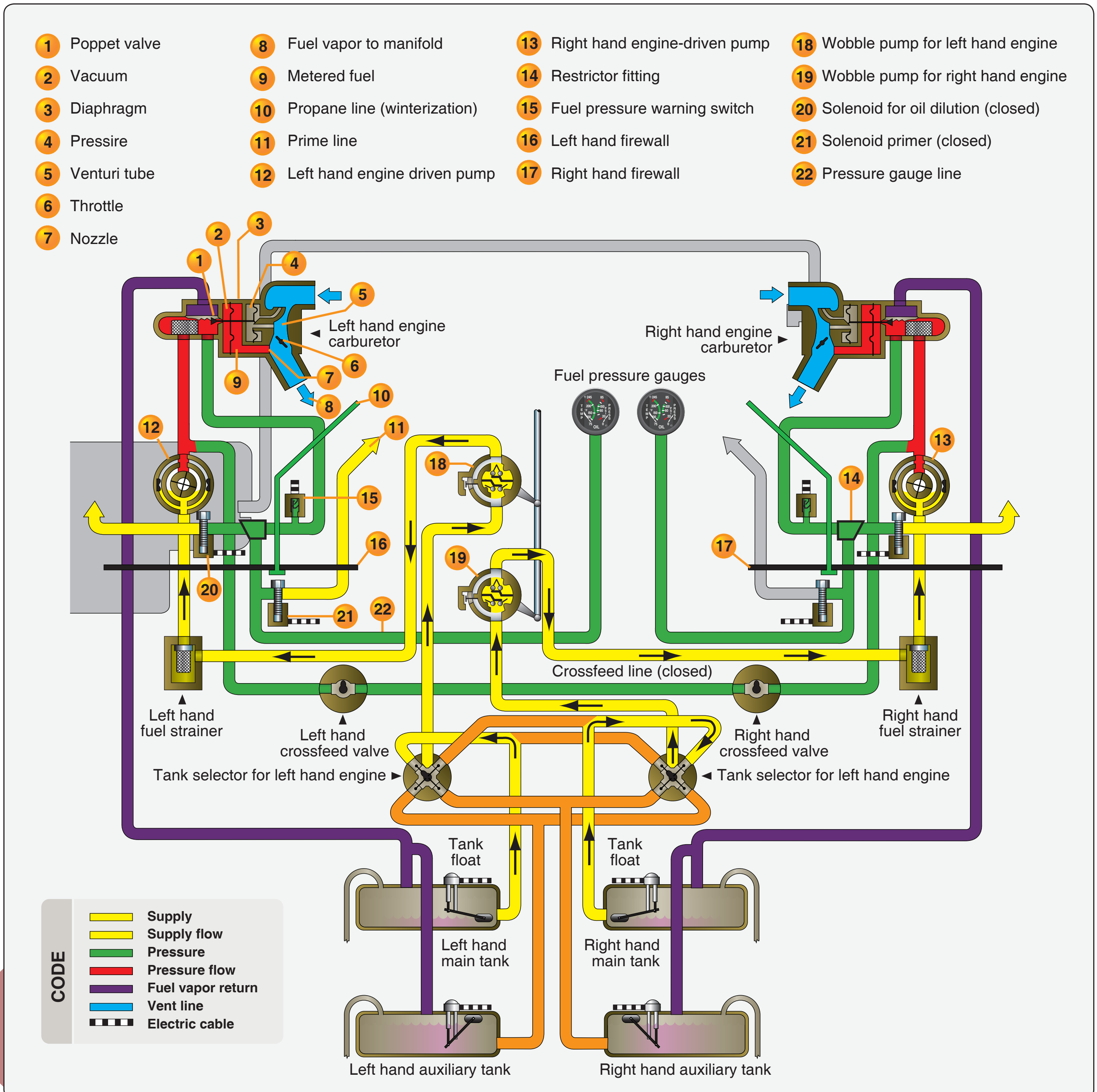


Figure 14-18. *DC-3 fuel system.*

Occasionally, defueling the aircraft is required for an inspection or repair. The same fueling station is used, and the hose from the fuel truck is connected to same receptacle used to fuel the aircraft. To allow fuel to exit the aircraft, a defueling valve is opened. Fuel can either be pumped out of the aircraft using the boost pumps located in the tanks that need to be emptied, or the pump in the refueling truck can be used to draw the fuel out of the tanks. Control over the operation is maintained by positioning various shutoff and crossfeed valves, as well as the defuel valve so that fuel travels from the tank to the fueling station and into the truck.

The fuel transfer system is a series of plumbing and valves that permits movement of fuel from one tank to another on board the aircraft. In-tank fuel boost pumps move the fuel into a manifold and, by opening the fuel valve (or refueling valve) for the desired tank, the fuel is transferred. Not all jet transports have such fuel transfer capability. Through the use of a fuel feed manifold and crossfeed valves, some aircraft simply allow engines to be run off fuel from any tank as a means for managing fuel location.

Tank	Gallons	Pounds*
Left main tank	9,560	64,000
Right main tank	9,560	64,000
Center tank	26,100	174,900
Total	45,200	302,900

* Usable fuel at level attitude
Fuel density = 6.7 pounds per U.S. gallon.

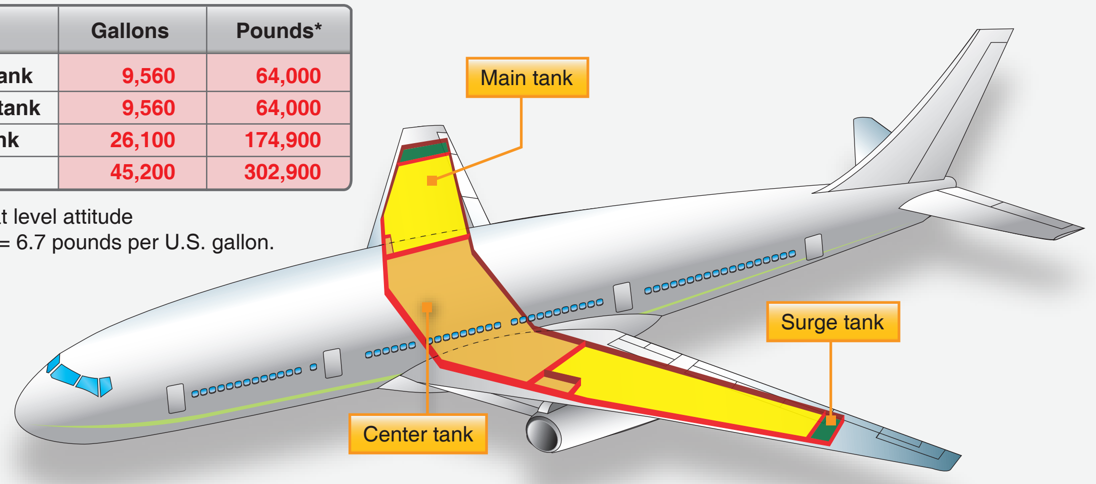


Figure 14-19. *Boeing 777 fuel tank locations and capacities.*

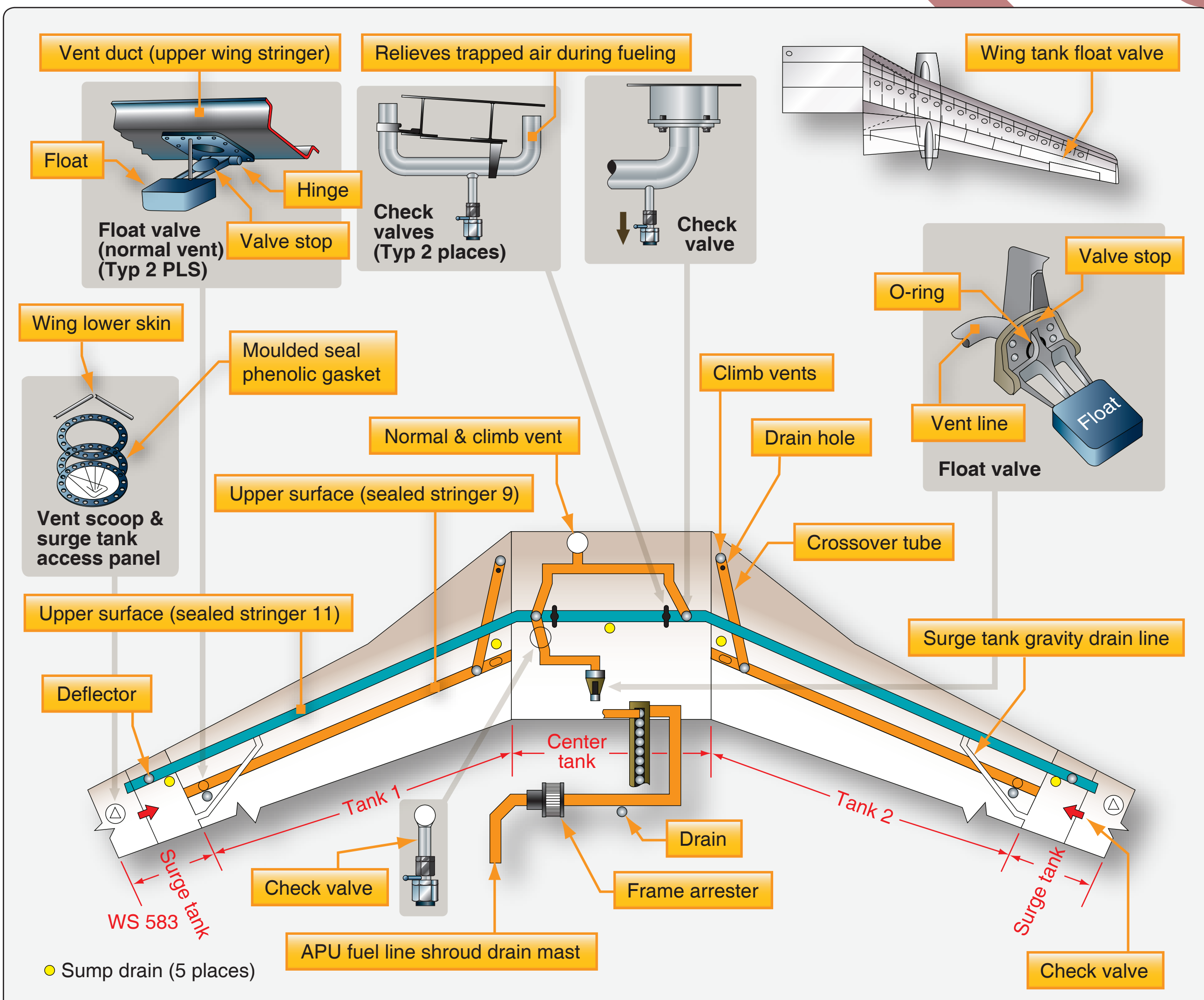


Figure 14-20. *A fuel vent system with associated float and check valves that stop fuel and keep the tanks vented regardless of the aircraft attitude.*

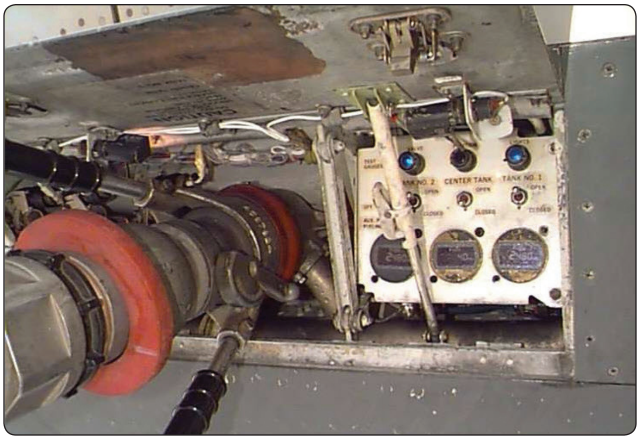


Figure 14-21. *A central pressure refueling station on a transport category aircraft allows all fuel tanks to be filled from one position.*

Figure 14-22 shows the fuel system diagram for a DC-10. Dedicated transfer boost pumps move fuel into a transfer manifold. Opening the fuel valve on one of the tanks transfers the fuel into that tank. The transfer manifold and boost pumps are also used to jettison fuel overboard by opening the proper dump valves with a transfer boost pump(s) operating. Additionally, the transfer system can function to supply the engines if the normal engine fuel feed malfunctions.

The fuel feed subsystem is sometimes considered part of the fuel distribution system. It is the heart of the fuel system since it delivers fuel to the engines. Jet transport aircraft supply fuel to the engines via in-tank fuel boost pumps, usually two per tank. They pump fuel under pressure through a shutoff valve for each engine. A manifold or connecting tubing typically allows any tank to supply any engine through the use of crossfeed valves. Boost pump bypasses allow fuel flow should a pump fail. Note that the engines are designed to be able to run without any fuel boost pumps operating. But, each engine's shutoff valve must be open to allow flow to the engines from the tanks.

Most jet transport fuel feed systems, or the engine fuel systems, have some means for heating the fuel usually through an exchange with hot air or hot oil taken from the engine. *Figure 14-23* shows the fuel cooled oil cooler (FCOC) on a Rolls Royce RB211 engine, which not only heats the fuel but also cools the engine oil.

Fuel indicating systems on jet transport aircraft monitor a variety of parameters, some not normally found on general aviation aircraft. Business jet aircraft share many of these features. True fuel flow indicators for each engine are used as the primary means for monitoring fuel delivery to the engines. A fuel temperature gauge is common as are fuel filter bypass warning lights. The temperature sensor is usually located in a main fuel tank. The indicator is located on the instrument panel or is displayed on a multifunction display (MFD). These allow the crew to monitor the fuel temperature during high altitude flight in extremely frigid conditions. The fuel filters have bypasses that permit fuel flow around the filters if clogged. Indicator light(s) illuminate in the cockpit when this occurs.

Low fuel pressure warning lights are also common on jet transport aircraft. The sensors for these are located in the boost pump outlet line. They give an indication of possible boost pump failure.

Fuel quantity gauges are important features on all aircraft. Indications exist for all tanks on a transport category aircraft. Often, these use a capacitance type fuel quantity indication system and a fuel totalizer as is discussed later in this chapter.

The location of fuel instrumentation varies depending on the type of cockpit displays utilized on the aircraft.

Helicopter Fuel Systems

Helicopter fuel systems vary. They can be simple or complex depending on the aircraft. Always consult the manufacturer's manuals for fuel system description, operation, and maintenance instructions.

Typically, a helicopter has only one or two fuel tanks located near the center of gravity (CG) of the aircraft, which is near the main rotor mast. Thus, the tank, or tanks, are usually located in or near the aft fuselage. Some helicopter fuel tanks are mounted above the engine allowing for gravity fuel feed. Others use fuel pumps and pressure feed systems.

Fundamentally, helicopter fuel systems differ little from those on fixed-wing aircraft. Gravity-feed systems have vented fuel tanks with an outlet strainer and shutoff valve. Fuel flows from the tank through a main filter to the carburetor. *[Figure 14-24]*

A slightly more complex system for a light turbine-powered helicopter is shown in *Figure 14-25*. Two in-tank electric boost pumps send fuel through a shutoff valve rather than a selector valve, since there is only one fuel tank. It flows through an airframe filter to an engine filter and then to the engine-driven fuel pump. The fuel tank is vented and contains an electrically operated sump drain valve. A pressure gauge is used to monitor boost pump output pressure and differential pressure switches warn of fuel filter restrictions. Fuel quantity is derived through the use of two in-tank fuel probes with transmitters.

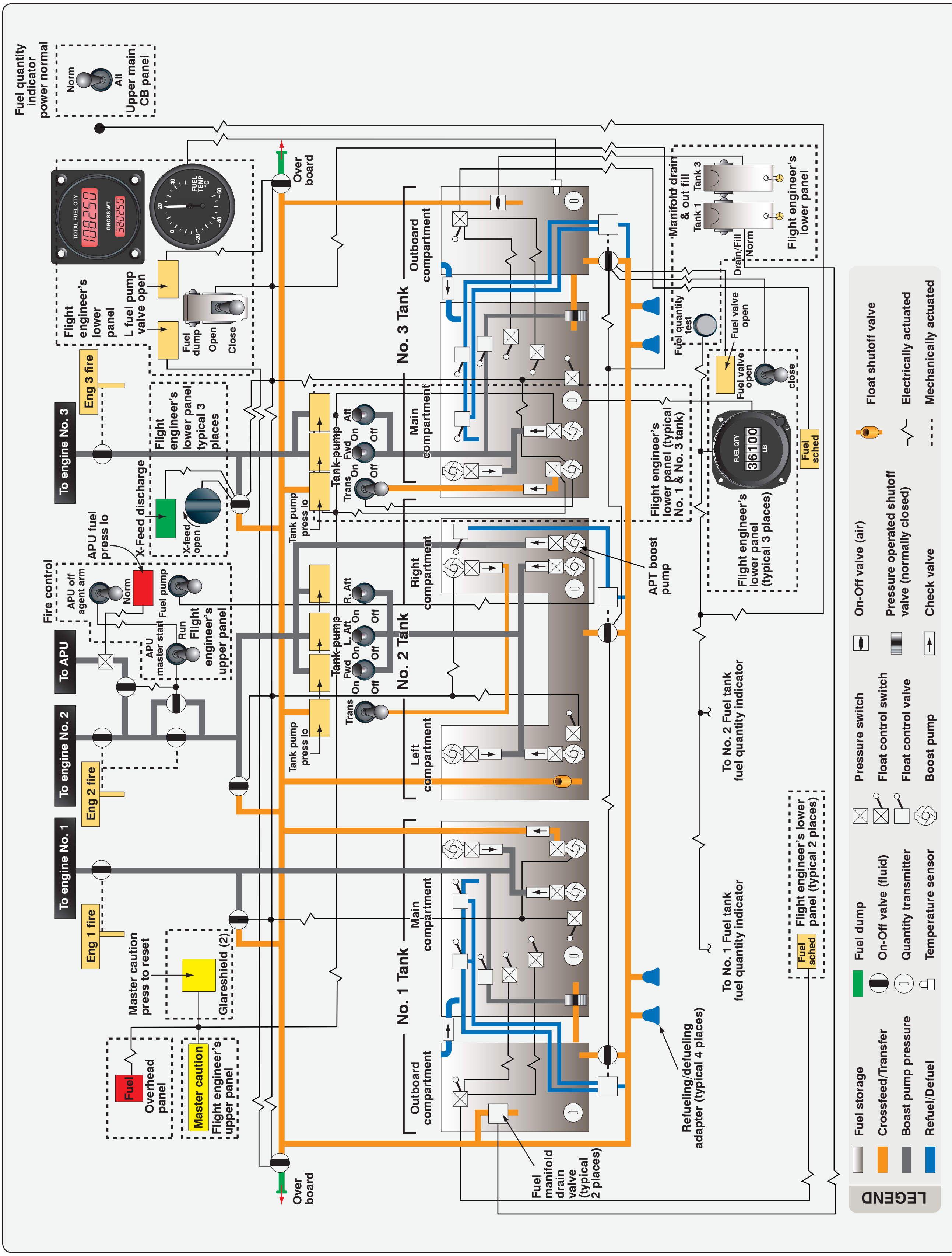


Figure 14-22. *The fuel distribution systems, components, and cockpit controls of a DC-10 airliner. Note: Fuel transfer system components and lines are used to complete the fuel dump system, the refuel/defuel system, back-up fuel delivery system, and the fuel storage system.*

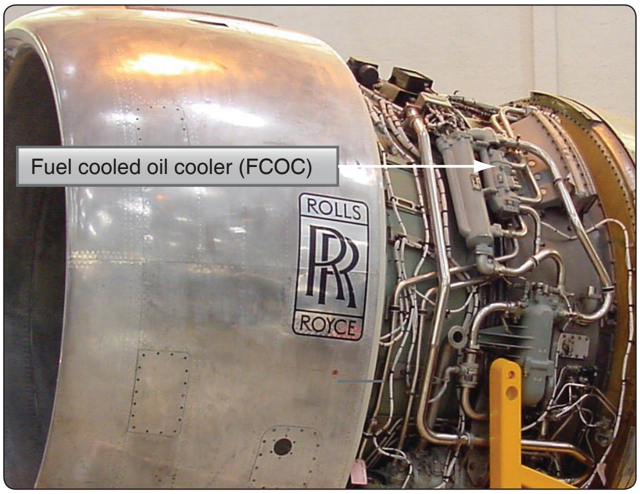


Figure 14-23. *Jet transport aircraft fly at high altitudes where temperatures can reach –50 °F. Most have fuel heaters somewhere in the fuel system to help prevent fuel icing. This fuel-cooled oil cooler on an RB211 turbofan engine simultaneously heats the fuel while cooling the oil.*

Larger, heavy, multiengine transport helicopters have complex fuel systems similar to jet transport fixed-wing aircraft. They may feature multiple fuel tanks, crossfeed systems, and pressure refueling.

Fuel System Components

To better understand aircraft fuel systems and their operation, the following discussion of various components of aircraft fuel systems is included.

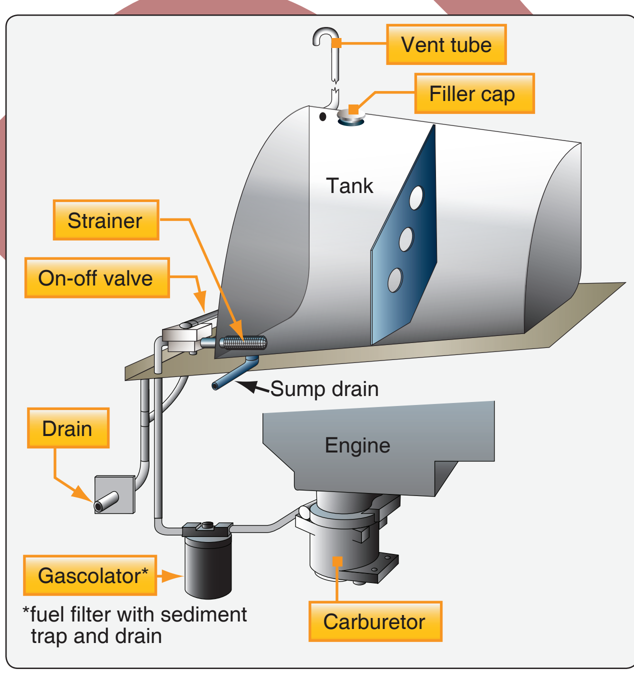


Figure 14-24. *A simple, gravity-feed fuel system on a Robinson helicopter.*

Fuel Tanks

There are three basic types of aircraft fuel tanks: rigid removable tanks, bladder tanks, and integral fuel tanks. The type of aircraft, its design and intended use, as well as the age of the aircraft determine which fuel tank is installed in an aircraft. Most tanks are constructed of noncorrosive material(s). They are typically made to be vented either through a vent cap or a vent line. Aircraft fuel tanks have a low area called a sump that is designed as a place for contaminants and water to settle. The sump is equipped with a drain valve used to remove the impurities during preflight walk-around inspection. *[Figure 14-26]* Most aircraft fuel tanks contain some sort of baffling to subdue the fuel from shifting rapidly during flight maneuvers. Use of a scupper constructed around the fuel fill opening to drain away any spilled fuel is also common.

Rigid Removable Fuel Tanks

Many aircraft, especially older ones, utilize an obvious choice for fuel tank construction. A rigid tank is made from various materials, and it is strapped into the airframe structure. The tanks are often riveted or welded together and can include baffles, as well as the other fuel tank features described above. They typically are made from 3003 or 5052 aluminum alloy or stainless steel and are riveted and seam welded to prevent leaks. Many early tanks were made of a thin sheet steel coated with a lead/tin alloy called terneplate. The terneplate tanks have folded and soldered seams. *Figure 14-27* shows the parts of a typical rigid removable fuel tank.

Regardless of the actual construction of removable metal tanks, they must be supported by the airframe and held in place with some sort of padded strap arrangement to resist shifting in flight. The wings are the most popular location for fuel tanks. *Figure 14-28* shows a fuel tank bay in a wing root with the tank straps. Some tanks are formed to be part of the leading edge of the wing. These are assembled using electric resistance welding and are sealed with a compound that is poured into the tank and allowed to cure. Many fuselage tanks also exist. *[Figure 14-29]* In all cases, the structural integrity of the airframe does not rely on the tank(s) being installed, so the tanks are not considered integral.

Note that as new materials are tested and used in aircraft, fuel tanks are being constructed out of materials other than aluminum, steel, and stainless steel. *Figure 14-30* shows a rigid removable fuel tank from an ultralight category aircraft that is constructed from Vipel® isophthalic polyester UL 1316/UL 1746 resin and composite. Its seamless, lightweight construction may lead to the use of this type of tank in other aircraft categories in the future.

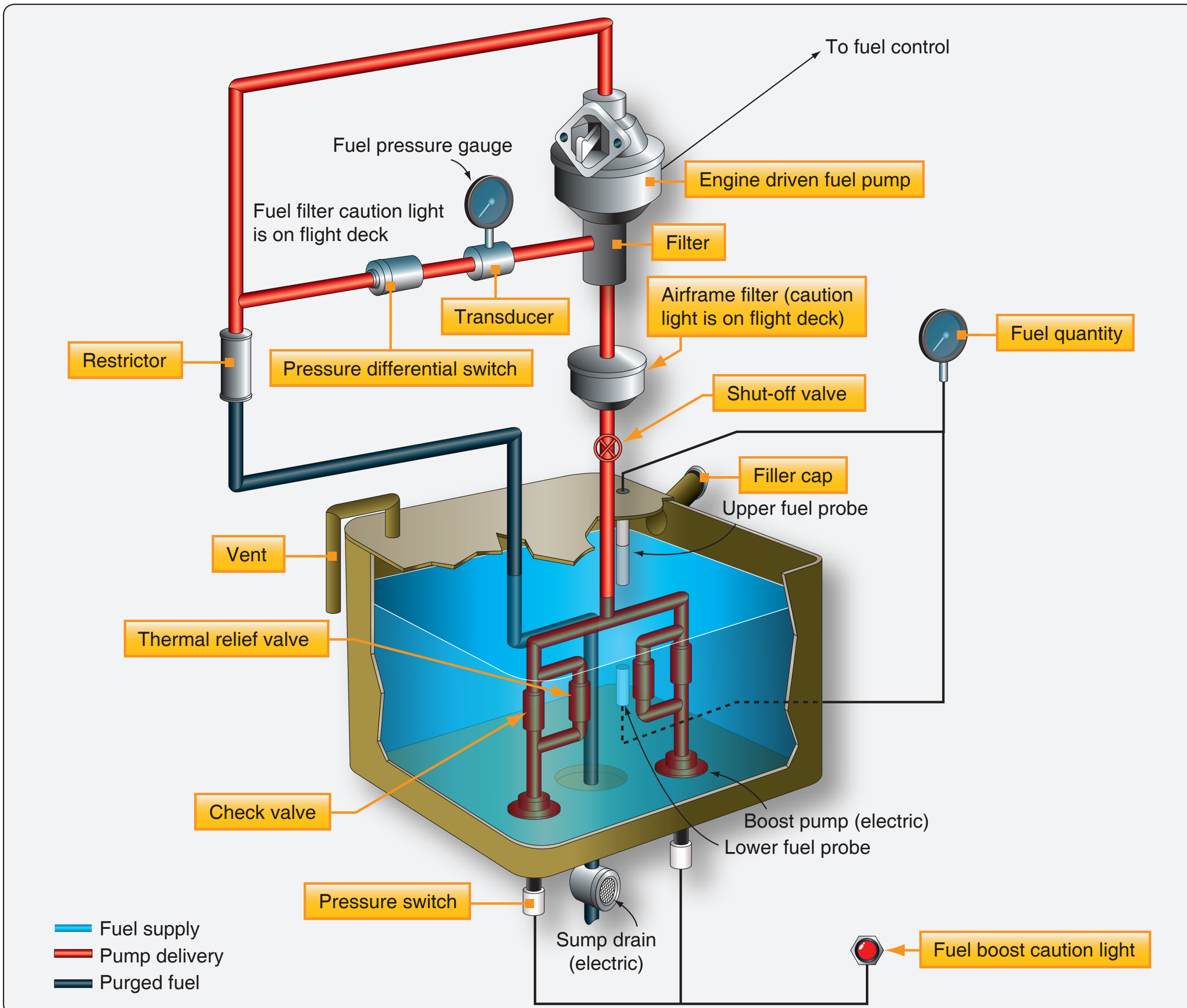


Figure 14-25. *A pressure-feed fuel system on a light turbine-powered helicopter.*

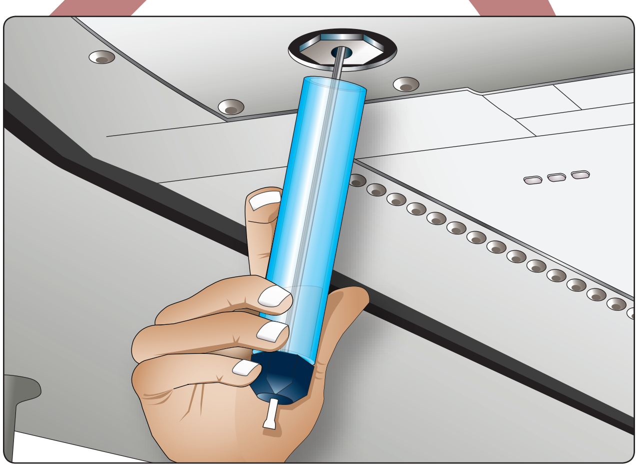


Figure 14-26. *Sumping a fuel tank with a fuel strainer that is designed to collect the sump drain material in the clear cylinder to be examined for the presence of contaminants.*

Being able to remove and repair, or replace, a fuel tank can be a great convenience if a leak or malfunction with the tank exists. Repairs to fuel tanks must be done in accordance with manufacturer's specifications. It is especially critical to follow all safety procedures when welding repairs are performed. Fuel vapors must be removed from the tank to prevent explosion. This typically involves washing out the tank with water and detergent, as well as some number of minutes that steam or water should be run through the tank (time varies by manufacturer). Once repaired, fuel tanks need to be pressure checked, usually while installed in the airframe, to prevent distortion while under pressure.

Bladder Fuel Tanks

A fuel tank made out of a reinforced flexible material called a bladder tank can be used instead of a rigid tank. A bladder tank contains most of the features and components of a rigid

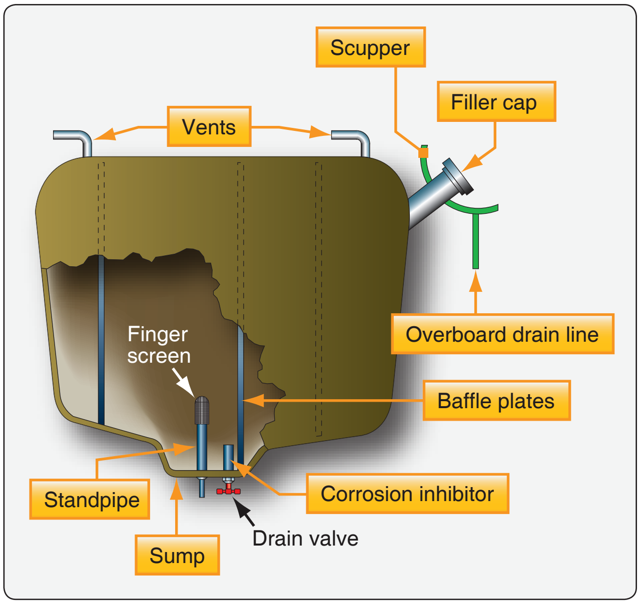


Figure 14-27. *A typical rigid removable aircraft fuel tank and its parts.*

Figure 14-28. *A fuel tank bay in the root of a light aircraft wing on a stand in a paint booth. Padded straps hold the fuel tank securely in the structure.*

tank but does not require as large an opening in the aircraft skin to install. The tank, or fuel cell as it is sometimes called, can be rolled up and put into a specially prepared structural bay or cavity through a small opening, such as an inspection opening. Once inside, it can be unfurled to its full size. Bladder tanks must be attached to the structure with clips or other fastening devices. They should lie smooth and unwrinkled in the bay. It is especially important that no wrinkles exist on the bottom surface so that fuel contaminants are not blocked from settling into the tank sump. *[Figure 14-31]*

Bladder fuel tanks are used on aircraft of all size. They are strong and have a long life with seams only around installed

Figure 14-29. *A fuselage tank for a light aircraft.*

Figure 14-30. *A composite tank from a Challenger ultralight aircraft.*

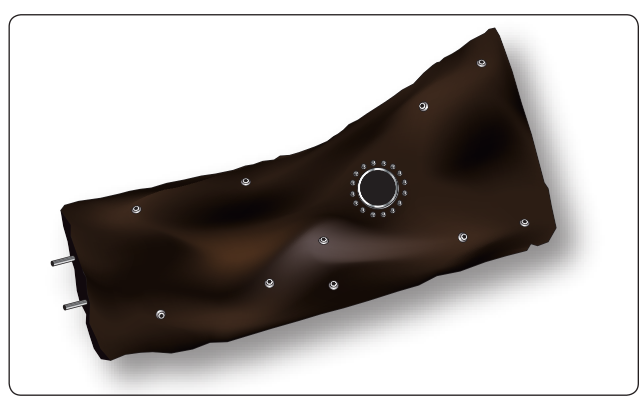


Figure 14-31. *A bladder fuel tank for a light aircraft.*

features, such as the tank vents, sump drain, filler spout, etc. When a bladder tank develops a leak, the technician can patch it following manufacturer's instructions. The cell can also be removed and sent to a fuel tank repair station familiar with and equipped to perform such repairs.

The soft flexible nature of bladder fuel tanks requires that they remain wet. Should it become necessary to store a bladder tank without fuel in it for an extended period of time, it is common to wipe the inside of the tank with a coating of clean engine oil. Follow the manufacturer's instructions for the dry storage procedures for fuel cells.

Integral Fuel Tanks

On many aircraft, especially transport category and high-performance aircraft, part of the structure of the wings or fuselage is sealed with a fuel resistant two-part sealant to form a fuel tank. The sealed skin and structural members provide the highest volume of space available with the lowest weight. This type of tank is called an integral fuel tank since it forms a tank as a unit within the airframe structure.

Integral fuel tanks in the otherwise unused space inside the wings are most common. Aircraft with integral fuel tanks in the wings are said to have wet wings. For fuel management purposes, sometimes a wing is sealed into separate tanks and may include a surge tank or an overflow tank, which is normally empty but sealed to hold fuel when needed.

When an aircraft maneuvers, the long horizontal nature of an integral wing tank requires baffling to keep the fuel from sloshing. The wing ribs and box beam structural members serve as baffles and others may be added specifically for that purpose. Baffle check valves are commonly used. These valves allow fuel to move to the low, inboard sections of the tank but prevent it from moving outboard. They ensure that the fuel boost pumps located in the bottom of the tanks at the lowest points above the sumps always have fuel to pump regardless of aircraft attitude. *[Figure 14-32]*

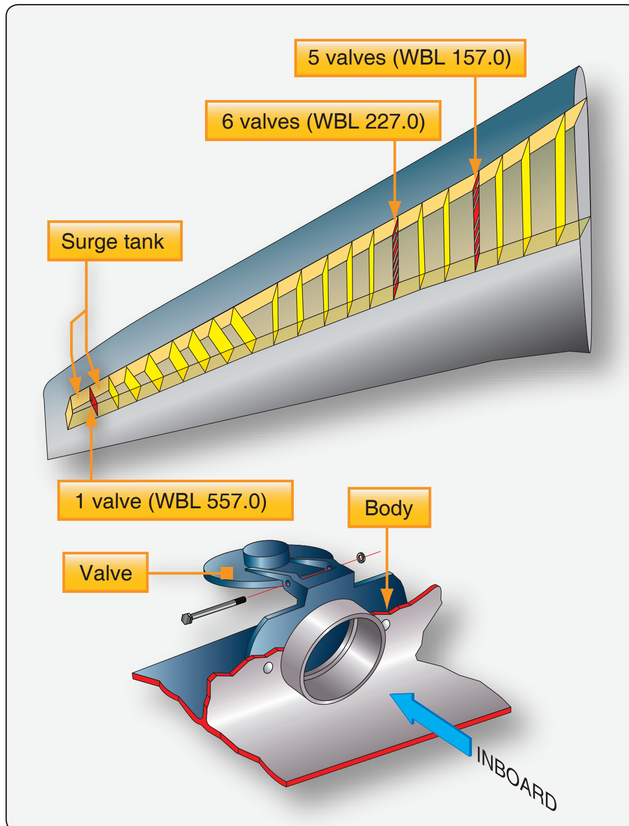


Figure 14-32. *Baffle check valves are installed in the locations shown in the integral tank rib structure of a Boeing 737 airliner. Fuel is prevented from flowing outboard during maneuvers. The tank boost pumps are located inboard of WBL 157.*

Integral fuel tanks must have access panels for inspection and repairs of the tanks and other fuel system components. On large aircraft, technicians physically enter the tank for maintenance. Transport category aircraft often have more than a dozen oval access panels or tank plates on the bottom surface of the wing for this purpose. *[Figure 14-33A]* These aluminum panels are each sealed into place with an O-ring and an aluminum gasket for electrostatic bonding. An outer clamp ring is tightened to the inner panel with screws, as shown in *Figure 14-33B.*

When entering and performing maintenance on an integral fuel tank, all fuel must be emptied from the tank and strict safety procedures must be followed. Fuel vapors must be purged from the tank and respiratory equipment must be used by the technician. A full-time spotter must be positioned just outside of the tank to assist if needed.

Aircraft using integral fuel tanks normally have sophisticated fuel systems that include in-tank boost pumps. There are usually at least two pumps in each tank that deliver fuel to the engine(s) under positive pressure. On various aircraft, these in-tank boost pumps are also used to transfer fuel to other tanks, jettison fuel, and defuel the aircraft.

Fuel Lines and Fittings

Aircraft fuel lines can be rigid or flexible depending on location and application. Rigid lines are often made of aluminum alloy and are connected with Army/Navy (AN) or military standard (MS) fittings. However, in the engine compartment, wheel wells, and other areas, subject to damage from debris, abrasion, and heat, stainless steel lines are often used.

Flexible fuel hose has a synthetic rubber interior with a reinforcing fiber braid wrap covered by a synthetic exterior.

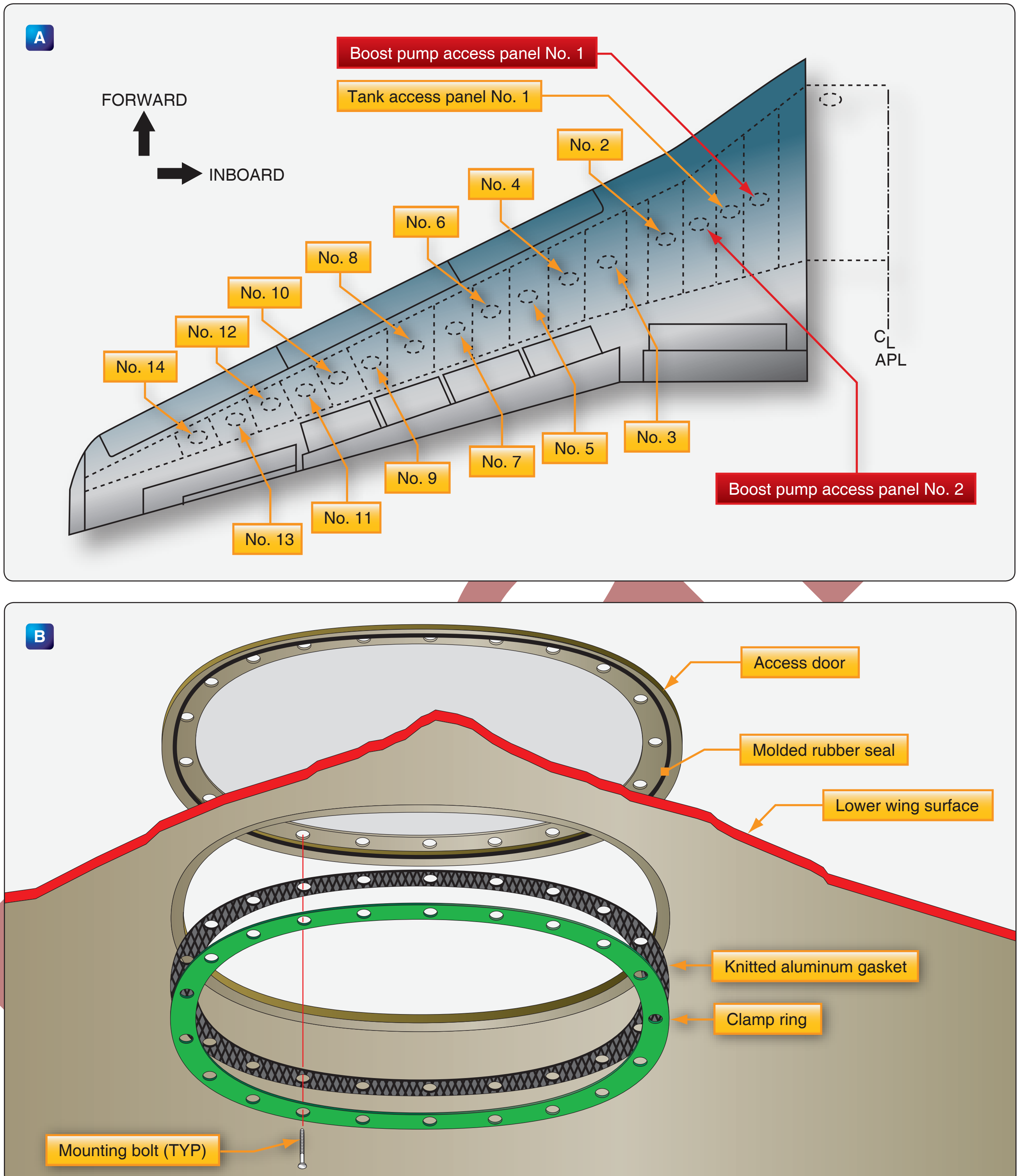


Figure 14-33. *Fuel tank access panel locations on a Boeing 737 (A), and typical fuel tank access panel seals (B).*

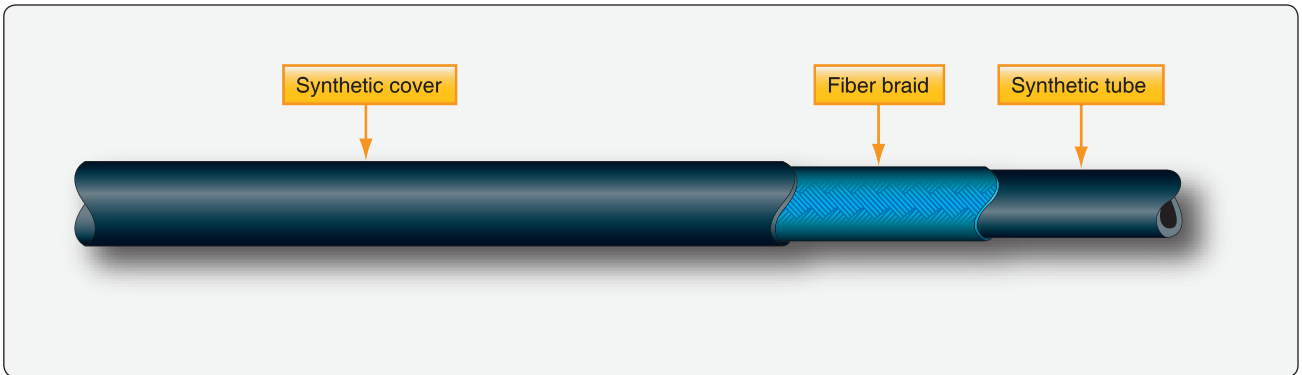


Figure 14-34. *A typical flexible aircraft fuel line with braided reinforcement.*

[Figure 14-34] The hose is approved for fuel and no other hose should be substituted. Some flexible fuel hose has a braided stainless-steel exterior. *[Figure 14-35]* The diameters of all fuel hoses and line are determined by the fuel flow requirements of the aircraft fuel system. Flexible hoses are used in areas where vibration exists between components, such as between the engine and the aircraft structure.

Sometimes manufacturers wrap either flexible or rigid fuel lines to provide even further protection from abrasion and especially from fire. A fire sleeve cover is held over the line with steel clamps at the end fittings. *[Figure 14-36]*

As mentioned, aircraft fuel line fitting are usually either AN or MS fittings. Both flared and flareless fitting are used. Problems with leaks at fittings can occur. Technicians are cautioned to not overtighten a leaky fitting. If the proper torque does not stop a leak, depressurize the line, disconnect the fitting and visually inspect it for a cause. The fitting or line should be replaced if needed. Replace all aircraft fuel lines and fittings with approved replacement parts from the manufacturer. If a line is manufactured in the shop, approved components must be used.

Several installation procedures for fuel hoses and rigid fuel lines exist. Hoses should be installed without twisting. The writing printed on the outside of the hose is used as a lay line to monitor fuel hose twist. Separation should be maintained between all fuel hoses and electrical wiring. Never clamp wires to a fuel line. When separation is not possible, always route the fuel line below any wiring. If a fuel leak develops, it does not drip onto the wires.

Metal fuel lines and all aircraft fuel system components need to be electrically bonded and grounded to the aircraft structure. This is important because fuel flowing through the fuel system generates static electricity that must have a place to flow to ground rather than build up. Special bonded cushion clamps are used to secure rigid fuel lines in place. They are supported at intervals shown in *Figure 14-37.*

All fuel lines should be supported so that there is no strain on the fittings. Clamp lines so that fittings are aligned. Never draw two fittings together by threading. They should thread easily, and a wrench should be used only for tightening. Additionally, a straight length of rigid fuel line should not be made between two components or fitting rigidly mounted to the airframe. A small bend is needed to absorb any strain from vibration or expansion and contraction due to temperature changes.

Fuel Valves

There are many fuel valve uses in aircraft fuel systems. They are used to shut off fuel flow or to route the fuel to a desired location. Other than sump drain valves, light aircraft fuel systems may include only one valve, the selector valve. It

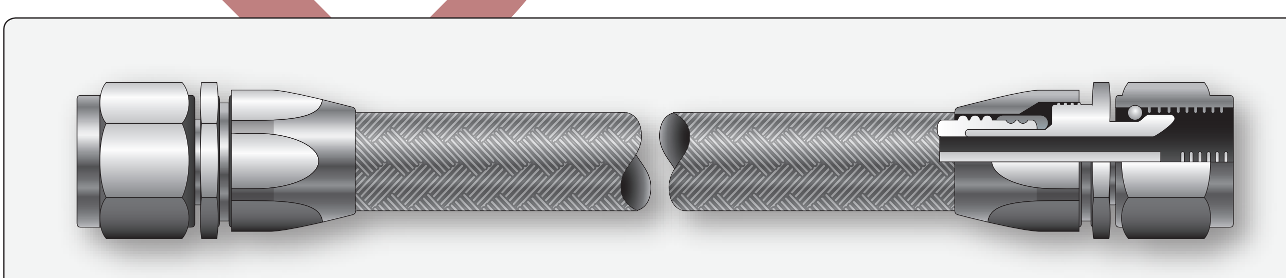
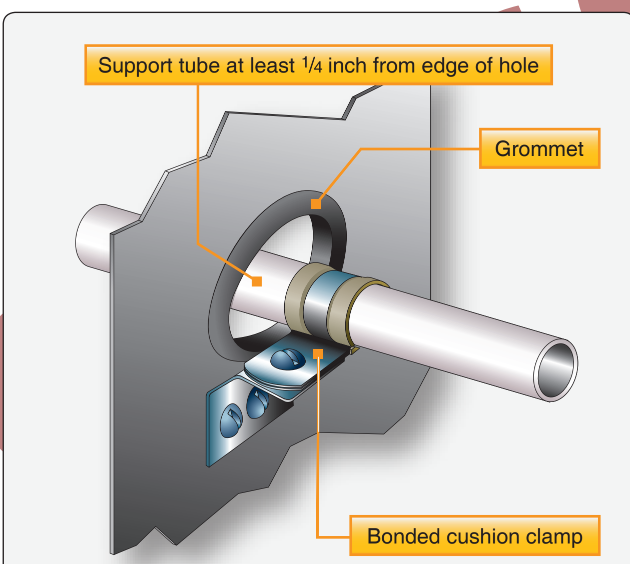


Figure 14-35. *A braided stainless steel exterior fuel line with fittings.*

Figure 14-36. *Exterior fuel hose wrap that protects from fire, as well as abrasion, shown with the clamps and pliers used to install it.*

incorporates the shutoff and selection features into a single valve. Large aircraft fuel systems have numerous valves. Most simply open and close and are known by different names related to their location and function in the fuel system (e.g., shutoff valve, transfer valve, crossfeed valve). Fuel valves can be manually operated, solenoid operated, or operated by electric motor.

A feature of all aircraft fuel valves is a means for positively identifying the position of the valve at all times. Hand-operated valves accomplish this through the use of detents into which a spring-loaded pin or similar protrusion locates when the valve is set in each position. Combined with labels and a directional handle, this makes it easy to identify by feel and by sight that the valve is in the desired position. *[Figure 14-38]* Motor- and solenoid-operated valves use position annunciator lights to indicate valve position in addition to the switch position. Flight management system (FMS) fuel pages also display the position of the fuel valves graphically in diagrams called up on the flat screen monitors. *[Figure 14-39]* Note that many valves have an exterior position handle, or lever, that indicates valve position. When maintenance personnel directly observe the valve, it can be manually positioned by the technician using this same lever. *[Figure 14-40]*



Tubing OD (inch)	Approximate distance between supports (inches)
1/8 to 3/16	9
1/4 to 5/16	12
3/8 to 1/2	16
5/8 to 3/4	22
7 to 1 1/4	30
1 1/2 to 2	40

Figure 14-37. *Rigid metallic fuel lines are clamped to the airframe with electrically bonded cushion clamps at specified intervals.*

Hand-Operated Valves

There are three basic types of hand-operated valves used in aircraft fuel systems. The cone-type valve and the poppet-type valve are commonly used in light general aviation aircraft as fuel selector valves. Gate valves are used on

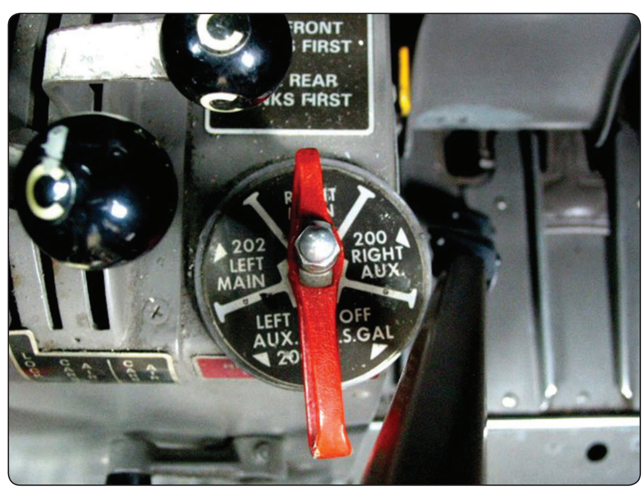


Figure 14-38. *Detents for each position, an indicating handle, and labeling aid the pilot in knowing the position of the fuel valve.*

Figure 14-39. *The graphic depiction of the fuel system on this electronic centralized aircraft monitor (ECAM) fuel page includes valve position information.*

transport category aircraft as shutoff valves. While many are motor operated, there are several applications in which gate valves are hand operated.

Cone Valves

A cone valve, also called a plug valve, consists of a machined valve housing into which a rotatable brass or nylon cone is set. The cone is manually rotated by the pilot with an attached handle. Passageways are machined through the cone so that, as it is rotated, fuel can flow from the selected source to the engine. This occurs when the passageway aligns with the desired fuel input port machined into the housing. *Figure 14-41* shows a cross sectional view of a cone valve. The cone can also be rotated to a position so that the passageway(s) does not align with any fuel input port. This is the fuel OFF position of the valve.

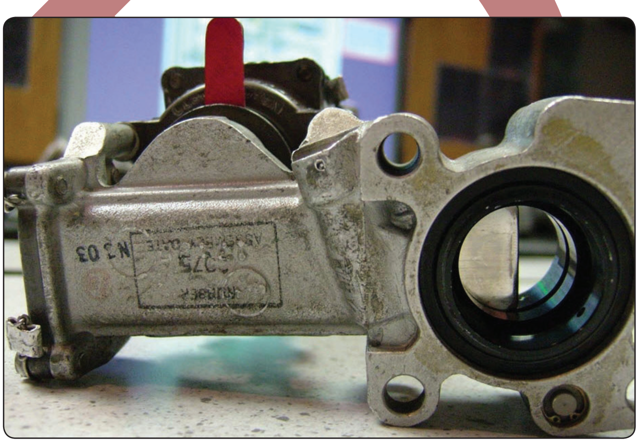


Figure 14-40. *This motor-operated gate valve has a red position indicating lever that can be used by maintenance personnel to identify the position of the valve. The lever can be moved by the technician to position the valve.*

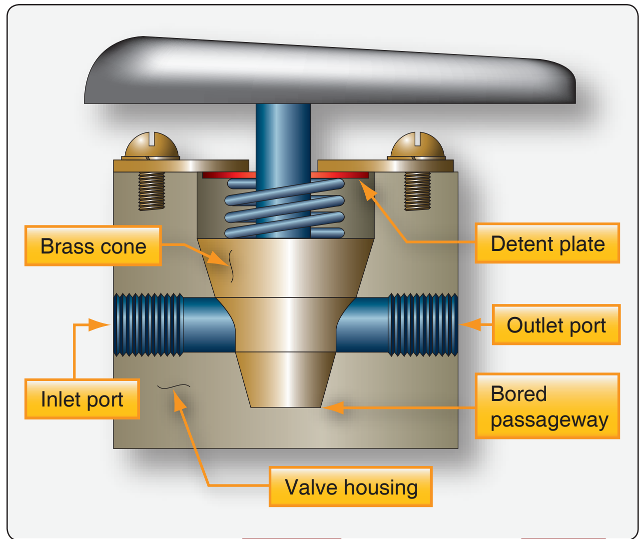


Figure 14-41. *A cone valve is open when the bored cone aligns the inlet and the outlet ports. It shuts off the flow when the un-bored portion of the cone is aligned with the inlet port(s).*

Poppet Valves

Selector valves are also commonly the poppet type. As the handle is rotated in this valve, a cam on the attached shaft lifts the poppet off the seat of the desired port being selected. At the same time, spring-assisted poppets close off the ports that are not selected. Detents lock the valve into position when the cam pushes a poppet fully off of its seat. There is also a positive detent when the cam engages none of the poppets, which is the OFF position of the valve. *[Figure 14-42]* Note that a similar mechanism is use in some selector valves, but balls are used instead of poppets.

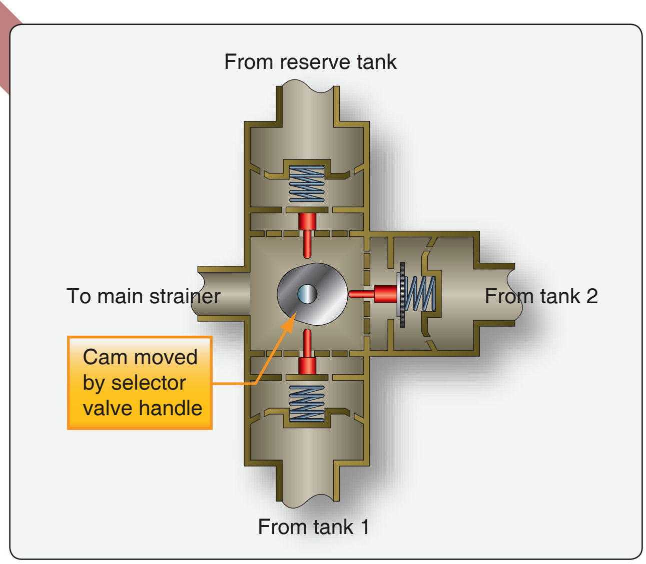


Figure 14-42. *The internal mechanism of a poppet-type fuel selector valve.*

Manually-Operated Gate Valves

A single selector valve is not used in complex fuel systems of transport category aircraft. Fuel flow is controlled with a series of ON/OFF, or shutoff, type valves that are plumbed between system components. Hand-operated gate valves can be used, especially as fire control valves, requiring no electrical power to shutoff fuel flow when the emergency fire handle is pulled. The valves are typically positioned in the fuel feed line to each engine. Hand-operated gate valves are also featured as ground-operated defuel valves and boost pump isolation valves, which shut off the fuel to the inlet of the boost pump, allowing it to be changed without emptying the tank.

Gate valves utilize a sealed gate or blade that slides into the path of the fuel, blocking its flow when closed. *Figure 14-43* shows a typical hand-operated gate valve.

When the handle is rotated, the actuating arm inside the valve moves the gate blade down between seals and into the fuel flow path. A thermal relief bypass valve is incorporated to relieve excess pressure buildup against the closed gate due to temperature increases.

Motor-Operated Valves

The use of electric motors to operate fuel system valves is common on large aircraft due to the remote location from the cockpit of fuel system components. The types of valves used are basically the same as the manually operated valves, but electric motors are used to actuate the units. The two most common electric motor operated fuel valves are the gate valve and the plug-type valve.

The motor-operated gate valve uses a geared, reversible electric motor to turn the actuating arm of the valve that moves the fuel gate into or out of the path of the fuel. As with the manually operated gate valve, the gate or blade is sealed. A manual override lever allows the technician to observe the position of the valve or manually position it. *[Figure 14-44]* Less common is the use of a motorized plug-type fuel valve; an electric motor is used to rotate the plug or drum rather than it being rotated manually. Regardless of the type of valve used, large aircraft fuel system valves either allow fuel to flow or shut off flow.

Solenoid-Operated Valves

An additional way to operate a remotely located fuel valve is through the use of electric solenoids. A poppet-type valve is opened via the magnetic pull developed when an opening solenoid is energized. A spring forces a locking stem into a notch in the stem of the poppet to lock the valve in the open position. Fuel then flows through the opening vacated by the poppet. To close the poppet and shut off fuel flow, a closing solenoid is energized. Its magnetic pull overcomes the force of the locking stem spring and pulls the locking

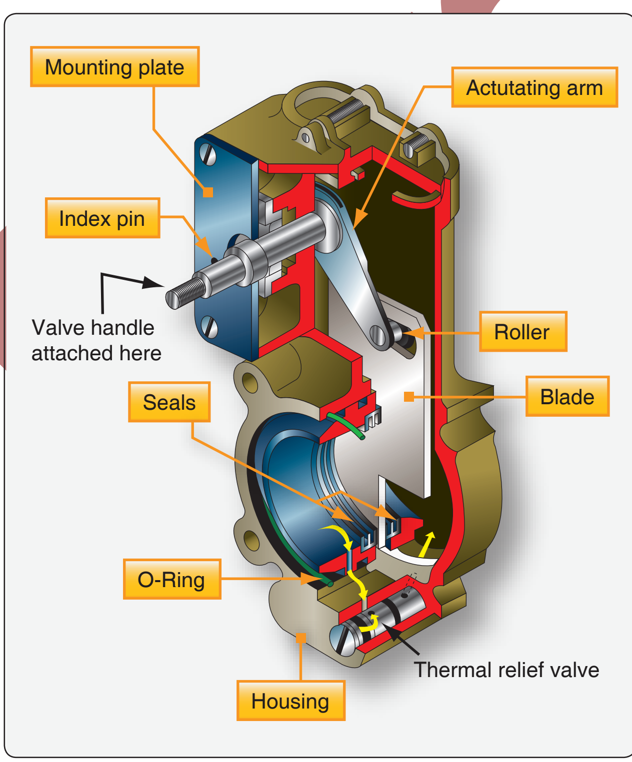


Figure 14-43. *A hand-operated gate valve used in transport category aircraft fuel systems.*

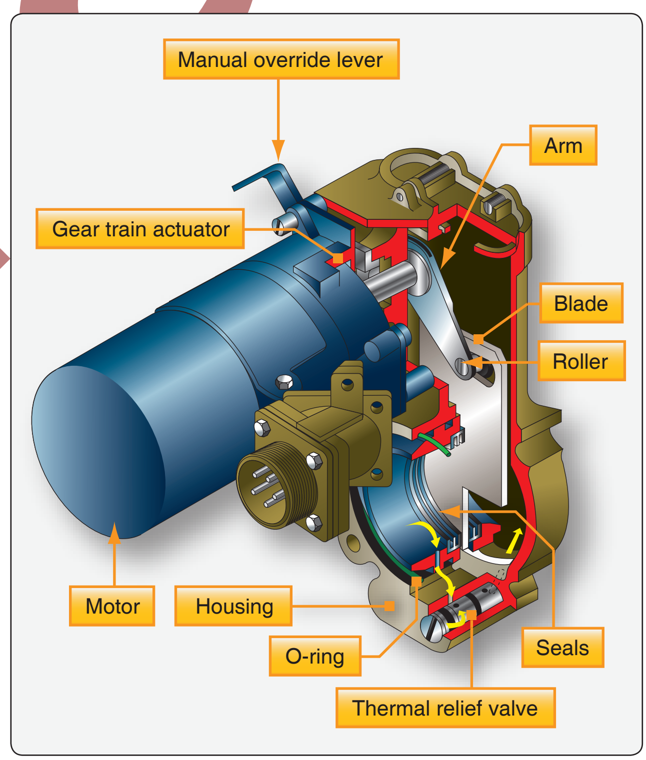


Figure 14-44. *An electric motor-driven gate valve commonly used in large aircraft fuel systems.*

stem out of the notch in the poppet stem. A spring behind the poppet forces it back onto its seat. A characteristic of solenoid-operated fuel valves is that they open and close very quickly. *[Figure 14-45]*

Fuel Pumps

Other than aircraft with gravity-feed fuel systems, all aircraft have at least one fuel pump to deliver clean fuel under pressure to the fuel metering device for each engine. Engine-driven pumps are the primary delivery device. Auxiliary pumps are used on many aircraft as well. Sometimes known as booster pumps or boost pumps, auxiliary pumps are used to provide fuel under positive pressure to the engine-driven pump and during starting when the engine-driven pump is not yet up to speed for sufficient fuel delivery. They are also used to back up the engine-driven pump during takeoff and at high altitude to guard against vapor lock. On many large aircraft, boost pumps are used to move fuel from one tank to another.

There are many different types of auxiliary fuel pumps in use. Most are electrically operated, but some hand-operated pumps are found on older aircraft. A discussion of the various pump types found in the aviation fleet follows.

Hand-Operated Fuel Pumps

Some older reciprocating engine aircraft have been equipped with hand-operated fuel pumps. They are used to back up the engine-driven pump and to transfer fuel from tank to tank. The wobble pumps, as they are known, are double-acting pumps that deliver fuel with each stroke of the pump handle. They are essentially vane-type pumps that have bored passages in the center of the pump, allowing a back-and-forth motion to pump the fuel rather than a full revolution of the vanes as is common in electrically driven or engine-driven vane-type pumps.

Figure 14-46 illustrates the mechanism found in a wobble pump. As the handle is moved down from where it is shown, the vane on the left side of the pump moves up, and the vane on the right side of the pump moves down. As the left vane moves up, it draws fuel into chamber A. Because chambers A and D are connected through the bored center, fuel is also drawn into chamber D. At the same time, the right vane forces fuel out of chamber B, through the bored passage in the center of the pump, into chamber C and out the fuel outlet through the check valve at the outlet of chamber C. When the handle is moved up again, the left vane moves down, forcing fuel out of chambers A and D because the check valve at the inlet of the A chamber prevents fuel from flowing back through the fuel inlet. The right vane moves up simultaneously and draws fuel into chambers B and C.

While simple with little to go wrong, a hand-operated pump requires fuel lines to be run into the cockpit to the pump, creating a potential hazard that can be avoided by the use of an electrically driven pump. Modern light reciprocating-engine aircraft usually use electric auxiliary pumps, but they often make use of a simple hand pump for priming the engine(s) during starting. These simple devices are single-acting piston pumps that pull fuel into the pump cylinder when the primer knob is pulled aft. When pushed forward, the fuel is pumped through lines to the engine cylinders. *[Figure 14-47]*

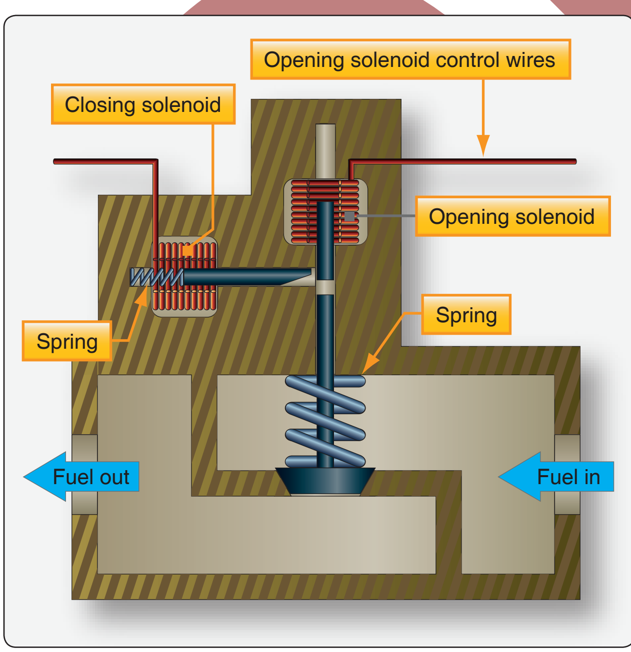


Figure 14-45. *A solenoid-operated fuel valve uses the magnetic force developed by energized solenoids to open and close a poppet.*

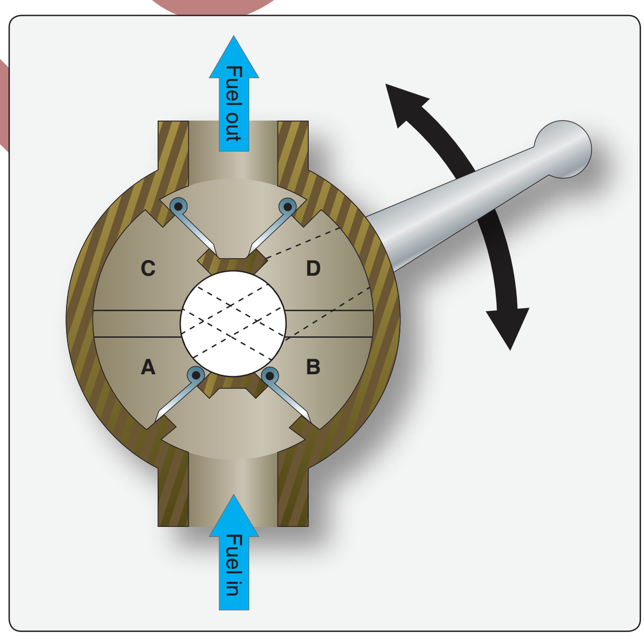


Figure 14-46. *A hand-operated wobble pump used for engine starting and fuel transfer on older transport category aircraft.*

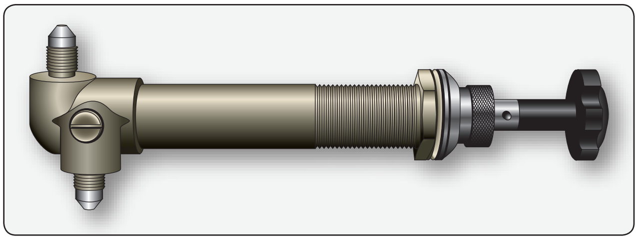


Figure 14-47. *This engine primer pump is a hand-operated piston type. It is mounted in the instrument panel and extends through the firewall where fuel intake and delivery lines are attached to the fittings on the left.*

Centrifugal Boost Pumps

The most common type of auxiliary fuel pump used on aircraft, especially large and high-performance aircraft, is the centrifugal pump. It is electric motor driven and most frequently is submerged in the fuel tank or located just outside of the bottom of the tank with the inlet of the pump extending into the tank. If the pump is mounted outside the tank, a pump removal valve is typically installed so the pump can be removed without draining the fuel tank. *[Figure 14-48]*

A centrifugal boost pump is a variable displacement pump. It takes in fuel at the center of an impeller and expels it to the outside as the impeller turns. *[Figure 14-49]* An outlet check valve prevents fuel from flowing back through the pump. A fuel feed line is connected to the pump outlet. A bypass valve may be installed in the fuel feed system to allow the engine-driven pump to pull fuel from the tank if the boost pump is not operating. The centrifugal boost pump is used to supply the engine-driven fuel pump, back up the engine-driven fuel pump, and transfer fuel from tank to tank if the aircraft is so designed.

Some centrifugal fuel pumps operate at more than one speed, as selected by the pilot, depending on the phase of aircraft operation. Single-speed fuel pumps are also common. Centrifugal fuel pumps located in fuel tanks ensure positive pressure throughout the fuel system regardless of temperature, altitude, or flight attitude thus preventing vapor lock. Submerged pumps have fuel proof covers for the electric motor since the motor is in the fuel. Centrifugal pumps mounted on the outside of the tank do not require this but have some sort of inlet that is located in the fuel. This can be a tube in which a shutoff valve is located so the pump can be changed without draining the tank. The inlet of both types of centrifugal pump is covered with a screen to prevent the ingestion of foreign matter. *[Figure 14-50]*

Ejector Pumps

Fuel tanks with in-tank fuel pumps, such as centrifugal pumps, are constructed to maintain a fuel supply to the pump inlet at all times. This ensures that the pump does not cavitate and that the pump is cooled by the fuel. The section of the fuel

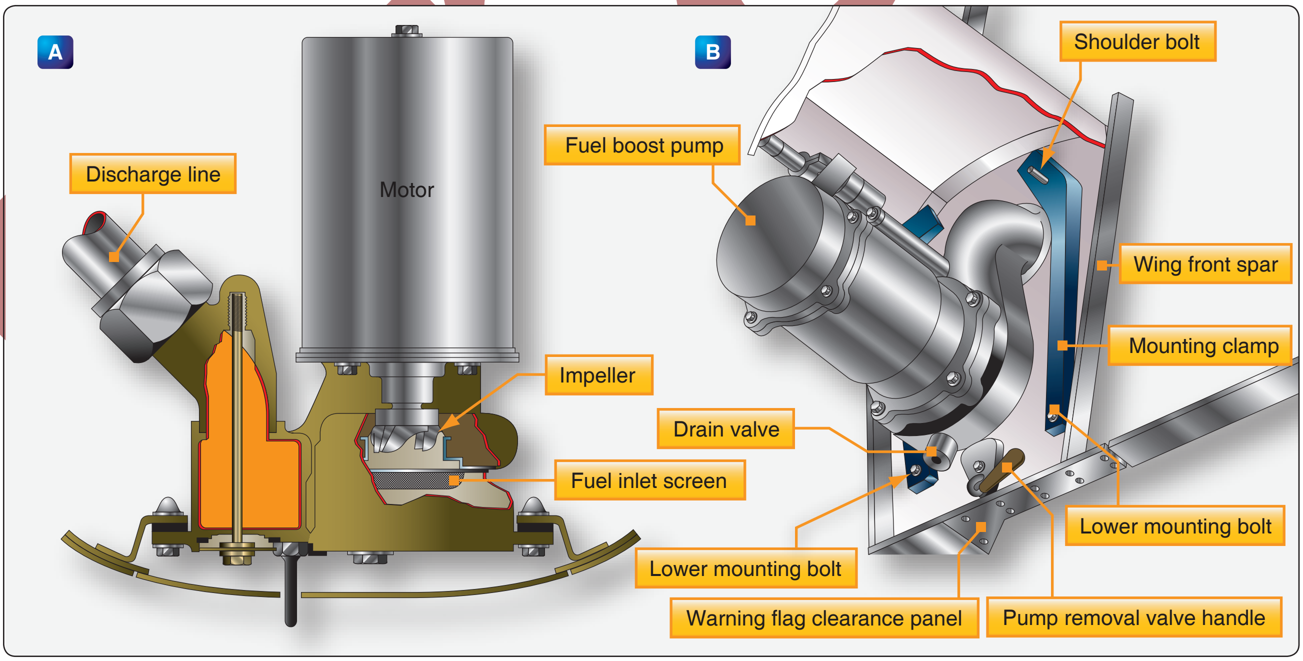


Figure 14-48. *A centrifugal fuel boost pump can be submersed in the fuel tank (A) or can be attached to the outside of the tank with inlet and outlet plumbing extending into the tank (B). The pump removal valve handle extends below the warning flag clearance panel to indicate the pump inlet is closed.*

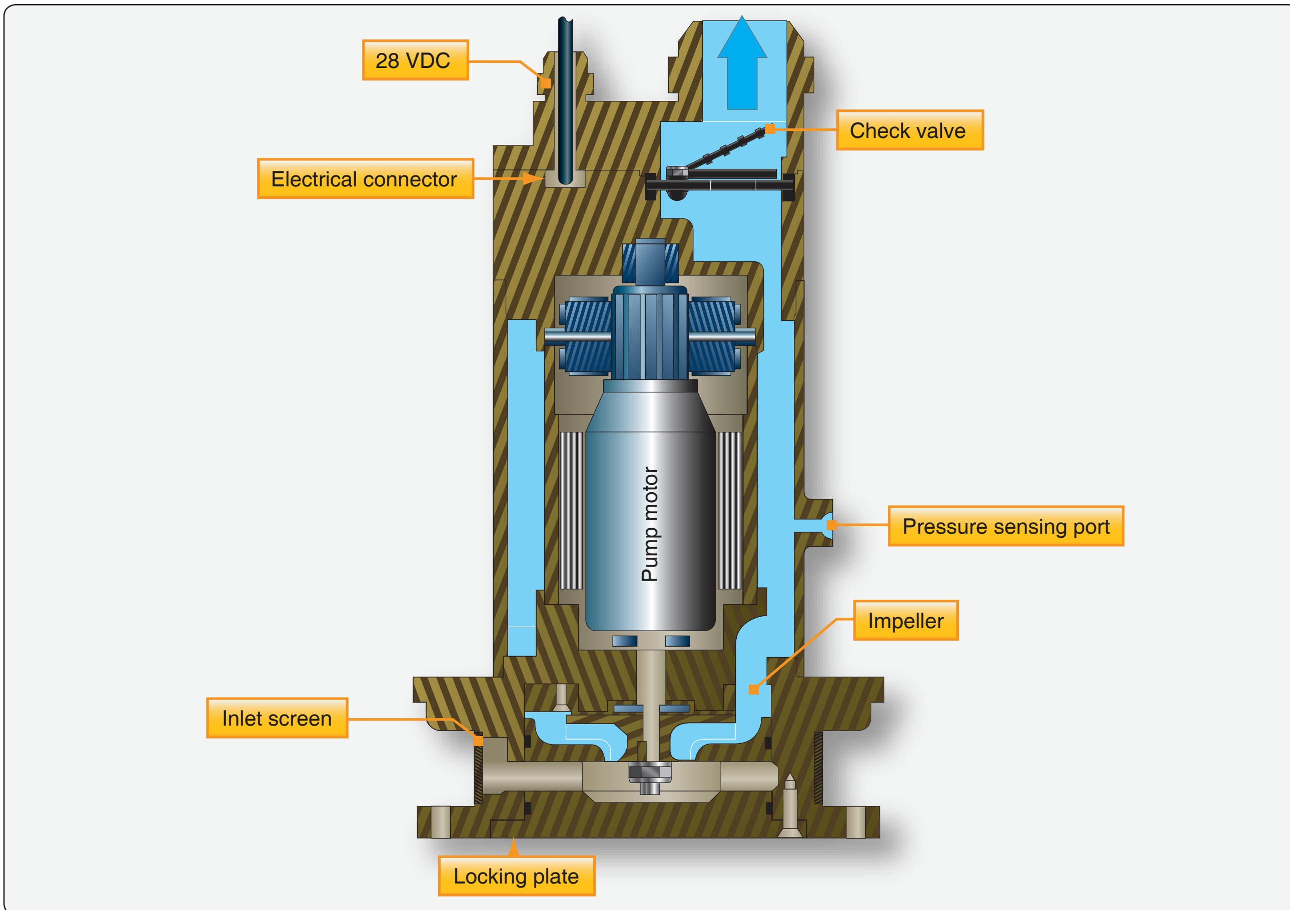


Figure 14-49. *The internal workings of a centrifugal fuel boost pump. Fuel is drawn into the center of the impeller through a screen. It is moved to the outside of the case by the impeller and out the fuel outlet tube.*

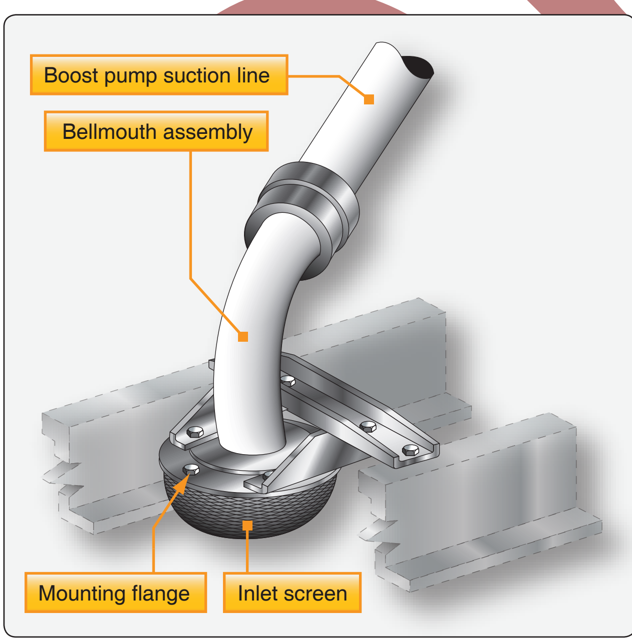


Figure 14-50. *A typical fuel boost pump inlet screen installation for a centrifugal pump mounted outside of the bottom of the tank.*

tank dedicated for the pump installation may be partitioned off with baffles that contain check valves, also known as flapper valves. These allow fuel to flow inboard to the pump during maneuvers but does not allow it to flow outboard.

Some aircraft use ejector pumps to help ensure that liquid fuel is always at the inlet of the pump. A relatively small diameter line circulates pump outflow back into the section of the tank where the pump is located. The fuel is directed through a venturi that is part of the ejector. As the fuel rushes through the venturi, low pressure is formed. An inlet, or line that originates outside of the tank pump area, allows fuel to be drawn into the ejector assembly where it is pumped into the fuel pump tank section. Together, with baffle check valves, ejector pumps keep a positive head of fuel at the inlet of the pump. *[Figure 14-51]*

Pulsating Electric Pumps

General aviation aircraft often make use of smaller, less expensive auxiliary fuel pumps. The pulsating electric pump, or plunger-type fuel pump, is common. It is usually used in

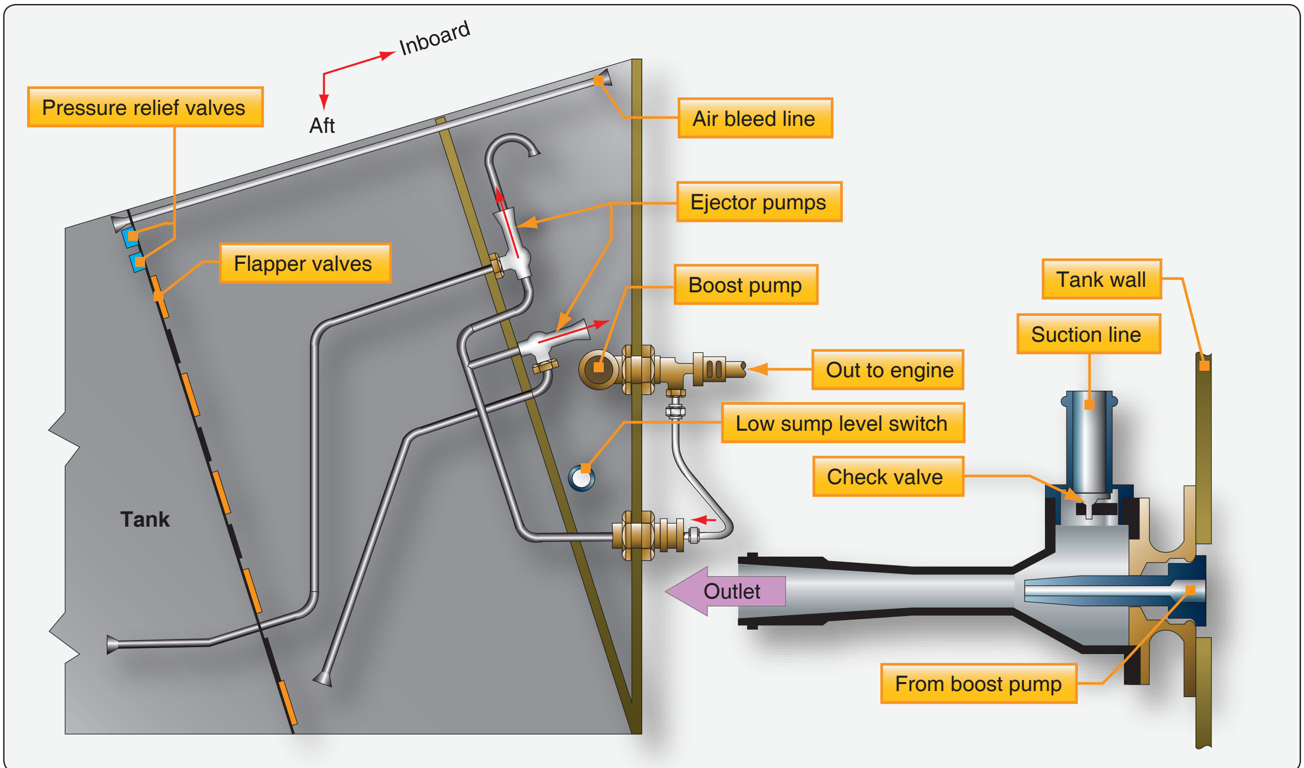


Figure 14-51. *An ejector pump uses a venturi to draw fuel into the boost pump sump area of the fuel tank.*

the same manner as a centrifugal fuel pump on larger aircraft, except it is located downstream of the fuel tank outlets. The pulsating electric fuel pump is plumbed in parallel with the engine-driven pump. During starting, it provides fuel before the engine-driven fuel pump is up to speed, and it can be used during takeoff as a backup. It also can be used at high altitudes to prevent vapor lock.

The pulsating electric pump uses a plunger to draw fuel in and push fuel out of the pump. It is powered by a solenoid that alternates between being energized and de-energized, which moves the plunger back and forth in a pulsating motion. *Figure 14-52* shows the internal workings of the pump. When switched ON, current travels through the solenoid coils, which pull the steel plunger down between the coils. Any fuel in chamber C is forced through the small check valve in the center of the plunger and into chamber D. When positioned between the solenoid, the plunger is far enough away from the magnet that it no longer attracts it, and the pivot allows the contacts to open. This disrupts the current to the solenoid.

The calibrated spring shown under the plunger is then strong enough to push the plunger up from between the solenoid coils. As the plunger rises, it pushes fuel in chamber D out the pump outlet port. Also, as the plunger rises, it draws fuel into chamber C and through the check valve into chamber C.

As the plunger rises, the magnet is attracted to it and the upward motion closes the points. This allows current flow to the solenoid coils, and the process begins again with the plunger pulled down between the coils, the magnet releasing, and the points opening.

The single-acting pulsating electric fuel pump responds to the pressure of the fuel at its outlet. When fuel is needed, the pump cycles rapidly with little pressure at the pump outlet. As fuel pressure builds, the pump slows because the calibrated spring meets this resistance while attempting to force the piston upwards. A spring in the center of the plunger dampens its motion. A diaphragm between the chamber D fuel and an airspace at the top of the pump dampens the output fuel pulses.

Vane-Type Fuel Pumps

Vane-type fuel pumps are the most common types of fuel pumps found on reciprocating-engine aircraft. They are used as both engine-driven primary fuel pumps and as auxiliary or boost pumps. Regardless, the vane-type pump is a constant displacement pump that moves a constant volume of fuel with each revolution of the pump. When used as an auxiliary pump, an electric motor rotates the pump shaft. On engine-driven applications, the vane pump is typically driven by the accessory gear box.

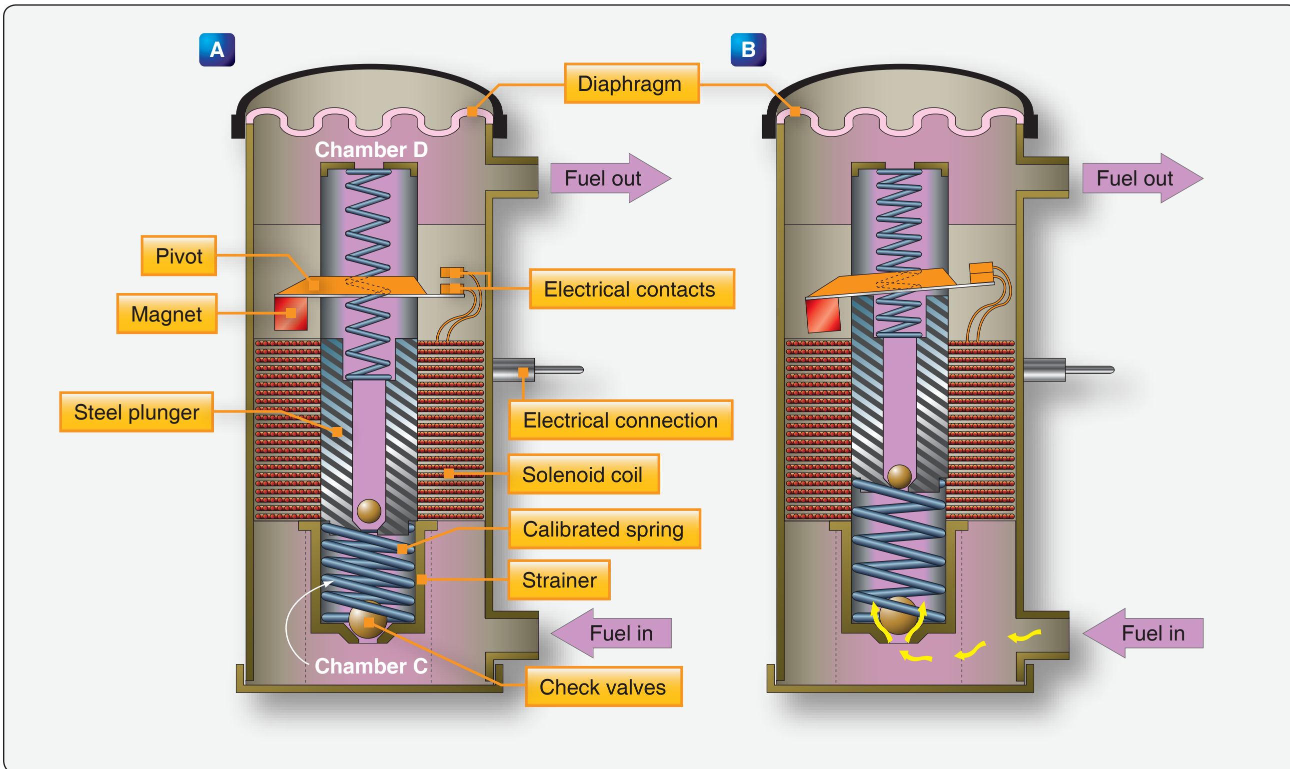


Figure 14-52. *A pulsating electric auxiliary fuel pump is used on many light reciprocating engine aircraft. In A, the pump is shown with its solenoid coil energized, which draws the plunger down between the coil. This opens the breaker points allowing the calibrated spring to push the plunger upwards, thus pumping fuel out the outlet B. This cycle repeats at a speed related to the fuel pressure buildup at the pump outlet.*

As with all vane pumps, an eccentric rotor is driven inside a cylinder. Slots on the rotor allow vanes to slide in and out and be held against the cylinder wall by a central floating spacer pin. As the vanes rotate with the eccentric rotor, the volume space created by the cylinder wall, the rotor, and the vanes increases and then decreases. An inlet port is located where the vanes create an increasing volume space, and fuel is drawn into the pump. Further around in the rotation, the space created becomes smaller. An outlet port located there causes fuel to be forced from the cylinder. *[Figure 14-53]*

The fuel metering device for the engine delivers more fuel than it needs to operate. However, the constant volume of a vane pump can be excessive. To regulate flow, most vane pumps have an adjustable pressure relief feature. It uses pressure built up at the outlet of the pump to lift a valve off its seat, which returns excess fuel to the inlet side of the pump. *Figure 14-54* shows a typical vane type fuel pump with this adjustable pressure relief function. By setting the relief at a certain pressure above the engine fuel metering device air intake pressure, the correct volume of fuel is delivered. The relief pressure is set via the pressure adjustment screw which tensions the relief valve spring.

During engine starting, or if the vane pump is inoperative, fuel must be able to flow through the pump to the fuel metering device. This is accomplished with the use of a bypass valve inside the pump. A lightly sprung plate under the relief valve overcomes spring pressure whenever the pump's inlet fuel

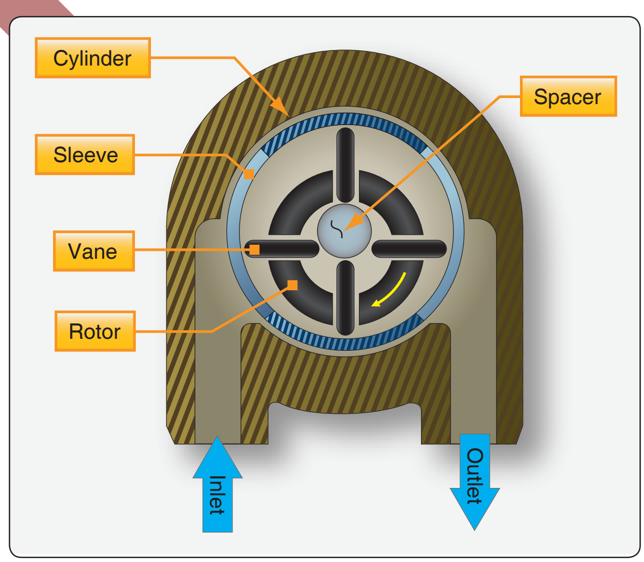


Figure 14-53. *The basic mechanism of a vane-type fuel pump.*

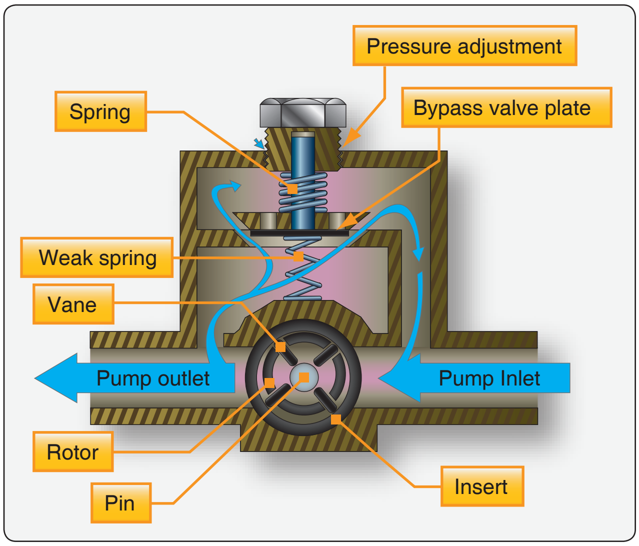


Figure 14-54. *The pressure relief valve in a vane-type fuel pump.*

pressure is greater than the outlet fuel press. The plate moves down, and fuel can flow through the pump. *[Figure 14-55]*

Compensated vane-type fuel pumps are used when the vane pump is the engine-driven primary fuel pump. The relief valve setting varies automatically to provide the correct delivery of fuel as the air inlet pressure of the fuel metering device changes due to altitude or turbocharger outlet pressure. A vent chamber above a diaphragm attached to the relief mechanism is connected to the inlet air pressure source. As air pressure varies, the diaphragm assists or resists the relief valve spring pressure, resulting in proper fuel delivery for the condition at the fuel metering device. *[Figure 14-56]*

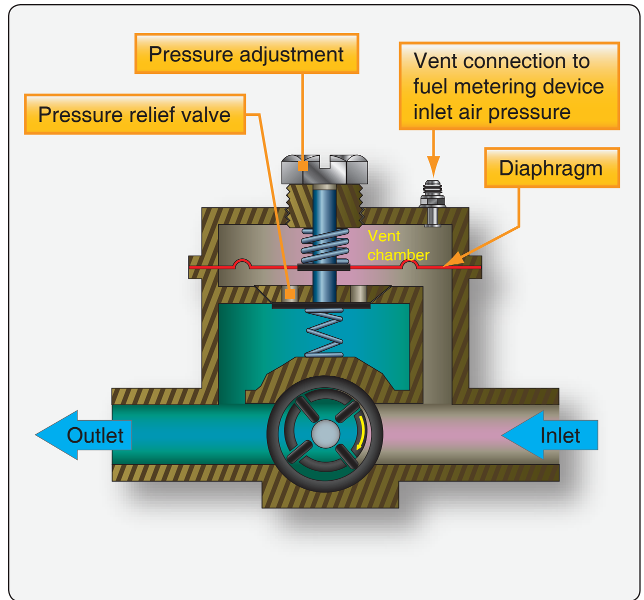


Figure 14-56. *A compensated vane pump is used in engine-driven applications. The fuel metering device inlet air pressure is connected to the vent chamber in the pump. The diaphragm assists or resists the relief valve mechanism depending on the pressure sensed in this chamber.*

Fuel Filters

Two main types of fuel cleaning device are utilized on aircraft. Fuel strainers are usually constructed of relatively coarse wire mesh. They are designed to trap large pieces of debris and prevent their passage through the fuel system. Fuel strainers do not inhibit the flow of water. Fuel filters generally are usually fine mesh. In various applications, they can trap fine sediment that can be only thousands of an inch in diameter and also help trap water. The technician should be aware that the terms "strainer" and "filter" are sometimes used interchangeably. Micronic filters are commonly used on turbine-powered aircraft. This is a type of filter that captures extremely fine particles in the range of 10–25 microns. A micron is 1⁄1,000 of a millimeter. *[Figure 14-57]*

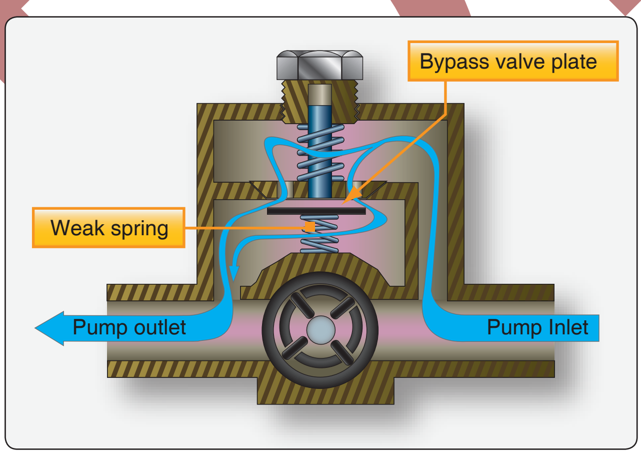


Figure 14-55. *The bypass feature in a vane-type fuel pump allows fuel to flow through the pump during starting or when the pump is inoperative.*

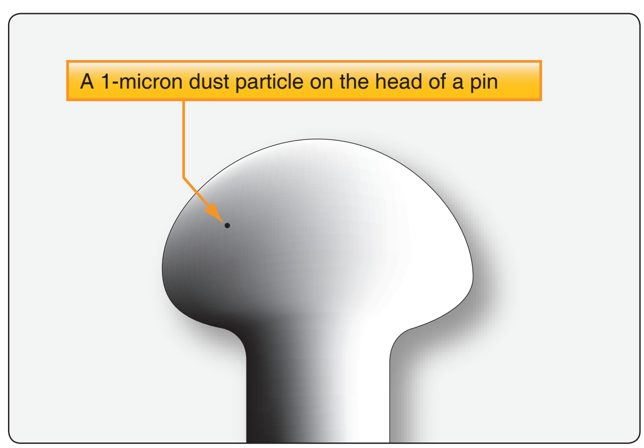


Figure 14-57. *Size comparison of 1-micron dust particle and pin head.*

All aircraft fuel systems have filters and strainers to ensure that the fuel delivered to the engine(s) is free from contaminants. The first of these is encountered at the outlet of the fuel tank. A sump is used to encourage the collection of debris in the lowest part of the tank, which can then be drained off before flight. The actual tank outlet for the fuel is positioned above this sump. Some type of screen is used to trap contaminants attempting to flow out of the tank into the fuel system. Finger screens are common on light aircraft. They effectively increase the area of the fuel tank outlet, allowing a large amount of debris to be trapped while still permitting fuel to flow. *Figure 14-58* illustrates finger screens that are screwed into a fitting welded in the tank outlet.

Fuel tank outlet screens on aircraft with more complex fuel systems are similarly designed. When in-tank boost pumps are used, the tank outlet strainer is located at the inlet to the boost pump as was shown in *Figure 14-50*. The screen's large area allows debris capture while still permitting sufficient fuel flow for operation. Regularly scheduled inspection and cleaning of these strainers are required.

An additional main strainer for the aircraft fuel system is required between the fuel tank outlet and the fuel metering device (in a carburetor or fuel-injection system). It is normally located between the fuel tank and the engine-driven fuel pump at the low point in the fuel system and is equipped with a drain for prefight sampling and draining. On light aircraft, the main strainer may be in the form of a gascolator. A gascolator is a fuel strainer, or filter, that also incorporates a sediment collection bowl. The bowl is traditionally glass to allow quick visual checks for contaminants; however, many gascolators also have opaque bowls. A gascolator has a drain, or the bowl can be removed to inspect and discard trapped debris and water. *[Figure 14-59]*

The main fuel strainer is often mounted at a low point on the engine firewall. The drain is accessible through an easy-access panel, or it simply extends through the bottom engine cowling. As with most filters or strainers, fuel is allowed to enter the unit but must travel up through the filtering element to exit. Water, which is heavier than fuel, becomes trapped and collects in the bottom of the bowl. Other debris too large to pass through the element also settles in the strainer bowl.

Higher performance light aircraft may have a main filter/strainer. *[Figure 14-60]* On twin-engine aircraft, there is a main strainer for each engine. As with single-engine aircraft, a strainer is often mounted low on the engine firewall in each nacelle.

Other larger fuel filters have double-screen construction. A cylindrical structural screen is wrapped with a fine mesh material through which inlet fuel must pass. Inside the cylinder is an additional cone-shaped screen. Fuel must pass up through the cone to get to the filter outlet. The mesh used in this filter assembly prevents water and particles from exiting the filter bowl. The contaminants collect at the bottom to be drained off through a drain valve. *[Figure 14-61]*

Figure 14-58. *Fuel tank outlet finger strainers are used in light aircraft.*

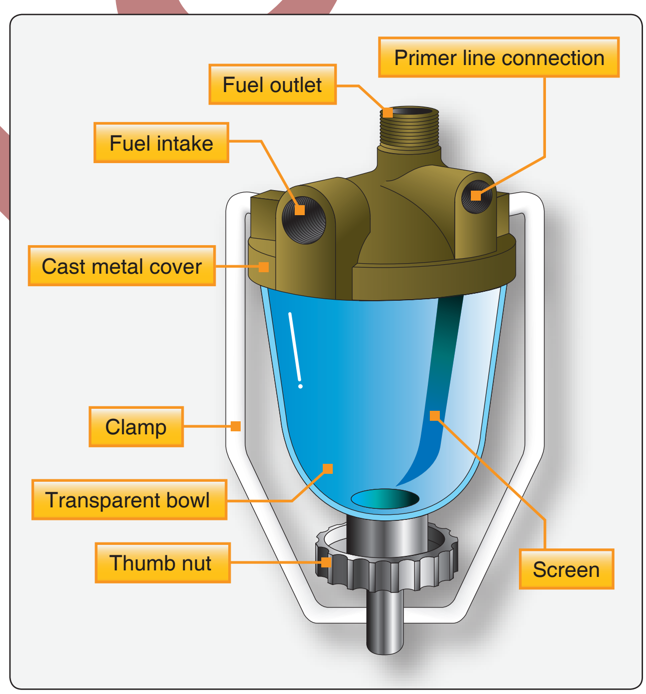


Figure 14-59. *A gascolator is the main fuel strainer between the fuel tanks and the fuel metering device on many light aircraft.*

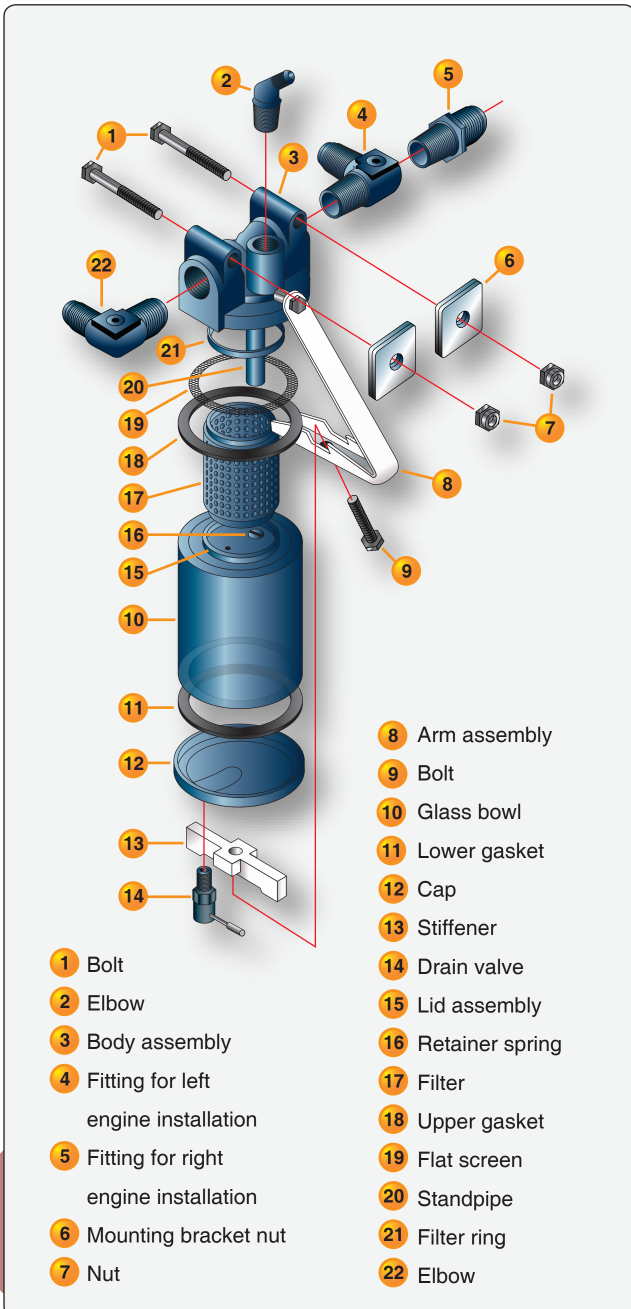


Figure 14-60. *A filter assembly on a light twin reciprocating-engine aircraft.*

Turbine engine fuel control units are extremely close tolerance devices. It is imperative that fuel delivered to them is clean and contaminant free. The used of micronic filters makes this possible. The changeable cellulose filter mesh type shown in *Figure 14-62* can block particles 10–200 microns in size and absorbs water if it is present. The small size of the mesh raises the possibility of the filter being blocked by debris or water. Therefore, a relief valve is included in the filter assembly that bypasses fuel through the unit should pressure build up from blockage.

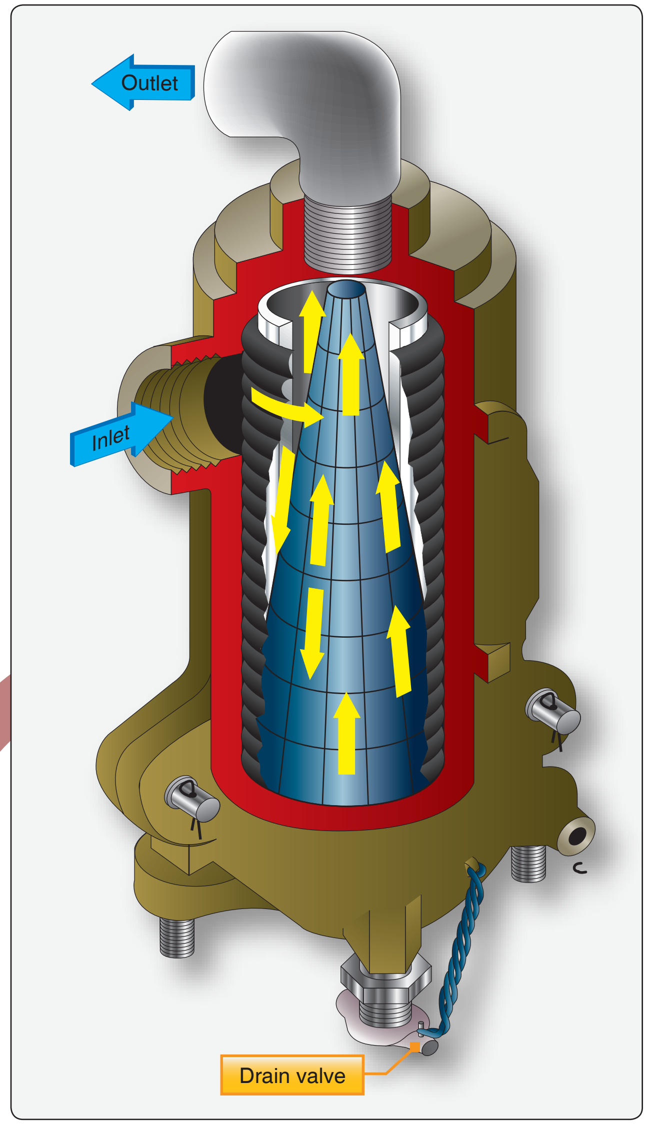


Figure 14-61. *A large-area double-screen filter passes fuel through the outer cylindrical mesh and the inner conical mesh.*

Fuel filters are often used between the engine-driven fuel pump and the fuel metering device on reciprocating, as well as turbine-engine aircraft. While these are technically part of the engine fuel system, a common type used on turbine engines is discussed here. It is also a micronic filter. It uses finely meshed disks or wafers stacked on a central core. These filters are able to withstand the higher pressure found in the engine fuel system downstream of the engine-driven pump. *[Figure 14-63]*

Indication of a filter blockage may also appear in the cockpit through the use of a bypass-activated switch or a pressure differential switch. The bypass valve physically activates a switch that closes the circuit to the annunciator in the first type. The differential pressure type indicator compares the input pressure of the fuel filter to the output pressure. A circuit is completed when a preset difference occurs. Thus,

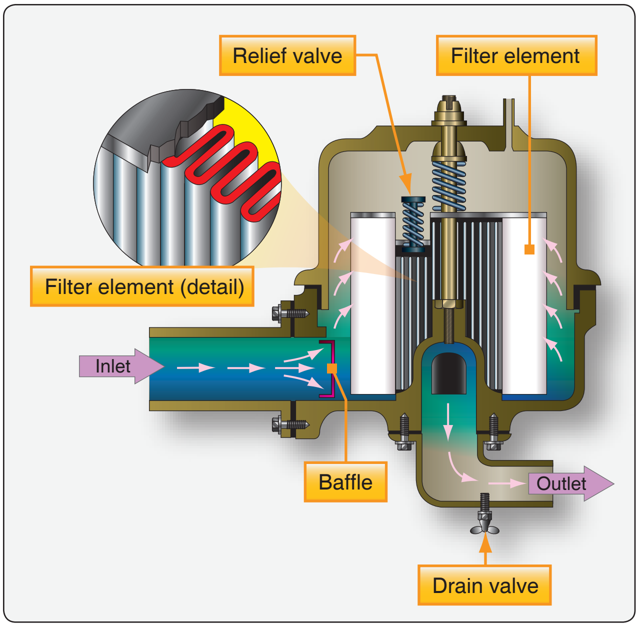


Figure 14-62. *A typical micronic fuel filter with changeable cellulose filter element.*

an indicator is illuminated should a blockage cause the bypass to open or the inlet and outlet pressures to vary significantly. Fuel temperature can also be monitored for the possibility of a blockage caused by frozen water.

Fuel Heaters and Ice Prevention

Turbine powered aircraft operate at high altitude where the temperature is very low. As the fuel in the fuel tanks cools, water in the fuel condenses and freezes. It may form ice crystals in the tank or as the fuel/water solution slows and contacts the cool filter element on its way through fuel filter to the engine(s). The formation of ice on the filter element blocks the flow of fuel through the filter. A valve in the filter unit bypasses unfiltered fuel when this occurs. Fuel heaters are used to warm the fuel so that ice does not form. These heat exchanger units also heat the fuel sufficiently to melt any ice that has already formed.

The most common types of fuel heaters are air/fuel heaters and oil/fuel heaters. An air/fuel heater uses warm compressor bleed air to heat the fuel. An oil/fuel exchanger heats the fuel with hot engine oil. This latter type is often referred to as a fuel-cooled oil cooler (FCOC). *[Figure 14-24]*

Fuel heaters often operate intermittently as needed. A switch in the cockpit can direct the hot air or oil through the unit or block it. The flight crew uses the information supplied by the filter bypass indicating lights and fuel temperature gauge *[Figure 14-64]* to know when to heat the fuel. Fuel heaters can also be automatic. A built-in thermostatic device opens or closes a valve that permits the hot air or hot oil to flow into the unit to cool the fuel. *[Figure 14-65]*

Note that some aircraft have a hydraulic fluid cooler in one of the aircraft fuel tanks. The fluid helps warm the fuel as it cools in this type of full-time heat exchanger.

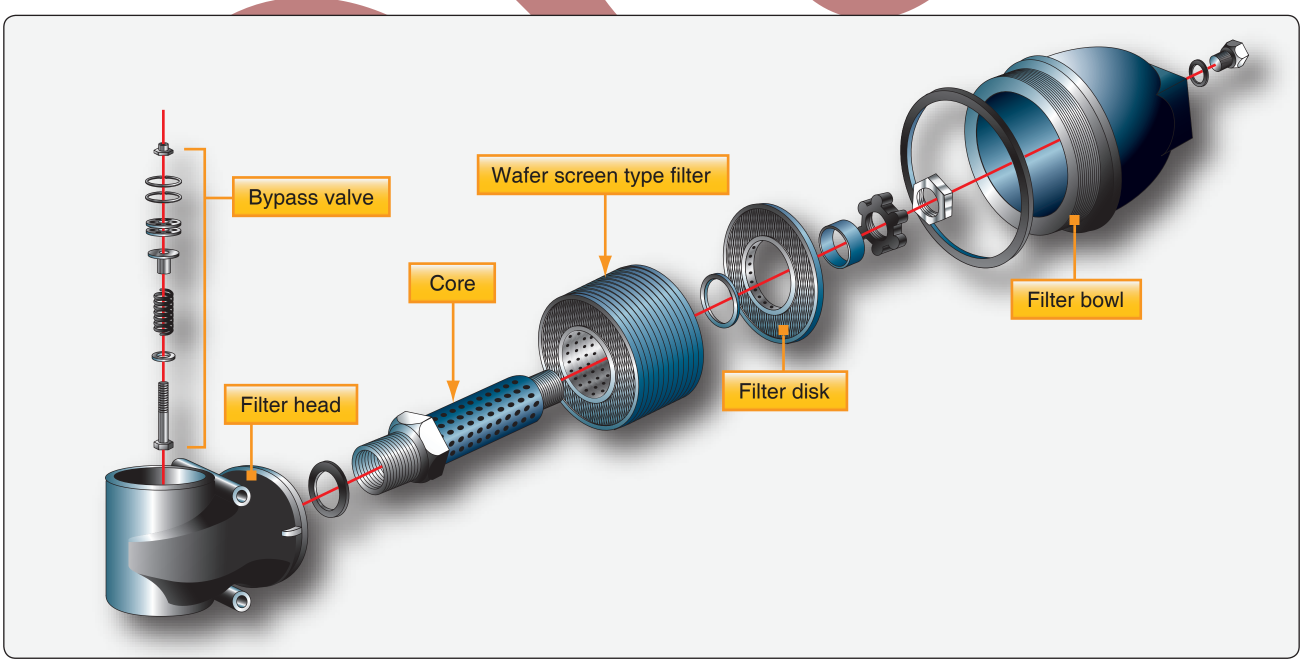


Figure 14-63. *A micronic wafer filter uses multiple screen wafers through which fuel must pass to exit the filter through the core. A spring loaded bypass valve in the filter housing unseats when the filter is clogged to continue delivery of fuel.*

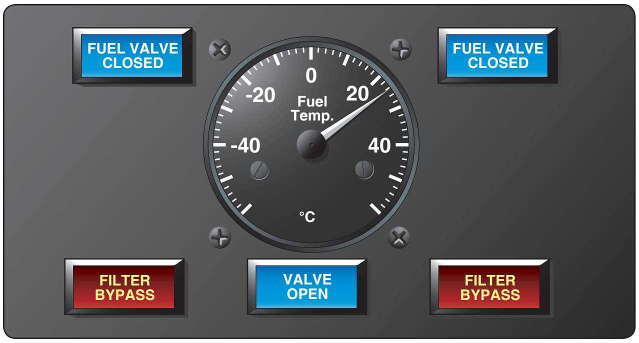


Figure 14-64. *A Boeing 737 cockpit fuel panel showing illuminated valve position indicators and fuel filter bypass lights. The fuel temperature in tank No.1 is also indicated.*

Fuel System Indicators

Aircraft fuel systems utilize various indicators. All systems are required to have some sort of fuel quantity indicator. Fuel flow, pressure, and temperature are monitored on many aircraft. Valve position indicators and various warning lights and annunciations are also used.

Fuel Quantity Indicating Systems

All aircraft fuel systems must have some form of fuel quantity indicator. These devices vary widely depending on the complexity of the fuel system and the aircraft on which they are installed. Simple indicators requiring no electrical power were the earliest type of quantity indicators and are still in use today. The use of these direct reading indicators is possible only on light aircraft in which the fuel tanks are in close proximity to the cockpit. Other light aircraft and larger aircraft require electric indicators or electronic capacitance-type indicators.

Figure 14-66. *The fuel quantity indicator on this Piper Cub is a float attached to a rod that protrudes through the fuel cap.*

A sight glass is a clear glass or plastic tube open to the fuel tank that fills with fuel to the same level as the fuel in the tank. It can be calibrated in gallons or fractions of a full tank that can be read by the pilot. Another type of sight gauge makes use of a float with an indicating rod attached to it. As the float moves up and down with the fuel level in the tank, the portion of the rod that extends through the fuel cap indicates the quantity of fuel in the tank. *[Figure 14-66]* These two mechanisms are combined in yet another simple fuel quantity indicator in which the float is attached to a rod that moves up or down in a calibrated cylinder. *[Figure 14-67]*

More sophisticated mechanical fuel quantity gauges are common. A float that follows the fuel level remains the primary sensing element, but a mechanical linkage is connected to move a pointer across the dial face of an instrument. This can be done with a crank and pinion arrangement that drives the pointer with gears, or with a magnetic coupling, to the pointer. *[Figure 14-68]*

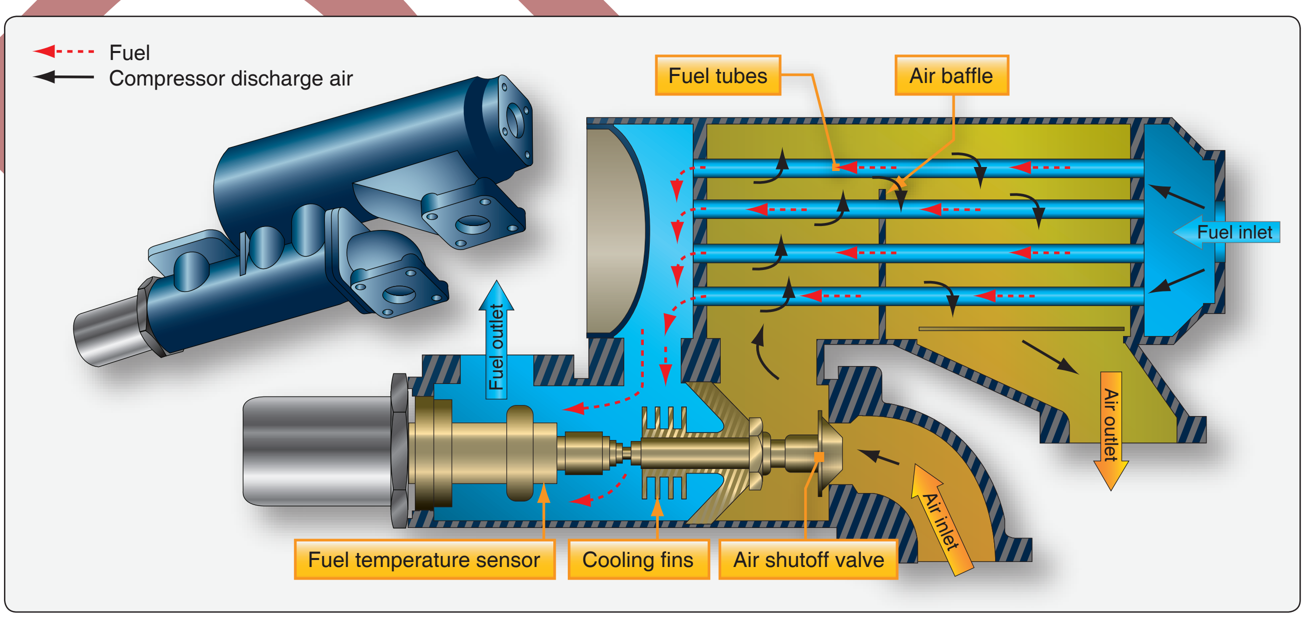


Figure 14-65. *An air-fuel heat exchanger uses engine compressor bleed air to warm the fuel on many turbine engine powered aircraft.*

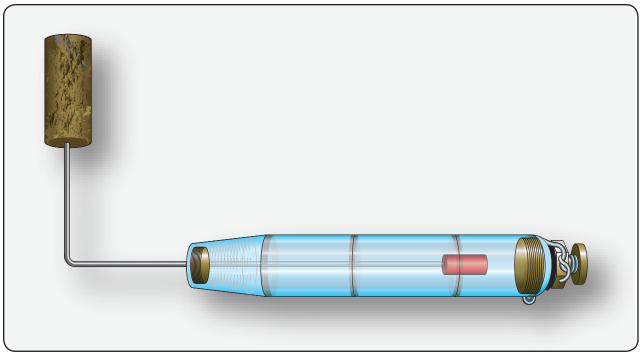


Figure 14-67. *A float-type sight gauge fuel quantity indicator.*

Electric fuel quantity indicators are more common than mechanical indicators in modern aircraft. Most of these units operate with direct current (DC) and use variable resistance in a circuit to drive a ratiometer-type indicator. The movement of a float in the tank moves a connecting arm to the wiper on a variable resistor in the tank unit. This resistor is wired in series with one of the coils of the ratiometer-type fuel gauge in the instrument panel. Changes to the current flowing through the tank unit resistor change the current flowing through one of the coils in the indicator. This alters the magnetic field in which the indicating pointer pivots. The calibrated dial indicates the corresponding fuel quantity. *[Figure 14-69]*

Digital indicators are available that work with the same variable resistance signal from the tank unit. They convert the variable resistance into a digital display in the cockpit instrument head. *[Figure 14-70]* Fully digital instrumentation systems, such as those found in a glass cockpit aircraft, convert the variable resistance into a digital signal to be processed in a computer and displayed on a flat screen panel.

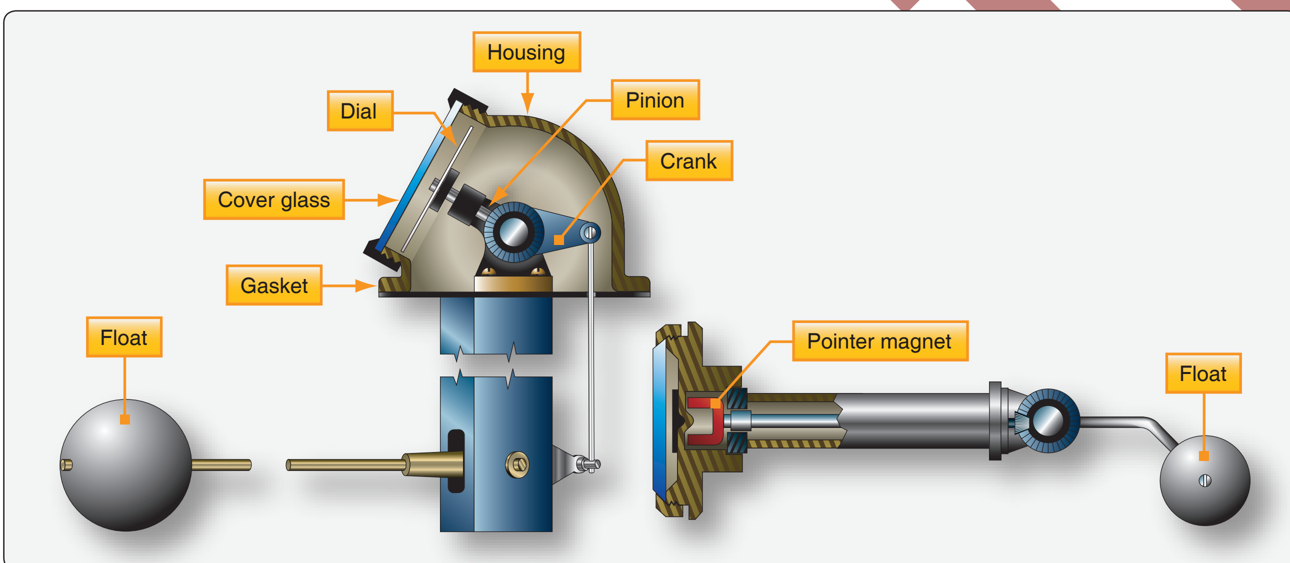


Figure 14-68. *Simple mechanical fuel indicators used on light aircraft with fuel tanks in close proximity to the pilot.*

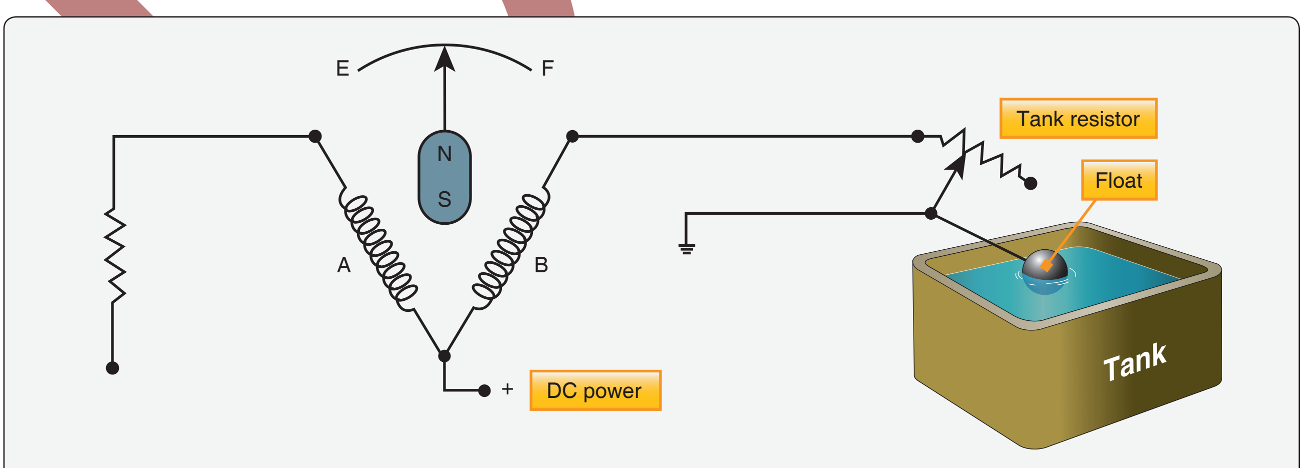


Figure 14-69. *A DC electric fuel quantity indicator uses a variable resistor in the tank unit, which is moved by a float arm.*

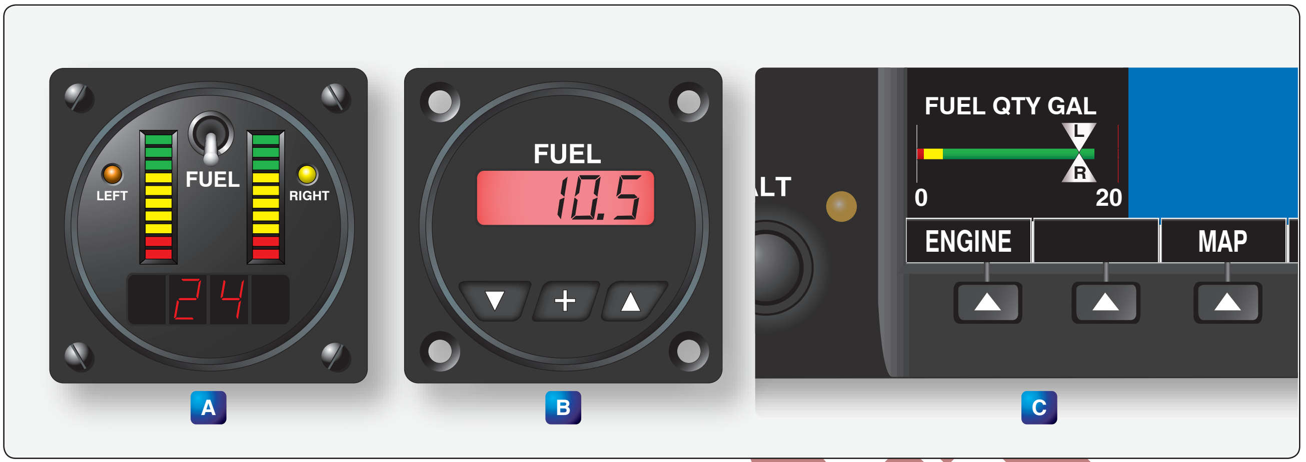


Figure 14-70. *Digital fuel quantity gauges that work off of variable resistance from the tank unit are shown in A and B. The fuel quantity indication of a Garmin G-1000 flat screen display is shown in C.*

Large and high-performance aircraft typically utilize electronic fuel quantity systems. These more costly systems have the advantage of having no moving parts in the tank sending units. Variable capacitance transmitters are installed in the fuel tanks extending from the top to the bottom of each tank in the usable fuel. Several of these tank units, or fuel probes as they are sometimes called, may be installed in a large tank. *[Figure 14-71]* They are wired in parallel. As the level of the fuel changes, the capacitance of each unit changes. The capacitance transmitted by all of the probes in a tank is totaled and compared in a bridge circuit by a microchip computer in the tank's digital fuel quantity indicator in the cockpit. As the aircraft maneuvers, some probes are in more fuel than others due to the attitude of the aircraft. The indication remains steady, because the total capacitance transmitted by all of the probes remains the same. A trimmer is used to match the capacitance output with the precalibrated quantity indicator.

A capacitor is a device that stores electricity. The amount it can store depends on three factors: the area of its plates, the distance between the plates, and the dielectric constant of the material separating the plates. A fuel tank unit contains two concentric plates that are a fixed distance apart. Therefore, the capacitance of a unit can change if the dielectric constant of the material separating the plates varies. The units are open at the top and bottom, so they can assume the same level of fuel as is in the tanks. Therefore, the material between the plates is either fuel (if the tank is full), air (if the tank is empty), or some ratio of fuel and air depending on how much fuel remains in the tank. *Figure 14-72* shows a simplified illustration of this construction.

The bridge circuit that measures the capacitance of the tank units uses a reference capacitor for comparison. When voltage is induced into the bridge, the capacitive reactance of the tank probes and the reference capacitor can be equal or different. The magnitude of the difference is translated into an indication of the fuel quantity in the tank calibrated in pounds. *Figure 14-73* represents the nature of this comparison bridge circuit.

The use of tank unit capacitors, a reference capacitor, and a microchip bridge circuit in the fuel quantity indicators is

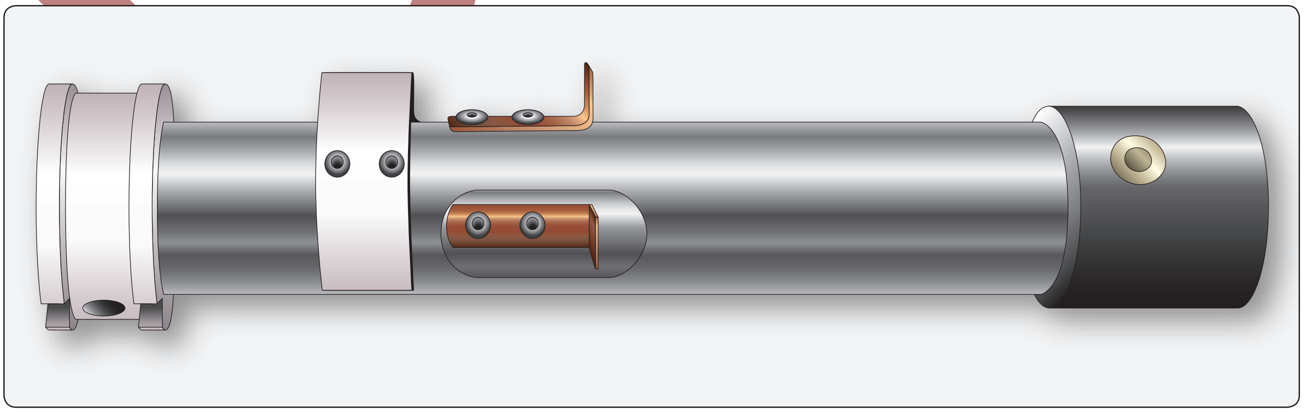


Figure 14-71. *A fuel tank transmitter for a capacitance-type fuel quantity indicating system.*

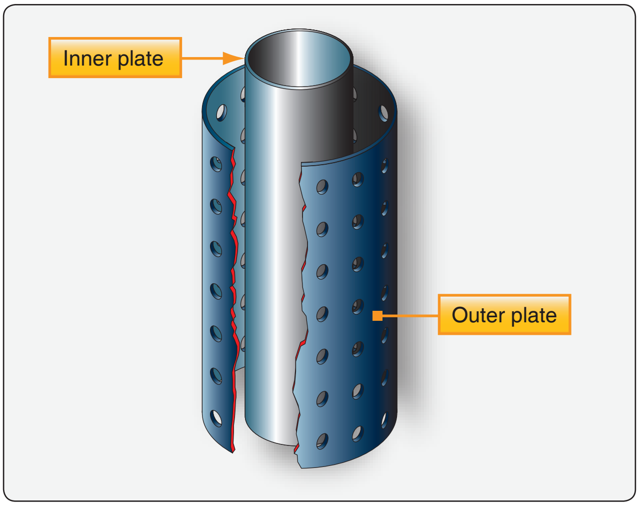


Figure 14-72. *The capacitance of tank probes varies in a capacitance-type fuel tank indicator system as the space between the inner and outer plates is filled with varying quantities of fuel and air depending on the amount of fuel in the tank.*

complicated by the fact that temperature affects the dielectric constant of the fuel. A compensator unit (mounted low in the tank so it is always covered with fuel) is wired into the bridge circuit. It modifies current flow to reflect temperature variations of the fuel, which affect fuel density and thus capacitance of the tank units. *[Figure 14-74]* An amplifier is also needed in older systems. The amplitude of the electric signals must be increased to move the servo motor in the analog indicator. Additionally, the dielectric constant of different turbine-engine fuels approved for a particular aircraft may also vary. Calibration is required to overcome this.

A fuel summation unit is part of the capacitance-type fuel quantity indication system. It is used to add the tank quantities from all indicators. This total aircraft fuel quantity can be

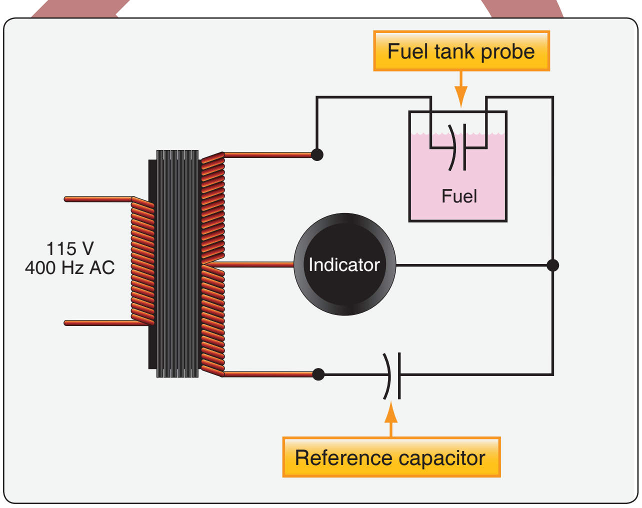


Figure 14-73. *A simplified capacitance bridge for a fuel quantity system.*

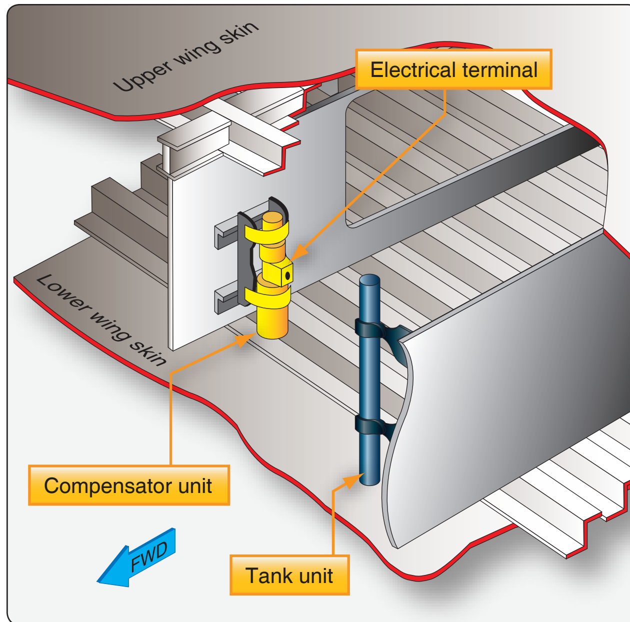


Figure 14-74. *A fuel quantity tank unit and compensator unit installed inside a wing tank.*

used by the crew and by flight management computers for calculating optimum airspeed and engine performance limits for climb, cruise, descent, etc. Capacitance-type fuel quantity system test units are available for troubleshooting and ensuring proper functioning and calibration of the indicating system components.

Many aircraft with capacitance-type fuel indicating systems also use a mechanical indication system to cross-check fuel quantity indications and to ascertain the amount of fuel onboard the aircraft when electrical power is not available. A handful of fuel measuring sticks, or drip sticks, are mounted throughout each tank. When pushed and rotated, the drip stick can be lowered until fuel begins to exit the hole on the bottom of each stick. This is the point at which the top of the stick is equal to the height of the fuel. The sticks have a calibrated scale on them. By adding the indications of all of the drip sticks and converting to pounds or gallons via a chart supplied by the manufacturer, the quantity of the fuel in the tank can be ascertained. *[Figure 14-75]*

Fuel Flowmeters

A fuel flowmeter indicates an engine's fuel use in real time. This can be useful to the pilot for ascertaining engine performance and for flight planning calculations. The types of fuel flow meter used on an aircraft depends primarily on the powerplant being used and the associated fuel system.

Measuring fuel flow accurately is complicated by the fact that the fuel mass changes with temperature or with the type of fuel used in turbine engines. In light aircraft with reciprocating

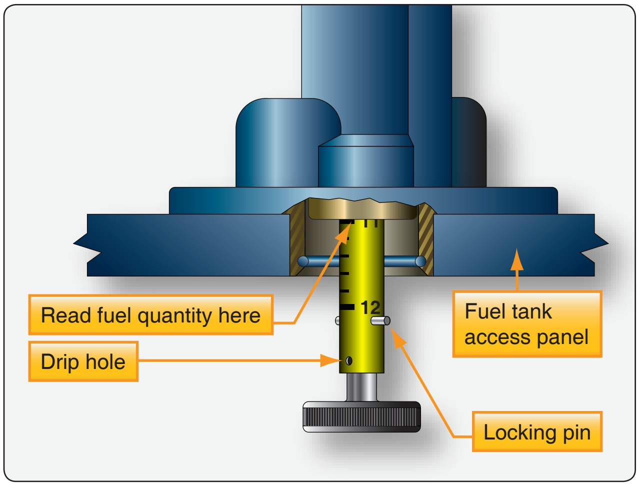


Figure 14-75. *A fuel drip stick is lowered from the fuel tank bottom until fuel drips out the hole at the bottom. By reading the calibrated scale and adding readings from all tank drip sticks, a chart can be consulted to arrive at the total fuel quantity on the aircraft by weight or by volume.*

engines, systems have been devised to measure fuel volume. The actual mass of fuel flowing to the engine is based on an assumption of the average weight of the fuel per unit volume.

The simplest fuel flow sensing device is used in conjunction with fuel injection systems installed on horizontally opposed reciprocating engines. A pressure gauge is used but it is calibrated in gallons per hour or pounds per hour. The amount of fuel that is flowing through the fuel injectors has a direct relationship to the pressure drop across the fuel injector orifices. Therefore, monitoring fuel pressure at the injector(s) closely approximates fuel flow and provides useful flow information for mixture control and flight planning.

There is a major limitation to the use of fuel pressure as a flow indicator. Should an injector become clogged, fuel flow is reduced. However, the pressure gauge indicates a higher fuel pressure (and greater fuel flow) due to the restriction. Operators must be aware of this potential condition and check the flowmeter against EGT to determine the nature of the elevated indication. *[Figure 14-76]*

Large reciprocating engine fuel systems may use a vane-type fuel flow meter that measures the volume of the fuel consumed by the engine. The fuel flow unit is typically located between the engine-driven fuel pump and the carburetor. The entire volume of fuel delivered to the engine is made to pass through the flowmeter. Inside, the fuel pushes against the vane, which counters the force of the fuel flow with a calibrated spring. The vane shaft rotates varying degrees matching the fuel flow rate through the unit. An autosyn transmitter deflects the pointer on the cockpit fuel flow gauge the same amount as the vane deflects. The dial face of the indicator is calibrated in gallons per hour or pounds per hour based on an average weight of fuel.

Since fuel fed to the engine must pass through the flowmeter unit, a relief valve is incorporated to bypass the fuel around the vane should it malfunction and restrict normal fuel flow. The vane chamber is eccentric. As more fuel pushes against the vane, it rotates further around in the chamber. The volume of the chamber gradually increases to permit the greater flow of fuel without restriction or pressure buildup. *[Figure 14-77]*

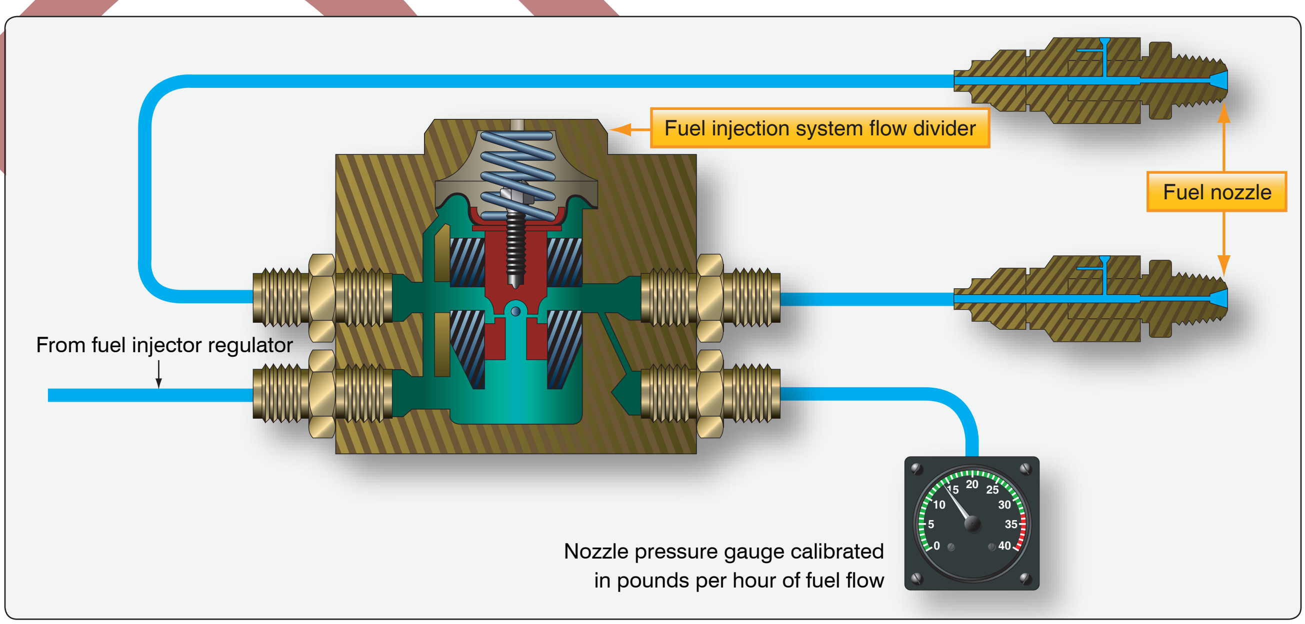


Figure 14-76. *The pressure drop across the fuel injector nozzles is used to represent fuel flow in light reciprocating-engine aircraft.*

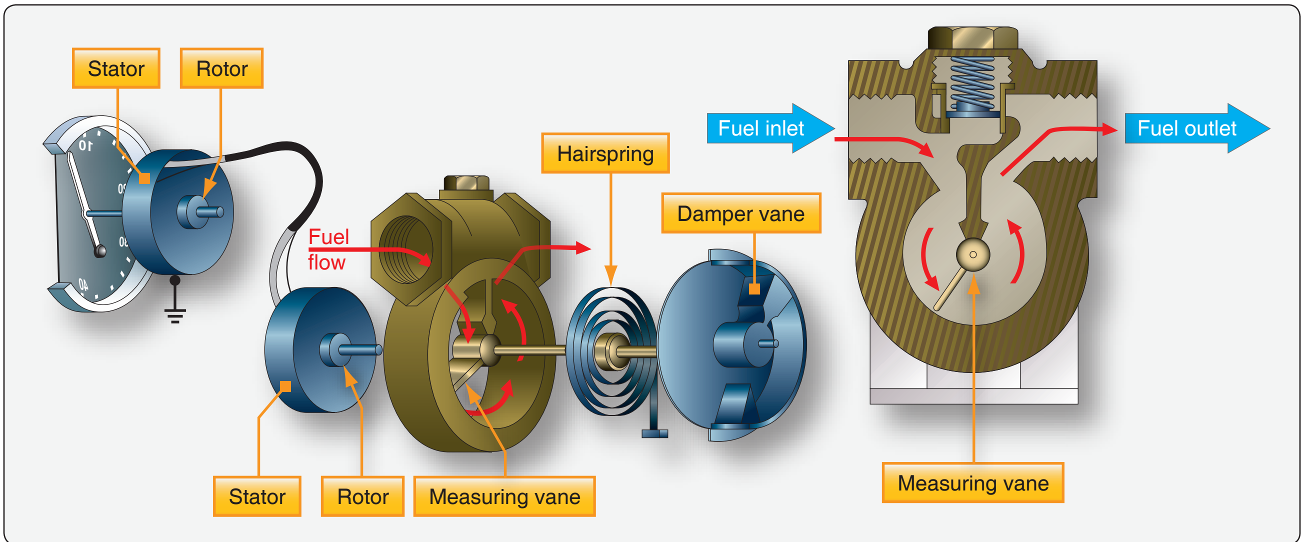


Figure 14-77. *A vane-type fuel flow meter. Greater flow volume increases deflection of the vane against a calibrated spring. An autosyn transmitter replicates the vane shaft rotation on the cockpit indicator that is calibrated in gallons or pounds of fuel flow per hour.*

Turbine-engine aircraft experience the greatest range of fuel density from temperature variation and fuel composition. An elaborate fuel flow device is used on these aircraft. It measures fuel mass for accurate fuel flow indication in the cockpit. The mass flow indicator takes advantage of the direct relationship between fuel mass and viscosity. Fuel is swirled by a cylindrical impeller that rotates at a fixed speed. The outflow deflects a turbine just downstream of the impeller. The turbine is held with calibrated springs. Since the impeller motor swirls, the fuel at a fixed rate, any variation of the turbine deflection is caused by the volume and viscosity of the fuel. The viscosity component represents the mass of the fuel. *[Figure 14-78]*

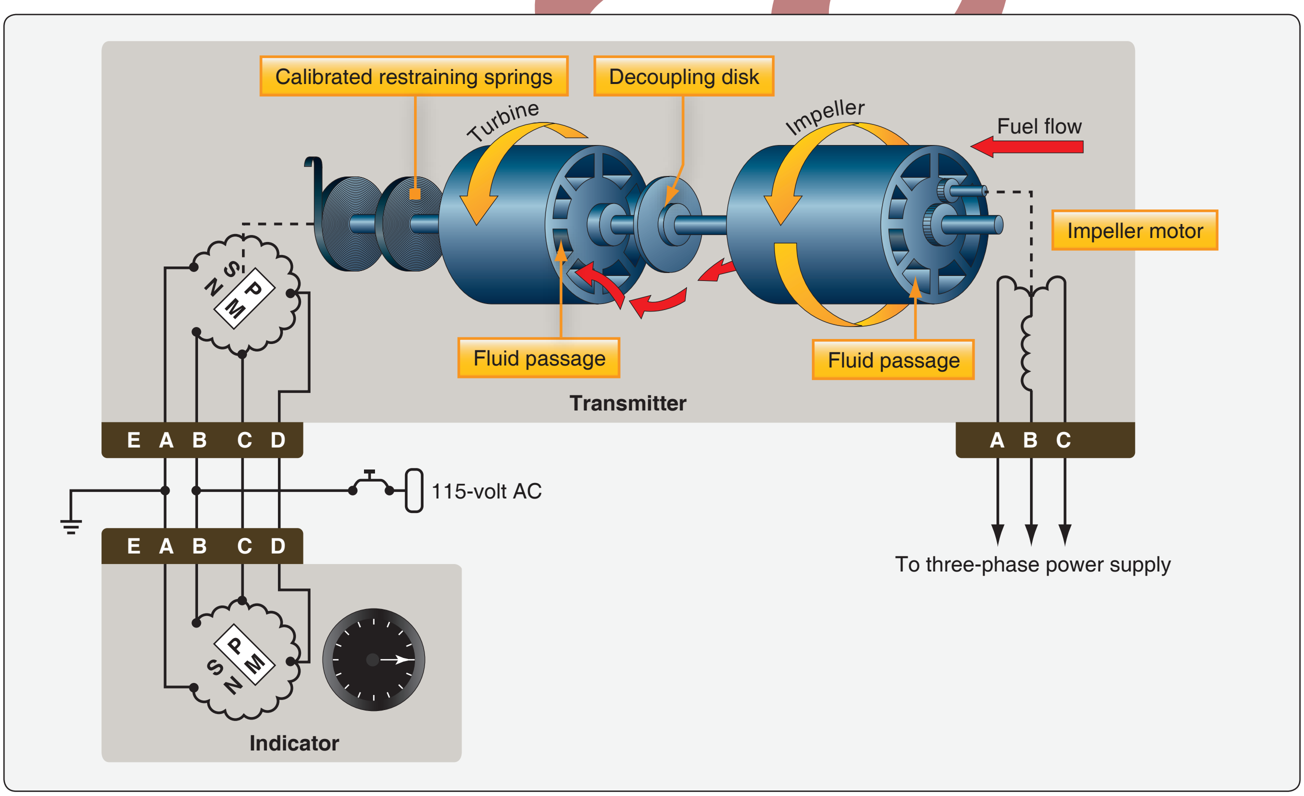


Figure 14-78. *A mass flow fuel flow indicating system used on turbine-engine aircraft uses the direct relationship between viscosity and mass to display fuel flow in pounds per hour.*

An alternating current (AC) synchro system is part of the mass fuel flowmeter. It is used to position a pointer against the cockpit indicator scale calibrated in pounds per hour.

With accurate fuel flow knowledge, numerous calculations can be performed to aid the pilot's situational awareness and flight planning. Most high-performance aircraft have a fuel totalizer that electronically calculates and displays information, such as total fuel used, total fuel remaining onboard the aircraft, total range and flight time remaining at the present airspeed, rate of fuel consumption, etc. On light aircraft, it is common to replace the original analog fuel indicators with electronic gauges containing similar capabilities and built-in logic. Some of these fuel computers, as they are called, integrate global positioning satellite (GPS) location information. *[Figure 14-79]* Aircraft with fully digital cockpits process fuel flow data in computers and display a wide array of fuel flow related information on demand.

Relatively new types of fuel flow sensors/transmitters are available in new aircraft and for retrofit to older aircraft. One type of device found in home-built and experimental aircraft uses a turbine that rotates in the fuel flow. The higher the flow rate is, the faster the turbine rotates. A Hall effect transducer is used to convert the speed of the turbine to an electrical signal to be used by an advanced fuel gauge similar to a fuel computer to produce a variety of calculated readouts and warnings. The turbine in this unit is in line with the fuel flow but is fail safe to allow adequate fuel flow without interruption should the unit malfunction. *[Figure 14-80]*

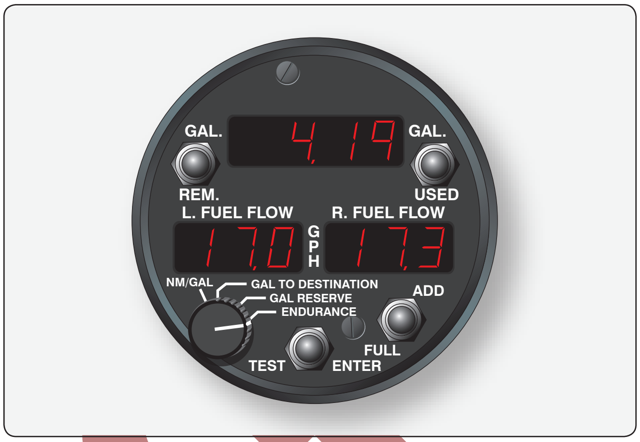


Figure 14-79. *A modern fuel management gauge uses a microprocessor to display fuel flow and numerous other fuel consumption related calculations.*

Another fuel flow sensor used primarily on light aircraft also detects the spinning velocity of a turbine in the fuel path. It too has a failsafe design should the turbine malfunction. In this unit, notches in the rotor interrupt an infrared light beam between an LED and phototransistor that creates a signal proportional to the amount fuel flow. *[Figure 14-81]* This type of sensor may be coupled with an electronic indicator.

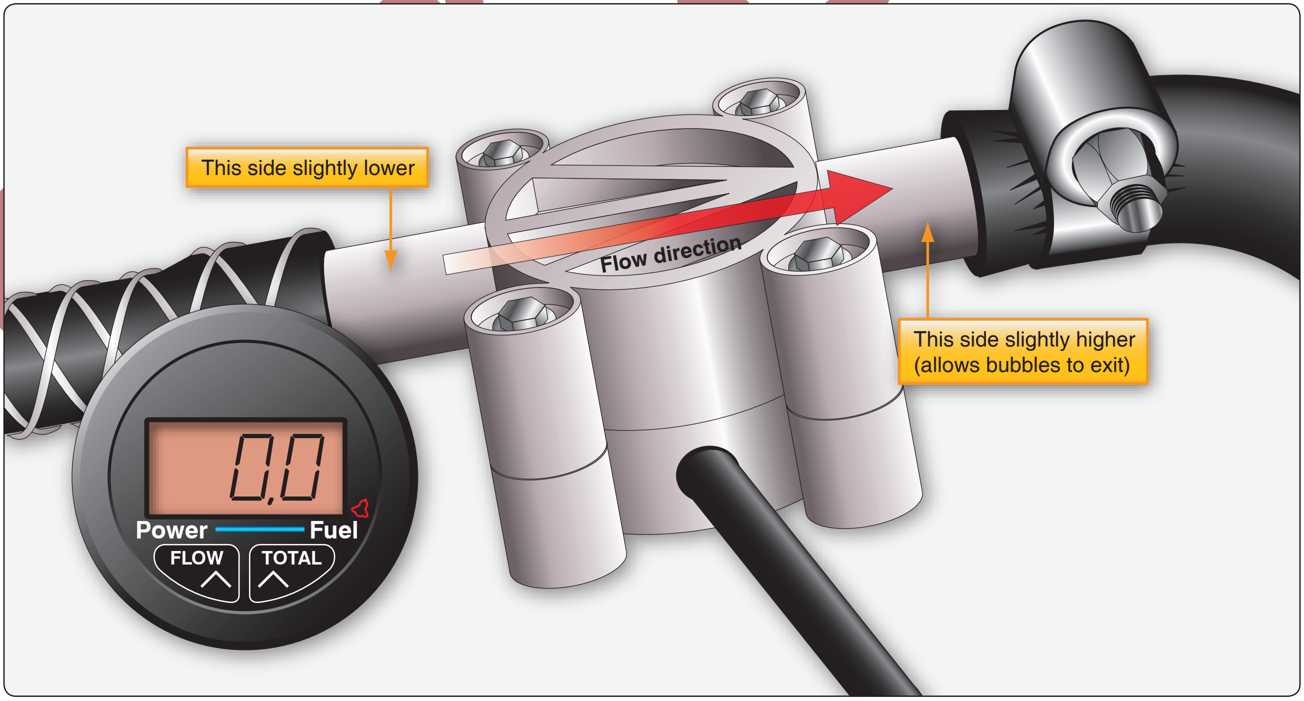


Figure 14-80. *A transducer and microprocessor for control functions are located in the base of this turbine fuel flow sensor. The gauge is menu driven with numerous display options.*

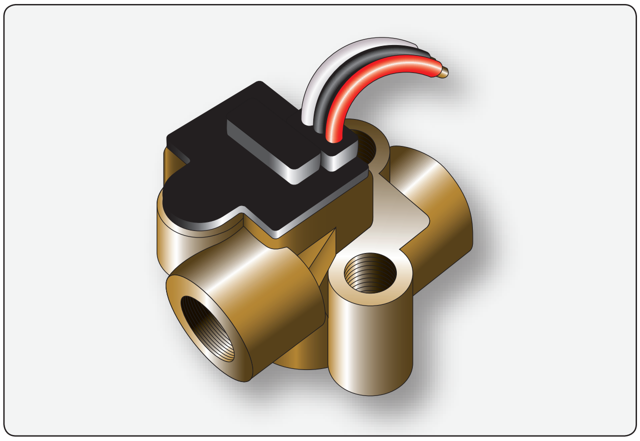


Figure 14-81. *A turbine flow transducer in this fuel flow sensor produces a current pulse signal from an opto-electronic pickup with a preamplifier.*

Increasing use of microprocessors and computers on aircraft enable the integration of fuel temperature and other compensating factors to produce highly accurate fuel flow information. Fuel flow sensing with digital output facilitates this with a high degree of reliability. Thermal dispersion technology provides flow sensing with no moving parts and digital output signals. The sensor consists of two resistance temperature detectors (RTDs). One is a reference RTD that measures the temperature of the fuel. The other is the active RTD. It is heated by an adjacent element to a temperature higher than the fuel. As the fuel flows, the active element cools proportionally to the fuel flow. The temperature difference between the two RTDs is highest at no flow.

The RTDs are connected to an electronic assembly that supplies power to the heater and uses sensing circuitry and a microprocessor to control a constant temperature difference between the heated and unheated RTDs. The electrical current to the heater is proportional to the mass flow of the fuel. As mentioned, the reference RTD is used as a temperature sensor to provide a temperature output and allow for temperature compensation of the flow measurement. *[Figure 14-82]*

Fuel Temperature Gauges

As previously mentioned, monitoring fuel temperature can inform the pilot when fuel temperature approaches that which could cause ice to form in the fuel system, especially at the fuel filter. Many large and high-performance turbine aircraft use a resistance type electric fuel temperature sender in a main fuel tank for this purpose. It can display on a traditional ratiometer gauge *[Figure 14-65]* or can be input into a computer for processing and digital display. A low fuel temperature can be corrected with the use of a fuel heater if the aircraft is so equipped. Also as mentioned, fuel temperature can be integrated into fuel flow

Figure 14-82. *Fuel flow sensing units using thermal dispersion technology have no moving parts and output digital signals.*

processing calculations. Viscosity differences at varying fuel temperatures that affect fuel flow sensing accuracy can be corrected via microprocessors and computers.

Fuel Pressure Gauges

Monitoring fuel pressure can give the pilot early warning of a fuel system related malfunction. Verification that the fuel system is delivering fuel to the fuel metering device can be critical. Simple light reciprocating-engine aircraft typically utilize a direct reading Bourdon tube pressure gauge. It is connected into the fuel inlet of the fuel metering device with a line extending to the back of the gauge in the cockpit instrument panel. A more complex aircraft may have a sensor with a transducer located at the fuel inlet to the metering device that sends electrical signals to a cockpit gauge. *[Figure 14-83]* In aircraft equipped with an auxiliary pump for starting and to back up the engine-driven pump, the fuel pressure gauge indicates the auxiliary pump pressure until the engine is started. When the auxiliary pump is switched off, the gauge indicates the pressure developed by the engine-driven pump.

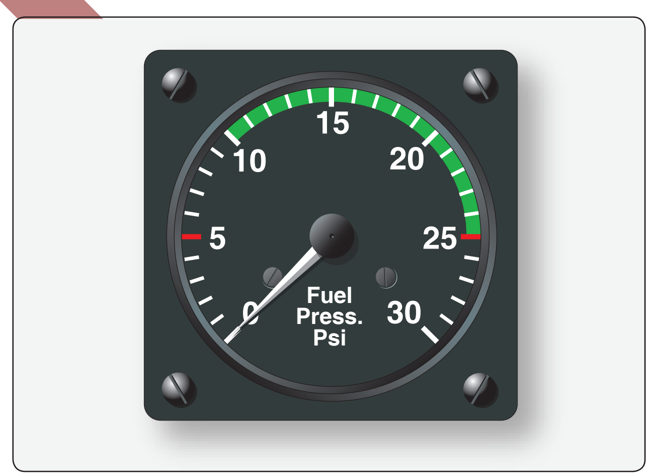


Figure 14-83. *A typical fuel gauge that uses a signal from a sensing transducer to display fuel inlet pressure at the metering device.*

Figure 14-84. *A differential fuel pressure gauge used on complex and high-performance reciprocating-engine aircraft compares the fuel inlet pressure to the air inlet pressure at the fuel metering device.*

More complex and larger reciprocating engine aircraft may use a differential fuel pressure gauge. It compares fuel inlet pressure to the air inlet pressure at the fuel metering device. A bellows type pressure gauge is normally used. *[Figure 14- 84]*

Modern aircraft may use a variety of sensors including solid state types and those with digital output signals or signals that are converted to digital output. These can be processed in the instrument gauge microprocessor, if so equipped, or in a computer and sent to the display unit. *[Figure 14-85]*

Pressure Warning Signal

On aircraft of any size, visual and audible warning devices are used in conjunction with gauge indications to draw the pilot's attention to certain conditions. Fuel pressure is an important parameter that merits the use of a warning signal when it falls outside of the normal operating range. Low fuel pressure warning lights can be illuminated through the use of simple pressure sensing switches. *[Figure 14-86]* The contacts of the switch will close when fuel pressure against the diaphragm is insufficient to hold them open. This allows current to flow to the annunciator or warning light in the cockpit.

Most turbine-powered aircraft utilize a low-pressure warning switch at the outlet of each fuel boost pump. The annunciator for each is typically positioned adjacent to the boost pump ON/OFF switch on the fuel panel in the cockpit. *[Figure 14-87]*

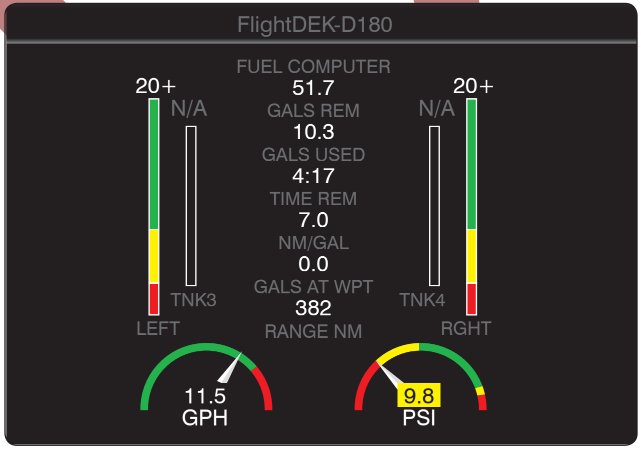


Figure 14-85. *An electronic display of fuel parameters, including fuel pressure.*

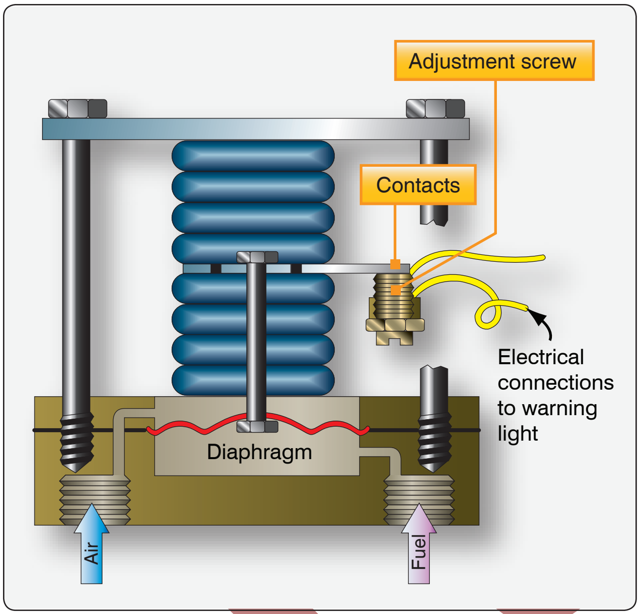


Figure 14-86. *A fuel pressure warning signal is controlled by a switch that closes when fuel pressure is low.*

Figure 14-87. *A transport category aircraft fuel panel with low pressure warning lights for each fuel boost pump.*

Valve-In-Transit Indicator Lights

Aircraft with multiple fuel tanks use valves and pumps to move fuel and to have it flow to desired locations, such as the engines, a certain tank, or overboard during fuel jettison. The functioning of the valves in the fuel system is critical. Some aircraft indicate to the crew when the valve is opening or closing with the use of valve-in-transit lights. Contacts in the valve control the lights that go out when the valve is fully open or when it is fully closed. Alternately, annunciator lights that show the valve position as OPEN or CLOSED are also used. Valve-in-transit and valve position indicators, or lights, are located on the fuel panel in the cockpit adjacent to the valve ON/OFF switches. *[Figure 14-88]* Sometimes the switch mechanism has the annunciator light built into it. Digital display systems graphically depict valve positions on screen.

Fuel System Repair

The integrity of an aircraft fuel system is critical and should not be compromised. Any evidence of malfunction or leak should be addressed before the aircraft is released for flight. The danger of fire, explosion, or fuel starvation in flight makes it imperative that fuel system irregularities be given top priority. Each manufacturer's maintenance and operation instructions must be used to guide the technician in maintaining the fuel system in airworthy condition. Follow the manufacturer's instructions at all times. Component manufacturers and STC holder instructions should be used when applicable. Some general instructions for fuel system maintenance and repair are given in the following sections.

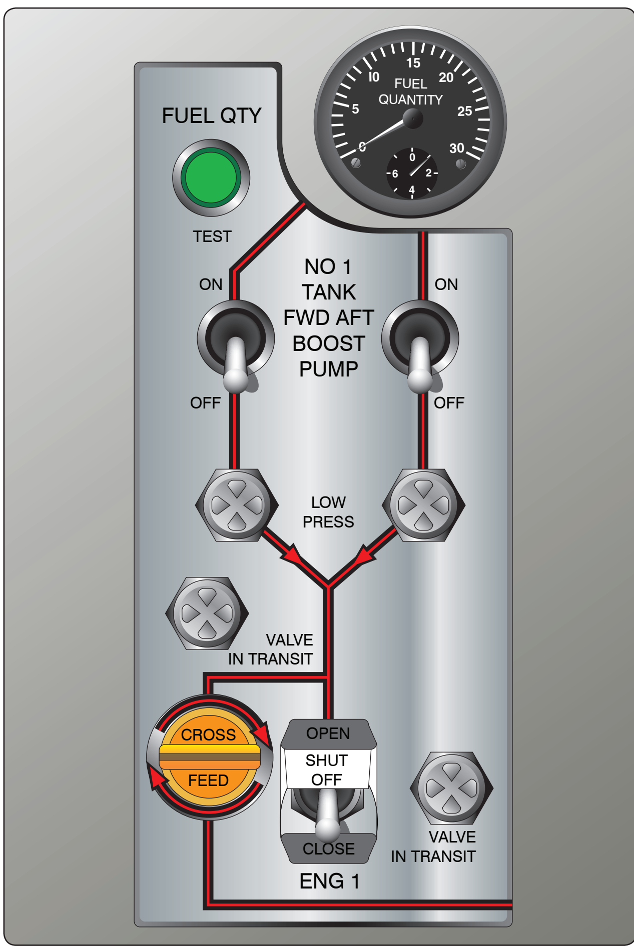


Figure 14-88. *Valve-in-transit lights are used on this section of a transport category aircraft fuel panel. Low boost pump pressure lights that look the same are also on the panel.*

Troubleshooting the Fuel System

Knowledge of the fuel system and how it operates is essential when troubleshooting. Manufacturers produce diagrams and descriptions in their maintenance manuals to aid the technician. Study these for insight. Many manuals have troubleshooting charts or flow diagrams that can be followed. As with all troubleshooting, a logical sequence of steps to narrow the problem to a specific component or location should be followed. Defects within the system can often be located by tracing the fuel flow from the tank through the system to the engine. Each component must be functioning as designed and the cause of the defect symptom must be ruled out sequentially.

Location of Leaks and Defects

Close visual inspection is required whenever a leak or defect is suspected in a fuel system. Leaks can often be traced to the connection point of two fuel lines or a fuel line and a component. Occasionally, the component itself may have an internal leak. Fuel leaks also occur in fuel tanks and are discussed below. Leaking fuel produces a mark where it travels. It can also cause a stronger than normal odor. Gasoline may collect enough of its dye for it to be visible or an area clean of dirt may form. Jet fuel is difficult to detect at first, but it has a slow evaporation rate. Dirt and dust eventually settle into it, which makes it more visible.

When fuel leaks into an area where the vapors can collect, the leak must be repaired before flight due to the potential for fire or explosion. Repair could be deferred for external leaks that are not in danger of being ignited. However, the source of the leak should be determined and monitored to ensure it does not become worse. Follow the aircraft manufacturer's instructions on the repair of fuel leaks and the requirements that need to be met for airworthiness. Detailed visual inspection can often reveal a defect.

Fuel Leak Classification

Four basic classifications are used to describe aircraft fuel leaks: stain, seep, heavy seep, and running leak. *[Figure 14-89]* In 30 minutes, the surface area of the collected fuel from a leak is a certain size. This is used as the classification standard. When the area is less than ¾ inch in

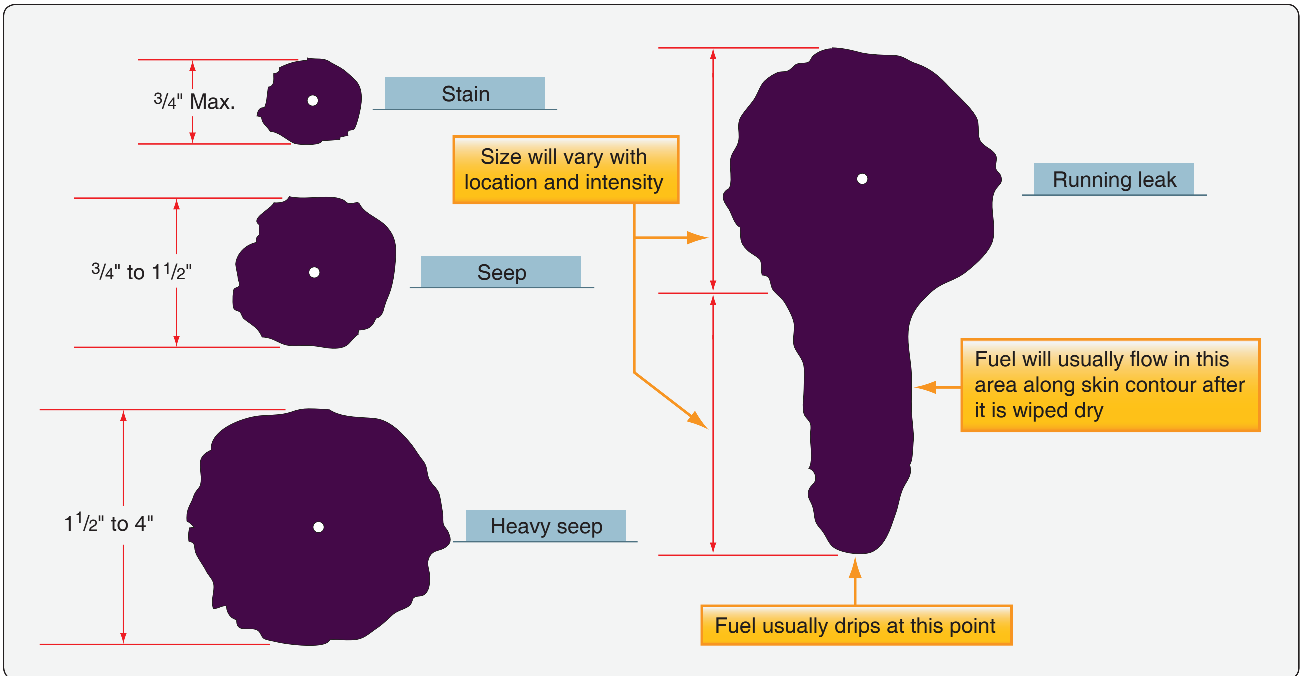


Figure 14-89. *The surface area of collected fuel from a leak is used to classify the leak into the categories shown.*

diameter, the leak is said to be a stain. From ¾ to 1½ inches in diameter, the leak is classified as a seep. Heavy seeps form an area from 1½ inches to 4 inches in diameter. Running leaks pool and actually drip from the aircraft. They may follow the contour of the aircraft for a long distance.

Replacement of Gaskets, Seals, and Packings

A leak can often be repaired by replacing a gasket or seal. When this occurs, or a component is replaced or reassembled after a maintenance operation, a new gasket, seal, or packing must be installed. Do not use the old one(s). Always be sure to use the correct replacement as identified by part number. Also, most gaskets, seals, and packings have a limited shelf life. They should be used only if they are within the service life stamped on the package.

Remove the entire old gasket completely and clean all mating surfaces. Clean surfaces and grooves allow a tight seal. Inspect new gaskets and seals for any flaws. Follow the manufacturer's instructions for replacement, including cleaning procedures and any sealing compound that you may need to apply during replacement. Torque assembly bolts evenly so as to provide even pressure and prevent pinching.

Fuel Tank Repair

Whether rigid removable, bladder-type, or integral, all fuel tanks have the potential to develop leaks. Repair a tank according to the manufacturer's instructions. Some general notes for repair of each tank type follow. Note that at the time a tank is repaired, a thorough inspection should be made. Corrosion, such as that caused by water and microbes, should be identified and treated at this time, even if it is not the cause of the leak.

Rigid removable fuel tanks can be riveted, welded, or soldered together. A leak can develop at any of these types of seams or can be elsewhere on the tank. Generally, the repair must match the construction in technique.

Some metal fuel tanks experiencing minor seepage can be repaired with a sloshing procedure. An approved sloshing compound is poured into the tank, and the tank is moved so that the compound coats the entire inner surface area of the tank. Any excess compound is then poured out and the compound in the tank is allowed to cure for a specified amount of time. Minor gaps in the seams of the tank and repairs are filled in this manner. The compound is fuel resistant once dry. Check with the aircraft manufacturer to ensure that sloshing is an airworthy repair for the aircraft fuel tank in question.

Welded Tanks

Welded tank repairs are usually done by welding. These tanks can be constructed from steel or weldable aluminum, such as 3003S or 5052SO. The tank is removed from the aircraft for the repair. It must be treated to remove any fuel vapors that remain in the tank before it is welded. This is critical to avoid serious injury from explosion should the fuel vapor ignite. The manufacturer usually gives a procedure for doing this. Some common methods for purging the tank include steam cleaning, hot water purging, and inert gas purging.

Most procedures involve running the steam, water, or gas through the tank for a stated period of time. Adapters may need to be fashioned or purchased for the fill port to enable proper cleaning. Follow the manufacturer's procedure for the proper time to keep the cleaning medium in the tank and for prepping the tank for welding in general.

After a seam or a damaged area is welded, you must clean the tank of any flux or debris that may have fallen into the tank. Water rinsing and acid solutions are commonly used. A leak check to ensure the repair is sound follows a welded repair. This can be done by pressurizing the tank with a specified amount of air pressure and using a soapy solution on all seams and the repaired area. Bubbles form should air escape. The amount of air pressure used for a leak check is very low. One half to 3.5 psi is common. Use an accurate regulator and pressure gauge to prevent overpressurization that could deform or otherwise damage the tank. Tanks ordinarily supported by aircraft structure when installed should be similarly supported or reinstalled in the airframe before pressurization. *Figure 14-90* shows an aircraft fuel tank being welded and the repaired tank installed in the frame of an antique aircraft.

Riveted Tanks

Riveted tanks are often repaired by riveting. The seams and rivets are coated with a fuel resistant compound when assembled to create a leak-free container. This practice is followed during a patch repair, or when repairing a seam, which may require replacing the rivets in the seam. Some minor leak repairs may only require the application of addition compound. Follow manufacturer's instructions. The compound used may be heat sensitive and require inert gas purging to prevent degradation from hot water or steam purging. Again, follow all manufacturer guidance to insure a safe airworthy repair.

Soldered Tanks

Terneplate aircraft fuel tanks that are assembled by soldering are also repaired by soldering. All patches have a minimum amount that must overlap the damaged area. Flux used in soldering must be removed from the tank after the repair with techniques similar to that used on a welded tank. Follow manufacturer's instructions.

Bladder Tanks

Bladder fuel tanks that develop leaks can also be repaired. Most commonly, they are patched using patch material, adhesive, and methods approved by the manufacturer. As with soldered tanks, the patch has a required overlap of the damaged area. Damage that penetrates completely through the bladder is repaired with an external, as well as internal, patch.

Synthetic bladder tanks have a limited service life. At some point, they seep fuel beyond acceptable limits and need to be replaced. Bladder tanks are usually required to remain wetted with fuel at all times to prevent drying and cracking of the bladder material. Storage of bladder tanks without fuel can be accomplished by coating the tanks with a substance to prevent drying, such as clean engine oil that can be flushed from the tank when ready to return to service. Follow all manufacturer's instructions for the care and repair of these common tanks. It is important to ensure that bladder tanks are correctly secured in place with the proper fasteners when reinstalling them in the aircraft after a repair.

Figure 14-90. *A rigid removable fuel tank with welded seams is repaired by welding.*

Integral Tanks

Occasionally, an integral tank develops a leak at an access panel. This can often be repaired by transferring fuel to another tank so the panel can be removed and the seal replaced. Use of the proper sealing compound and bolt torque are required.

Other integral fuel tank leaks can be more challenging and time consuming to repair. They occur when the sealant used to seal the tank seams loses its integrity. To repair, fuel needs to be transferred or defueled out of the tank. You must enter large tanks on transport category aircraft. Preparing the tank for safe entry requires a series of steps outlined by the aircraft manufacturer. These include drying the tank and venting it of dangerous vapors. The tank is then tested with a combustible-gas indicator to be certain it can be entered safely. Clothing that does not cause static electricity and a respirator is worn.

An observer is stationed outside of the tank to assist the technician in the tank. *[Figure 14-91]* A continuous flow of ventilating air is made to flow through the tank. A checklist for fuel tank preparation for entry taken from a transport category maintenance manual is shown in *Figure 14-92*. The details of the procedures are also given in the manual.

Once the location of the leak is determined, the tank sealant is removed, and new sealant is applied. Remove old sealant with a nonmetallic scraper. Aluminum wool can be used to remove the final traces of the sealant. After cleaning the area with the recommended solvent, apply new sealant as instructed by the manufacturer. Observe cure time and leak checks as recommended before refilling the tank.

Fire Safety

Fuel vapor, air, and a source of ignition are the requirements for a fuel fire. Whenever working with fuel or a fuel system component, the technician must be vigilant to prevent these elements from coming together to cause a fire or explosion. A source of ignition is often the most controllable. In addition to removing all sources of ignition from the work area, care must be exercised to guard against static electricity. Static electricity can easily ignite fuel vapor, and its potential for igniting fuel vapor may not be as obvious as a flame or an operating electrical device. The action of fuel flowing through a fuel line can cause a static buildup as can many other situations in which one object moves past another. Always assess the work area and take steps to remove any potential static electricity ignition sources.

AVGAS is especially volatile. It vaporizes quickly due to its high vapor pressure and can be ignited very easily. Turbine engine fuel is less volatile but still possesses enormous capacity to ignite. This is especially true if atomized, such as when escaping out of a pressurized fuel hose or in a hot engine compartment on a warm day. Treat all fuels as potential fire hazards in all situations. As was discussed, empty fuel tanks have an extreme potential for ignition or explosion. Although the liquid fuel has been removed, ignitable fuel vapor can remain for a long period of time. Purging the vapor out of any empty fuel tank is an absolute necessity before any repair is initiated.

A fire extinguisher should be on hand during fuel system maintenance or whenever fuel is being handled. A fuel

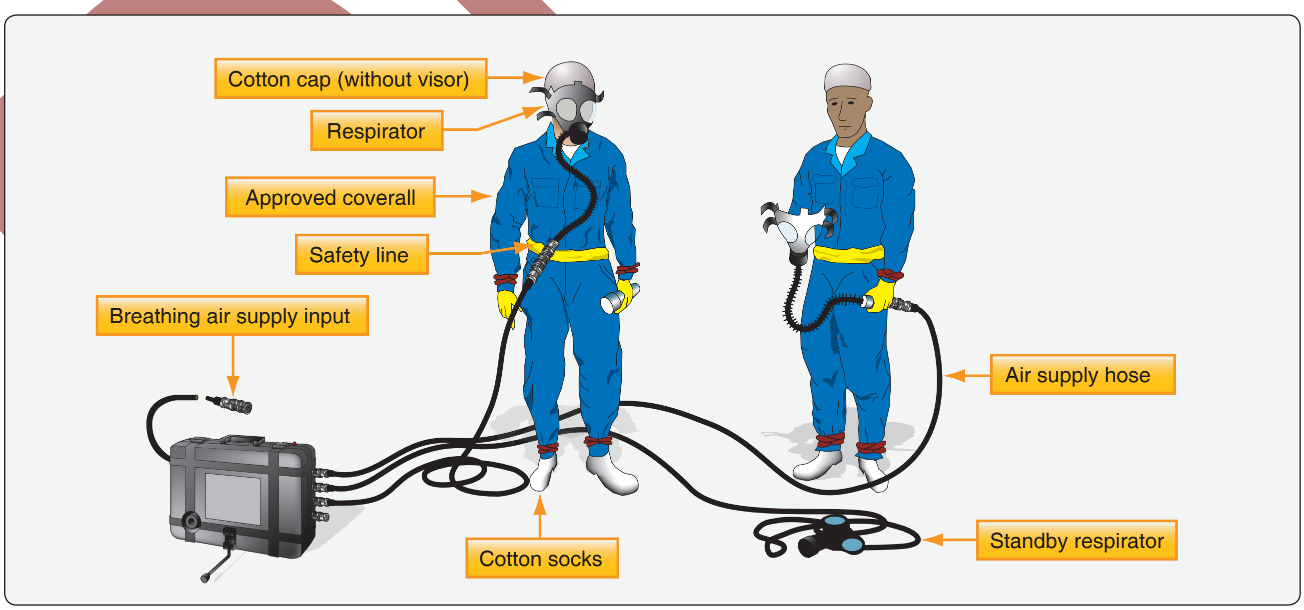


Figure 14-91. *Wear a nonstatic protective suit and respirator when entering an integral fuel tank for inspection or repair.*

This checklist must be completed prior to start of wet fuel cell entry and/or at shift change PRIOR to work assignment for the continuation of tank work started by a previous shift.

Wet fuel cell entry location

Area or building: ____________ Stall: ____________ Airplane: ____________ Tank: ____________

Shift: ____________ Date: ____________ Supervisor: ____________

1. Airplane and adjacent equipment properly grounded.
2. Area secured and warning signs positioned.
3. Boost pump switches off and circuit breakers pulled and placarded.
4. No power on airplane: battery disconnected, external power cord disconnected from airplane, and external power recepacle placarded.
5. Radio and radar equipment off (see separation distance requirements).
6. Only approved explosion-proof equipment and tools will be used for fuel cell entry (lights, blowers, pressure and test equipment, etc.).
7. Ensure requirements listed on aircraft confined space entry permit are complied with, including appropriate personal protective equipment: OSH class 110 respirator at a minimum, approved coveralls, cotton cap and foot coverings, and eye protection.
8. Trained attendant and confined space logsheet required for all wet fuel cell entries.
9. Aerators checked for cleanliness prior to use.
10. Sponges available for residual fuel mop out.
11. All plugs in use have streamers attached.
12. Mechanical ventilation (venturis or blowers) installed to ventilate all open fuel cells.

    Note: Ventilation system must remain in operation at all times while fuel cells are open. If ventilation system fails or any ill effects, such as dizziness, irriation, or excessive odors, are noted, all work shall stop and fuel cells must be evacuated.
13. Shop personnel entering cells and standby observers have current "fuel cell entry" certification cards. Certification requires the following training:
    - Aircraft confined space entry safety
    - Respirator use and maintenance
    - Wet fuel cell entry
14. Fire department notified.

Meter Reading

15. Oxygen reading (%): ____________ By: ____________
16. Fuel vapor level reading (ppm): ____________ By: ____________
17. Combustible gas meter (LEL) reading: ____________ By (FD): ____________

I confirm that all entry requirements were met prior to any entry.

____________________ ____________________

Signature of supervisor or designee Date

Figure 14-92. *Fuel tank checklist entry.*

fire can be put out with a typical carbon dioxide (CO_2) fire extinguisher. Aim the extinguisher nozzle at the base of the flame and spray in a sweeping motion to have the agent fall over the flames to displace the oxygen and smother the fire. Dry chemical fire extinguishers rated for fuel can also be used. These leave behind a residue that requires cleanup that can be extensive and expensive. Do not use a water-type extinguisher. Fuel is lighter than water and could be spread without being extinguished. Additional precautions used to prevent fire are discussed below in the fueling–defueling section of this chapter.

Fuel System Servicing

Maintaining aircraft fuel systems in acceptable condition to deliver clean fuel to the engine(s) is a major safety factor in aviation. Personnel handling fuel or maintaining fuel systems should be properly trained and use best practices to ensure that the fuel, or fuel system, are not the cause of an incident or accident.

Checking for Fuel System Contaminants

Continuous vigilance is required when checking aircraft fuel systems for contaminants. Daily draining of strainers and sumps is combined with periodic filter changes and inspections to ensure fuel is contaminant free. Turbine powered engines have highly refined fuel control systems through which flow hundreds of pounds of fuel per hour of operation. Sumping alone is not sufficient. Particles are suspended longer in jet fuel due to its viscosity. Engineers design a series of filters into the fuel system to trap foreign matter. Technicians must supplement these with cautious procedures and thorough visual inspections to accomplish the overall goal of delivering clean fuel to the engines.

Keeping a fuel system clean begins with an awareness of the common types of contamination. Water is the most common. Solid particles, surfactants, and microorganisms are also common. However, contamination of fuel with another fuel not intended for use on a particular aircraft is possibly the worst type of contamination.

Water

Water can be dissolved into fuel or entrained. Entrained water can be detected by a cloudy appearance to the fuel. Close examination is required. Air in the fuel tends to cause a similar cloudy condition but is near the top of the tank. The cloudiness caused by water in the fuel tends to be more towards the bottom of the tank as the water slowly settles out.

As previously discussed, water can enter a fuel system via condensation. The water vapor in the vapor space above the liquid fuel in a fuel tank condenses when the temperature changes. It normally sinks to the bottom of the fuel tank into the sump where it can be drained off before flight. *[Figure 14-93]* However, time is required for this to happen. On some aircraft, a large amount of fuel needs to be drained before settled water reaches the drain valve. Awareness of this type of sump idiosyncrasy for a particular aircraft is important. The condition of the fuel and recent fueling practices need to be considered and are equally important. If the aircraft has been flown often and filled immediately after flight, there is little reason to suspect water contamination beyond what would be exposed during a routine sumping. An aircraft that has sat for a long period of time with partially full fuel tanks is a cause of concern.

Figure 14-93. *A sump drain tool used to open and collect fuel and contaminants from the fuel system sumps. Daily sump draining is part of the procedures needed to remove water from fuel that is to be delivered to the engine(s).*

It is possible that water is introduced into the aircraft fuel load during refueling with fuel that already contains water. Any suspected contamination from refueling or the general handling of the aircraft should be investigated. A change in fuel supplier may be required if water continues to be an issue despite efforts being made to keep the aircraft fuel tanks full and sumps drained on a regular basis. Note that fuel below freezing temperature may contain entrained water in ice form that may not settle into the sump until melted. Use of an anti-icing solution in turbine fuel tanks helps prevent filter blockage from water that condenses out of the fuel as ice during flight.

Note that the fuel anti-ice additive level should be monitored so that recommended quantity for the tank capacity is maintained. After repeated fueling, the level can be obscured. A field hand-held test unit can be used to check the amount of anti-ice additive already in a fuel load. *[Figure 14-94]*

Figure 14-94. *A hand-held refractometer with digital display measures the amount of fuel anti-ice additive contained in a fuel load.*

Strainers and filters are designed with upward flow exits to have water collect at the bottom of the fuel bowl to be drained off. This should not be overlooked. Entrained water in small quantities that makes it to the engine usually poses no problem. Large amounts of water can disrupt engine operation. Settled water in tanks can cause corrosion. This can be magnified by microorganisms that live in the fuel/water interface. High quantities of water in the fuel can also cause discrepancies in fuel quantity probe indications.

Solid Particle Contaminants

Solid particles that do not dissolve in the fuel are common contaminants. Dirt, rust, dust, metal particles, and just about anything that can find its way into an open fuel tank is of concern. Filter elements are designed to trap these contaminants and some fall into the sump to be drained off. Pieces of debris from the inside of the fuel system may also accumulate, such as broken-off sealant, or pieces of filter elements, corrosion, etc.

Preventing solid contaminant introduction into the fuel is critical. Whenever the fuel system is open, care must be taken to keep out foreign matter. Lines should be capped immediately. Fuel tank caps should not be left open for any longer than required to refuel the tanks. Clean the area adjacent to wherever the system is opened before it is opened. Coarse sediments are those visible to the naked eye. Should they pass beyond system filters, they can clog in fuel metering device orifices, sliding valves, and fuel nozzles. Fine sediments cannot actually be seen as individual particles. They may be detected as a haze in the fuel or they may refract light when examining the fuel. Their presence in fuel controls and metering devices is indicated by dark shellac-like marks on sliding surfaces.

The maximum amount of solid particle contamination allowable is much less in turbine engine fuel systems than in reciprocating-engine fuel systems. It is particularly important to regularly replace filter elements and investigate any unusual solid particles that collect therein. The discovery of significant metal particles in a filter could be a sign of a failing component upstream of the filter. A laboratory analysis is possible to determine the nature and possible source of solid contaminants.

Surfactants

Surfactants are liquid chemical contaminants that naturally occur in fuels. They can also be introduced during the refining or handling processes. These surface-active agents usually appear as tan to dark brown liquid when they are present in large quantities. They may even have a soapy consistency. Surfactants in small quantities are unavoidable and pose little threat to fuel system functioning. Larger quantities of surfactants do pose problems. In particular, they reduce the surface tension between water and the fuel and tend to cause water and even small particles in the fuel to remain suspended rather than settling into the sumps. Surfactants also tend to collect in filter elements making them less effective.

Surfactants are usually in the fuel when it is introduced into the aircraft. Discovery of either excessive quantities of dirt and water making their way through the system or a sudsy residue in filters and sumps may indicate their presence. The source of fuel should be investigated and avoided if found to contain a high level of these chemicals. As mentioned, slow settling rates of solids and water into sumps is a key indicator that surfactant levels are high in the fuel. Most quality fuel providers have clay filter elements on their fuel dispensing trucks and in their fixed storage and dispensing systems.

These filters, if renewed at the proper intervals, remove most surfactants through adhesion. Surfactants discovered in the aircraft systems should be traced to the fuel supply source and the use and condition of these filters. *[Figure 14-95]*

Microorganisms

The presence of microorganisms in turbine engine fuels is a critical problem. There are hundreds of varieties of these life forms that live in free water at the junction of the water and fuel in a fuel tank. They form a visible slime that is dark brown, grey, red, or black in color. This microbial growth can

Figure 14-95. *Clay filter elements remove surfactants. They are used in the fuel dispensing system before fuel enters the aircraft.*

multiply rapidly and can cause interference with the proper functioning of filter elements and fuel quantity indicators. Moreover, the slimy water/microbe layer in contact with the fuel tank surface provides a medium for electrolytic corrosion of the tank. *[Figure 14-96]*

Since the microbes live in free water and feed on fuel, the most powerful remedy for their presence is to keep water from accumulating in the fuel. Fuel 100 percent free of water is not practicable. By following best practices for sump draining and filter changes, combined with care of fuel stock tanks used to refuel aircraft, much of the potential for water to accumulate in the aircraft fuel tanks can be mitigated. The addition of biocides to the fuel when refueling also helps by killing organisms that are present.

Foreign Fuel Contamination

Aircraft engines operate effectively only with the proper fuel. Contamination of an aircraft's fuel with fuel not intended for use in that particular aircraft can have disastrous consequences. It is the responsibility of all aviators to put forth effort continuously to ensure that only the fuel designed for the operation of the aircraft's engine(s) is put into the fuel tanks. Each fuel tank receptacle or fuel cap area is clearly marked to indicate which fuel is required. *[Figure 14-97]*

If the wrong fuel is put into an aircraft, the situation must be rectified before flight. If discovered before the fuel pump is operated and an engine is started, drain all improperly filled tanks. Flush out the tanks and fuel lines with the correct fuel and then refill the tanks with the proper fuel. However, if discovered after an engine has been started or attempted to be started, the procedure is more in depth. The entire fuel system, including all fuel lines, components, metering device(s) and tanks, must be drained and flushed. If the engines have been operated, a compression test should be accomplished, and the combustion chamber and pistons should be borescope inspected. Engine oil should be drained, and all screens and filters examined for any evidence of damage. Once reassembled and the tanks have been filled with the correct fuel, a full engine run-up check should be performed before releasing the aircraft for flight.

Contaminated fuel caused by the introduction of small quantities of the wrong type of fuel into an aircraft may not look any different when visually inspected, making a dangerous situation more dangerous. Any person recognizing that this error has occurred must ground the aircraft. The lives of the aircraft occupants are at stake.

Detection of Contaminants

Visual inspection of fuel should always reveal a clean, bright looking liquid. Fuel should not be opaque, which could be a sign of contamination and demands further investigation. As mentioned, the technician must always be aware of the fuel's appearance, as well as when and from what sources refueling has taken place. Any suspicion of contamination must be investigated.

In addition to the detection methods mentioned for each type of contamination above, various field and laboratory tests can be performed on aircraft fuel to expose contamination. A common field test for water contamination is performed by adding a dye that dissolves in water but not fuel to a test sample drawn from the fuel tank. The more water present in the fuel, the greater the dye disperses and colors the sample.

Another common test kit commercially available contains a grey chemical powder that changes color to pink or purple when the contents of a fuel sample contains more than 30 parts per million (ppm) of water. A 15-ppm test is available for turbine engine fuel. *[Figure 14-98]* These levels of water are considered generally unacceptable and not safe for operation of the aircraft. If levels are discovered above these amounts, time for the water to settle out of the fuel should be given or the aircraft should be defueled and refueled with acceptable fuel.

Figure 14-96. *This fuel-water sample has microbial growth at the interface of the two liquids.*

Figure 14-97. *All entry points of fuel into the aircraft are marked with the type of fuel to be used. Never introduce any other fuel into the aircraft other than that which is specified.*

Figure 14-98. *This kit allows periodic testing for water in fuel.*

The presence and level of microorganisms in a fuel tank can also be measured with a field device. The test detects the metabolic activity of bacteria, yeast, and molds, including sulfate reducing bacteria, and other anaerobe microorganisms. This could be used to determine the amount of anti-microbial agent to be added to the fuel. The testing unit is shown in *Figure 14-99.*

Figure 14-99. *A capture solution is put into a 1 liter sample of fuel and shaken. The solution is then put into the analyzer shown to determine the level of microorganisms in the fuel.*

Bug test kits test fuel specifically for bacteria and fungus. While other types of microorganisms may exist, this semi-quantitative test is quick and easy to perform. Treat a fuel sample with the product and match the color of the sample to the chart for an indication of the level of bacteria and fungus present. These are some of the most common types of microorganisms that grow in fuel; if growth levels of fungus and bacteria are acceptable, the fuel could be usable. *[Figure 14-100]*

Fuel trucks and fuel farms may make use of laser contaminant identification technology. All fuel exiting the storage tank going into the servicing hose is passed through the analyzer unit. Laser sensing technology determines the difference between water and solid particle contaminants. When an excessive level of either is detected, the unit automatically shuts off flow to the fueling nozzle. Thus, aircraft are fueled only with clean dry fuel. When surfactant filters are combined with contaminant identification technology and microorganism detection, chances of delivering clean fuel to the aircraft engines are good. *[Figure 14-101]*

Before various test kits were developed for use in the field by nonscientific personnel, laboratories provided complete fuel composition analysis to aviators. These services are still available. A sample is sent in a sterilized container to the lab. It can be tested for numerous factors including water, microbial growth, flash point, specific gravity, cetane index (a measure of combustibility and burning characteristics), and more. Tests for microbes involve growing cultures of whatever organisms are present in the fuel. *[Figure 15-102]*

Fuel Contamination Control

A continuous effort must be put forth by all those in the aviation industry to ensure that each aircraft is fueled only

Figure 14-100. *Fuel bug test kits identify the level of bacteria and fungus present in a fuel load by comparing the color of a treated sample with a color chart.*

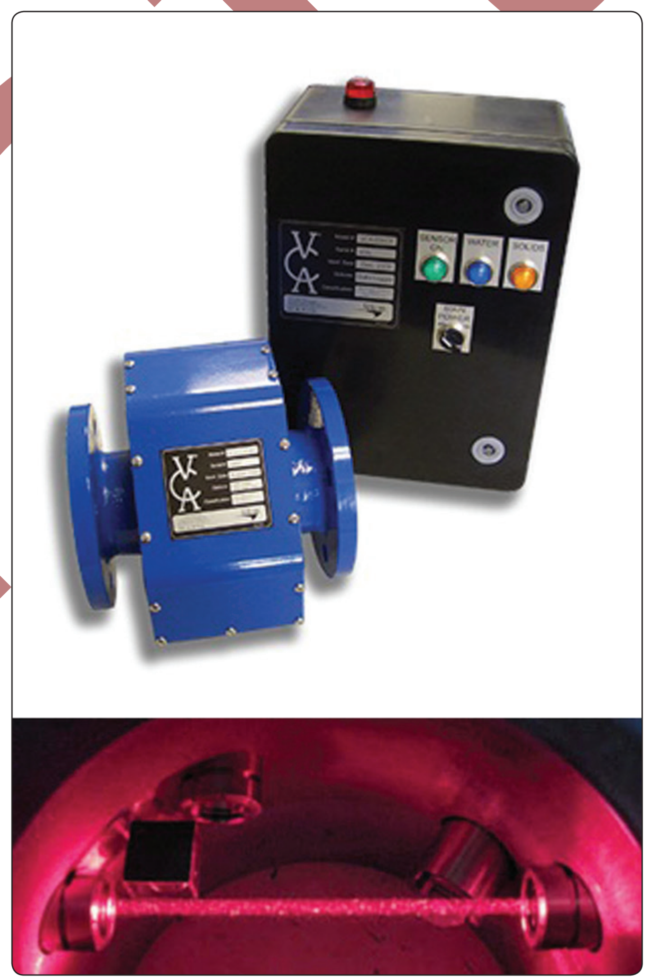


Figure 14-101. *This contaminant analyzer is used on fuel supply source outflow, such as that on a refueling truck. Water and solid contaminant levels are detected using laser identification technology. The valve to the fill hose is automatically closed when levels of either are elevated beyond acceptable limits.*

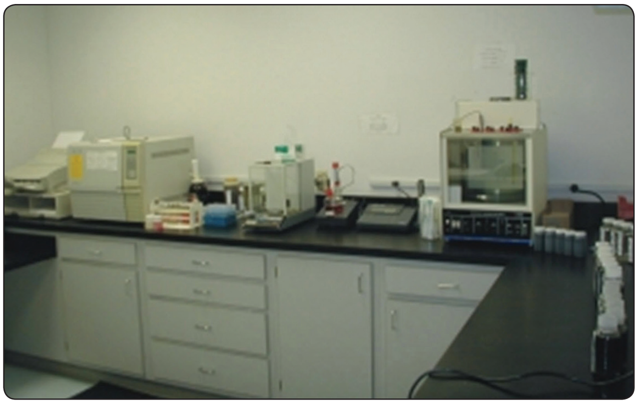


Figure 14-102. *Laboratory tests of fuel samples are available.*

with clean fuel of the correct type. Many contaminants, both soluble and insoluble, can contaminate an aircraft's fuel supply. They can be introduced with the fuel during fueling or the contamination may occur after the fuel is onboard.

Contamination control begins long before the fuel gets pumped into an aircraft fuel tank. Many standard petroleum industry safeguards are in place. Fuel farm and delivery truck fuel handling practices are designed to control contamination. Various filters, testing, and treatments effectively keep fuel contaminant free or remove various contaminants once discovered. However, the correct clean fuel for an aircraft should never be taken for granted. The condition of all storage tanks and fuel trucks should be monitored. All filter changes and treatments should occur regularly and on time. The fuel supplier should take pride in delivering clean, contaminant-free fuel to its customers.

Onboard aircraft fuel systems must be maintained and serviced according to manufacturer's specifications. Samples from all drains should be taken and inspected on a regular basis. Filters should be changed at the specified intervals. The fuel load should be visually inspected and tested from time to time or when there is a potential contamination issue. Particles discovered in filters should be identified and investigated if needed. Inspection of the fuel system during periodic inspections should be treated with highest concern.

Most importantly, the choice of the correct fuel for an aircraft should never be in question. No one should ever put a fuel into an aircraft fuel tank unless absolutely certain it is the correct fuel for that aircraft and its engine(s). Personnel involved in fuel handling should be properly trained. All potential contamination situations should be investigated and remedied.

Fueling and Defueling Procedures

Maintenance technicians are often asked to fuel or defuel aircraft. Fueling procedure can vary from aircraft to aircraft. Tanks may need to be fueled in a prescribed sequence to prevent structural damage to the airframe. The proper procedure should be confirmed before fueling an unfamiliar aircraft.

Fueling

Always fuel aircraft outside, not in a hangar where fuel vapors may accumulate and increase the risk and severity of an accident. Generally, there are two types of fueling process: over-the-wing refueling and pressure refueling. Over-the-wing refueling is accomplished by opening the fuel tank cap on the upper surface of the wing or fuselage, if equipped with fuselage tanks. The fueling nozzle is carefully inserted into the fill opening and fuel is pumped into the tank. This process is similar to the process used to refuel an automobile gas tank. When finished, the cap is secured, and subsequent tanks are opened and refilled until the aircraft has the desired fuel load onboard. Pressure refueling occurs at the bottom, front, or rear of the fuel tank. A pressure refueling nozzle locks onto the fueling port at the aircraft fueling station. Fuel is pumped into the aircraft through this secured and sealed connection. Gauges are monitored to ascertain when the tanks are properly loaded. An automatic shutoff system may be part of the aircraft system. It closes the fueling valve when the tanks are full. *[Figure 14-103]*

Precautions should be used with either type of fueling. First and foremost, it is absolutely essential that the correct fuel be put in the aircraft. The type of fuel to be used is placarded near the fill port on over-the-wing systems and at the fueling station on pressure refueled aircraft. If there is any question about which fuel to use, the pilot in command, other knowledgeable personnel, or the manufacturer's

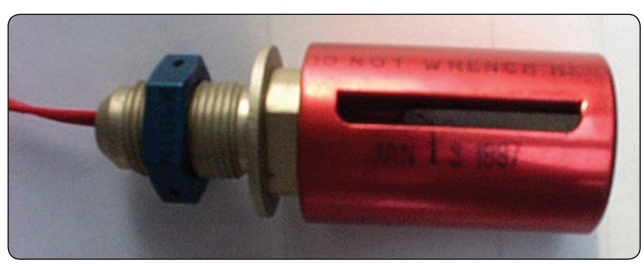


Figure 14-103. *A float switch installed in a fuel tank can close the refueling valve when the tanks are full during pressure fueling of an aircraft. Other more sophisticated automatic shutoff systems exist.*

maintenance/operations manual should be consulted before proceeding. Note that an over-the-wing refueling nozzle for turbine engine fuel should be too large to fit into the fill opening on an aircraft utilizing gasoline.

Clean the area adjacent to the fill port when refueling over the wing. Ensure the fuel nozzle is also clean. Aviation fuel nozzles are equipped with static bonding wires that must be attached to the aircraft before the fuel cap is opened. *[Figure 14-104]* Open the cap only when ready to dispense the fuel. Insert the nozzle into the opening with care. The aircraft structure is much more delicate than the fuel nozzle, which could easily damage the aircraft. Do not insert the neck of the nozzle deeply enough to hit bottom. This could dent the tank, or the aircraft skin, if it is an integral tank. Exercise caution to avoid damage to the surface of the airframe by the heavy fuel hose. Lay the hose over your shoulder or use a refueling mat to protect the paint. *[Figure 14-105]*

When pressure refueling, the aircraft receptacle is part of a fueling valve assembly. When the fueling nozzle is properly connected and locked, a plunger unlocks the aircraft valve so fuel can be pumped through it. Normally, all tanks can be fueled from a single point. Valves in the aircraft fuel system are controlled at the fueling station to direct the fuel into the proper tank. *[Figure 14-106]* Ensure that the pressure developed by the refueling pump is correct for the aircraft before pumping fuel. Note that, while similar, pressure fueling panels and their operation are different on different aircraft. Refueling personnel should be guided through the correct use of each panel. Do not guess at how the panel and associated valves operate.

When fueling from a fuel truck, precautions should be taken. If the truck is not in continuous service, all sumps should be drained before moving the truck, and the fuel should be visually inspected to be sure it is bright and clean. Turbine fuel should be allowed to settle for a few hours if the fuel truck tank has recently been filled or the truck has been jostled, such as when driven over a bumpy service road at the airport. Properly maneuver the fuel truck into position for refueling.

The aircraft should be approached slowly. The truck should be parked parallel to the wings and in front of the fuselage if possible. Avoid backing toward the aircraft. Set the parking brake and chock the wheels. Connect a static bonding cable from the truck to the aircraft. This cable is typically stored on a reel mounted on the truck.

There are other miscellaneous good practices that should be employed when refueling an aircraft. A ladder should be used if the refuel point is not accessible while standing on the ground. Climbing on an expensive aircraft to access the fueling ports is possible but does not give the stability of a ladder and may not be appreciated by the aircraft owner. If it is necessary to walk on the wings of the aircraft, do so only in designated areas, which are safe.

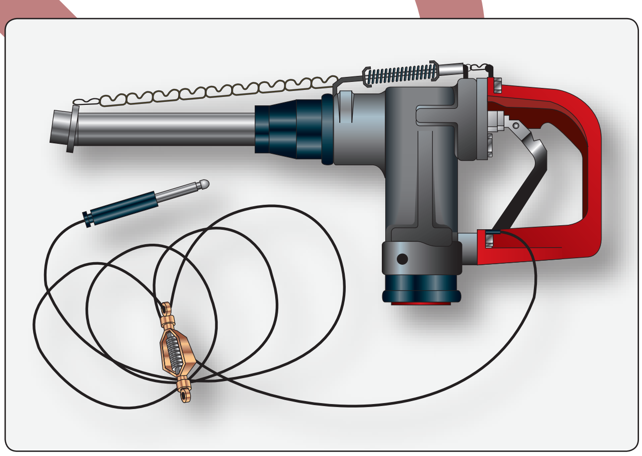


Figure 14-104. *An AVGAS fueling nozzle with static bonding grounding wire.*

Figure 14-105. *Over-the-wing refueling a Cessna.*

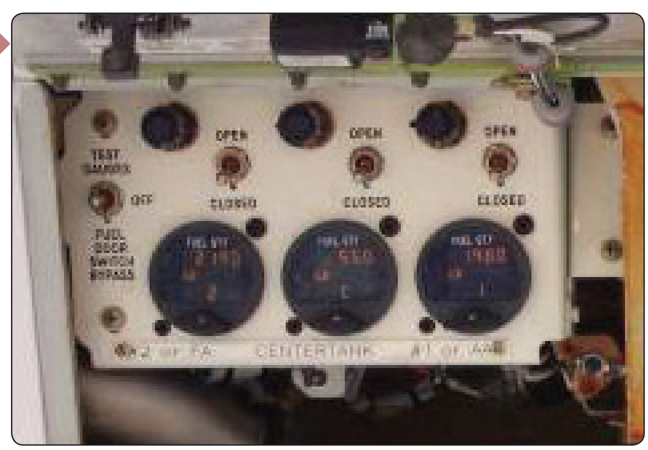


Figure 14-106. *This panel at the pressure refueling station has valve position switches and quantity gauges to be used during refueling. Valve open position lights are adjacent to the switches for each tank.*

Filler nozzles should be treated as the important tools that they are. They should not be dropped or dragged across the apron. Most have attached dust caps that should be removed only for the actual fueling process and then immediately replaced. Nozzles should be clean to avoid contamination of the fuel. They should not leak and should be repaired at the earliest sign of leak or malfunction. Keep the fueling nozzle in constant contact with the filler neck spout when fueling. Never leave the nozzle in the fill spout unattended. When fueling is complete, always doublecheck the security of all fuel caps and ensure that bonding wires have been removed and stowed.

Defueling

Removing the fuel contained in aircraft fuel tanks is sometimes required. This can occur for maintenance, inspection, or due to contamination. Occasionally, a change in flight plan may require defueling. Safety procedures for defueling are the same as those for fueling. Always defuel outside. Fire extinguishers should be on hand. Bonding cables should be attached to guard against static electricity buildup. Defueling should be performed by experienced personnel, and inexperienced personnel must be checked out before doing so without assistance.

Remember that there may be a sequence in defueling an aircraft's fuel tanks just as there is when fueling to avoid structural damage. Consult the manufacturer's maintenance/operations manual(s) if in doubt.

Pressure fueled aircraft normally defuel through the pressure fueling port. The aircraft's in-tank boost pumps can be used to pump the fuel out. The pump on a fuel truck can also be used to draw fuel out. These tanks can also be drained through the tank sump drains, but the large size of the tanks usually makes this impractical. Aircraft fueled over the wing are normally drained through the tank sump drains. Follow the manufacturer's procedure for defueling the aircraft.

What to do with the fuel coming out of a tank depends on a few factors. First, if the tank is being drained due to fuel contamination or suspected contamination, it should not be mixed with any other fuel. It should be stored in a separate container from good fuel, treated if possible, or disposed of properly. Take measures to ensure that contaminated fuel is never placed onboard an aircraft or mixed with good fuel. Second, the manufacturer may have requirements for good fuel that has been defueled from an aircraft, specifying whether it can be reused and the type of storage container in which it must be stored. Above all, fuel removed from an aircraft must not be mixed with any other type of fuel.

Good fuel removed from an aircraft must be handled with all precautions used when handling any fuel. It must only be put into clean tanks and efforts must be made to keep it clean. It may be put back in the aircraft or another aircraft if the manufacturer allows. Large aircraft can often transfer fuel from a tank requiring maintenance to another tank to avoid the defueling process.

Fire Hazards When Fueling or Defueling

Due to the combustible nature of AVGAS and turbine engine fuel, the potential for fire while fueling and defueling aircraft must be addressed. Always fuel and defuel outside, not in a hangar that serves as an enclosed area for vapors to build up to a combustible level. Clothing worn by refueling personnel should not promote static electricity buildup. Synthetics, such as nylon, should be avoided. Cotton has proved to be safe for fuel handling attire.

As previously mentioned, the most controllable of the three ingredients required for fire is the source of ignition. It is absolutely necessary to prevent a source of ignition anywhere near the aircraft during fueling or refueling. Any open flame, such as a lit cigarette, must be extinguished. Operation of any electrical devices must be avoided. Radio and radar use is prohibited. It is important to note that fuel vapors proliferate well beyond the actual fuel tank opening and a simple spark, even one caused by static electricity, could be enough for ignition. Any potential for sparks must be nullified.

Spilled fuel poses an additional fire hazard. A thin layer of fuel vaporizes quickly. Small spills should be wiped up immediately. Larger spills can be flooded with water to dissipate the fuel and the potential for ignition. Do not sweep fuel that has spilled onto the ramp.

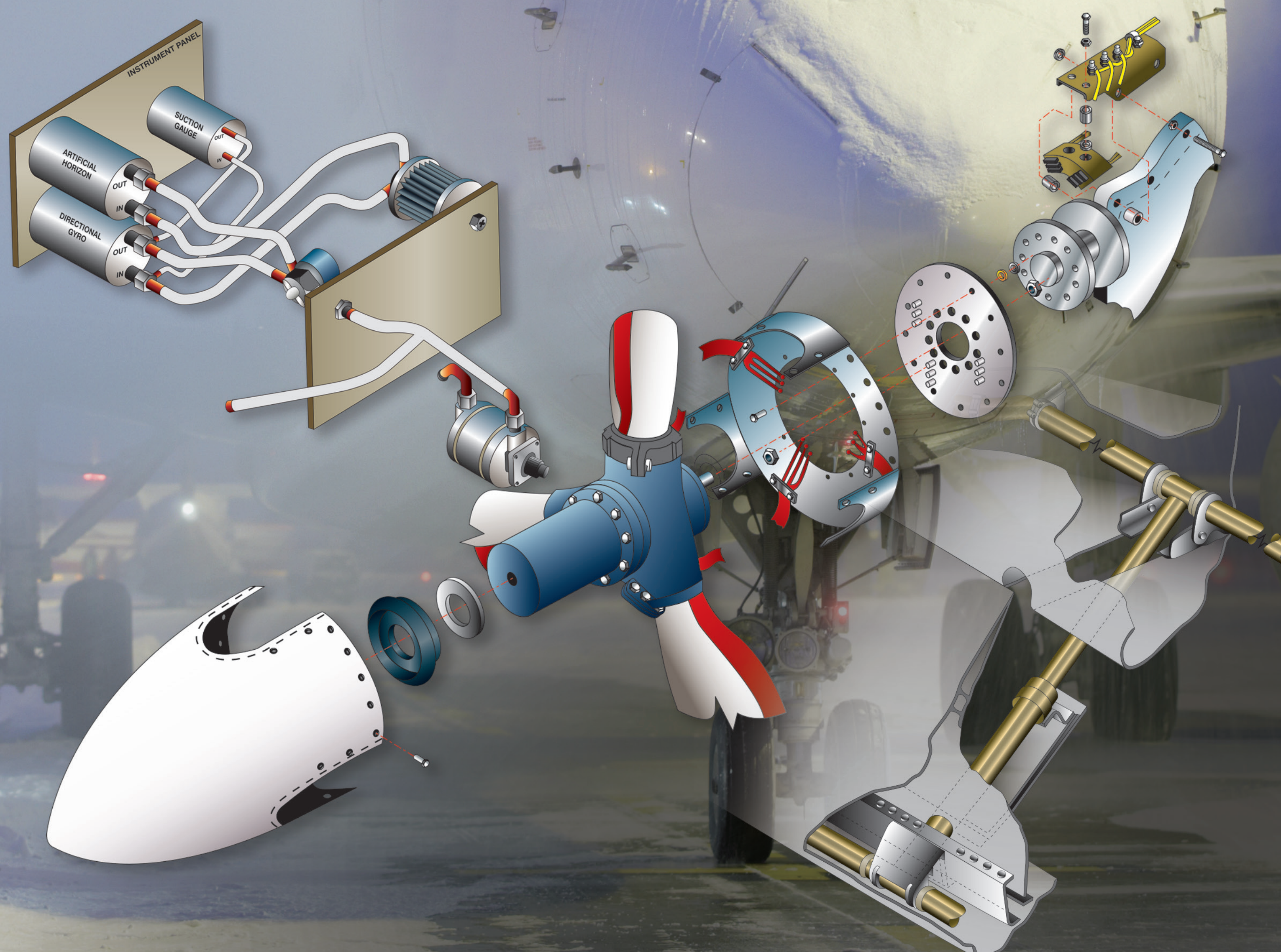
Class B fire extinguishers need to be charged and accessible nearby during the fueling and defueling processes. Fueling personnel must know exactly where they are and how to use them. In case of an emergency, the fuel truck, if used, may need to be quickly driven away from the area. For this reason alone, it should be positioned correctly on the ramp relative to the aircraft.

Chapter 15

Ice and Rain Protection

Ice Control Systems

Rain, snow, and ice are transportation's longtime enemies. Flying has added a new dimension, particularly with respect to ice. Under certain atmospheric conditions, ice can build rapidly on airfoils and air inlets. On days when there is visible moisture in the air, ice can form on aircraft leading-edge surfaces at altitudes where freezing temperatures start. Water droplets in the air can be supercooled to below freezing without actually turning into ice unless they are disturbed in some manner. This unusual occurrence is partly due to the surface tension of the water droplet not allowing the droplet to expand and freeze. However, when aircraft surfaces disturb these droplets, they immediately turn to ice on the aircraft surfaces.



The two types of ice encountered during flight are clear and rime. Clear ice forms when the remaining liquid portion of the water drop flows out over the aircraft surface, gradually freezing as a smooth sheet of solid ice. Formation occurs when droplets are large, such as in rain or in cumuliform clouds. Clear ice is hard, heavy, and tenacious. Its removal by deicing equipment is especially difficult.

Rime ice forms when water drops are small, such as those in stratified clouds or light drizzle. The liquid portion remaining after initial impact freezes rapidly before the drop has time to spread over the aircraft surface. The small frozen droplets trap air giving the ice a white appearance. Rime ice is lighter in weight than clear ice and its weight is of little significance. However, its irregular shape and rough surface decrease the effectiveness of the aerodynamic efficiency of airfoils, reducing lift and increasing drag. Rime ice is brittle and more easily removed than clear ice.

Mixed clear and rime icing can form rapidly when water drops vary in size or when liquid drops intermingle with snow or ice particles. Ice particles become imbedded in clear ice, building a very rough accumulation sometimes in a mushroom shape on leading edges. Ice may be expected to form whenever there is visible moisture in the air and temperature is near or below freezing. An exception is carburetor icing, which can occur during warm weather with no visible moisture present.

Ice or frost forming on aircraft creates two basic hazards:

1. The resulting malformation of the airfoil that could decrease the amount of lift.
2. The additional weight and unequal formation of the ice that could cause unbalancing of the aircraft, making it hard to control.

Enough ice to cause an unsafe flight condition can form in a very short period of time, thus some method of ice prevention or removal is necessary. *Figure 15-1* shows the effects of ice on a leading edge.

Icing Effects

Ice buildup increases drag and reduces lift. It causes destructive vibration and hampers true instrument readings. Control surfaces become unbalanced or frozen. Fixed slots are filled and movable slots jammed. Radio reception is hampered, and engine performance is affected. Ice, snow, and slush have a direct impact on the safety of flight. Not only because of degraded lift, reduced takeoff performance, and/or maneuverability of the aircraft, but when chunks break off, they can also cause engine failures and structural damage. Fuselage aft-mounted engines are particularly susceptible

Figure 15-1. *Formation of ice on aircraft leading edge.*

to this foreign object damage (FOD) phenomenon. Wing-mounted engines are not excluded however. Ice can be present on any part of the aircraft and, when it breaks off, there is some probability that it could go into an engine. The worst case is that ice on the wing breaks off during takeoff due to the flexing of the wing and goes directly into the engine, leading to surge, vibration, and complete thrust loss. Light snow that is loose on the wing surfaces and the fuselage can also cause engine damage leading to surge, vibration, and thrust loss.

Whenever icing conditions are encountered, the performance characteristics of the airplane deteriorate. *[Figure 15-2]* Increased aerodynamic drag increases fuel consumption, reducing the airplane's range and making it more difficult to maintain speed. Decreased rate of climb must be anticipated, not only because of the decrease in wing and empennage efficiency but also because of the possible reduced efficiency of the propellers and increase in gross weight. Abrupt maneuvering and steep turns at low speeds must be avoided

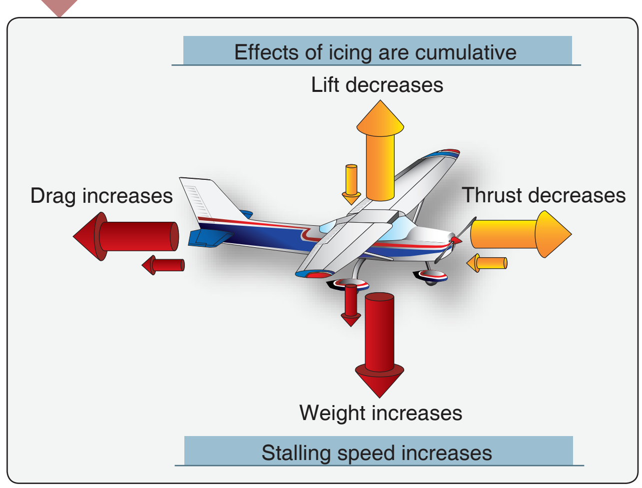


Figure 15-2. *Effects of structural icing.*

because the airplane stalls at higher-than-published speeds with ice accumulation. On final approach for landing, increased airspeed must be maintained to compensate for this increased stall speed. After touchdown with heavy ice accumulation, landing distances may be as much as twice the normal distance due to the increased landing speeds. In this chapter, ice prevention and ice elimination using pneumatic pressure, application of heat, and the application of fluid is discussed.

The ice and rain protection systems used on aircraft keep ice from forming on the following airplane components:

- Wing leading edges
- Horizontal and vertical stabilizer leading edges
- Engine cowl leading edges
- Propellers
- Propeller spinner
- Air data probes
- Flight deck windows
- Water and waste system lines and drains
- Antenna

Figure 15-3 gives an overview of ice and rain protection systems installed in a large transport category aircraft. In modern aircraft, many of these systems are automatically controlled by the ice detection system and onboard computers.

Ice Detector System

Ice can be detected visually, but most modern aircraft have one or more ice detector sensors that warn the flight crew of icing conditions. An annunciator light comes on to alert the flight crew. In some aircraft models, multiple ice detectors are used, and the ice detection system automatically turns on the WAI systems when icing is detected. *[Figure 15-4]*

Ice Prevention

Several means to prevent or control ice formation are used in aircraft today:

1. Heating surfaces with hot air
2. Heating by electrical elements
3. Breaking up ice formations, usually by inflatable boots
4. Chemical application

Equipment is designed for anti-icing or for deicing. Anti-icing equipment is turned on before entering icing conditions and is designed to prevent ice from forming. A surface may be anti-iced by keeping it dry, by heating to a temperature that evaporates water upon impingement, or by heating the surface just enough to prevent freezing, maintaining it running wet.

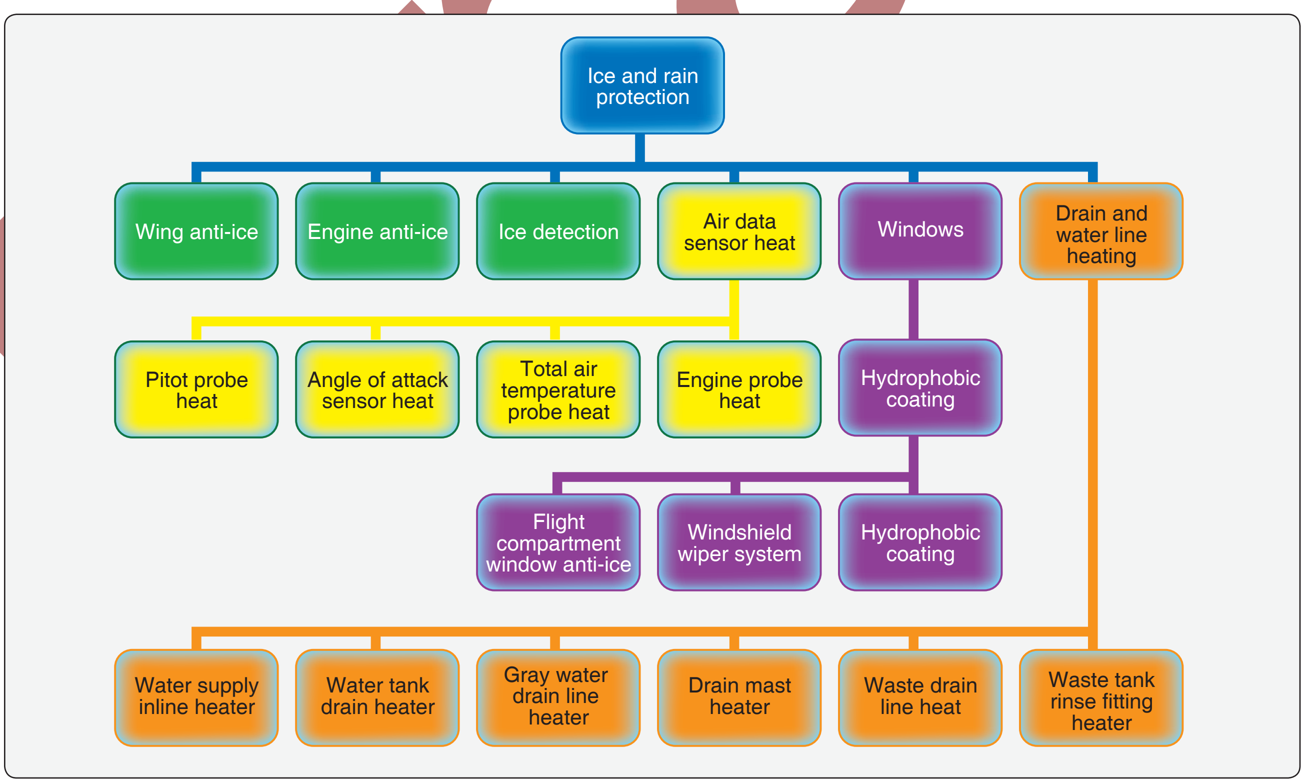


Figure 15-3. *Ice and rain protection systems.*

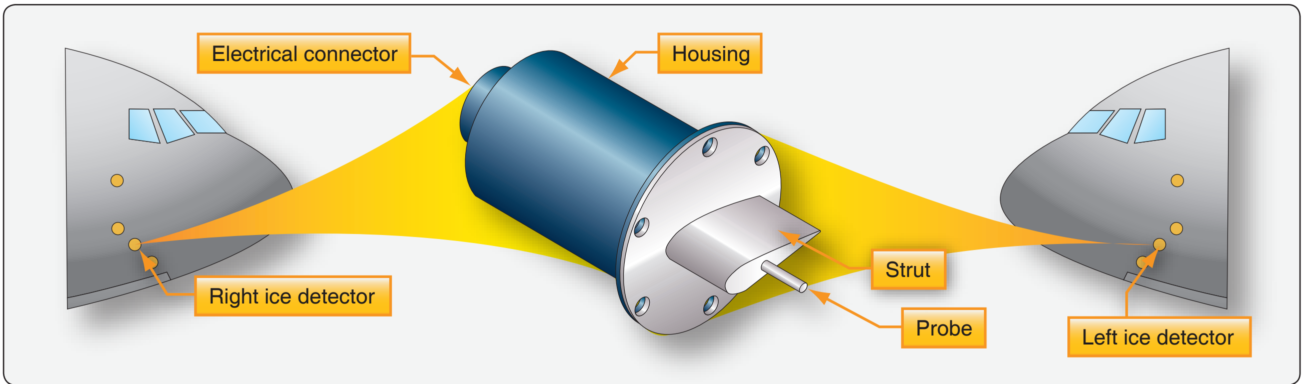


Figure 15-4. *An ice detector alerts the flight crew of icing conditions and, on some aircraft, automatically activates ice protection systems. One or more detectors are located on the forward fuselage.*

Deicing equipment is designed to remove ice after it begins to accumulate typically on the wings and stabilizer leading edges. Ice may be controlled on aircraft structure by the methods described in *Figure 15-5.*

Wing and Horizontal and Vertical Stabilizer Anti-Icing Systems

The wing leading edges, or leading-edge slats, and horizontal and vertical stabilizer leading edges of many aircraft make and models have anti-icing systems installed to prevent the formation of ice on these components. The most common anti-icing systems used are thermal pneumatic, thermal electric, and chemical. Most general aviation (GA) aircraft equipped to fly in icing conditions use pneumatic deicing boots or a chemical anti-ice system. High-performance aircraft may have "weeping wings." Large transport-category aircraft are equipped with advanced thermal pneumatic or thermal electric anti-icing systems that are controlled automatically to prevent the formation of ice.

Thermal Pneumatic Anti-icing

Thermal systems used for the purpose of preventing the formation of ice or for deicing airfoil leading edges usually use heated air ducted spanwise along the inside of the leading edge of the airfoil and distributed around its inner surface. These thermal pneumatic anti-icing systems are used for wings, leading edge slats, horizontal and vertical stabilizers, engine inlets, and more. There are several sources of heated air, including hot air bled from the turbine compressor, engine exhaust heat exchangers, and ram air heated by a combustion heater.

Wing Anti-Ice (WAI) System

Thermal wing anti-ice (WAI or TAI) systems for business jet and large-transport category aircraft typically use hot air bled from the engine compressor. *[Figure 15-6]* Relatively large amounts of very hot air can be bled off the compressor, providing a satisfactory source of anti-icing heat. The hot air is routed through ducting, manifolds, and valves to components that need to be anti-iced. *Figure 15-7* shows a typical WAI system schematic for a business jet. The bleed air is routed to each wing leading edge by an ejector in each

Location of ice	Method of control
Leading edge of the wing	Thermal pneumatic, thermal electric, chemical, and pneumatic (deice)
Leading edges of vertical and horizontal stabilizers	Thermal pneumatic, thermal electric, and pneumatic (deice)
Windshield, windows	Thermal pneumatic, thermal electric, and chemical
Heater and engine air inlets	Thermal pneumatic and thermal electric
Pitot and static air data sensors	Thermal electric
Propeller blade leading edge and spinner	Thermal electric and chemical
Carburetor(s)	Thermal pneumatic and chemical
Lavatory drains and portable water lines	Thermal electric

Figure 15-5. *Typical ice control methods.*

Figure 15-6. *Aircraft with thermal WAI system.*

wing inboard area. The ejector discharges the bleed air into piccolo tubes for distribution along the leading edge. Fresh ambient air is introduced into the wing leading edge by two flush-mounted ram air scoops in each wing leading edge, one at the wing root and one near the wingtip. The ejectors entrain ambient air, reduce the temperature of the bleed air, and increase the mass airflow in the piccolo tubes. The wing leading edge is constructed of two skin layers separated by a narrow passageway. *[Figure 15-8]* The air directed against the leading edge can only escape through the passageway,

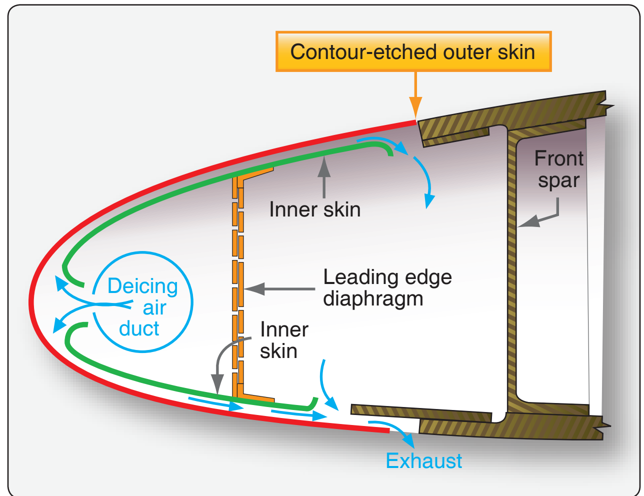


Figure 15-8. *Heated wing leading edge.*

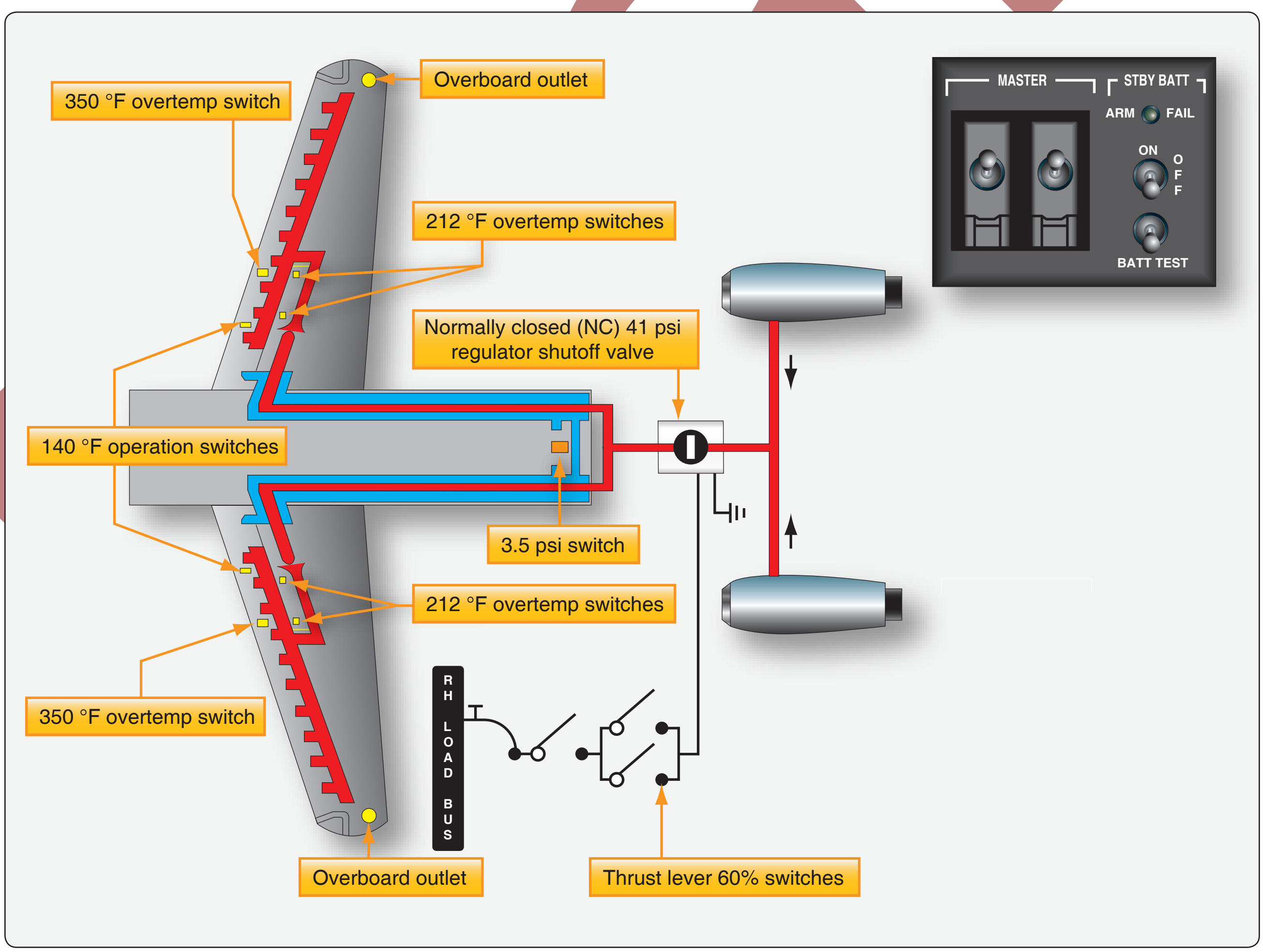


Figure 15-7. *Thermal WAI system.*

after which it is vented overboard through a vent in the bottom of the wingtip.

When the WAI switch is turned on, the pressure regulator is energized, and the shutoff valve opens. When the wing leading edge temperature reaches approximately +140 °F, temperature switches turn on the operation light above the switch. If the temperature in the wing leading edge exceeds approximately +212 °F (outboard) or +350 °F (inboard), the red WING OV HT warning light on the annunciator panel illuminates.

The ducting of WAI systems usually consists of aluminum alloy, titanium, stainless steel, or molded fiberglass tubes. The tube, or duct, sections are attached to each other by bolted end flanges or by band-type V-clamps. The ducting is lagged with a fire-resistant, heat-insulating material, such as fiberglass. In some installations, thin stainless-steel expansion bellows are used. Bellows are located at strategic positions to absorb any distortion or expansion of the ducting that may occur due to temperature variations. The joined sections of ducting are hermetically sealed by sealing rings. These seals are fitted into annular recesses in the duct joint faces.

When installing a section of duct, make certain that the seal bears evenly against and is compressed by the adjacent joint's flange. When specified, the ducts should be pressure tested at the pressure recommended by the manufacturer of the aircraft concerned. Leak checks are made to detect defects in the duct that would permit the escape of heated air. The rate of leakage at a given pressure should not exceed that recommended in the aircraft maintenance manual.

Air leaks can often be detected audibly and are sometimes revealed by holes in the lagging or thermal insulation material. However, if difficulty arises in locating leaks, a soap-and-water solution may be used. All ducting should be inspected for security, general condition, or distortion. Lagging or insulating blankets must be checked for security and must be free of flammable fluids, such as oil or hydraulic fluid.

Leading Edge Slat Anti-Ice System

Aircraft that utilize leading edge slats often use bleed air from the engine compressor to prevent the formation of frost on these surfaces. On a modern transport category aircraft, the pneumatic system supplies bleed air for this purpose. WAI valves control the air flow from the pneumatic system to WAI ducts. The WAI ducts carry the air to the slats. Holes in the bottom of each slat let the air out.

The airfoil and cowl ice protection system (ACIPS) computer card controls the WAI valves, and pressure sensors send duct air pressure data to the computer. The aircrew can select an auto or manual mode with the WAI selector. In the auto mode, the system turns on when the ice detection system detects ice. The off and on positions are used for manual control of the WAI system. The WAI system is only used in the air, except for ground tests. The weight on wheels system and/or airspeed data disarms the system when the aircraft is on the ground. *[Figure 15-9]*

WAI Valve

The WAI valve controls the flow of bleed air from the pneumatic system to the WAI ducts. The valve is electrically controlled and pneumatically actuated. The torque motor controls operation of the valve. With no electrical power to the torque motor, air pressure on one side of the actuator holds the valve closed. Electrical current through the torque motor allows air pressure to open the valve. As the torque motor current increases, the valve opening increases. *[Figure 15-10]*

WAI Pressure Sensor

The WAI pressure sensor senses the air pressure in the WAI duct after the WAI valve. The ACIPS system card uses the pressure information to control the WAI system.

WAI Ducts

The WAI ducts move air from the pneumatic system through the wing leading edge to the leading-edge slats. *Figure 15-9* shows that only leading edge slat sections 3, 4, and 5 on the left wing and 10, 11, and 12 on the right wing receive bleed air for WAI. Sections of the WAI ducting are perforated. The holes allow air to flow into the space inside the leading-edge slats. The air leaves the slats through holes in the bottom of each slat. Some WAI ducts have connecting "T" ducts that telescope to direct air into the slats while extended. The telescoping section attached to the slat on one end, slides over the narrow diameter "T" section that is connected into the WAI duct. A seal prevents any loss of air. This arrangement allows warm air delivery to the slats while retracted, in transit, and fully deployed. *[Figure 15-11]*

WAI Control System

Modern aircraft use several onboard computers to control aircraft systems. The WAI system is controlled by the ACIPS computer card. The ACIPS computer card controls both WAI valves. The required positions of the WAI valves change as bleed air temperature and altitude change. The left and right valves operate at the same time to heat both wings equally. This keeps the airplane aerodynamically stable in icing conditions. The WAI pressure sensors supply feedback information to the WAI ACIPS computer card for WAI valve control and position indication. If either pressure sensor fails, the WAI ACIPS computer card sets the related WAI valve to either fully open or fully closed. If either valve fails closed, the WAI computer card keeps the other valve closed.

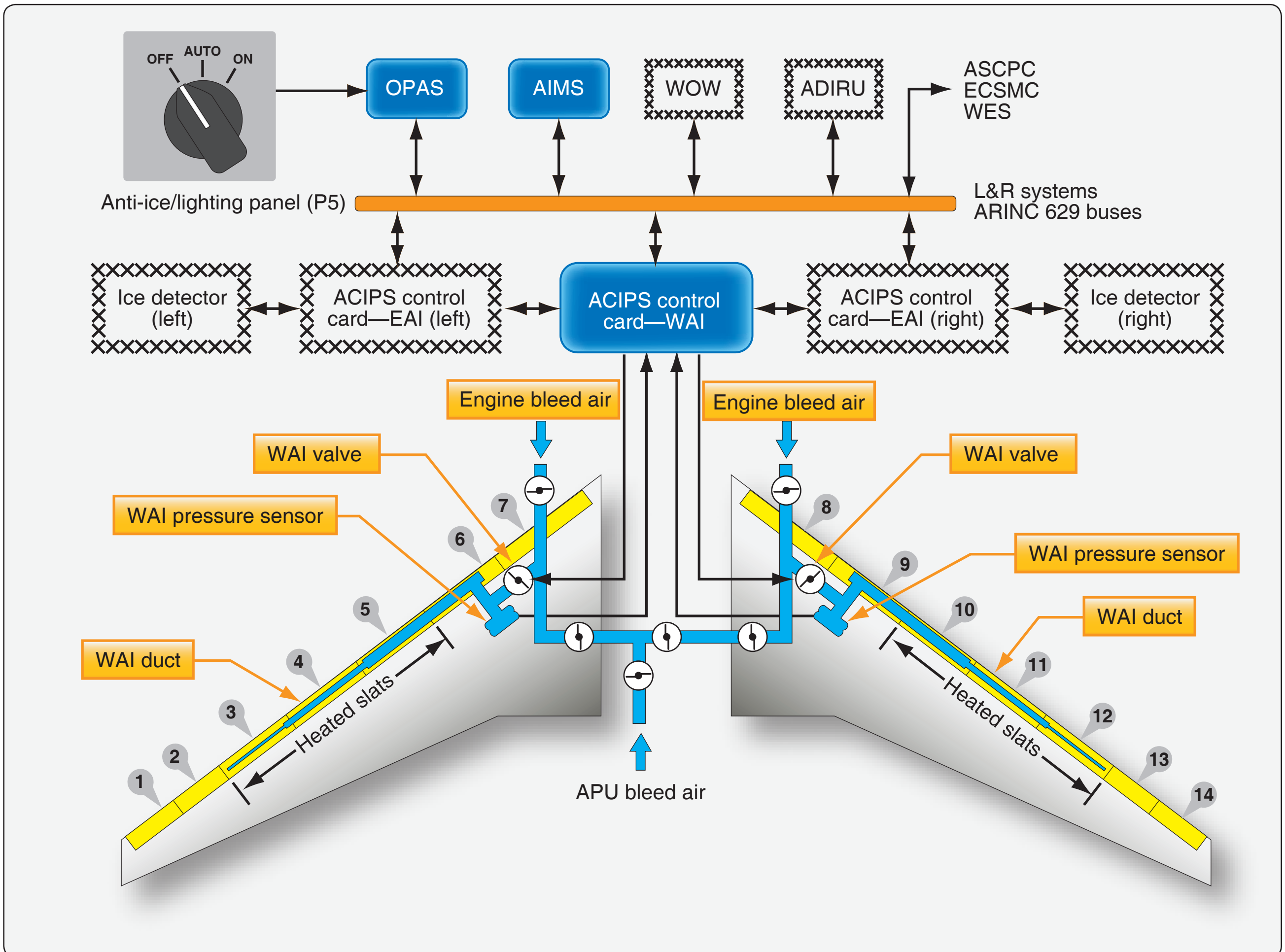


Figure 15-9. *Wing leading edge slat anti-ice system.*

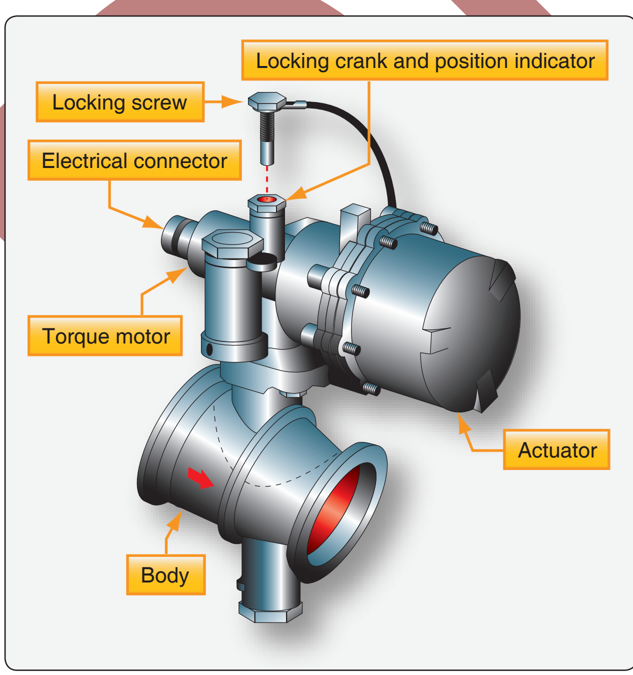


Figure 15-10. *A wing anti-ice valve.*

There is one selector for the WAI system. The selector has three positions: auto, on, and off. With the selector in auto and no operational mode inhibits, the WAI ACIPS computer card sends a signal to open the WAI valves when either ice detector detects ice. The valves close after a 3-minute delay when the ice detector no longer detects ice. The time delay prevents frequent on/off cycles during intermittent icing conditions. With the selector on and no operational mode inhibits, the WAI valves open. With the selector off, the WAI valves close. The operational mode for the WAI valves can be inhibited by many different sets of conditions. *[Figure 15-12]*

The operational mode is inhibited if all of these conditions occur:

- Auto mode is selected
- Takeoff mode is selected
- Airplane has been in the air less than 10 minutes

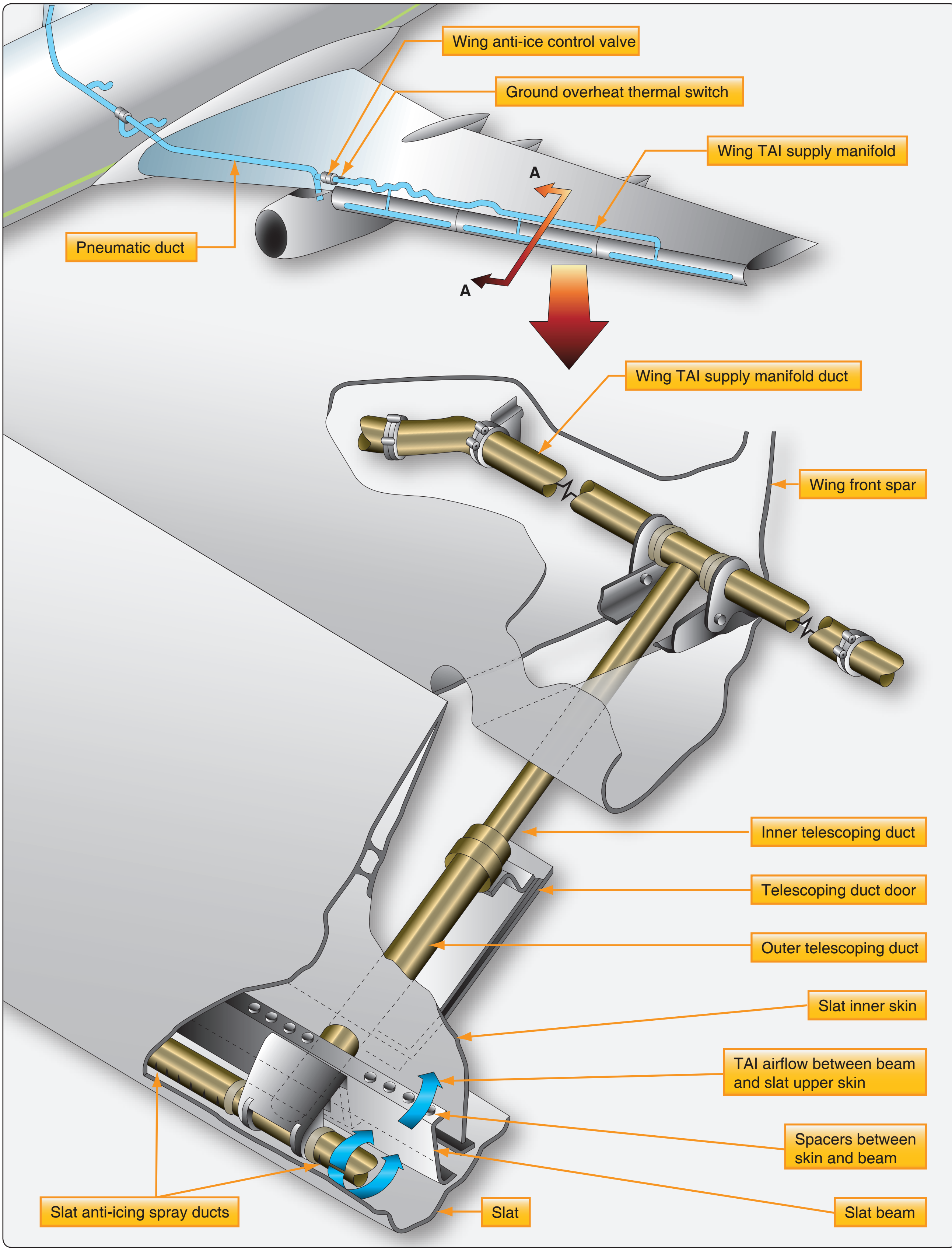


Figure 15-11. *WAI ducting.*

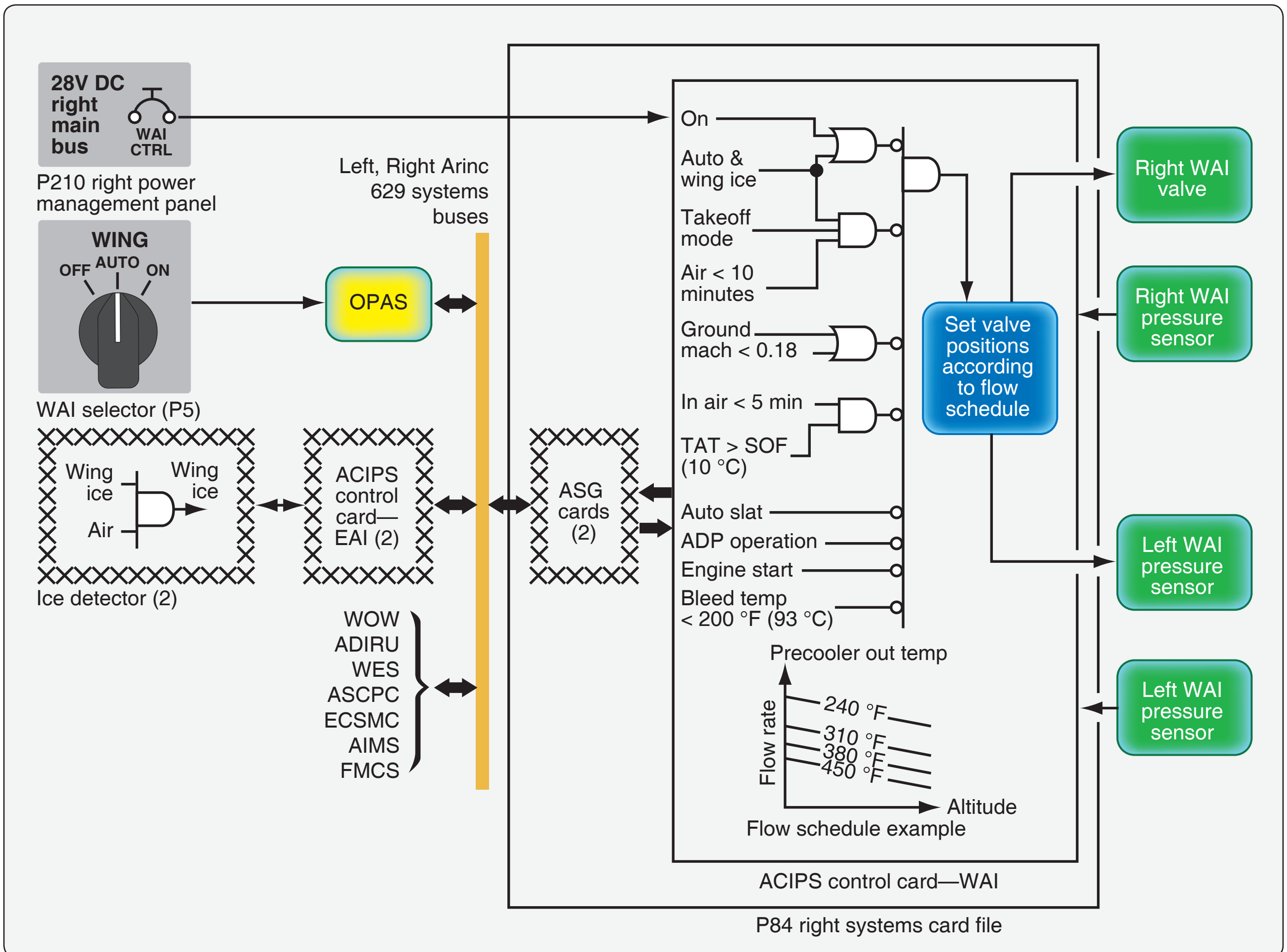


Figure 15-12. *WAI inhibit logic schematic.*

With auto or on selected, the operational mode is inhibited if any of these conditions occur:

- Airplane on the ground (except during an initiated or periodic built-in test equipment (BITE) test)
- Total Air Temperature (TAT) is more than 50 °F (10 °C) and the time since takeoff is less than 5 minutes
- Auto slat operation
- Air-driven hydraulic pump operation
- Engine start
- Bleed air temperature less than 200 °F (93 °C).

The WAI valves stay closed as long as the operational mode inhibit is active. If the valves are already open, the operational mode inhibit causes the valves to close.

WAI Indication System

The aircrew can monitor the WAI system on the onboard computer maintenance page. *[Figure 15-13]* The following information is shown:

- WING MANIFOLD PRESS—pneumatic duct pressure in PSIG
- VALVE—WAI valve open, closed, or regulating
- AIR PRESS—pressure downstream of the WAI valves in PSIG
- AIR FLOW—air flow through the WAI valves in pounds per minute

WAI System (BITE) Test

BITE circuits in the WAI ACIPS computer card continuously monitor the WAI system. Faults that affect the dispatch of the aircraft cause status messages. Other faults cause

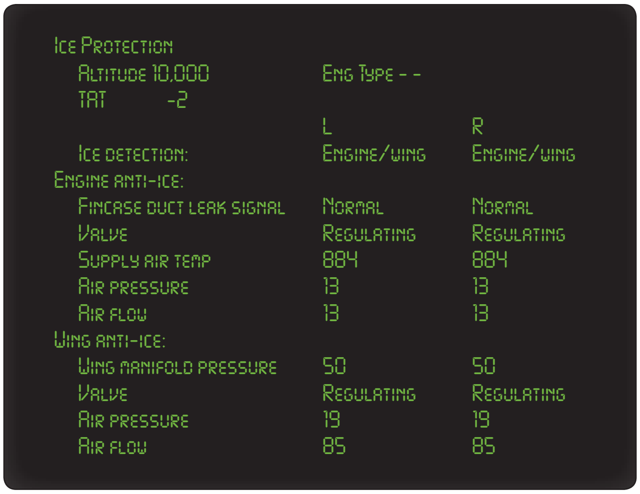


Figure 15-13. *Ice protection onboard computer maintenance page.*

central maintenance computer system (CMCS) maintenance messages. The BITE in the WAI ACIPS computer card also performs automatic power-up and periodic tests. Faults found during these tests that affect dispatch cause status messages. Other faults cause CMCS maintenance messages. The power-up test occurs when the card gets power. BITE does a test of the card hardware and software functions and the valve and pressure sensor interfaces. The valves do not move during this test.

The periodic test occurs when all these conditions are true:

- The airplane has been on the ground between 1 and 5 minutes.
- The WAI selector is set to auto or on.
- Air-driven hydraulic pumps are not in intermittent operation.
- Bleed pressure is sufficient to open the WAI valves.
- The time since the last periodic test is more than 24 hours.
- During this test, the WAI valves cycle open and closed. This test makes sure that valve malfunctions are detected.

Thermal Electric Anti-Icing

Electricity is used to heat various components on an aircraft so that ice does not form. This type of anti-ice is typically limited to small components due to high amperage draw. Effective thermal electric anti-ice is used on most air data probes, such as pitot tubes, static air ports, TAT and AOA probes, ice detectors, and engine P2/T2 sensors. Water lines, waste water drains, and some turboprop inlet cowls are also heated with electricity to prevent ice from forming. Transport category and high-performance aircraft use thermal electric anti-icing in windshields.

In devices that use thermal electric anti-ice, current flows through an integral conductive element that produces heat. The temperature of the component is elevated above the freezing point of water, so ice cannot form. Various schemes are used, such as an internal coil wire, externally wrapped blankets or tapes, as well as conductive films and heated gaskets. A basic discussion of probe heat follows. Windshield heat and portable water heat anti-ice are discussed later in this chapter. Propeller deice boots, which also are used for anti-ice, are also thermal electric and discussed in this chapter.

Data probes that protrude into the ambient airstream are particularly susceptible to ice formation in flight. *Figure 15-14* illustrates the types and location probes that use thermal electric heat on one airliner. A pitot tube, for example, contains an internal electric element that is controlled by a switch in the cockpit. Use caution checking the function of the pitot heat when the aircraft is on the ground. The tube gets extremely hot since it must keep ice from forming at altitude in temperatures near -50 °F at speeds possibly over 500 miles per hour. An ammeter or load meter in the circuit can be used as a substitute to touching the probe, if so equipped.

Simple probe heat circuits exist on GA aircraft with a switch and a circuit breaker to activate and protect the device. Advanced aircraft may have more complex circuitry in which control is by computer and flight condition of the aircraft is considered before thermal electric heaters are activated automatically. *Figure 15-15* shows such a circuit for a pitot tube. The primary flight computer (PFC) supplies signals for the air data card (ADC) to energize ground and air heat control relays to activate probe heat. Information concerning speed of the aircraft, whether it is in the air or on the ground, and if the engines are running are factors considered by the ADC logic. Similar control is use for other probe heaters.

Chemical Anti-Icing

Chemical anti-icing is used in some aircraft to anti-ice the leading edges of the wing, stabilizers, windshields, and propellers. The wing and stabilizer systems are often called weeping wing systems or are known by their trade name of TKS™ systems. Ice protection is based upon the freezing point depressant concept. An antifreeze solution is pumped from a reservoir through a mesh screen embedded in the leading edges of the wings and stabilizers. Activated by a switch in the cockpit, the liquid flows over the wing and tail surfaces, preventing the formation of ice as it flows. The solution mixes with the supercooled water in the cloud, depresses its freezing point, and allows the mixture to flow off of the aircraft without freezing. The system is designed to anti-ice, but it is also capable of deicing an aircraft as well. When ice has accumulated on the leading edges,

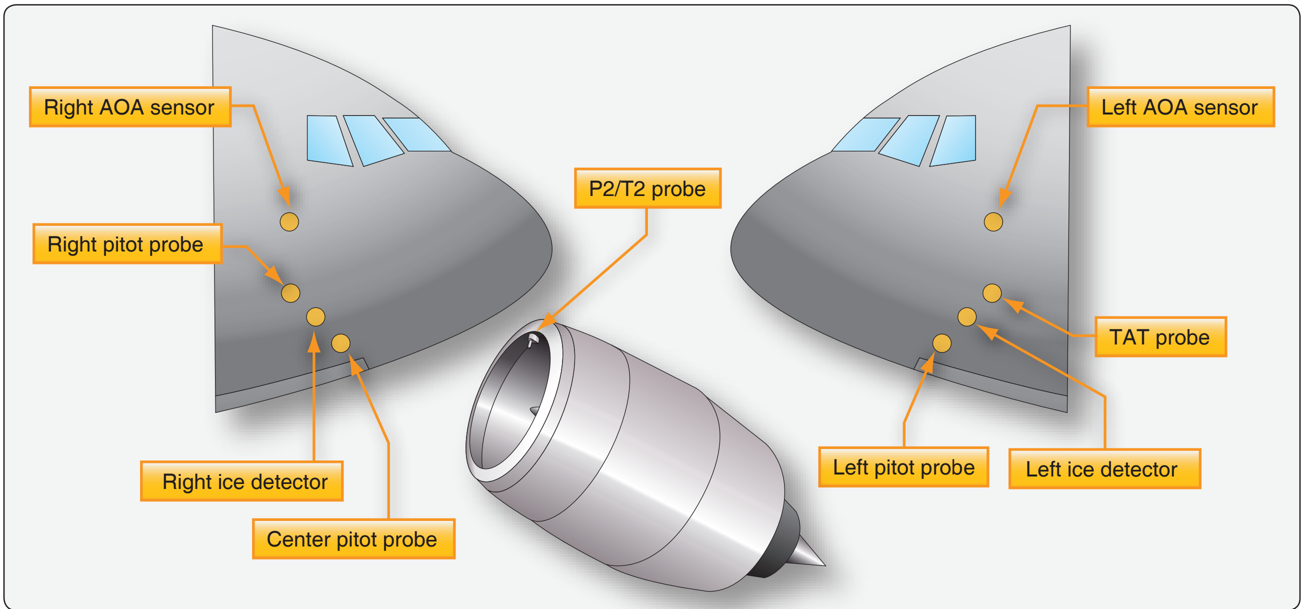


Figure 15-14. *Probes with thermal electric anti-icing on one commercial airliner.*

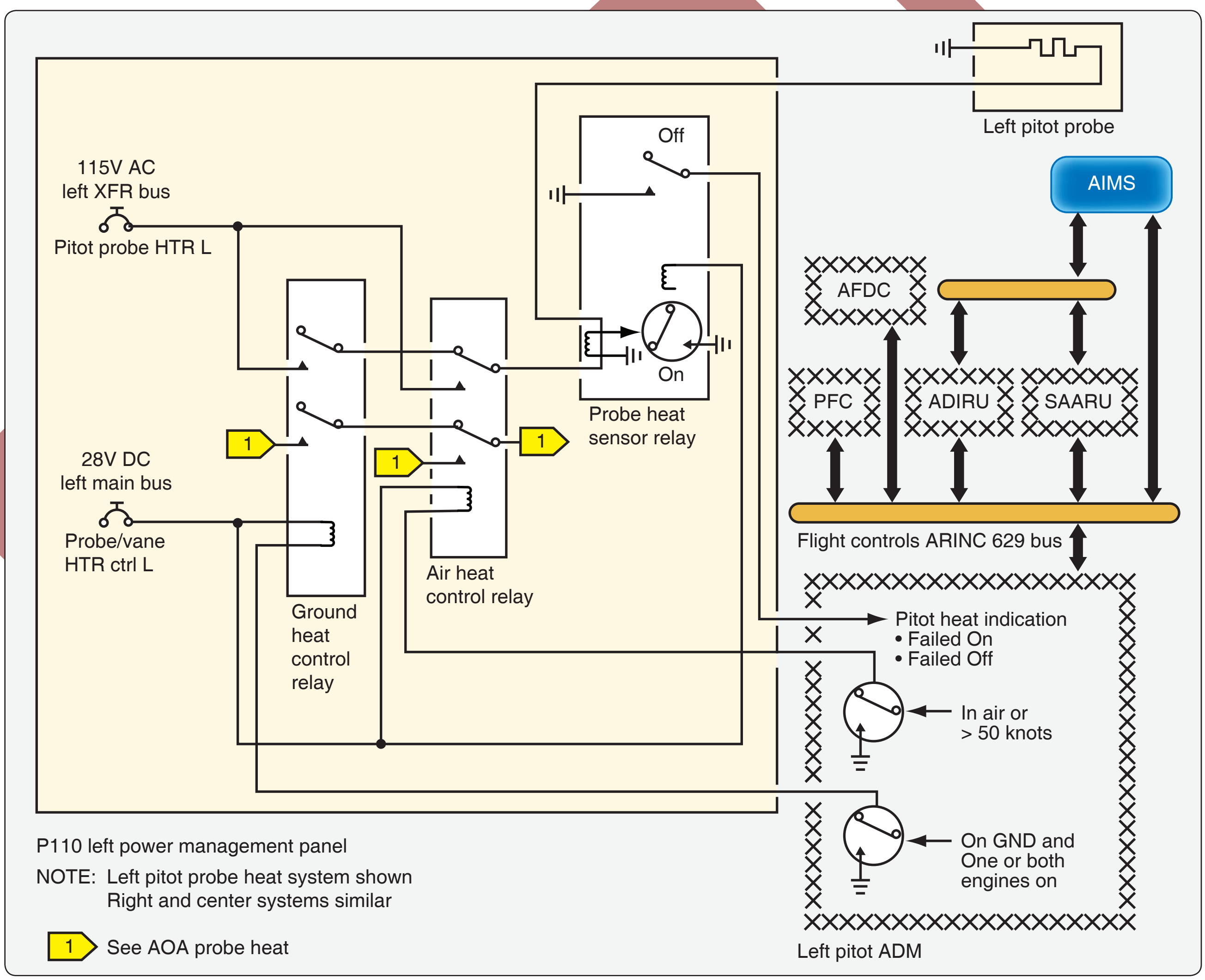


Figure 15-15. *Pitot probe heat system.*

the antifreeze solution chemically breaks down the bond between the ice and airframe. This allows aerodynamic forces to carry the ice away. Thus, the system clears the airframe of accumulated ice before transitioning to anti-ice protection. *Figure 15-16* shows a chemical anti-ice system.

The TKS™ weeping wing system contains formed titanium panels that are laser drilled with over 800 tiny holes (.0025-inch diameter) per square inch. These are mated with non-perforated stainless-steel rear panels and bonded to wing and stabilizer leading edges. As fluid is delivered from a central reservoir and pump, it seeps through the holes. Aerodynamic forces cause the fluid to coat the upper and lower surfaces of the airfoil. The glycol-based fluid prevents ice from adhering to the aircraft structure.

Some aircraft with weeping wing systems are certified to fly into known icing conditions. Others use it as a hedge against unexpected ice encountered in flight. The systems are basically the same. Reservoir capacity permits 1- 2 hours of operation. TKS™ weeping wings are used primarily on reciprocating aircraft that lack a supply of warm bleed air for the installation of a thermal anti-ice system. However, the system is simple and effective leading to its use on some turbine powered corporate aircraft as well.

Wing and Stabilizer Deicing Systems

GA aircraft and turboprop commuter-type aircraft often use a pneumatic deicing system to break off ice after it has formed on the leading-edge surfaces. The leading edges of the wings and stabilizers have inflatable boots attached to them. The boots expand when inflated by pneumatic pressure, which breaks away ice accumulated on the boot. Most boots are inflated for 6 to 8 seconds. They are deflated by vacuum suction. The vacuum is continuously applied to hold the boots tightly against the aircraft while not in use.

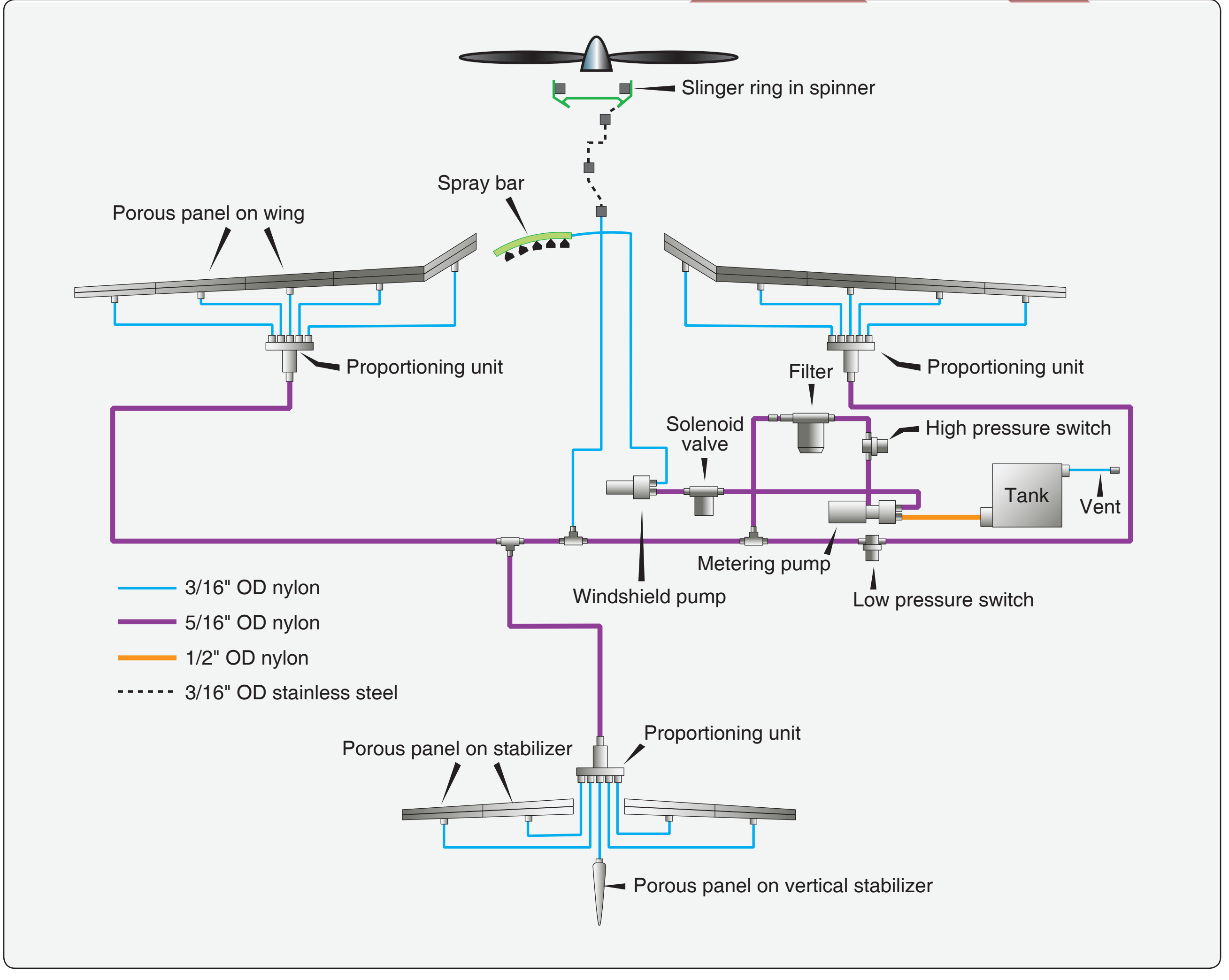


Figure 15-16. *Chemical deicing system.*

Sources of Operating Air

The source of operating air for deice boot systems varies with the type of powerplant installed on the aircraft. Reciprocating engine aircraft typically use a dedicated engine-driven air pump mounted on the accessory drive gear box of the engine. The suction side of the pump is used to operate the gyroscopic instruments installed on the aircraft. It is also used to hold the deice boots tight to the aircraft when they are not inflated. The pressure side of the pump supplies air to inflate the deice boots, which breaks up ice that has formed on the wing and stabilizer leading edges. The pump operates continuously. Valves, regulators, and switches in the cockpit are used to control the flow of source air to the system.

Turbine Engine Bleed Air

The source of deice boot operating air on turbine engine aircraft is typically bleed air from the engine compressor(s). A relatively low volume of air on an intermittent basis is required to operate the boots. This has little effect on engine power enabling use of bleed air instead of adding a separate engine-driven air pump. Valves controlled by switches in the cockpit deliver air to the boots when requested.

Pneumatic Deice Boot System for GA Aircraft

GA aircraft, especially twin-engine models, are commonly equipped with pneumatic deicer systems. Rubber boots are attached with glue to the leading edges of the wings and stabilizers. These boots have a series of inflatable tubes. During operation, the tubes are inflated and deflated in an alternating cycle. *[Figure 15-17]* This inflation and deflation causes the ice to crack and break off. The ice is then carried away by the airstream. Boots used in GA aircraft typically inflate and deflate along the length of the wing. In larger turbo prop aircraft, the boots are installed in sections along the wing with the different sections operating alternately and symmetrically about the fuselage. This is done so that any disturbance to airflow caused by an inflated tube is kept to a minimum by inflating only short sections on each wing at a time.

GA System Operation

Figure 15-18 shows a deice system used on a GA twin-engine aircraft with reciprocating engines. In normal flight, all of the components in the deice system are de-energized. Discharge air from the dry air pumps is dumped overboard through the deice control valves. The deflate valve is open connecting the deice boots to the suction side of the pump through the check valve manifold and the vacuum regulator. The gyroscopic instruments are also connected to the vacuum side of the dry air pump. The vacuum regulator is set to supply the optimum suction for the gyros, which is sufficient to hold the boots tightly against the airfoil surfaces.

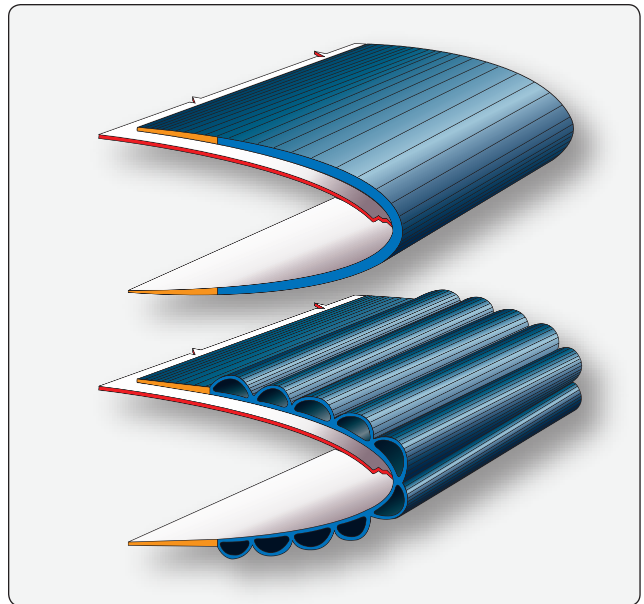


Figure 15-17. *Cross-section of a pneumatic deicing boot uninflated (top) and inflated (bottom).*

When the switch shown in *Figure 15-19* is pushed ON, the solenoid-operated deice control valves in each nacelle open and the deflate valve energizes and closes. Pressurized air from the discharge side of the pumps is routed through the control valves to the deice boot. When the system reaches 17 psi, pressure switches located on the deflate valve de-energize the deice control valve solenoids. The valves close and route pump air output overboard. The deflate valve opens and the boots are again connected to vacuum.

On this simple system, the pilot must manually start this inflation/deflation cycle by pushing the switch each time deice is required. Larger aircraft with more complex systems may include a timer, which will cycle the system automatically until turned OFF. The use of distributor valves is also common. A distributor valve is a multi-position control valve controlled by the timer. It routes air to different deice boots in a sequence that minimizes aerodynamic disturbances as the ice breaks of the aircraft. Boots are inflated symmetrically on each side of the fuselage to maintain control in flight while deicing occurs. Distributor valves are solenoid operated and incorporate the deflate valve function to reconnect the deice boots with the vacuum side of the pump after all have been inflated.

Combining functional components of a deice system into a single unit is fairly common. *Figure 15-20* illustrates the right side of a large aircraft deice boot system. The left side is the same. In addition to the distributor valves, which combine functions of a control valve and deflate valve, the

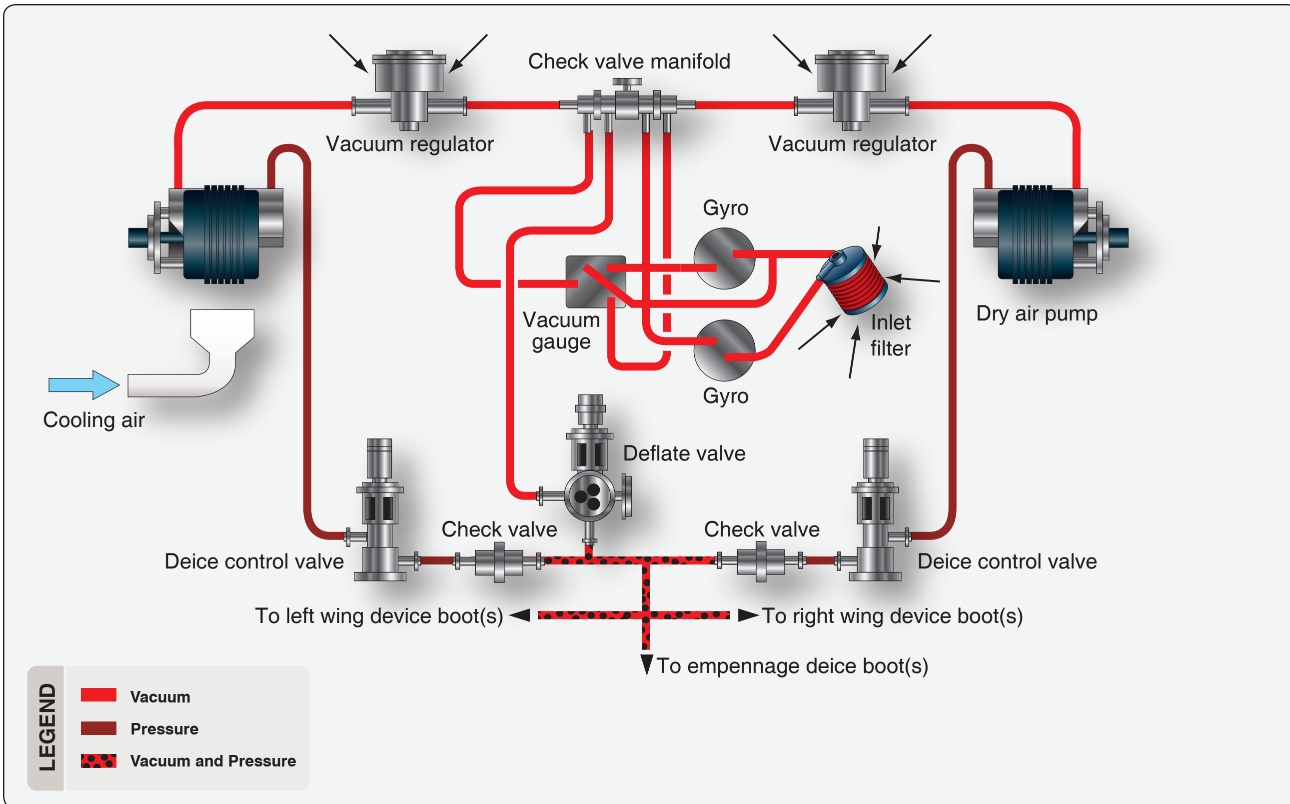


Figure 15-18. *Pneumatic deicing system for a twin engine GA aircraft with reciprocating engines.*

system also uses a combination unit. This unit combines the functions of a shutoff control valve for all pump supply air, as well as a pressure regulator for the system. It also contains a secondary air filter.

Deice System for Turboprop Aircraft

Figure 15-21 shows a pneumatic deice system used on a turboprop aircraft. The source of pneumatic air is engine bleed air, which is used to inflate two inboard wing boots, two outboard boots, and horizontal stabilizer boots. Additional bleed air is routed through the brake deice valve to the brakes. A three-position switch controls the operation of the boots. This switch is spring loaded to the center OFF position. When ice has accumulated, the switch should be selected to

Figure 15-19. *Wing deice switch.*

the single-cycle (up) position and released. *[Figure 15-22]* Pressure-regulated bleed air from the engine compressors supply air through bleed air flow control units and pneumatic shutoff valves to a pneumatic control assembly that inflates the wing boots. After an inflation period of 6 seconds, an electronic timer switches the distributor in the control assembly to deflate the wing boots, and a 4-second inflation begins in the horizontal stabilizer boots. After these boots have been inflated and deflated, the cycle is complete, and all boots are again held down tightly against the wings and horizontal stabilizer by vacuum. The spring-loaded switch must be selected up again for another cycle to occur.

Each engine supplies a common bleed air manifold. To ensure the operation of the system, if one engine is inoperative, a flow control unit with check valve is incorporated in the bleed air line from each engine to prevent the loss of pressure through the compressor of the inoperative engine. If the boots fail to function sequentially, they may be operated manually by selecting the DOWN position of the same deice cycle switch. Depressing and holding it in the manual DOWN position inflates all the boots simultaneously. When the switch is released, it returns to the (spring-loaded) off position, and each boot is deflated and held by vacuum. When operated manually, the boot should not be left inflated for more than 7 to 10 seconds, as a new layer of ice may begin

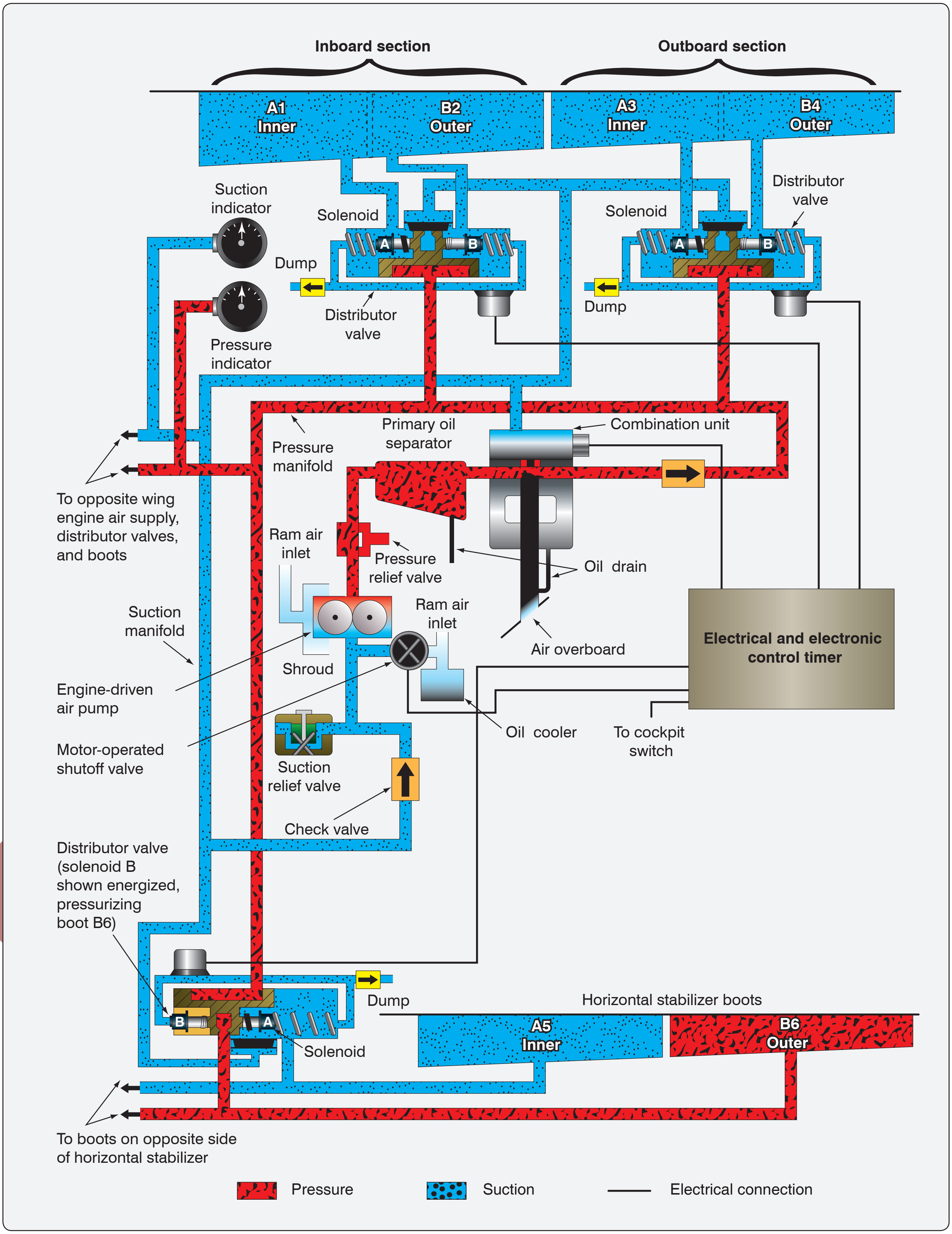


Figure 15-20. *Right-side deice boot system on a large aircraft (left side similar).*

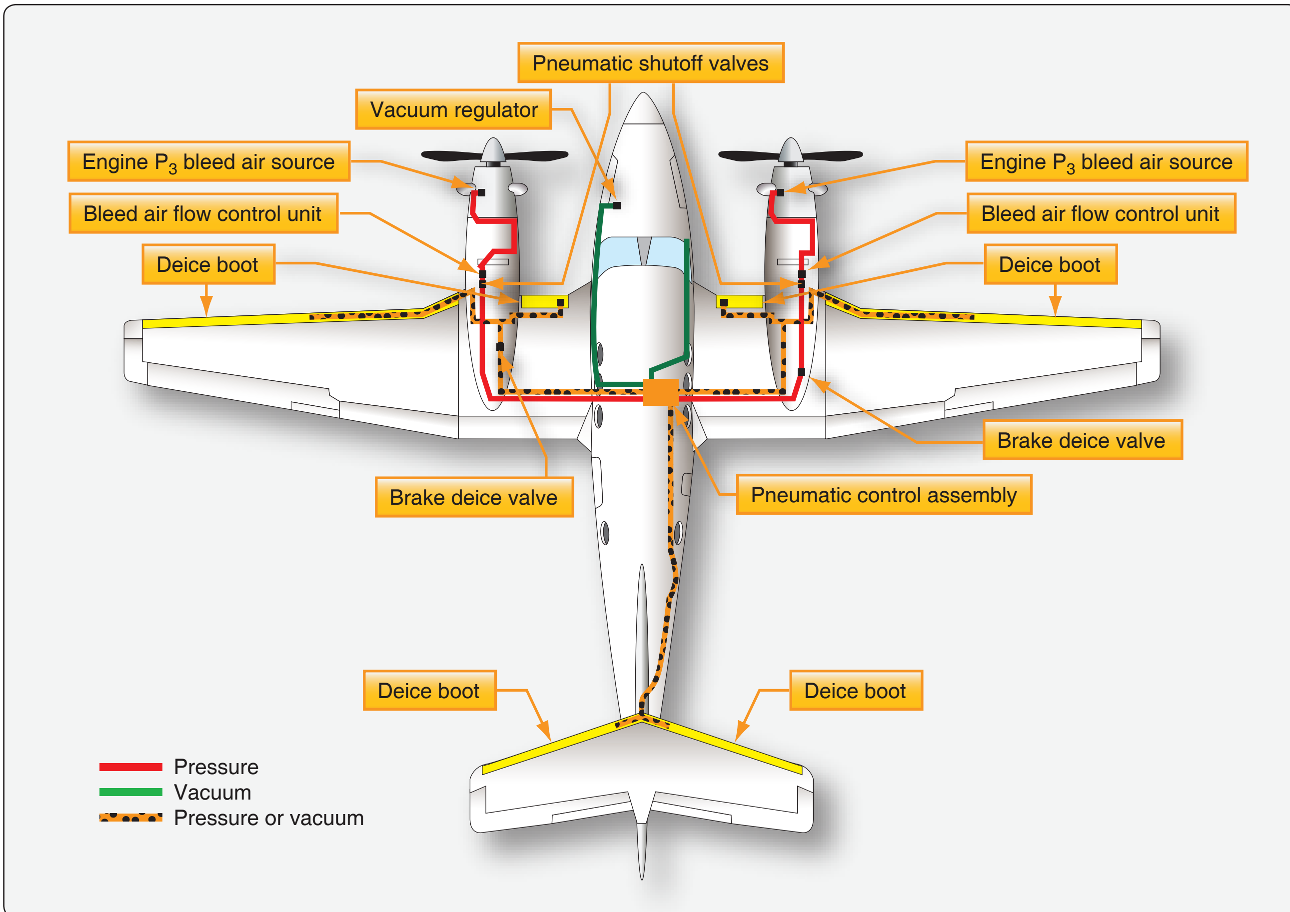


Figure 15-21. *Wing deice system for turboprop aircraft.*

to form on the expanded boots and become un-removable. If one engine is inoperative, the loss of its pneumatic pressure does not affect boot operation. Electric power to the boot system is required to inflate the boots in either single-cycle or manual operation. When electric power is lost, the vacuum holds the boots tightly against the leading edge.

Figure 15-22. *Ice protection panel on a turboprop aircraft with deice boots.*

Deicing System Components

Several components are used to construct all deice boot systems. The components may differ slightly in name and location within the system depending on the aircraft. Components may also combine functions to save space and weight. The basic functions of filtering, pressure regulation, distribution, and attachment to a vacuum when boots are not in use must all be present. Check valves must also be installed to prevent back flow in the system. Manifolds are common on multiengine aircraft to allow sourcing of low pressure air from both engine pumps. Note that air-pump pressure is typically expelled overboard when not needed. Bleed air is shut off by a valve when not needed for deice boot operation on turbine engine aircraft. A timer, or control unit with an automatic mode, exists on many aircraft to repeat the deice cycle periodically.

Wet-Type Engine-Driven Air Pump

To provide pressure for the deice boots, older aircraft may use a wet-type engine-driven air pump mounted on the accessory drive gear case of the engine. Some modern aircraft may also use a wet-type air pump because of its durability. The pump is typically a four vane, positive displacement pump.

Engine oil passes from the accessory case through the pump mounting base flange to lubricate the pump. Some of the oil is entrained in the output air and must be removed by an oil separator before it is sent through other components in the deice system. When installing a wet-type pump, care should be taken to ensure that the oil passage in the gasket, pump, and mounting flange are aligned to ensure lubrication. *[Figure 15-23]*

Dry-Type Engine-Driven Air Pump

Most modern GA aircraft are equipped with a dry-type engine-driven air pump. It is also mounted on the engine accessory drive case; however, it is not lubricated with engine oil. The pump is constructed with carbon rotor vanes and bearings. The carbon material wears at a controlled rate to provide adequate lubrication without the need for oil. This keeps output air oil-free; thus, the use of an oil separator is not required. Caution should be used to prevent oil, grease, or degreasing fluids from entering the pump or the air system to ensure proper pump and system operation. *[Figure 15-24]* Dry-type and wet-type pumps are virtually maintenance free. Mounting bolts should be checked for security as should all hose connections. Wet-type pumps have a longer time before requiring overhaul, but dry-type pumps give the assurance that the deice system will not be contaminated with oil.

Oil Separator

An oil separator is required for each wet-type air pump. Pump output air flows through the separator where most of the oil is removed and sent back to the engine though a drain line. Some systems may include a secondary separator to ensure oil free air is delivered to the deice system. There are no moving parts in an oil separator. A convoluted interior allows the air to pass, while the oil condenses and drains back to the engine. The only maintenance required on the separator is flushing the interior of the unit with a specified solvent. This should be done at intervals prescribed in the applicable maintenance manual. *[Figure 15-25]*

Control Valve

A control valve is a solenoid operated valve that allows air from the pump to enter the deice system. When energized by the deice switch in the cockpit, the valve opens. The control

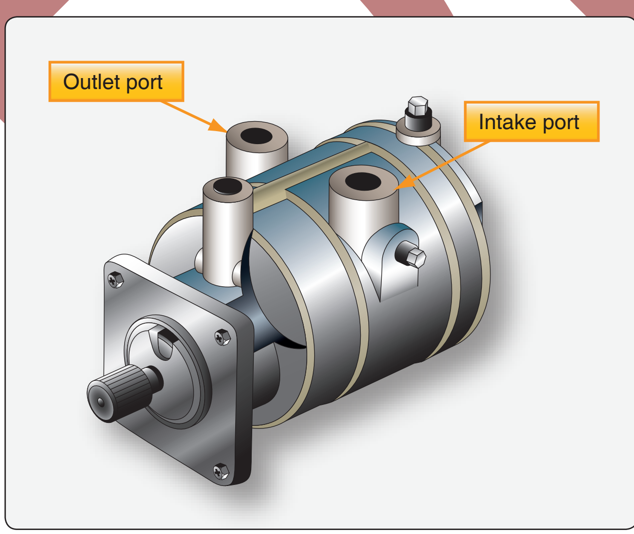


Figure 15-23. *A wet-type air pump with engine oil lubricating ports in the mounting flange.*

Figure 15-24. *Dry-type engine-driven air pump.*

Figure 15-25. *An oil separator used with a wet-type engine-driven air pump.*

valve dumps pump air overboard when the deice system is not in use. Many control valves are built in combination with pressure relief valves that keeps the deice system safe from over pressure. *[Figure 15-26]*

Deflate Valve

All deice boot systems require a means for connecting vacuum from the air pump to the boots when the boots are not in use. This ensures the boots are held tightly deflated against the aircraft structure to provide the significant change in size and shape needed to break off accumulated ice when the boots inflate. One single deflate valve is used on simple deice boot systems. The deflate valve is solenoid operated. It is located at a point in the system where when closed, air is delivered to the boots. When open, vacuum is applied. Often, the deflate function is built into another unit, such as a distributor valve discussed next.

Distributor Valve

A distributer valve is a type of control valve used in relatively complex deice boot systems. It is an electrically-operated solenoid valve controlled by the deice boot system timer or control unit. On some systems, a distributor valve is assigned to each set of deice boots it controls. It differs from a control valve in that it has the deflate valve function built into it. Therefore, the distributor valve transfers connection of the boots from the pressure side of the air pump to the vacuum side of the pump once the proper inflation time has elapsed. The valve also dumps the unneeded air from the pump overboard.

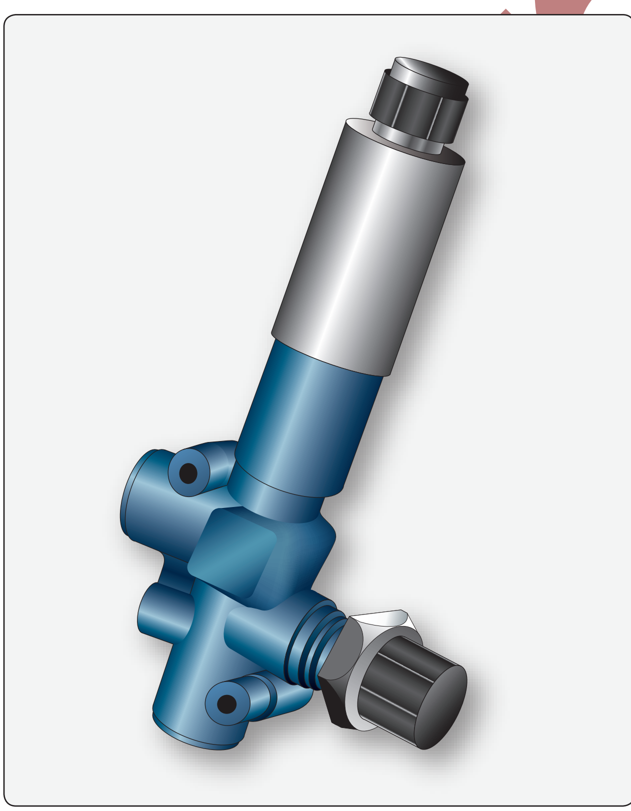


Figure 15-26. *A solenoid operated deice control valve.*

Another type of distributor valve exists that handles the inflation and deflation of numerous sets of deice boots in a single unit. It also connects the boots to vacuum and dumps pump air when deice is not needed. A servo motor is used to position the multi-position valve. These centralized units are controlled by a timer or control unit. They inflate and deflate all of the boots on the aircraft. The timer may be built into the unit on some models.

Timer/Control Unit

All but the simplest of deice systems contain a timer or control unit. This device controls the action of the distributor valve(s) to ensure all boots are inflated in the proper sequence and for the correct duration. Six seconds of inflation is common to break off accumulated ice. The boot then must be immediately deflated so that ice does not adhere to the inflated geometry of the boot. This could cause it to fail to deflate or break off ice when the boot is re-inflated. The timer, or control unit, can also be made to cycle through the inflation and deflation of all boots periodically, thus relieving the flight crew of repetitive manual activation of the system. The function and capabilities of timers and control units vary. Consult the manufacturer's maintenance information for the performance characteristics of the timer/control unit on the aircraft in question.

The timer, or control unit, may be an independent device, or it may be built-in as part of another deice system component, such as a central distribution valve.

NOTE: A modern system design may use a pressure switch to signal deflation of the deice boots. When pressure builds in the boots to a preset amount, the switch signals the control valve to close and connect the boots to vacuum. However, this system retains a control unit for automatic cycling of the system at a set time interval.

Regulators and Relief Valves

Both the pressure and vacuum developed by an air pump must be regulated for use in the deice boot system. Typical boot inflation air pressure is between 15 and 20 psi. Vacuum pressure is set for the requirements of the gyroscopic instruments operated by the vacuum side of the air pump. Measured in inches of mercury, normal vacuum pressure (suction) is 4.5 to 5.5 "Hg.

Deice boot system air pressure is controlled by a pressure regulator valve located somewhere in the system downstream of the pump or oil separator, if installed. The regulator may be a stand-alone unit, or it may be combined into another deice system component. Regardless, the spring-loaded valve relieves pressure overboard when it exceeds the limit for which the system is designed.

A vacuum regulator is installed in the vacuum manifold on the suction side of the air pump to maintain the vacuum at the designed level. Also known as a suction regulating valve or similar, the spring-loaded valve contains a filter for the ambient air drawn through the valve during operation. This filter must be changed or kept clean per manufacturer's instructions. *[Figure 15-27]*

Manifold Assembly

In all pneumatic deice boot systems, it is necessary for check valves to be installed to prevent backflow of air in the system. The location(s) depend on system design. Sometimes, the check valve is built into another system component. On twin-engine aircraft, it is common to unite the air supplied from each engine-driven pump to provide redundancy. Check valves are required to guard against backflow should one pump fail. A manifold assemble is commonly used to join both sides of the system. *[Figure 15-28]* It contains the required check valves in a single assembly.

Inlet Filter

The air used in a deice boot system is ambient air drawn in upstream of the gyroscopic instruments on the suction side of the engine-driven air pump. This air must be free of contaminants for use spinning the gyros, as well as for inflation of the deice boots. To ensure clean air, an inlet filter is installed as the air intake point for the system. This filter must be regularly maintained as per manufacturer's

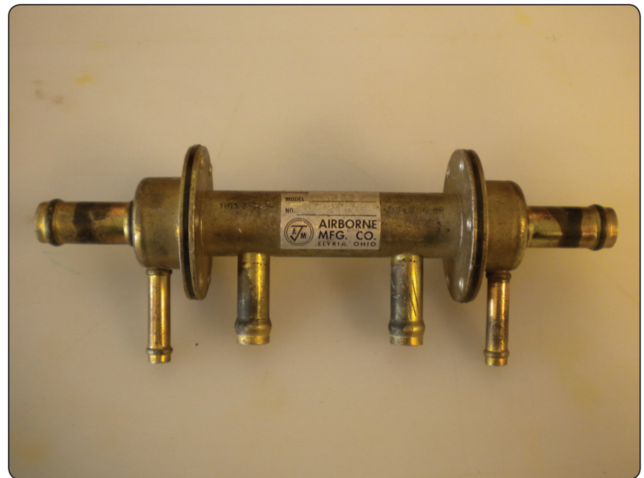


Figure 15-28. *A manifold assembly used in multiengine aircraft deice systems.*

instructions. *Figure 15-29* shows a typical inlet air filter. *Figure 15-30* shows the relationship of the vacuum regulator and inlet air filter to other system components.

Construction and Installation of Deice Boots

Deicer boots are made of soft, pliable rubber, or rubberized fabric, and contain tubular air cells. The outer ply of the deicer boot is of conductive neoprene to provide resistance to deterioration by the elements and many chemicals. The neoprene also provides a conductive surface to dissipate static electricity charges. These charges, if allowed to accumulate, would eventually discharge through the boot to the metal skin beneath, causing static interference with the radio equipment. *[Figure 15-31]*

On modern aircraft, the deicer boots are bonded with an adhesive to the leading edge of wing and tail surfaces. The trailing edges of this type boot are tapered to provide a smooth

Figure 15-27. *A vacuum regulator.*

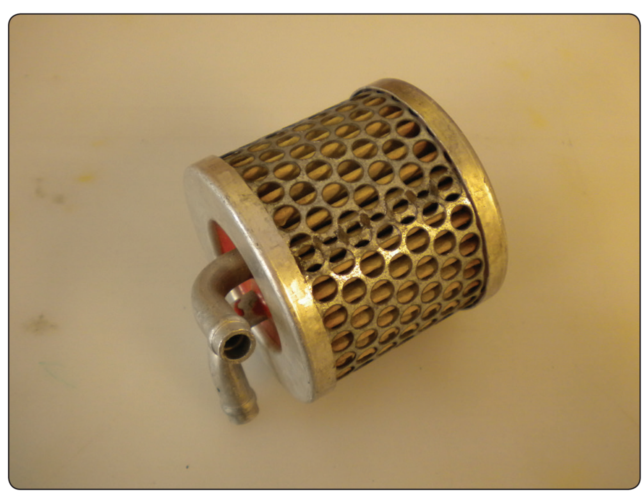


Figure 15-29. *Air filter for vacuum system.*

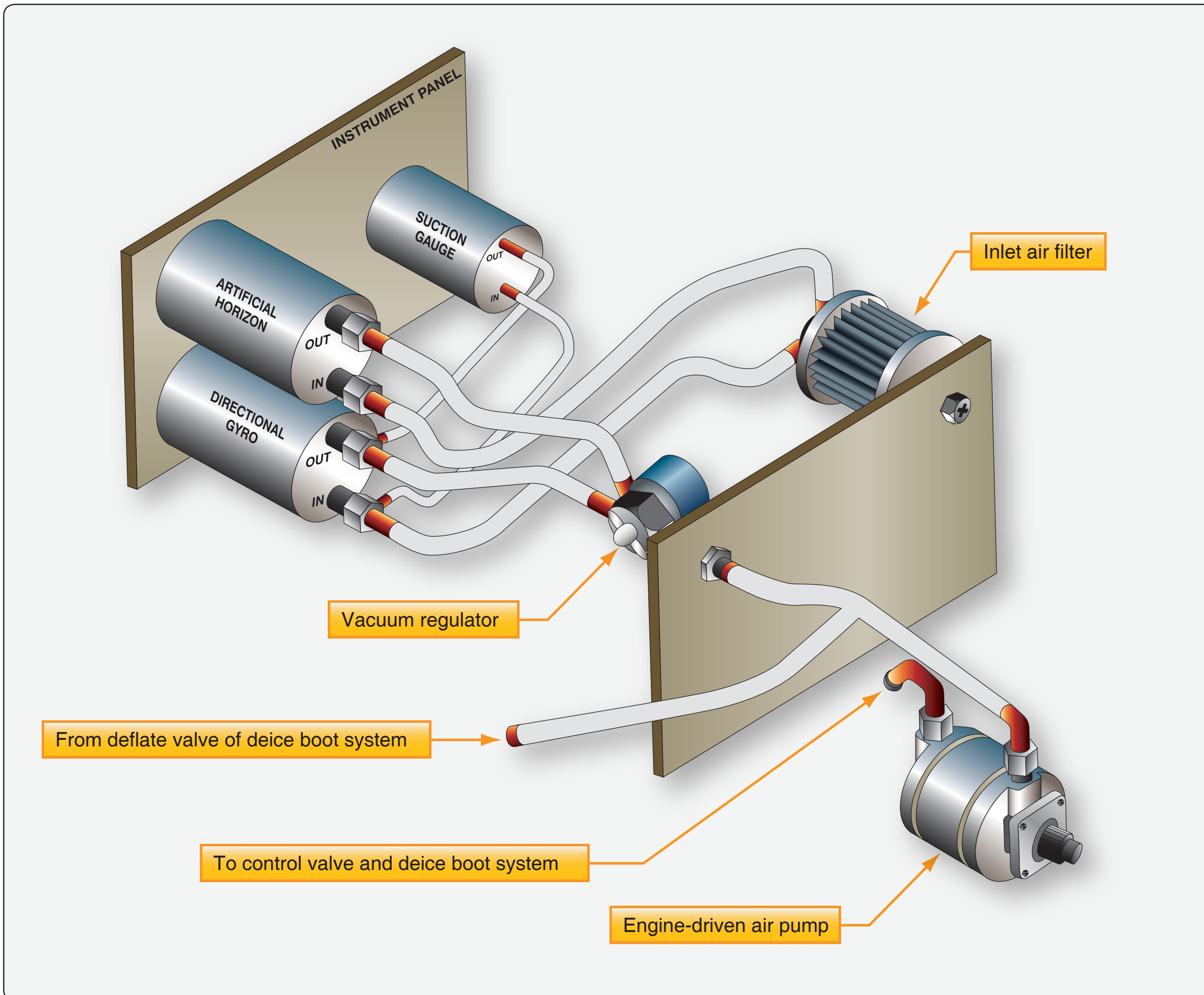


Figure 15-30. *Location of the inlet air filter in relationship to other components in a gyro instrument/pneumatic deice boot system.*

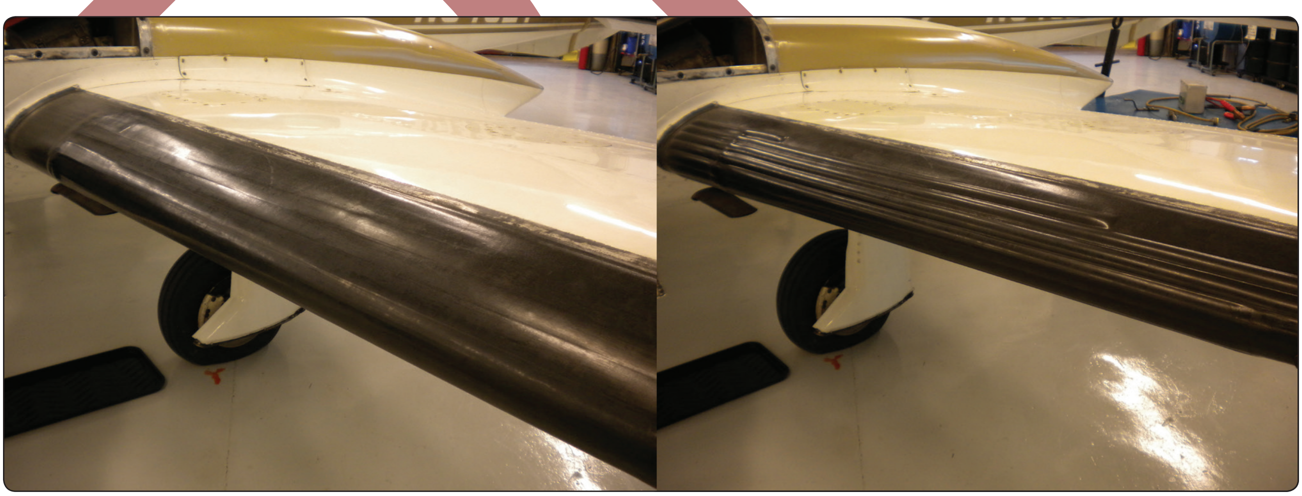


Figure 15-31. *Deicing boots inflated (left) and deflated (right).*

airfoil. Elimination of fairing strips, screws, and rivnuts used on older types of deicing boots reduces the weight of the deice system. The deicer boot air cells are connected to system pressure and vacuum lines by non-kinking flexible hose.

When gluing the deice boots to the leading edge of wings and stabilizers, the manufacturer's instruction must be strictly followed. The glue is typically a contact cement normally spread on both the airfoil and the boot and allowed to become tacky before mating the surfaces. Clean, paint-free surfaces are required for the glue to adhere properly. Removal of old boots is performed by re-softening the cement with solvent.

Inspection, Maintenance, and Troubleshooting of Rubber Deicer Boot Systems

Maintenance on pneumatic deicing systems varies with each aircraft model. The instructions of the airframe or system components manufacturer should be followed in all cases. Depending on the aircraft, maintenance usually consists of operational checks, adjustments, troubleshooting, and inspection.

Operational Checks

An operational check of the system can be made by operating the aircraft engines or by using an external source of air. Most systems are designed with a test plug to permit ground checking the system without operating the engines. When using an external air source, make certain that the air pressure does not exceed the test pressure established for the system. Before turning the deicing system on, observe the vacuum-operated instruments. If any of the gauges begin to operate, it is an indication that one or more check valves have failed to close and that reverse flow through the instruments is occurring. Correct the difficulty before continuing the test. If no movement of the instrument pointers occurs, turn on the deicing system. With the deicer system controls in their proper positions, check the suction and pressure gauges for proper indications. The pressure gauge fluctuates as the deicer tubes inflate and deflate. A relatively steady reading should be maintained on the vacuum gauge. It should be noted that not all systems use a vacuum gauge. If the operating pressure and vacuum are satisfactory, observe the deicers for actuation. With an observer stationed outside the aircraft, check the inflation sequence to be certain that it agrees with the sequence indicated in the aircraft maintenance manual. Check the timing of the system through several complete cycles. If the cycle time varies more than is allowable, determine the difficulty and correct it. Inflation of the deicers must be rapid to provide efficient deicing. Deflation of the boot being observed should be completed before the next inflation cycle. *[Figure 15-32]*

Adjustments

Examples of adjustments that may be required include adjusting the deicing system control cable linkages, adjusting system pressure relief valves, and deicing system vacuum (suction) relief valves. A pressure relief valve acts as a safety device to relieve excess pressure in the event of regulator valve failure. To adjust this valve, operate the aircraft engines and adjust a screw on the valve until the deicing pressure gauge indicates the specified pressure at which the valve should relieve. Vacuum relief valves are installed in a system that uses a vacuum pump to maintain constant suction during varying vacuum pump speeds. To adjust a vacuum relief valve, operate the engines. While watching the vacuum (suction) gauge, an assistant should adjust the suction relief valve adjusting screw to obtain the correct suction specified for the system.

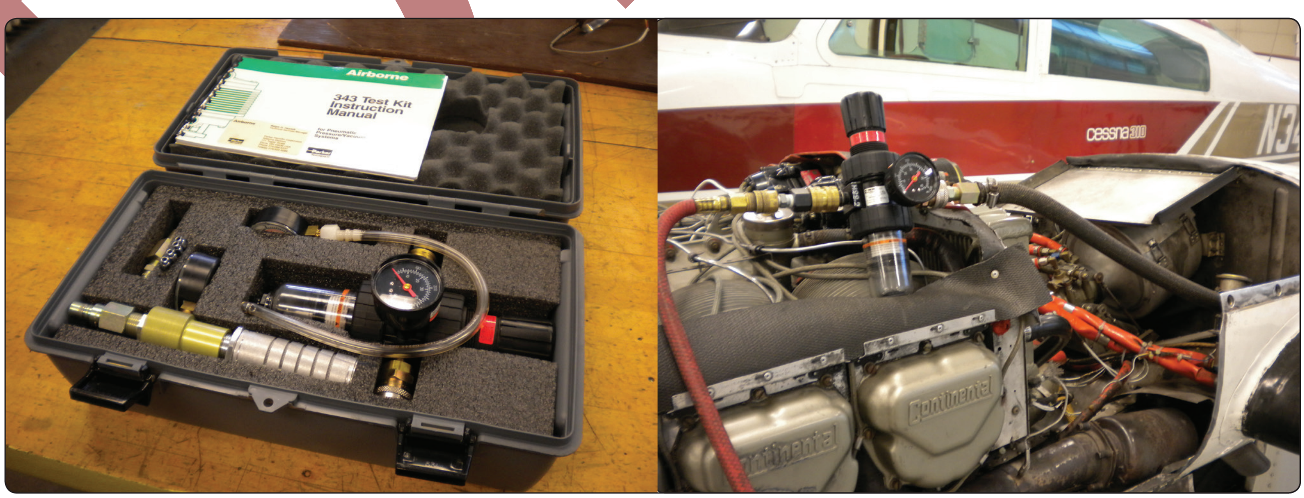


Figure 15-32. *Test equipment used to test a wing deice system (left), and test equipment installed in the aircraft for testing (right).*

Troubleshooting

Not all troubles that occur in a deicer system can be corrected by adjusting system components. Some troubles must be corrected by repair or replacement of system components or by tightening loose connections. Several troubles common to pneumatic deicing systems are shown in the left-hand column of the chart in *Figure 15-33.* Note the probable causes and the remedy of each trouble listed in the chart. In addition to using troubleshooting charts, operational checks are sometimes necessary to determine the possible cause of trouble.

Inspection

During each preflight and scheduled inspection, check the deicer boots for cuts, tears, deterioration, punctures, and security; during periodic inspections, go a little further and check deicer components and lines for cracks. If weather cracking of rubber is noted, apply a coating of conductive cement. The cement, in addition to sealing the boots against weather, dissipates static electricity so that it does not puncture the boots by arcing to the metal surfaces.

Deice Boot Maintenance

The life of the deicers can be greatly extended by storing them when they are not needed and by observing these rules when they are in service:

1. Do not drag gasoline hoses over the deicers.
2. Keep deicers free of gasoline, oil, grease, dirt, and other deteriorating substances.

Problem	Causes (most of which can be identified with a 343 Test Kit)	Corrective action(s)
Boots do not inflate	• Open circuit breaker • Faulty deflate valve Solenoid inoperable: 1. Improper voltage at solenoid 2. Blocked air vent in solenoid 3. Inoperative plunger Diaphragm not seated 1. Blocked vent orifice located in rivet bottom at center of diaphragm 2. Dirty diaphragm seal area 3. Diaphragm ruptured • Two faulty deice control valves of faulty two-stage regulators • Faulty check valve • Relay not functioning • Leak in system boots	• Reset circuit breaker • Check deflate valves as follows: Solenoid inoperable: 1. Correct electrical system 2. Clean with alcohol or replace 3. Clean with alcohol or replace Diaphragm not seated 1. Clean with .010 diameter wire and alcohol 2. Clean with blunt instrument and alcohol 3. Replace valve • Clean or replace valve assembly as noted above • Replace check valve • Check wiring or replace relay • Repair as needed
Slow boot inflation	• Lines blocked or disconnected • Low air pump capacity • One or more deice control valves not functioning properly • Deflate valve not fully closed • Ball check in deflate valve inoperative • Leaks in system or boots	• Check and replace lines • Replace air pump • Clean or replace valve assembly as noted above • Clean or replace valve assembly as noted above • Clean check valve or replace deflate valve • Repair as needed
System will not cycle	• Pressure in system not reaching specified psi to activate pressure switch • Leak in system or boots • Pressure switch on deflate valve inoperative	• Clean or replace deice control valve as noted above • Clean or replace deflate valve, as noted above • Repair as needed, tighten all hose connections • Replace switch
Slow deflation	• Low vacuum • Faulty deflate valve (indicated by temporary reduction in suction gauge reading)	• Repair as needed • Clean or replace valve assembly as noted above
No vacuum for boot hold down	• Malfunctioning deflate valve or deice valve • Leak in system or boots	• Clean or replace valve assembly as noted above • Repair as needed
Boots will not deflate during cycle	• Faulty deflate valve	• Check and replace valve
Boots appear to inflate on aircraft climb	• Vacuum source for boot holddown inoperative • Lines running through pressurized cabin loose or disconnected	• Check operation of ball check in deflate valve • Check for loose or disconnected vacuum lines and repair

Figure 15-33. *Troubleshooting guide for wing deice system.*

3. Do not lay tools on or lean maintenance equipment against the deicers.
4. Promptly repair or resurface the deicers when abrasion or deterioration is noted.
5. Wrap deice boots in paper or canvas when storing.

Thus far, preventive maintenance has been discussed. The actual work on the deicers consists of cleaning, resurfacing, and repairing. Cleaning should ordinarily be done at the same time the aircraft is washed, using a mild soap and water solution. Grease and oil can be removed with a cleaning agent, such as naptha, followed by soap and water scrubbing. Whenever the degree of wear is such that it indicates that the electrical conductivity of the deicer surface has been destroyed, it may be necessary to resurface the deicer. The resurfacing substance is a black, conductive neoprene cement. Prior to applying the resurfacing material, the deicer must be cleaned thoroughly and the surface roughened. Cold patch repairs can be made on a damaged deicer. The deicer must be relieved of its installed tension before applying the patch. The area to be patched must be clean and buffed to roughen the surface slightly. Patches are glued in place. Follow manufacturer's instructions for all repairs.

Electric Deice Boots

A few modern aircraft are equipped with electric deice boots on wing sections or on the horizontal stabilizer. These boots contain electric heating elements which are bonded to the leading edges similarly to pneumatic deice boots. When activated, the boots heat up and melt the ice off of leading edge surfaces. The elements are controlled by a sequence timer in a deice controller. Ice detector and ram air temperature probe inputs initiate operation when other flight condition parameters exist. The boot elements turn ON and OFF in paired sections to avoid aerodynamic imbalance. The system is inoperative while the aircraft is on the ground. *Figure 15-34* illustrated such a system. A benefit of electric deice boots is the conservation of engine bleed air. Current draw is limited to only those periods when de-ice is required.

Propeller Deice System

The formation of ice on the propeller leading edges, cuffs, and spinner reduces the efficiency of the powerplant system.

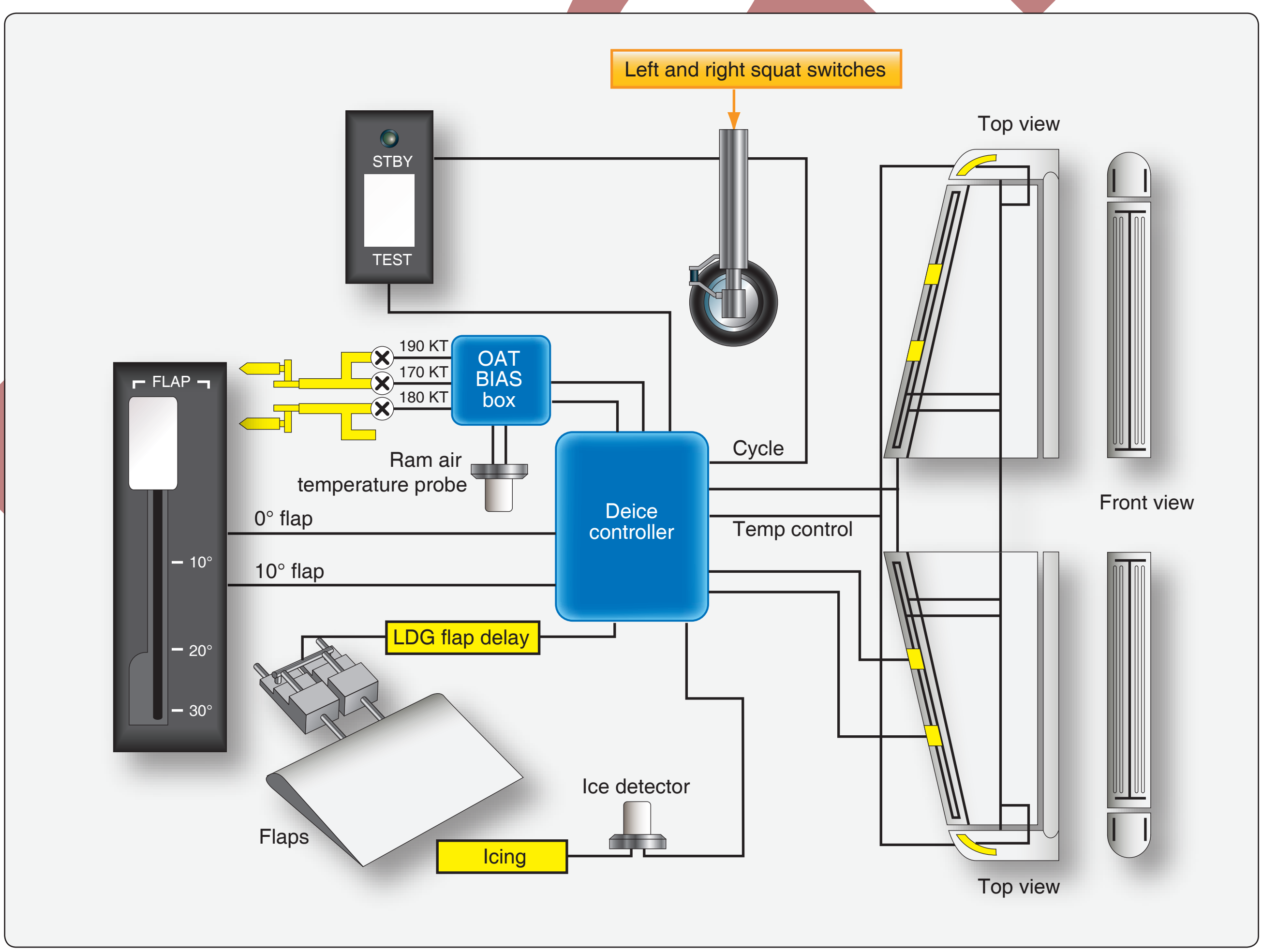


Figure 15-34. *Electric stabilizer deice system..*

Deice systems using electrical heating elements and systems using chemical deicing fluid are used.

Electrothermal Propeller Device System

Many propellers are deiced by an electrically heated boot on each blade. The boot, firmly cemented in place, receives current from a slip ring and brush assembly on the spinner bulkhead. The slip ring transmits current to the deice boot. The centrifugal force of the spinning propeller and air blast breaks the ice particles loose from the heated blades. *[Figure 15-35]*

On one aircraft model, the boots are heated in a preset sequence, which is an automatic function controlled by a timer. This sequence is as follows: 30 seconds for the right prop outer elements; 30 seconds for the right prop inner elements; 30 seconds for the left prop outer elements; and, 30 seconds for the left prop inner elements. Once the system is turned on for automatic is activated, it cycles continuously. A manual bypass of the timer is incorporated. *[Figure 15-36]*

Chemical Propeller Deice

Some aircraft models, especially single-engine GA aircraft, use a chemical deicing system for the propellers. Ice usually appears on the propeller before it forms on the wing. The glycol-based fluid is metered from a tank by a small electrically driven pump through a microfilter to the slinger rings on the prop hub. The propeller system can be a stand-alone system, or it can be part of a chemical wing and stabilizer deicing system such as the TKS™ weeping system.

Ground Deicing of Aircraft

The presence of ice on an aircraft may be the result of direct precipitation, formation of frost on integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear following taxiing through snow or slush. In accordance with the Federal Aviation Administration (FAA) Advisory Circular (AC) 120-60, the aircraft must be free of all frozen contaminants adhering to the wings, control surfaces, propellers, engine inlets, or other critical surfaces before takeoff.

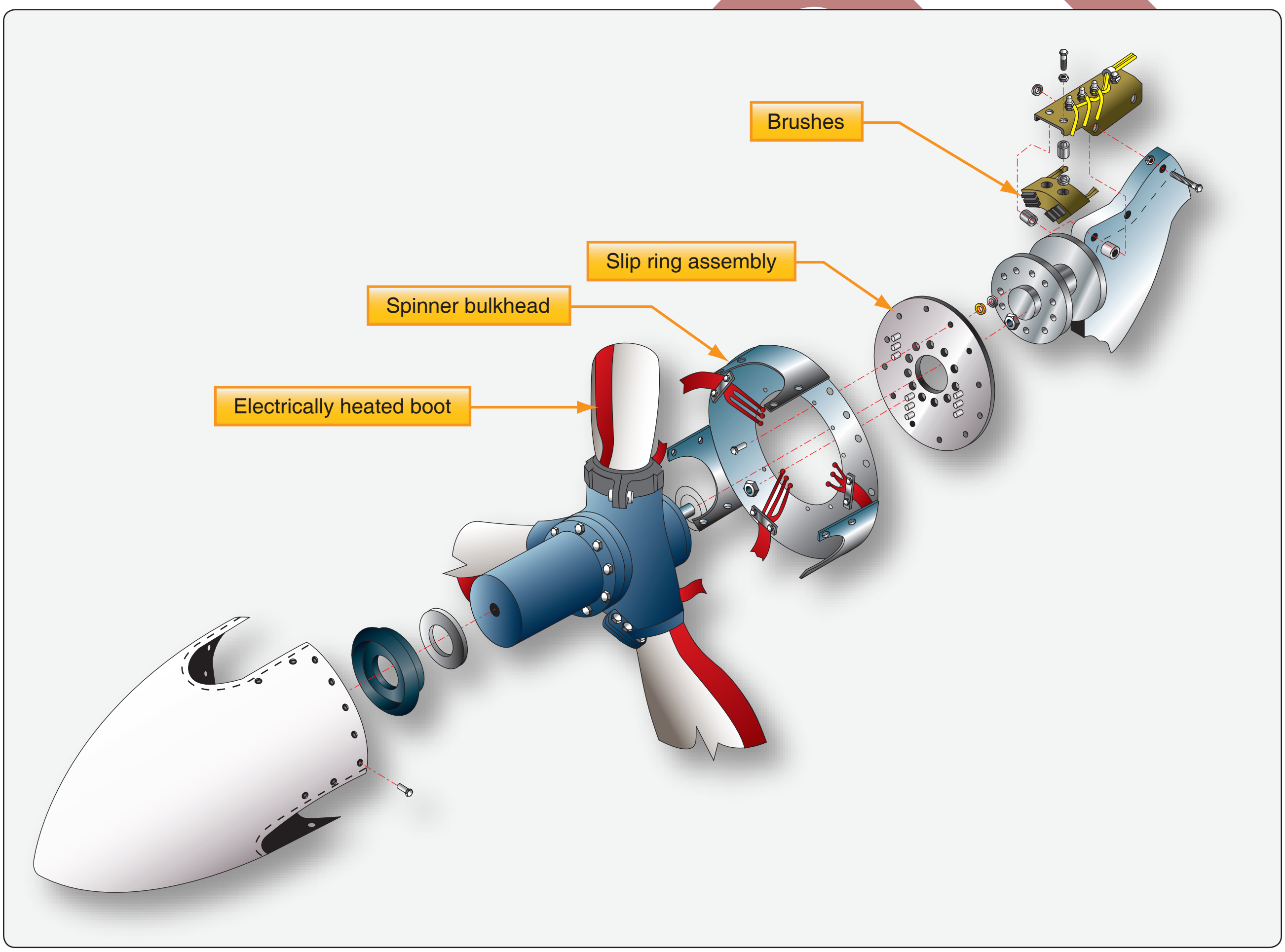


Figure 15-35. *Electro thermal propeller deice system components.*

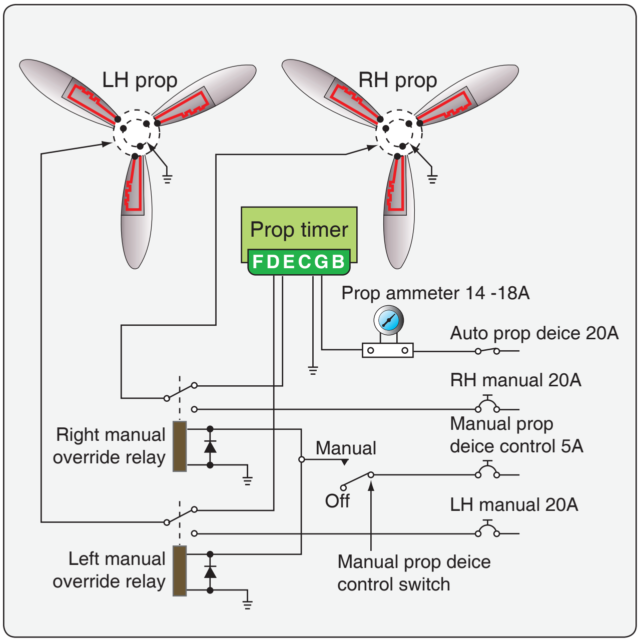


Figure 15-36. *Propeller electrical deice system schematic.*

Figure 15-37. *An American Airlines aircraft being deiced at Syracuse Hancock International Airport.*

Any deposits of ice, snow, or frost on the external surfaces of an aircraft may drastically affect its performance. This may be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the airfoil surfaces, or it may be due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges, valves, microswitches, or by the ingestion of ice into the engine. When aircraft are hangared to melt snow or frost, any melted snow or ice may freeze again if the aircraft is subsequently moved into subzero temperatures. Any measures taken to remove frozen deposits while the aircraft is on the ground must also prevent the possible refreezing of the liquid.

Frost Removal

Frost deposits can be removed by placing the aircraft in a warm hangar or by using a frost remover or deicing fluid. These fluids normally contain ethylene glycol and isopropyl alcohol and can be applied either by spray or by hand. It should be applied within 2 hours of flight. Deicing fluids may adversely affect windows or the exterior finish of the aircraft, only the type of fluid recommended by the aircraft manufacturer should be used. Transport category aircraft are often deiced on the ramp or a dedicated deicing location on the airport. Deicing trucks are used to spray the deicing and/or anti-icing fluid on aircraft surfaces. *[Figure 15-37]*

Deicing and Anti-icing of Transport Type Aircraft

Deicing Fluid

The deicing fluid must be accepted according to its type for holdover times, aerodynamic performance, and material compatibility. The coloring of these fluids is also standardized. In general, glycol is colorless, Type-I fluids are orange, Type-II fluids are white/pale yellow, and Type-IV fluids are green. The color for Type-III fluid has not yet been determined.

When aircraft surfaces are contaminated by frozen moisture, they must be deiced prior to dispatch. When freezing precipitation exists, and there is a risk of contamination of the surface at the time of dispatch, aircraft surfaces must be anti-iced. If both deicing and anti-icing are required, the procedure may be performed in one or two steps. The selection of a one- or two-step process depends upon weather conditions, available equipment, available fluids, and the holdover time to be achieved.

Holdover Time (HOT)

Holdover Time (HOT) is the estimated time that deicing/anti-icing fluid prevents the formation of frost or ice and the accumulation of snow on the critical surfaces of an aircraft. HOT begins when the final application of deicing/anti-icing fluid commences and expires when the deicing/anti-icing fluid loses its effectiveness. *Figure 15-38* shows a holdover timetable for Type IV fluid.

Critical Surfaces

Basically, all surfaces that have an aerodynamic, control, sensing, movement, or measuring function must be clean. These surfaces cannot necessarily be cleaned and protected in the same conventional deicing/anti-icing manner as the wings. Some areas require only a cleaning operation, while others need protection against freezing. The procedure of deicing may also vary according to aircraft limitations. The use of hot air may be required when deicing (e.g., landing gear or propellers).

FAA Type IV Holdover Time Guidelines

Guidelines for holdover times anticipated for SAE type IV fluid mixtures as function of weather conditions and OAT.
CAUTION: This table is for use in departure planning only, and it should be used in conjunction with pretakeoff check procedures.

OAT °C	OAT °F	SAE type IV fluid concentration neat fluid water (vol. %/vol.%)	Frost*	Freezing Fog	Snow◊	Freezing drizzle***	Light free rain	Rain on cold soaked wing	Other*
			Approximate holdover times under various weather conditions (hours:minutes)						
above 0	above 32	100/0	18:00	1:05–2:15	0:35–1:05	0:40–1:10	0:25–0:40	0:10–0:50	CAUTION: no holdover time guidelines exist
		72/25	6:00	1:05–1:45	0:30–1:05	0:35–0:50	0:15–0:30	0:05–0:35	
		50/50	4:00	0:15–0:35	0:05–0:20	0:10–0:20	0:05–0:10	CAUTION: clear ice may require louch for confirmation	
0 through −3	32 through 27	100/0	12:00	1:05–2:15	0:30–0:55	0:40–1:10	0:15–0:40		
		75/25	5:00	1:05–2:15	0:25–0:50	0:35–0:50	0:15–0:30		
		50/50	3:00	1:15–0:35	0:05–0:15	0:10–0:20	0:05–0:15		
below −3 through −14	below 27 through 7	100/0	12:00	0:20–0:50	0:20–0:40	**0:20–0:45	**0:10–0:25		
		75/25	5:00	0:25–0:50	0:15–0:25	**0:15–0:30	**0:10–0:20		
below −14 through −25	below 7 through −13	100/0	12:00	0:15–0:40	0:15–0:30				
below −25	below −13	100/0	SAE type IV fluid may be used below −25 °C(−13 °F) if the freezing point of the fluid is at least 7 °C(13 °F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE type I when SAE type IV fluid cannot be used.						

°C = degrees Celsius
°F = degrees Fahrenheit
OAT= outside air temperature
VOL = volume

The responsiblity for the application of these data remains with the user.
* During conditions that apply to aircraft protection for ACTIVE FROST
** No holdover time guidelines exist for this condition below −10 °C (14 °F)
*** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible
‡ Snow pellets, ice pellets, heavy snow, moderate and heavy freezing rain, hail.
◊ Snow includes snow grains

CAUTIONS:
- The time of protection will be shortened in heavy weather conditions: heavy precipitation rates or high moisture contents.
- High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range.
- Holdover time may be reduced when aircraft skin temperature is lower than OAT.

Figure 15-38. *FAA deice holdover time guidelines.*

Figure 15-39 shows critical areas on an aircraft that should not be sprayed directly. Some critical elements and procedures that are common for most aircraft are:

- Deicing/anti-icing fluids must not be sprayed directly on wiring harnesses and electrical components (e.g., receptacles, junction boxes), onto brakes, wheels, exhausts, or thrust reversers.
- Deicing/anti-icing fluid shall not be directed into the orifices of pitot heads, static ports, or directly onto airstream direction detectors probes/angle of attack airflow sensors.
- All reasonable precautions shall be taken to minimize fluid entry into engines, other intakes/outlets, and control surface cavities.
- Fluids shall not be directed onto flight deck or cabin windows as this can cause crazing of acrylics or penetration of the window seals.
- Any forward area from which fluid can blow back onto windscreens during taxi or subsequent takeoff shall be free of residues prior to departure.
- If Type II, III, or IV fluids are used, all traces of the fluid on flight deck windows should be removed prior to departure, particular attention being paid to windows fitted with wipers.
- Landing gear and wheel bays shall be kept free from buildup of slush, ice, or accumulations of blown snow.
- When removing ice, snow, slush, or frost from aircraft surfaces, care shall be taken to prevent it entering and accumulating in auxiliary intakes or control surface hinge areas (e.g., manually remove snow from wings and stabilizer surfaces forward toward the leading edge and remove from ailerons and elevators back towards the trailing edge).

Ice and Snow Removal

Probably the most difficult deposit to deal with is deep, wet snow when ambient temperatures are slightly above the freezing point. This type of deposit should be removed with a soft brush or squeegee. Use care to avoid damage to antennas, vents, stall warning devices, vortex generators, etc., that

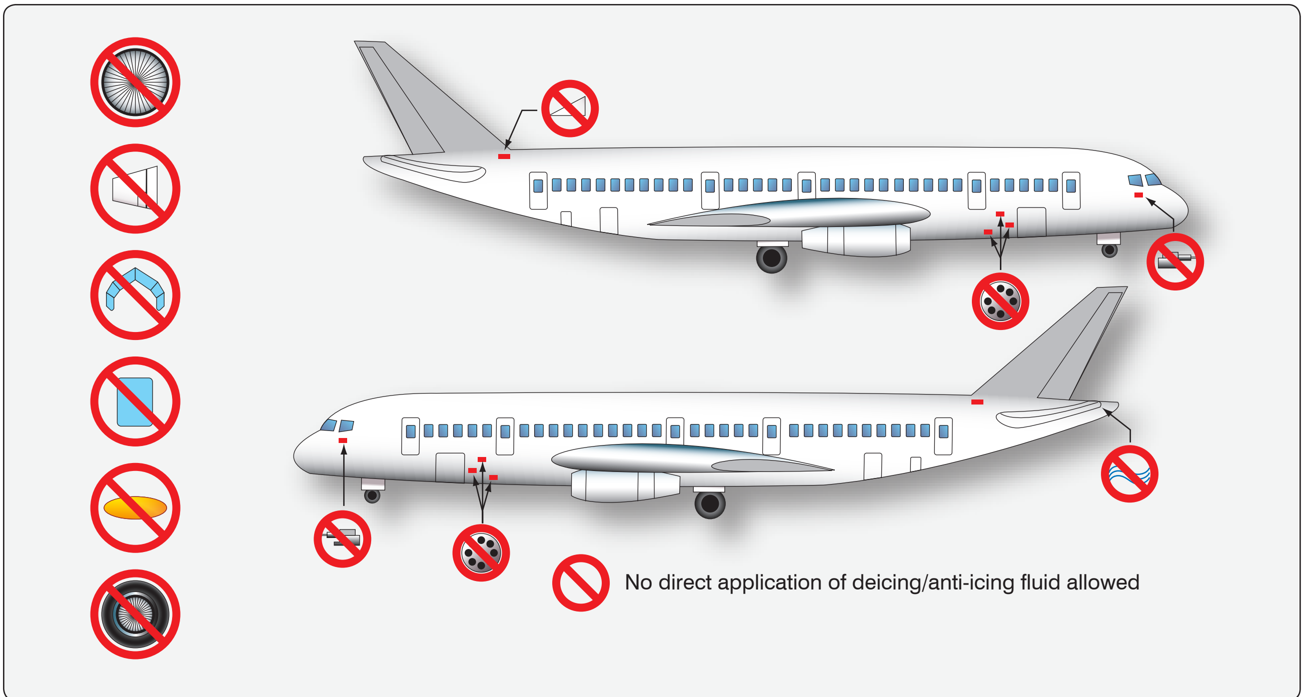


Figure 15-39. *No direct application of deicing/anti-icing fluid allowed.*

may be concealed by the snow. Light, dry snow in subzero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a deicing fluid. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of deicing operations, inspect the aircraft to ensure that its condition is satisfactory for flight. All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control gaps and hinges. Check the drain and pressure sensing ports for obstructions. When it becomes necessary to physically remove a layer of snow, all protrusions and vents should be examined for signs of damage. Control surfaces should be moved to ascertain that they have full and free movement. The landing gear mechanism, doors and bay, and wheel brakes should be inspected for snow or ice deposits and the operation of up-locks and microswitches checked.

Snow or ice can enter turbine engine intakes and freeze in the compressor. If the compressor cannot be turned by hand for this reason, hot air should be blown through the engine until the rotating parts are free.

Rain Control Systems

There are several different ways to remove the rain from the windshields. Most aircraft use one or a combination of the following systems: windshield wipers, chemical rain repellent, pneumatic rain removal (jet blast), or windshields treated with a hydrophobic surface seal coating.

Windshield Wiper Systems

In an electrical windshield wiper system, the wiper blades are driven by an electric motor(s) that receive (s) power from the aircraft's electrical system. On some aircraft, the pilot's and copilot's windshield wipers are operated by separate systems to ensure that clear vision is maintained through one of the windows should one system fail. Each windshield wiper assembly consists of a wiper, wiper arm, and a wiper motor/converter. Almost all windshield wiper systems use electrical motors. Some older aircraft might be equipped with hydraulic wiper motors. *[Figure 15-40]*

Maintenance performed on windshield wiper systems consists of operational checks, adjustments, and troubleshooting. An operational check should be performed whenever a system component is replaced or whenever the system is suspected of not working properly. During the check, make sure that the windshield area covered by the wipers is free of foreign matter and is kept wet with water. Adjustment of a windshield wiper system consists of adjusting the wiper blade tension, the angle at which the blade sweeps across the windshield, and proper parking of the wiper blades.

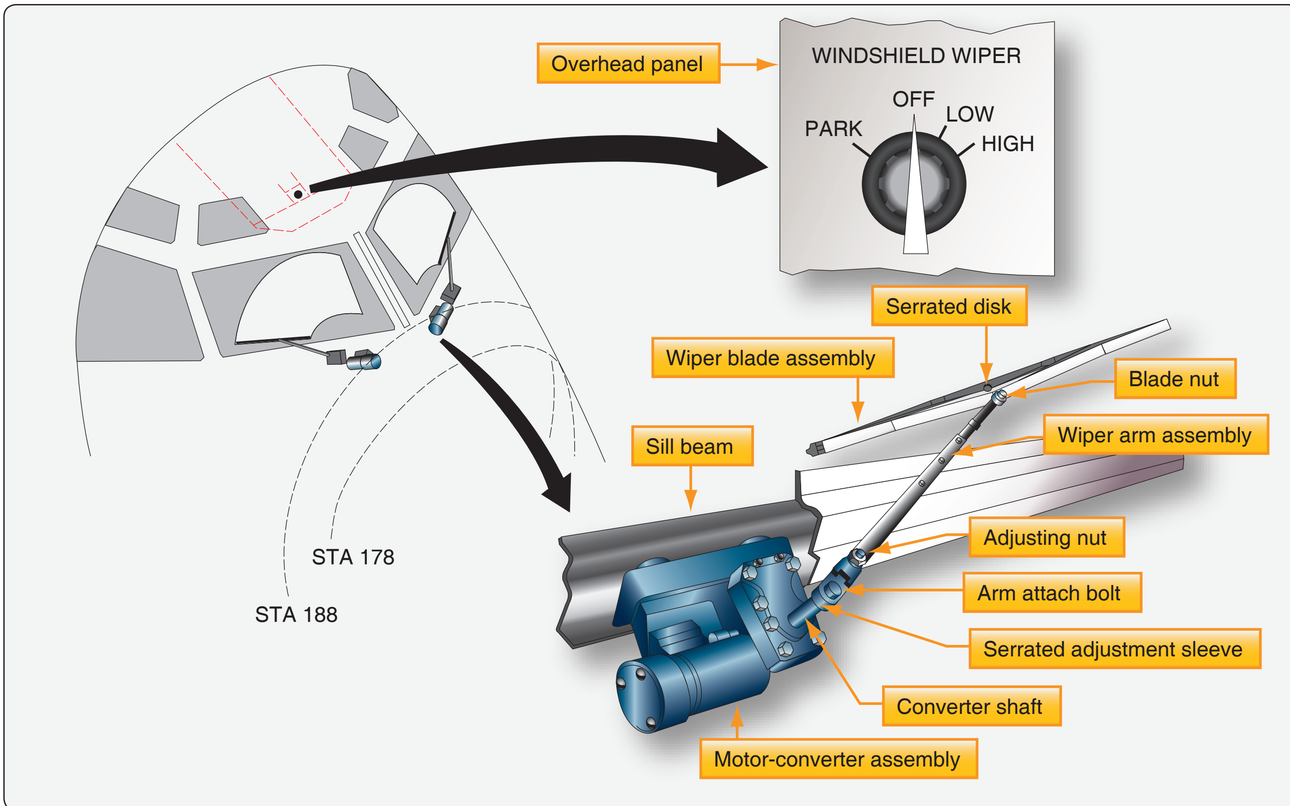


Figure 15-40. *Windshield wiper assembly/installation on a transport catgory aircraft. The motor-converter is mountd under the aircraft skin.*

Chemical Rain Repellant

Water poured onto clean glass spreads out evenly. Even when the glass is held at a steep angle or subjected to air velocity, the glass remains wetted by a thin film of water. However, when glass is treated with certain chemicals, a transparent film is formed that causes the water to behave very much like mercury on glass. The water draws up into beads that cover only a portion of the glass and the area between beads is dry. The water is readily removed from the glass. This principle lends itself quite naturally to removing rain from aircraft windshields. The high-velocity slipstream continually removes the water beads, leaving a large part of the window dry.

A rain repellant system permits application of the chemical repellant by a switch or push button in the cockpit. The proper amount of repellant is applied regardless of how long the switch is held. On some systems, a solenoid valve controlled by a time delay module meters the repellent to a nozzle which sprays it on the outside of the windshield. Two such units exist — one each for the forward glass of the pilot and copilot. *[Figure 15-41]*

This system should only be used in very wet conditions. The rain repellant system should not be operated on dry windows because heavy undiluted repellant restricts window visibility. Should the system be operated inadvertently, do not operate the windshield wipers or rain clearing system as this tends to increase smearing. Also, the rain repellant residues caused by application in dry weather or very light rain can cause staining or minor corrosion of the aircraft skin. To prevent this, any concentrated repellant or residue should be removed by a thorough fresh water rinse at the earliest opportunity. After application, the repellant film slowly deteriorates with continuing rain impingement. This makes periodic reapplication necessary. The length of time between applications depends upon rain intensity, the type of repellant used, and whether windshield wipers are used.

Windshield Surface Seal Coating

Some aircraft models use a surface seal coating, also called hydrophobic coating that is on the outside of the pilot's/copilot's windshield. *[Figure 15-42]* The word hydrophobic means to repel or not absorb water. The windshield hydrophobic coating is on the external surface of the windows (windshields). The coatings cause raindrops to bead up and roll off, allowing the flight crew to see through the windshield with very little distortion. The hydrophobic windshield coating reduces the need for wipers and gives the flight crew better visibility during heavy rain.

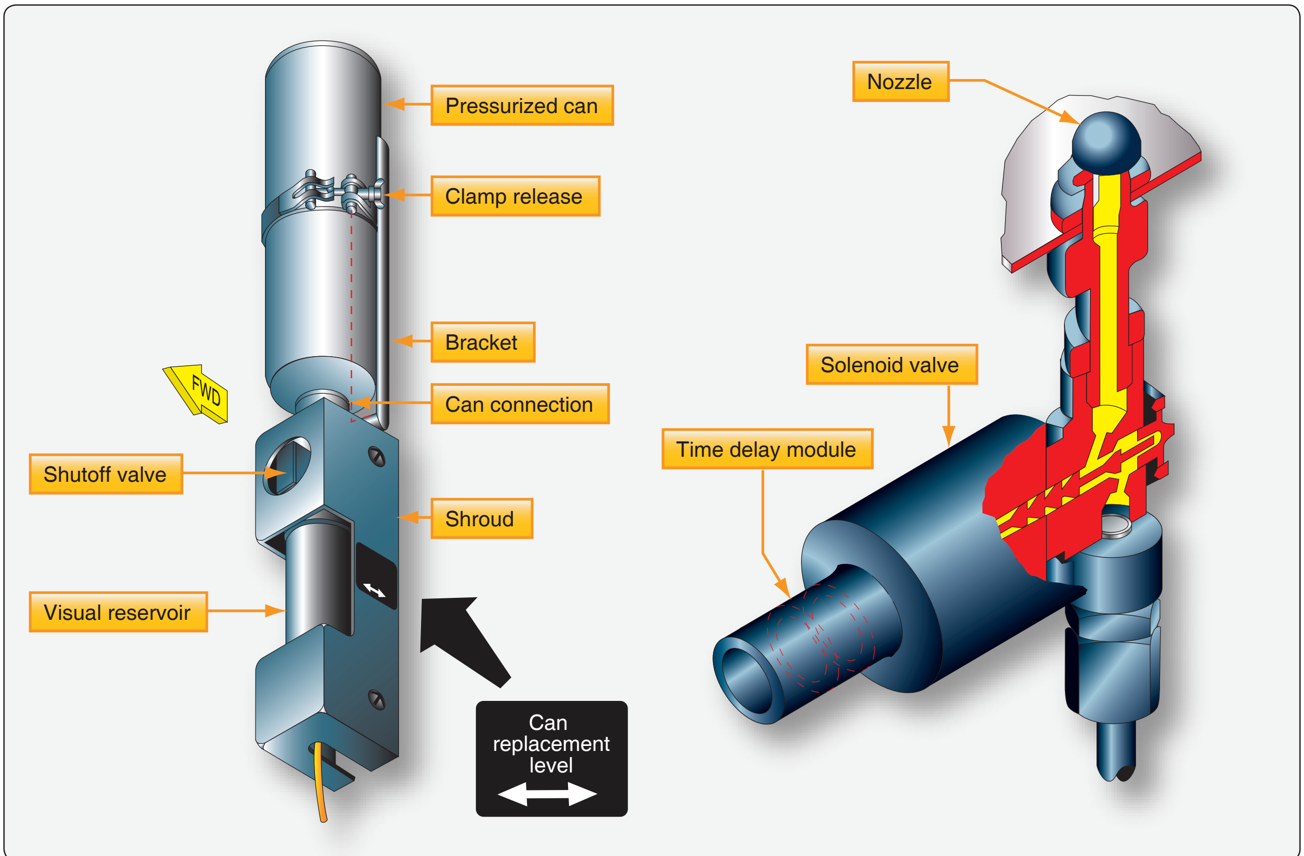


Figure 15-41. *Cockpit rain repellant canister and reservoir.*

Most new aircraft windshields are treated with surface seal coating. The manufacturer's coating process deeply penetrates the windshield surface providing hydrophobic action for quite some time. When effectiveness declines, products made to be applied in the field are used. These liquid treatments rubbed onto the surface of the windshield maintain the beading action of rain water. They must be applied periodically or as needed.

Pneumatic Rain Removal Systems

Windshield wipers characteristically have two basic problem areas. One is the tendency of the slipstream aerodynamic forces to reduce the wiper blade loading pressure on the window, causing ineffective wiping or streaking. The other is in achieving fast enough wiper oscillation to keep up with high rain impingement rates during heavy rain falls. As a result, most aircraft wiper systems fail to provide satisfactory vision in heavy rain.

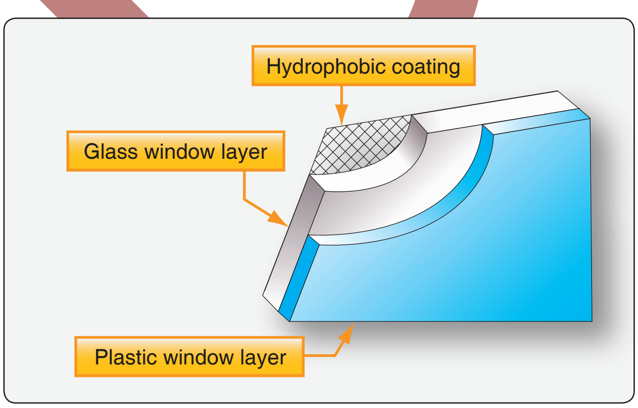


Figure 15-42. *Hydrophobic coating on windshield.*

The rain removal system shown in *Figure 15-43* controls windshield icing and removes rain by directing a flow of heated air over the windshield. This heated air serves two purposes. First, the air breaks the rain drops into small particles that are then blown away. Secondly, the air heats the windshield to prevent the moisture from freezing. The air can be supplied by an electric blower or by bleed air.

Windshield Frost, Fog, and Ice Control Systems

In order to keep windshield areas free of ice, frost, and fog, window anti-icing, deicing, and defogging systems are used. These can be electric, pneumatic, or chemical depending on the type and complexity of the aircraft. A few of these systems are discussed in this section.

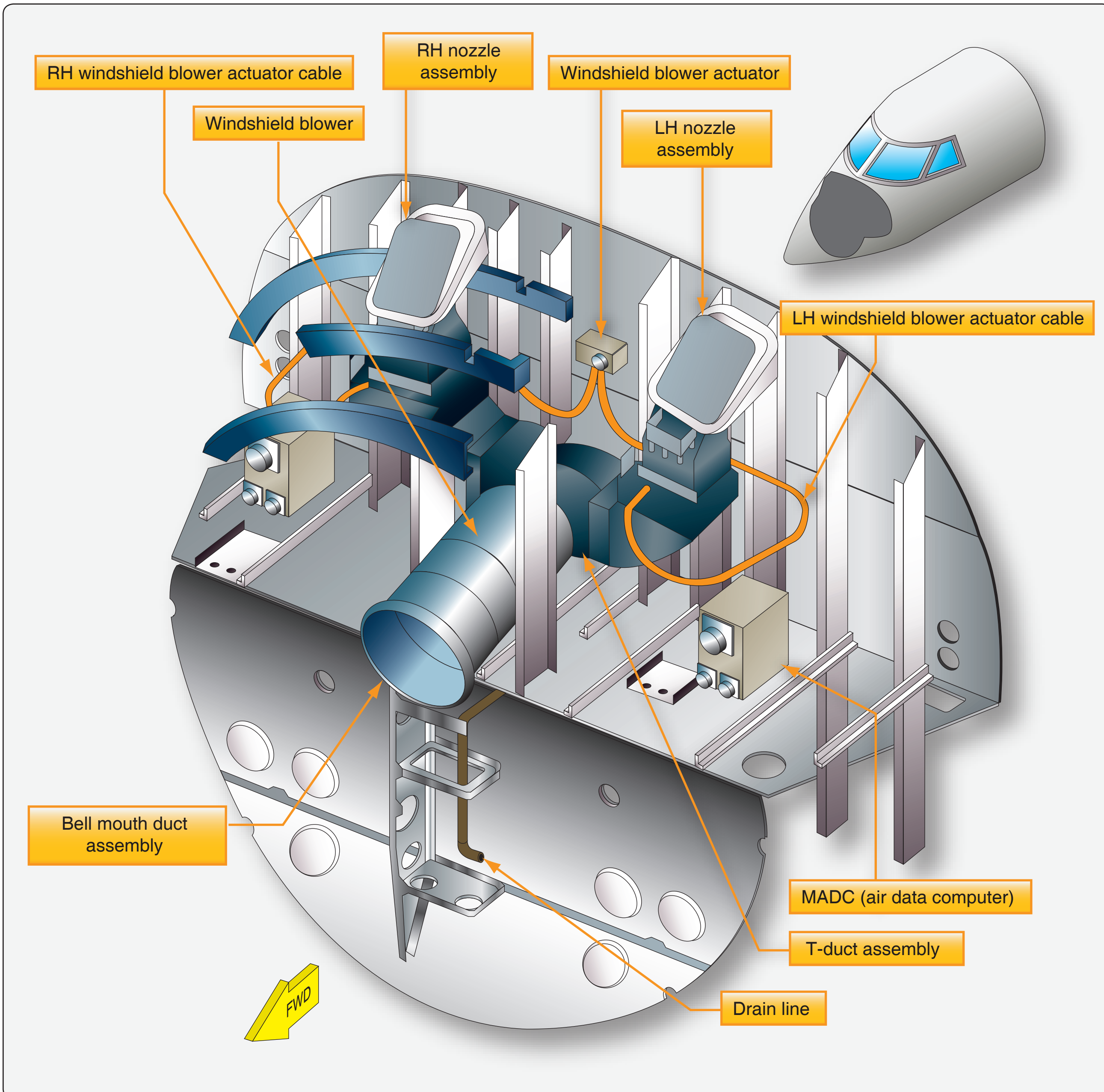


Figure 15-43. *Windshield rain and frost removal system.*

Electric

High performance and transport category aircraft windshields are typically made of laminated glass, polycarbonate, or similar ply material. Typically, clear vinyl plies are also included to improve performance characteristics. The laminations create the strength and impact resistance of the windshield assembly. These are critical feature for windshields as they are subject to a wide range of temperatures and pressures. They must also withstand the force of a 4-pound bird strike at cruising speed to be certified. The laminated construction facilitates the inclusion of electric heating elements into the glass layers, which are used to keep the windshield clear of ice, frost, and fog. The elements can be in the form of resistance wires or a transparent conductive material may be used as one of the window plies. To ensure enough heating is applied to the outside of the windshield, heating elements are placed on the inside of the outer glass ply. Windshields are typically bonded together by the application of pressure and heat without the use of cement. *Figure 15-44* illustrates the plies in one transport category aircraft windshield.

Whether resistance wires or a laminated conductive film is used, aircraft window heat systems have transformers to

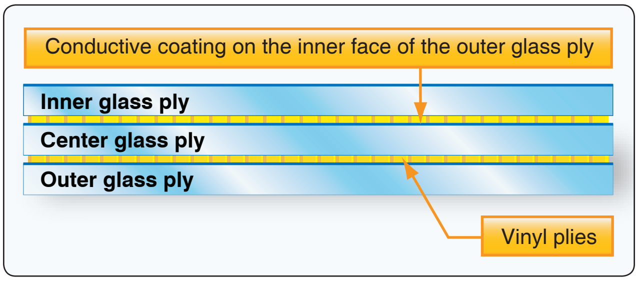


Figure 15-44. *Cross-section of a transport category windshield.*

supply power and feedback mechanisms, such as thermistors, to provide a window heat control unit with information used to keep operating temperature within acceptable limits. Some systems are automatic while others are controlled by cockpit switches. Separate circuits for pilot and co-pilot are common to ensure visibility in case of a malfunction. Consult the manufacturer's maintenance information for details on the particular window heat system in question.

Some windshield heating systems can be operated at two heat levels. On these aircraft, NORMAL heating supplied heat to the broadest area of windshield. HIGH heating supplies a higher intensity of heat to a smaller but more essential viewing area. Typically, this window heating system is always on and set in the NORMAL position. *Figure 15-45* illustrates a simplified windshield heat system of this type.

Pneumatic

Some laminated windshields on older aircraft have a space between the plies that allows the flow of hot air to be directed between the glass to keep it warm and fog free. The source of air is bleed air or conditioned air from the environmental control system. Small aircraft may utilize ducted warm air, which is released to flow over the windshield inner surface to defrost and defog. These systems are similar to those used in automobiles. The source of air could be ambient (defog only), the aircraft's heating system, or a combustion heater. While these pneumatic windshield heat systems are effective for the aircraft on which they are installed, they are not approved for flying into known icing conditions and, as such, are not effective for anti-ice.

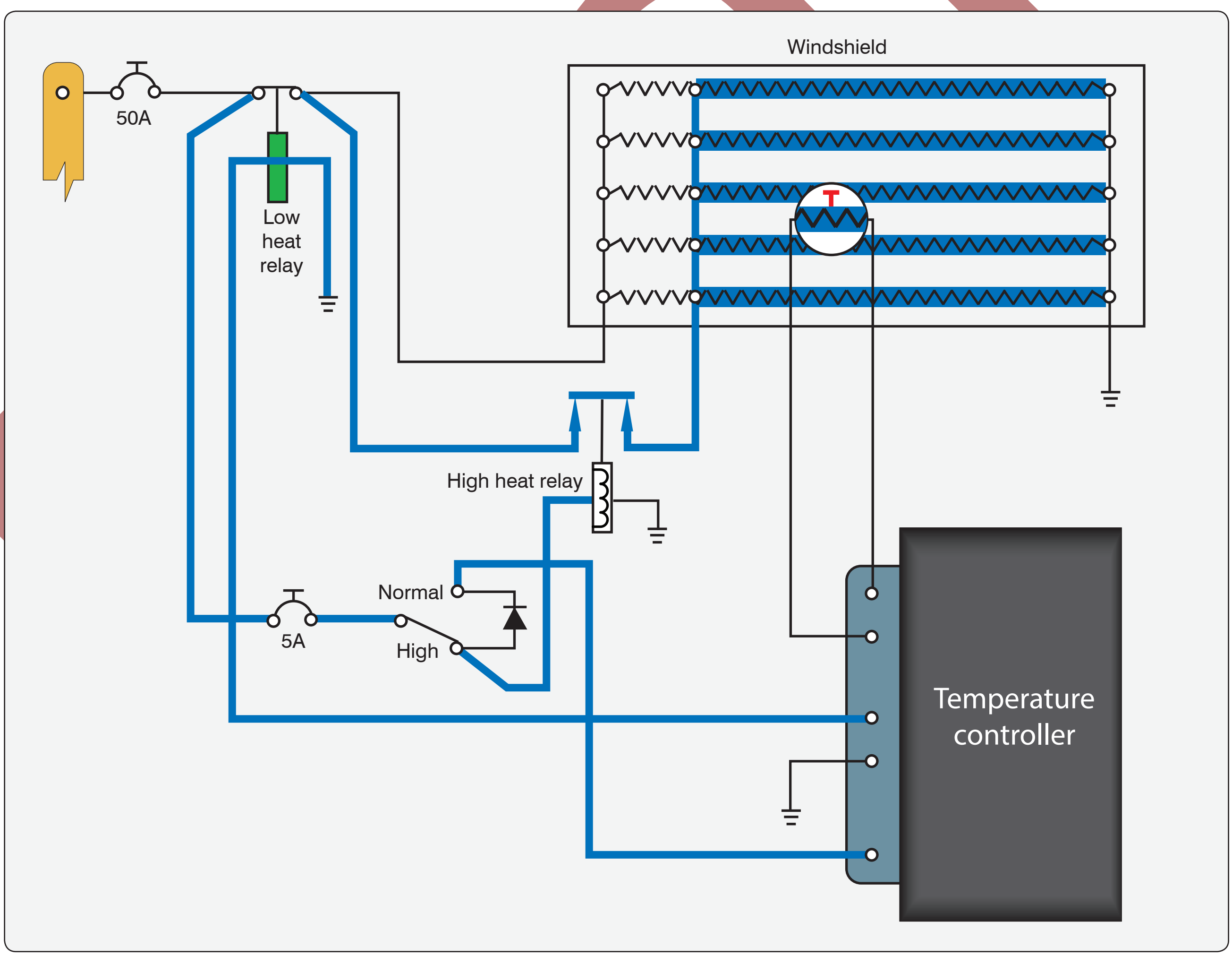


Figure 15-45. *Electric windshield heat schematic.*

Figure 15-46. *Chemical deicing spray tubes.*

Large aircraft equipped with pneumatic jet blast rain repellant systems achieve some anti-icing effects from operating this system although electric windshield heat is usually used.

Chemical

As previously mentioned in this chapter, chemical anti-ice systems exist generally for small aircraft. This type of anti-ice is also used on windshields. Whether alone or part of a TKS™ system or similar, the liquid chemical is sprayed through a nozzle onto the outside of the windshield which prevents ice from forming. The chemical can also deice the windshield of ice that may have already formed. Systems such as these have a fluid reservoir, pump, control valve, filter, and relief valve. Other components may exist. *Figure 15-46* shows a set of spray tubes for application of chemical anti-ice on an aircraft windshield.

Water and Waste Tank Ice Prevention

Transport type aircraft have water and waste systems on board, and electrical heaters are often used to prevent the formation of ice in the water lines of these systems. Water lines carry water from the potable tanks to the lavatories and galleys. The waste water tanks collect the gray water from the galleys and lavatories. Heater blankets, in-line heaters, or heater boots are often used to heat the water supply lines, water tank drain hoses, waste drain lines, waste tank rinse fittings, and drain masts. Thermostats in the water lines supply temperature data to the control unit that turns the electrical heaters on and off. When the temperature falls below freezing, the electrical heaters turn on and stay on until the temperature reaches a safe temperature. *Figure 15-47* is a schematic of a water supply line heater system, and *Figure 15-48* shows the location of the waste water tanks and heater blanket.

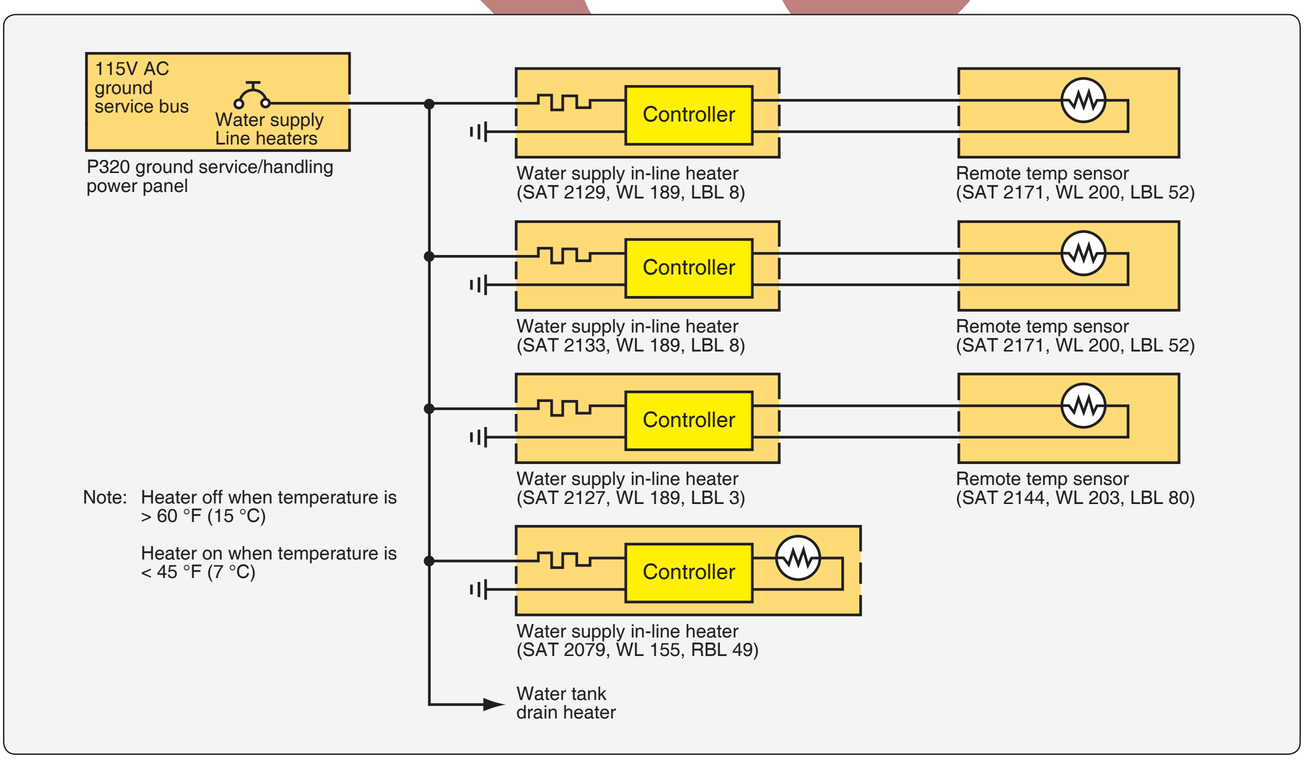


Figure 15-47. *Water supply line heater system.*

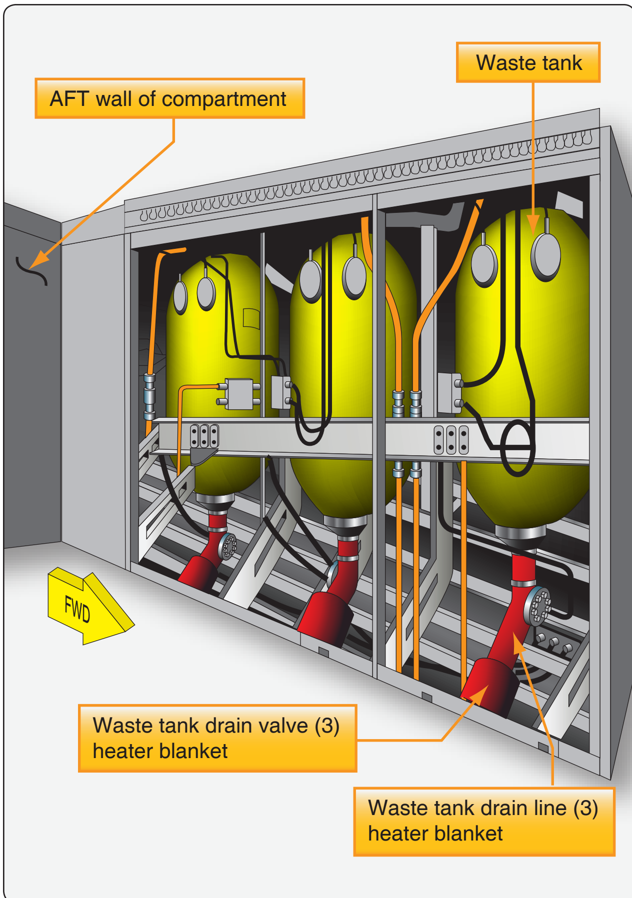
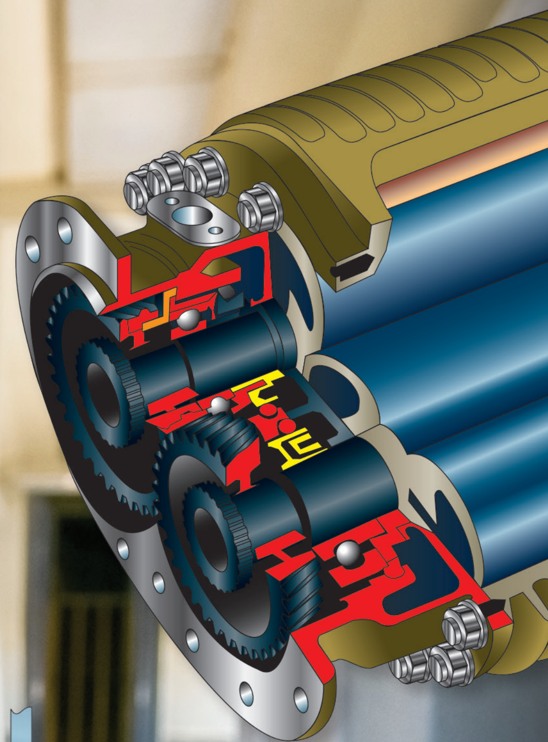


Figure 15-48. *Waste water tanks and heater blankets.*

Chapter 16

Cabin Environmental Control Systems

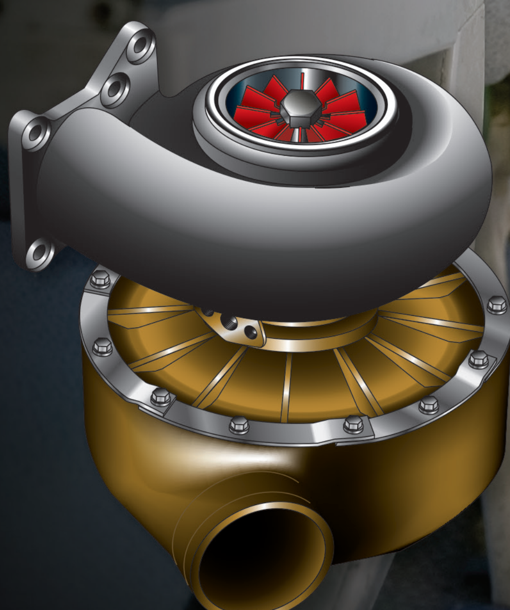


Physiology of Flight

Composition of the Atmosphere

The mixture of gases that make up the earth's atmosphere is commonly called air. It is composed principally of 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent is made up of various gases in smaller quantities. Some of these are important to human life, such as carbon dioxide, water vapor, and ozone. *Figure 16-1* indicates the respective percentage of the quantity of each gas in its relation to the total mixture.

As altitude increases, the total quantity of all the atmospheric gases reduces rapidly. However, the relative proportions of nitrogen and oxygen remain unchanged up to about 50 miles above the surface of the earth. The percentage of carbon dioxide is also fairly stable. The amounts of water vapor and ozone vary.



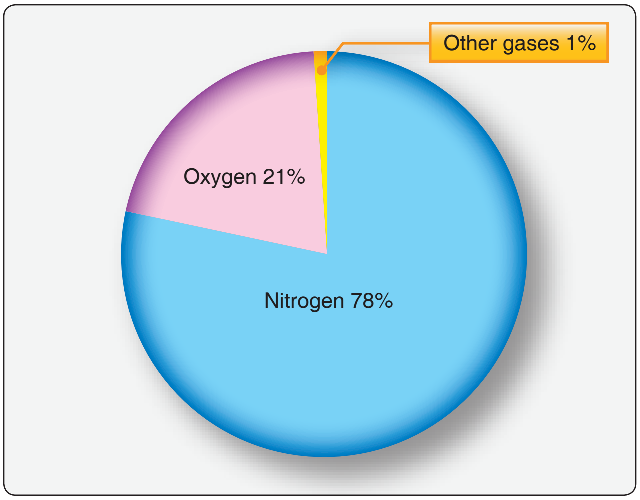


Figure 16-1. *The percentage of the various gases that comprise the atmosphere.*

Nitrogen is an inert gas that is not used directly by man for life processes; however, many compounds containing nitrogen are essential to all living matter.

The small quantity of carbon dioxide in the atmosphere is utilized by plants during photosynthesis. Thus, the food supply for all animals, including man, depends on it. Carbon dioxide also helps control breathing in man and other animals.

The amount of water vapor in the atmosphere is variable but, even under humid conditions at sea level, it rarely exceeds 5 percent. Water also occurs in the atmosphere as ice crystals. All forms of water in the atmosphere absorb far more energy from the sun than do the other gases. Water plays an important role in the formation of weather.

Ozone is a form of oxygen. It contains three oxygen atoms per molecule, rather than the usual two. Most of the atmosphere's ozone is formed by the interaction of oxygen and the sun's rays near the top of the stratosphere in an area called the ozone layer. This is important to living organisms because ozone filters out most of the sun's harmful ultraviolet (UV) radiation. Ozone is also produced by electrical discharges, such as lightning strikes. It has a faint odor, somewhat like that of weak chlorine, that may be detected after a thunderstorm. Auroras and cosmic rays may also produce ozone. Ozone is of great consequence to living creatures on earth and to the circulation of the upper atmosphere.

Human Respiration and Circulation

Oxygen and Hypoxia

The second most prevalent substance in the atmosphere, oxygen, is essential for most living processes. Without oxygen, humans and animals die very rapidly. A reduction in the normal oxygen supply alters the human condition. It causes important changes in body functions, thought processes, and the maintainable degree of consciousness. The resultant sluggish condition of mind and body produced by insufficient oxygen is called hypoxia.

There are several scenarios that can result in hypoxia. During aircraft operations, it is brought about by a decrease in the pressure of oxygen in the lungs at high altitudes. The air contains the typical 21 percent of oxygen, but the rate at which oxygen can be absorbed into the blood depends upon the oxygen pressure. Greater pressure pushes the oxygen from the lung alveoli into the bloodstream. As the pressure is reduced, less oxygen is forced into and absorbed by the blood.

At sea level, oxygen pressure in the lungs is approximately three pounds per square inch (psi). This is sufficient to saturate the blood with oxygen and permit the mind and body to function normally. As altitude is increased, this pressure decreases. Below 7,000 feet above sea level, the available oxygen quantity and pressure remain sufficient for saturation of the blood with oxygen. Above 7,000 feet, however, the oxygen pressure becomes increasingly insufficient to saturate the blood. At 10,000 feet mean sea level (MSL), saturation of the blood with oxygen is only about 90 percent of normal. Long durations at this altitude can result in headache and fatigue, both symptoms of hypoxia. At 15,000 feet MSL, oxygen transfer to the bloodstream drops to 81 percent of saturation. This typically results in sleepiness, headache, blue lips and fingernails, and increased pulse and respiration. Worse yet, vision and judgment become impaired and safe operation of an aircraft becomes compromised. Higher in the atmosphere, decreasing pressure causes even less oxygen to enter the bloodstream; only 68 percent saturation at 22,000 feet MSL. Remaining at 25,000 feet MSL for 5 minutes, where oxygen transfer to the blood is reduced to approximately 50 percent saturation, causes unconsciousness. *[Figure 16-2]*

Altitude MSL (feet)	Oxygen pressure (psi)
0	3.08
5,000	2.57
10,000	2.12
15,000	1.74
20,000	1.42
25,000	1.15
30,000	0.92
35,000	0.76
40,000	0.57

Figure 16-2. *Oxygen pressure in the atmosphere at various altitudes.*

Hyperventilation

Another physiological phenomenon of interest to aviators is hyperventilation. Its symptoms greatly resemble hypoxia. When various cells in the body use oxygen and food delivered to them by the blood, carbon dioxide is a by-product. Blood carries this carbon dioxide to the lungs where it is exhaled.

Carbon dioxide functions in the body to regulate the depth and frequency of breathing. A high level of carbon dioxide in the blood triggers rapid, deep breathing to expel it. This also promotes the intake of a greater amount of oxygen for active cells to use. A low carbon dioxide level causes more relaxed breathing resulting in less oxygen intake. Therefore, an oxygen/carbon dioxide balance exists in the blood.

Occasionally, fear, panic, or pain triggers excessive rapid breathing in a person. With it comes a reduction of carbon dioxide in the blood, even though the body does not need this. The lower carbon dioxide level signals the body that there is enough oxygen available and blood vessels constrict, causing hypoxia-like symptoms because insufficient oxygen is being delivered to the cells. Note that the onset of hypoxia described in the previous section occurs without the rapid breathing that accompanies hyperventilation. Hyperventilation can often be alleviated by having the person calm down and breathe normally, which restores the oxygen/carbon dioxide balance in the bloodstream.

Carbon Monoxide Poisoning

Carbon monoxide is a colorless, odorless gas produced by incomplete combustion of hydrocarbon fuels, such as those used in aviation. The human body does not require this gas to function. Its presence, however, can prevent a sufficient level of oxygen to be maintained in the body, resulting in hypoxia. This is also known as carbon monoxide poisoning. As with all forms of oxygen deprivation, extended exposure to carbon monoxide can result in unconsciousness and even death.

Hemoglobin is the substance in the blood that attaches to oxygen in the lungs and circulates it to cells in the body for use. Carbon monoxide more readily attaches itself to hemoglobin than oxygen. If carbon monoxide is present in the lungs, hemoglobin attaches to it and not oxygen. This results in cells not receiving the amount of oxygen they need. The insufficient oxygen level results in hypoxia-like symptoms.

A real danger of carbon monoxide poisoning is that long exposure to slight traces of carbon monoxide can result in oxygen deprivation just as easily as short-term exposure to a concentrated amount. The onset of its effects can be very subtle.

There are many types of carbon monoxide detectors available to alert aviators of the presence of this gas. Some are made to be permanently installed in the instrument panel, while others are portable. The simplest carbon monoxide detectors are chemical tabs mounted on cardboard that hang on or adhere to something in the cockpit. When carbon monoxide is present, the tab changes color due to a chemical reaction. More sophisticated detectors provide a digital output in parts per million of carbon monoxide present or illuminate a light and/or an audible alarm sounds. *[Figure 16-3]* If contaminated, a carbon monoxide portable test unit can be returned to service by installing a new indicating element.

Aircraft that utilize exhaust shroud-type heating systems or combustion heaters are more likely to have carbon monoxide introduced into the cabin from these devices. It is very important to discover the source of carbon monoxide if it is detected. Various leak checks and testing for cracks are performed regularly whenever a combustion source is also the source for cabin heat.

Aircraft Oxygen Systems

The negative effects of reduced atmospheric pressure at flight altitudes, forcing less oxygen into the blood, can be overcome. There are two ways this is commonly done: increase the pressure of the oxygen or increase the quantity of oxygen in the air mixture.

Figure 16-3. *An example of a carbon monoxide detector sold in the aviation market.*

Large transport-category and high-performance passenger aircraft pressurize the air in the cabin. This serves to push more of the normal 21 percent oxygen found in the air into the blood for saturation. Techniques for pressurization are discussed later in this chapter. When utilized, the percentage of oxygen available for breathing remains the same; only the pressure is increased.

By increasing the quantity of oxygen available in the lungs, less pressure is required to saturate the blood. This is the basic function of an aircraft oxygen system. Increasing the level of oxygen above the 21 percent found in the atmosphere can offset the reduced pressure encountered as altitude increases. Oxygen may be regulated into the air that is breathed so as to maintain a sufficient amount for blood saturation. Normal mental and physical activity can be maintained at indicated altitudes of up to about 40,000 feet with the sole use of supplemental oxygen.

Oxygen systems that increase the quantity of oxygen in breathing air are most commonly used as primary systems in small and medium size aircraft designed without cabin pressurization. Pressurized aircraft utilize oxygen systems as a means of redundancy should pressurization fail. Portable oxygen equipment may also be aboard for first aid purposes.

Forms of Oxygen and Characteristics

Gaseous Oxygen

Oxygen is a colorless, odorless, and tasteless gas at normal atmospheric temperatures and pressures. It transforms into a liquid at –183 °C (its boiling point). Oxygen combines readily with most elements and numerous compounds. This combining is called oxidation. Typically, oxidation produces heat. When something burns, it is actually rapidly combining with oxygen. Oxygen itself does not burn because it does not combine with itself, except to form oxygen or ozone. But, pure oxygen combines violently with petroleum products creating a significant hazard when handling these materials in close proximity to each other. Nevertheless, oxygen and various petroleum fuels combine to create the energy produced in internal combustion engines.

Pure gaseous oxygen, or nearly pure gaseous oxygen, is stored and transported in high-pressure cylinders that are typically painted green. Technicians should be cautious to keep pure oxygen away from fuel, oil, and grease to prevent unwanted combustion. Not all oxygen in containers is the same. Aviator's breathing oxygen is tested for the presence of water. This is done to avoid the possibility of it freezing in the small passage ways of valves and regulators. Ice could prevent delivery of the oxygen when needed. Aircraft often operate in subzero temperatures, increasing the possibility of icing. The water level should be a maximum of .02ml per liter of oxygen. The words "Aviator's Breathing Oxygen" should be marked clearly on any cylinders containing oxygen for this purpose. *[Figure 16-4]*

Production of gaseous oxygen for commercial or aircraft cylinders is often through a process of liquefying air. By controlling temperature and pressure, the nitrogen in the air can be allowed to boil off leaving mostly pure oxygen. Oxygen may also be produced by the electrolysis of water. Passing electric current through water separates the oxygen from the hydrogen. One further method of producing gaseous oxygen is by separating the nitrogen and oxygen in the air through the use of a molecular sieve. This membrane filters out nitrogen and some of the other gases in air, leaving nearly pure oxygen for use. Onboard oxygen sieves, or oxygen concentrators as they are sometimes called, are used on some military aircraft. Their use in civil aviation is expected.

Use of portable pulse oximeters has become more common in aviation. These devices measure the oxygen saturation level of the blood. With this information, adjustments to the oxygen flow rates of onboard oxygen equipment can be made to prevent hypoxia. *Figure 16-5* shows an oximeter into which a finger is inserted to measure oxygen saturation of the blood in percentage. Heart rate is also displayed.

Liquid Oxygen

Liquid oxygen (LOX) is a pale blue, transparent liquid. Oxygen can be made liquid by lowering the temperature to

Figure 16-4. *"Aviator's breathing oxygen" is marked on all oxygen cylinders designed for this purpose.*

Figure 16-5. *A portable pulse-type oximeter displays percentage of oxygen saturation of the blood and heart rate. Pilots can adjust oxygen supply levels to maintain saturation and avoid hypoxia.*

below –183 °C or by placing gaseous oxygen under pressure. A combination of these is accomplished with a Dewar bottle. This special container is used to store and transport liquid oxygen. It uses an evacuated, double-walled insulation design to keep the liquid oxygen under pressure at a very low temperature. *[Figure 16-6]* A controlled amount of oxygen is allowed to vaporize and is plumbed into a gaseous oxygen delivery system downstream of a converter that is part of the container assembly.

Figure 16-6. *A spherical liquid oxygen onboard container used by the military.*

A small quantity of LOX can be converted to an enormous amount of gaseous oxygen, resulting in the use of very little storage space compared to that needed for high-pressure gaseous oxygen cylinders. However, the difficulty of handling LOX, and the expense of doing so, has resulted in the container system used for gaseous oxygen to proliferate throughout civilian aviation. LOX is used in military aviation and some medical helicopter applications for patient oxygen.

Chemical or Solid Oxygen

Sodium chlorate has a unique characteristic. When ignited, it produces oxygen as it burns. This can be filtered and delivered through a hose to a mask that can be worn and breathed directly by the user. Solid oxygen candles, as they are called, are formed chunks of sodium chlorate wrapped inside insulated stainless-steel housings to control the heat produced when activated. The chemical oxygen supply is often ignited by a spring-loaded firing pin that when pulled, releases a hammer that smashes a cap creating a spark to light the candle. Electric ignition via a current-induced hot wire also exists. Once lit, a sodium chlorate oxygen generator cannot be extinguished. It produces a steady flow of breathable oxygen until it burns out, typically generating 10–20 minutes of oxygen. *[Figure 16-7]*

Solid oxygen generators are primarily used as backup oxygen devices on pressurized aircraft. They are one-third as heavy as gaseous oxygen systems that use heavy storage tanks for the same quantity of oxygen available. Sodium chlorate chemical oxygen generators also have a long shelf life, making them perfect as a standby form of oxygen. They are inert below 400 °F and can remain stored with little maintenance or inspection until needed, or until their expiration date is reached.

The feature of not extinguishing once lit limits the use of solid oxygen since it becomes an all-or-nothing source. The generators must be replaced if used, which can greatly increase the cost of using them as a source of oxygen for short periods of time. Moreover, chemical oxygen candles must be transported with extreme caution and as hazardous materials. They must be properly packed, and their ignition devices deactivated.

Onboard Oxygen Generating Systems (OBOGS)

The molecular sieve method of separating oxygen from the other gases in air has application in flight, as well as on the ground. The sieves are relatively light in weight and relieve the aviator of a need for ground support for the oxygen supply. Onboard oxygen generating systems on military aircraft pass bleed air from turbine engines through a sieve that separates

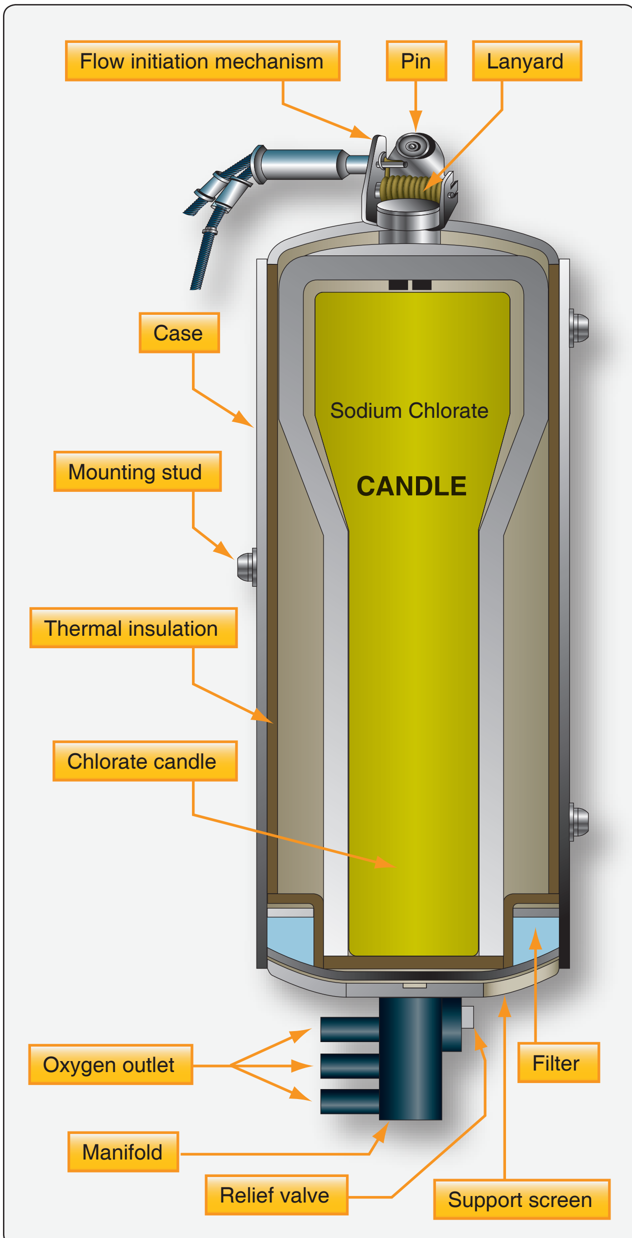


Figure 16-7. *A sodium chlorate solid oxygen candle is at the core of a chemical oxygen generator.*

the oxygen for breathing use. Some of the separated oxygen is also used to purge the sieve of the nitrogen and other gases that keep it fresh for use. Use of this type of oxygen production in civilian aircraft is anticipated. *[Figure 16-8]*

Oxygen Systems and Components

Built-in and portable oxygen systems are used in civilian aviation. They use gaseous or solid oxygen (oxygen generators) as suits the purpose and aircraft. LOX systems and molecular sieve oxygen systems are not discussed, as current applications on civilian aircraft are limited.

Figure 16-8. *This onboard oxygen generating system uses molecular sieve technology.*

Gaseous Oxygen Systems

The use of gaseous oxygen in aviation is common; however, applications vary. On a light aircraft, it may consist of a small carry-on portable cylinder with a single mask attached via a hose to a regulator on the bottle. Larger portable cylinders may be fitted with a regulator that divides the outlet flow for 2–4 people. Built-in oxygen systems on high performance and light twin-engine aircraft typically have a location where oxygen cylinders are installed to feed a distribution system via tubing and a regulator. The passenger compartment may have multiple breathing stations plumbed so that each passenger can individually plug in a hose and mask if oxygen is needed. A central regulator is normally controlled by the flight crew who may have their own separate regulator and oxygen cylinder. Transport category aircraft may use an elaborate built-in gaseous oxygen system as a backup system to cabin pressurization. In all of these cases, oxygen is stored as a gas at atmospheric temperature in high-pressure cylinders. It is distributed through a system with various components that are described in this section.

Oxygen Storage Cylinders

Gaseous oxygen is stored and transported in high-pressure cylinders. Traditionally, these have been heavy steel tanks rated for 1800–1850 psi of pressure and capable of maintaining pressure up to 2,400 psi. While these performed adequately, lighter weight tanks were sought. Some newer cylinders are comprised of a lightweight aluminum shell wrapped by Kevlar®. These cylinders are capable of carrying the same amount of oxygen at the same pressure as steel tanks but weigh much less. Also available are heavy-walled all-aluminum cylinders. These units are common as carry-on portable oxygen used in light aircraft.

Most oxygen storage cylinders are painted green, but yellow and other colors may be used as well. They are certified to Department of Transportation (DOT) specifications. To ensure serviceability, cylinders must be hydrostatically tested periodically. In general, a hydrostatic test consists of filling the container with water and pressurizing it to 5⁄3 of its certified rating. It should not leak, rupture, or deform beyond an established limit. *Figure 16-9* shows a hydrostatic cylinder testing apparatus.

Most cylinders also have a limited service life after which they can no longer be used. After a specified number of filling cycles or calendar age, the cylinders must be removed from service. The most common high-pressure steel oxygen cylinders used in aviation are the 3AA and the 3HT. They come in various sizes but are certified to the same specifications. Cylinders certified under DOT-E-8162 are also popular for their extremely light weight. These cylinders typically have an aluminum core around which Kevlar® is wrapped. The DOT-E 8162 approved cylinders are now approved under DOT-SP-8162 specifications. The SP certification has extended the required time between hydrostatic testing to 5 years (previously 3 years). [*Figure 16-10]*

The manufactured date and certification number is stamped on each cylinder near the neck. Subsequent hydrostatic test dates are also stamped there as well. Composite cylinders use placards rather than stamping. The placard must be covered with a coat of clear epoxy when additional information is added, such as a new hydrostatic test date.

Oxygen cylinders are considered empty when the pressure inside drops below 50 psi. This ensures that air containing water vapor has not entered the cylinder. Water vapor could cause corrosion inside the tank, as well as presenting the possibility of ice forming and clogging a narrow passageway in the cylinder valve or oxygen system. Any installed tank allowed to fall below this pressure should be removed from service.

Figure 16-9. *This test stand is used for hydrostatic testing of oxygen cylinders. The water-filled cylinder is lowered into the barrel on the left where it is pressurized to the proper level as monitored via gauges mounted on the control panel. A displacement container on the top left of the control board collects water from the barrel to measure the expansion of the cylinder when pressurized to ensure it is within limits.*

Oxygen Systems and Regulators

The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements, and whether the aircraft has a pressurization system. Systems are often characterized by the type of regulator used to dispense the oxygen: continuous-flow and demand flow. In some aircraft, a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the

Certification Type	Material	Rated pressure (psi)	Required hydrostatic test	Service life (years)	Service life (fillings)
DOT 3AA	Steel	1,800	5	Unlimited	N/A
DOT 3HT	Steel	1,850	3	24	4,380
DOT-E-8162	Composite	1,850	3	15	N/A
DOT-SP-8162	Composite	1,850	5	15	N/A
DOT 3AL	Aluminum	2,216	5	Unlimited	N/A

Figure 16-10. *Common cylinders used in aviation with some certification and testing specifications.*

larger transport aircraft. Many aircraft have a combination of both systems that may be augmented by portable equipment.

Continuous-Flow Systems

In its simplest form, a continuous-flow oxygen system allows oxygen to exit the storage tank through a valve and passes it through a regulator/reducer attached to the top of the tank. The flow of high-pressure oxygen passes through a section of the regulator that reduces the pressure of the oxygen, which is then fed into a hose attached to a mask worn by the user. Once the valve is opened, the flow of oxygen is continuous. Even when the user is exhaling, or when the mask is not in use, a preset flow of oxygen continues until the tank valve is closed. On some systems, fine adjustment to the flow can be made with an adjustable flow indicator that is installed in the hose in line to the mask. A portable oxygen setup for a light aircraft exemplifies this type of continuous-flow system and is shown in *Figure 16-11.*

Figure 16-11. *A typical portable gaseous oxygen cylinder complete with valve, pressure gauge, regulator/reducer, hose, adjustable flow indicator, and rebreather cannula. A padded carrying case/bag can be strapped to the back of a seat in the cabin to meet certification and testing specifications.*

A more sophisticated continuous-flow oxygen system uses a regulator that is adjustable to provide varying amounts of oxygen flow to match increasing need as altitude increases. These regulators can be manual or automatic in design. Manual continuous-flow regulators are adjusted by the crew as altitude changes. Automatic continuous-flow regulators have a built in aneroid. As the aneroid expands with altitude, a mechanism allows more oxygen to flow though the regulator to the users. [*Figure 16-12]*

Many continuous-flow systems include a fixed location for the oxygen cylinders with permanent delivery plumbing installed to all passenger and crew stations in the cabin. In large aircraft, separate storage cylinders for crew and passengers are typical. Fully integrated oxygen systems usually have separate, remotely mounted components to reduce pressure and regulate flow. A pressure relief valve is also typically installed in the system, as is some sort of filter and a gauge to indicate the amount of oxygen pressure remaining in the storage cylinder(s). *Figure 16-13* diagrams the type of continuous-flow system that is found on small to medium sized aircraft.

Built-in continuous-flow gaseous oxygen systems accomplish a final flow rate to individual user stations through the use of a calibrated orifice in each mask. Larger diameter orifices are usually used in crew masks to provide greater flow than that for passengers. Special oxygen masks provide even greater

Figure 16-12. *A manual continuous flow oxygen system may have a regulator that is adjusted by the pilot as altitude varies. By turning the knob, the left gauge can be made to match the flight altitude thus increasing and decreasing flow as altitude changes.*

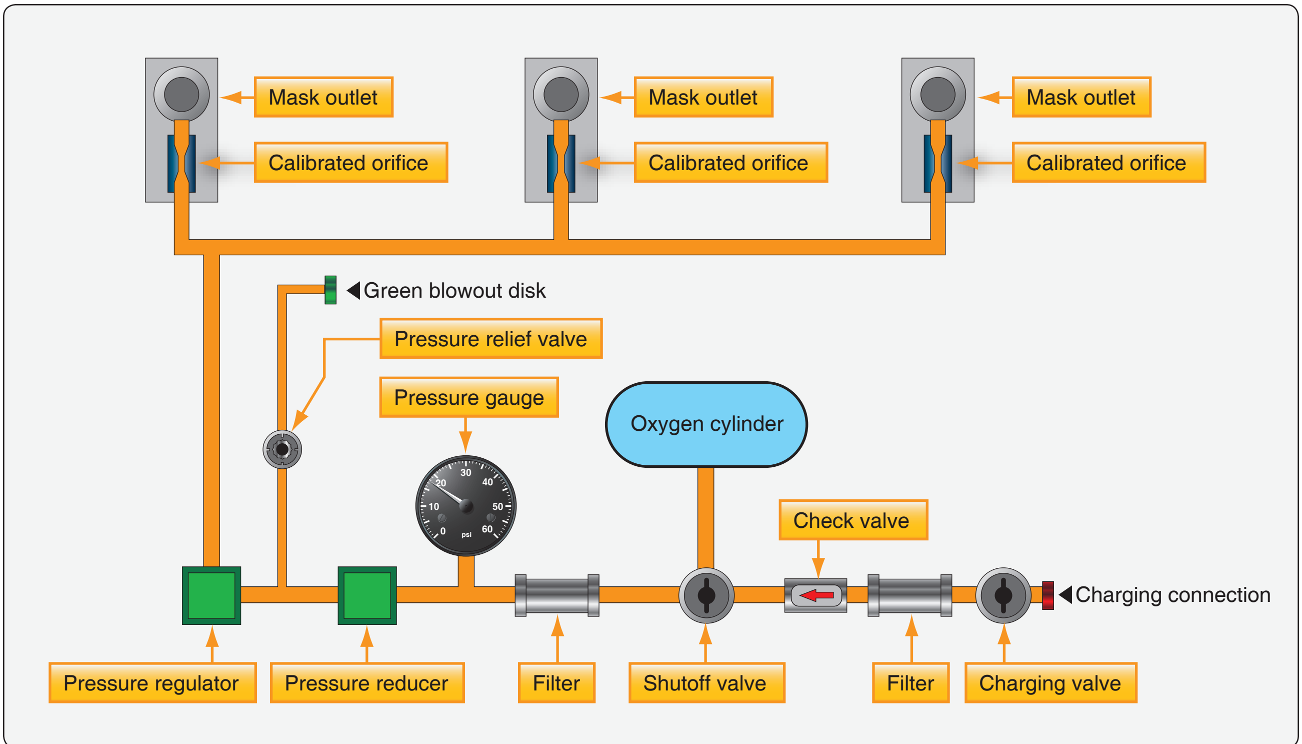


Figure 16-13. *Continuous flow oxygen system found on small to medium size aircraft.*

flow via larger orifices for passengers traveling with medical conditions requiring full saturation of the blood with oxygen.

Allowing oxygen to continuously flow from the storage cylinder can be wasteful. Lowest sufficient flow rates can be accomplished through the use of rebreather apparatus. Oxygen and air that is exhaled still contains usable oxygen. By capturing this oxygen in a bag, or in a cannula with oxygen absorbing reservoirs, it can be inhaled with the next breath, reducing waste. *[Figure 16-14]*

The passenger section of a continuous-flow oxygen system may consist of a series of plug-in supply sockets fitted to the cabin walls adjacent to the passenger seats to which oxygen masks can be connected. Flow is inhibited until a passenger manually plugs in. When used as an emergency system in pressurized aircraft, depressurization automatically triggers the deployment of oxygen ready continuous-flow masks at each passenger station. A lanyard attached to the mask turns on the flow to each mask when it is pulled toward the passenger for use. The masks are normally stowed overhead in

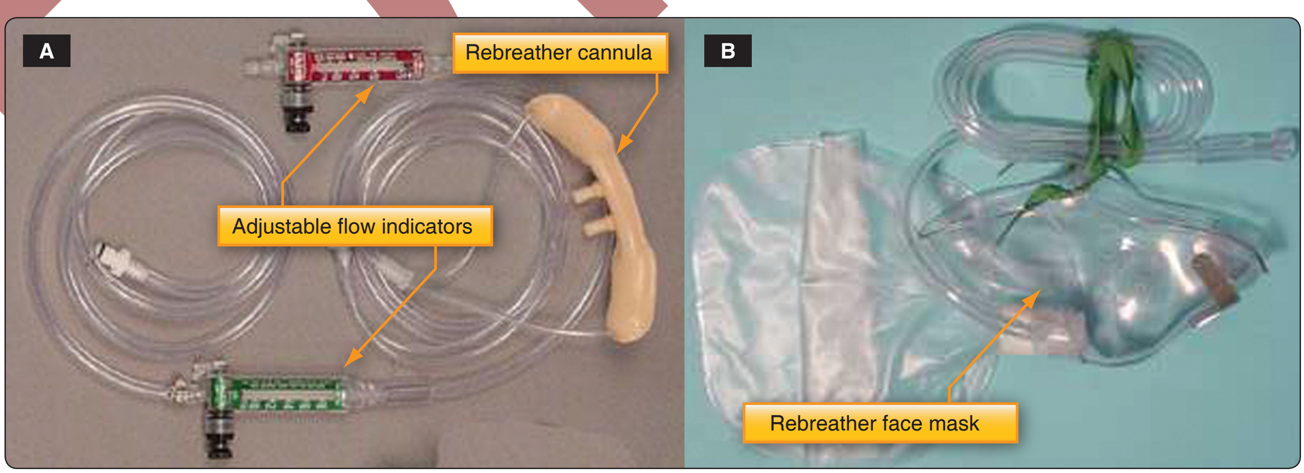


Figure 16-14. *A rebreather cannula (A) and rebreather bag (B) capture exhaled oxygen to be inhaled on the next breath. This conserves oxygen by permitting lower flow rates in continuous flow systems. The red and green devices are optional flow indicators that allow the user to monitor oxygen flow rate. The type shown also contains needle valves for final regulation of the flow rate to each user.*

the passenger service unit (PSU). *[Figure 16-15]* Deployment of the emergency continuous-flow passenger oxygen masks may also be controlled by the crew. *[Figure 16-16]*

Continuous-flow oxygen masks are simple devices made to direct flow to the nose and mouth of the wearer. They fit snugly but are not air tight. Vent holes allow cabin air to mix with the oxygen and provide escape for exhalation. In a rebreather mask, the vents allow the exhaled mixture that is not trapped in the rebreather bag to escape. This is appropriate, because this is the air-oxygen mixture that has been in the lungs the longest, so it has less recoverable oxygen to be breathed again. *[Figure 16-17]*

Demand-Flow Systems

When oxygen is delivered only as the user inhales, or on demand, it is known as a demand-flow system. During the hold and exhalation periods of breathing, the oxygen supply is stopped. Thus, the duration of the oxygen supply is prolonged as none is wasted. Demand-flow systems are used most frequently by the crew on high performance and air transport category aircraft. *[Figure 16-18]*

Demand-flow systems are similar to continuous-flow systems in that a cylinder delivers oxygen through a valve when opened. The tank pressure gauge, filter(s), pressure relief valve, and any plumbing installed to refill the cylinder while installed on the aircraft are all similar to those in a continuous-flow system. The high-pressure oxygen also passes through a pressure reducer and a regulator to adjust the pressure and flow to the user. But, demand-flow oxygen regulators differ significantly from continuous-flow oxygen regulators. They work in conjunction with close-fitting demand-type masks to control the flow of oxygen. *[Figure 16-19]*

Figure 16-15. *A passenger service unit (psu) is hinged over each row of seats in an airliner. Four yellow continuous flow oxygen masks are shown deployed. They are normally stored behind a separate hinged panel that opens to allow the masks to fall from the PSU for use.*

Figure 16-16. *The crew can deploy passenger emergency continuous-flow oxygen masks and supply with a switch in the cockpit.*

In a demand-flow oxygen system, the system pressure-reducing valve is sometimes called a pressure regulator. This device lowers the oxygen pressure from the storage cylinder(s) to roughly 60–85 psi and delivers it to individual regulators dedicated for each user. A pressure reduction also occurs at the inlet of the individual regulator by limiting the size of the inlet orifice. There are two types of individual regulators: the diluter-demand type and the pressure-demand type. *[Figure 16-20]*

The diluter-demand type regulator holds back the flow of oxygen until the user inhales with a demand-type oxygen mask. The regulator dilutes the pure oxygen supply with cabin air each time a breath is drawn. With its control toggle switch set to normal, the amount of dilution depends on the cabin altitude. As altitude increases, an aneroid allows more oxygen and less cabin air to be delivered to the user by adjusting flows through a metering valve. At approximately 34,000

Figure 16-17. *Examples of different continuous-flow oxygen masks.*

feet, the diluter-demand regulator meters 100 percent oxygen. This should not be needed unless cabin pressurization fails. Additionally, the user may select 100 percent oxygen delivery at any time by positioning the oxygen selection lever on the regulator. A built-in emergency switch also delivers 100 percent oxygen, but in a continuous flow as the demand function is bypassed. *[Figure 16-21]*

Pressure-demand oxygen systems operate similarly to diluter-demand systems, except that oxygen is delivered through the individual pressure regulator(s) under higher pressure. When the demand valve is unseated, oxygen under pressure forces its way into the lungs of the user. The demand function still operates, extending the overall supply of oxygen beyond that of a continuous-flow system. Dilution with cabin air also occurs if cabin altitude is less than 34,000 feet.

Pressure-demand regulators are used on aircraft that regularly fly at 40,000 feet and above. They are also found on many airliners and high-performance aircraft that may not typically fly that high. Forcing oxygen into the lungs under pressure ensures saturation of the blood, regardless of altitude or cabin altitude.

Both diluter-demand and pressure-demand regulators also come in mask-mounted versions. The operation is essentially the same as that of panel-mounted regulators. *[Figure 16-22]*

Flow Indicators

Flow indicators, or flow meters, are common in all oxygen systems. They usually consist of a lightweight object, or apparatus, that is moved by the oxygen stream. When flow exists, this movement signals the user in some way. *[Figure 16-23]* Many flow meters in continuous-flow oxygen systems also double as flow rate adjusters. Needle valves fitted into the flow indicator housing can fine-adjust the oxygen delivery rate. Demand-flow oxygen systems usually have flow indicators built into the individual regulators at each user station. Some contain a blinking device that activates when the user inhales and oxygen is delivered. Others move a colored pith object into a window. Regardless, flow indicators provide a quick verification that an oxygen system is functioning.

Different flow indicators are used to provide verification that the oxygen system is functioning. Other demand-flow indicators are built into the oxygen regulators. *[Figure 16-23]*

A recent development in general aviation oxygen systems is the electronic pulse demand oxygen delivery system (EDS). A small, portable EDS unit is made to connect between the oxygen source and the mask in a continuous-flow oxygen system. It delivers timed pulses of oxygen to the wearer on demand, saving oxygen normally lost during the hold and exhale segments of the breathing cycle. Advanced pressure sensing and processing allows the unit to deliver oxygen only when an inhalation starts. It can also sense differences in users' breathing cycles and physiologies and adjust the flow of oxygen accordingly. A built-in pressure-sensing device adjusts the amount of oxygen released as altitude changes. *[Figure 16-24]*

Permanently mounted EPD systems are also available. They typically integrate with an electronic valve/regulator on the oxygen cylinder and come with an emergency bypass switch to provide continuous-flow oxygen should the system malfunction. A liquid crystal display (LCD) monitor/control panel displays numerous system operating parameters and allows adjustments to the automatic settings. This type of

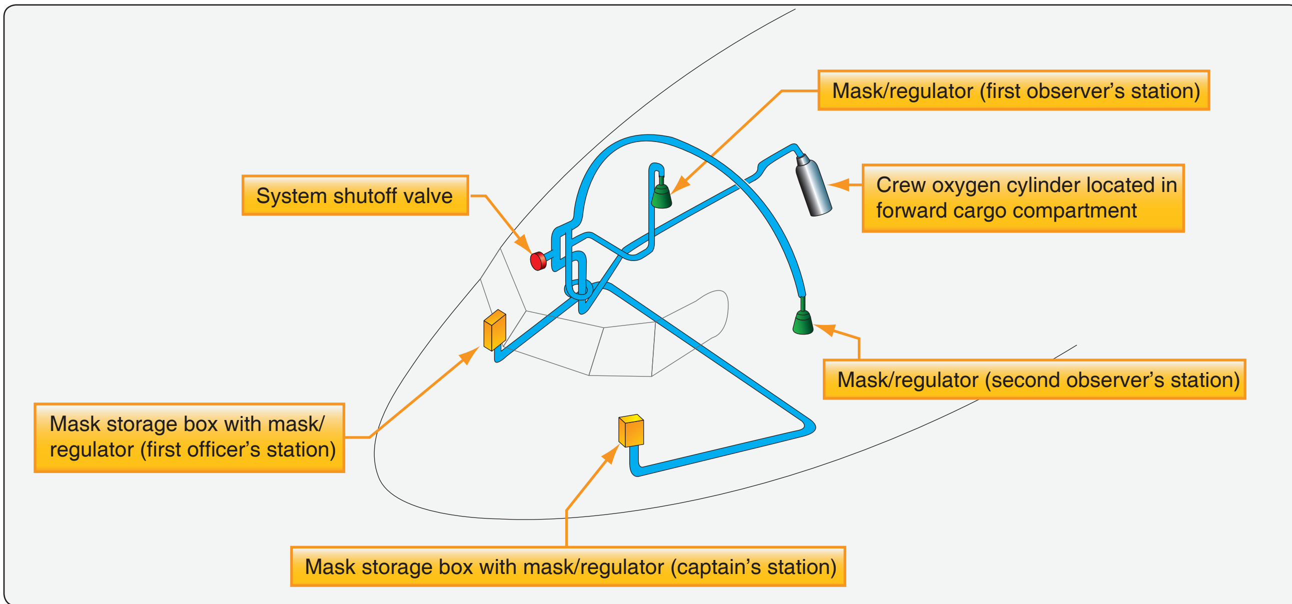


Figure 16-18. *Location of demand-flow oxygen components on a transport category aircraft.*

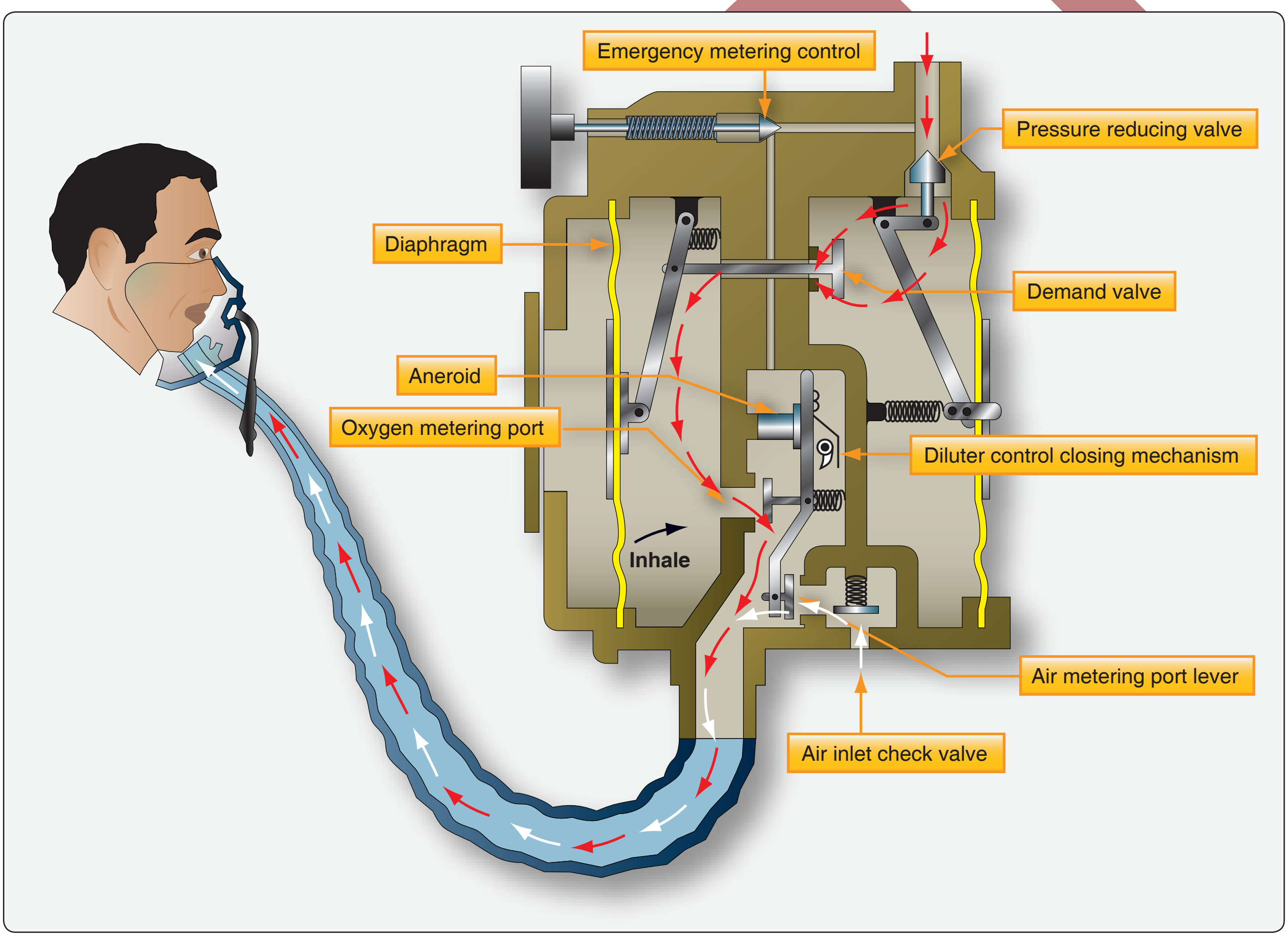


Figure 16-19. *A demand regulator and demand-type mask work together to control flow and conserve oxygen. Demand-flow masks are close fitting so that when the user inhales, low pressure is created in the regulator, which allows oxygen to flow. Exhaled air escapes through ports in the mask, and the regulator ceases the flow of oxygen until the next inhalation.*

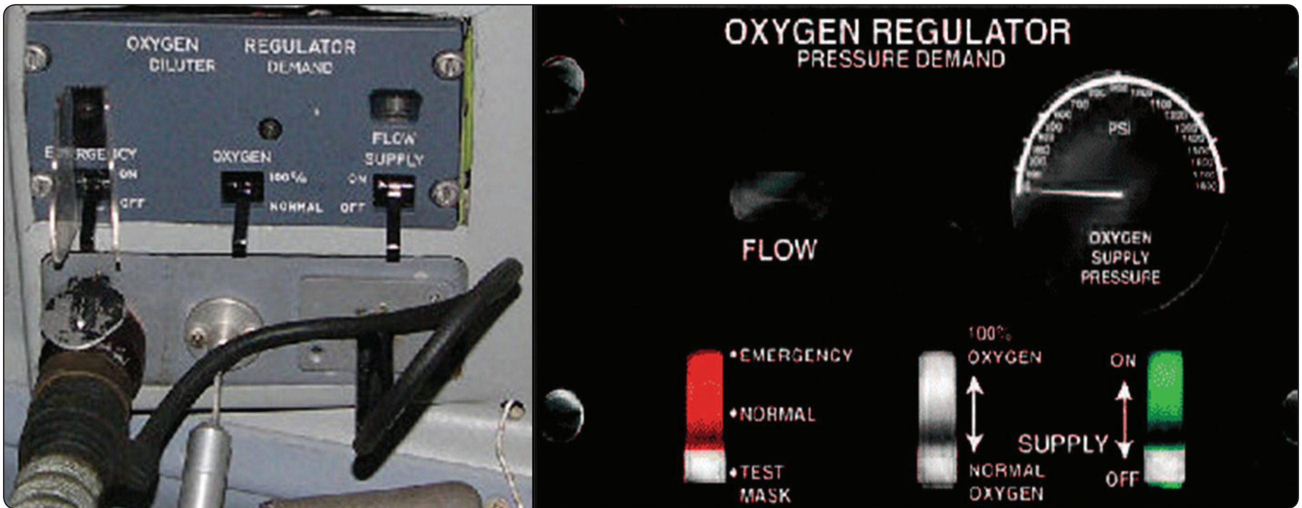


Figure 16-20. *The two basic types of regulators used in demand flow oxygen systems. The panel below the diluter demand regulator on the left is available for mask hose plug in (left), lanyard mask hanger (center), and microphone plug in (right). Most high performance demand type masks have a microphone built-in.*

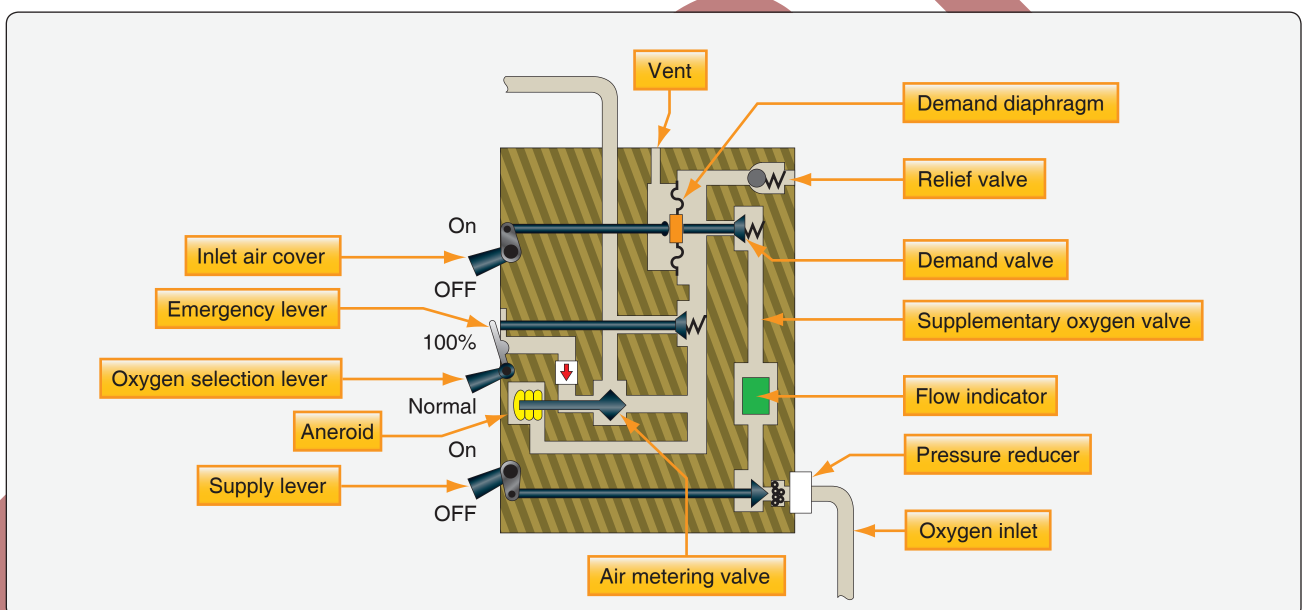


Figure 16-21. *A diluter-demand regulator operates when low pressure caused by inhalation moves the demand diaphragm. A demand valve connected to the diaphragm opens, letting oxygen flow through the metering valve. The metering valve adjusts the mixture of cabin air and pure oxygen via a connecting link to an aneroid that responds to cabin altitude.*

Figure 16-22. *A mask-mounted version of a miniature diluter-demand regulator designed for use in general aviation (left), a mechanical quick-donning diluter-demand mask with the regulator on the mask (center), and an inflatable quick-donning mask (right). Squeezing the red grips directs oxygen into the hollow straps.*

Figure 16-23. *Different flow indicators are used to provide verification that the oxygen system is functioning: continuous-flow, in-line (left); continuous-flow, in-line with valve adjuster (center); and old style demand flow (right).*

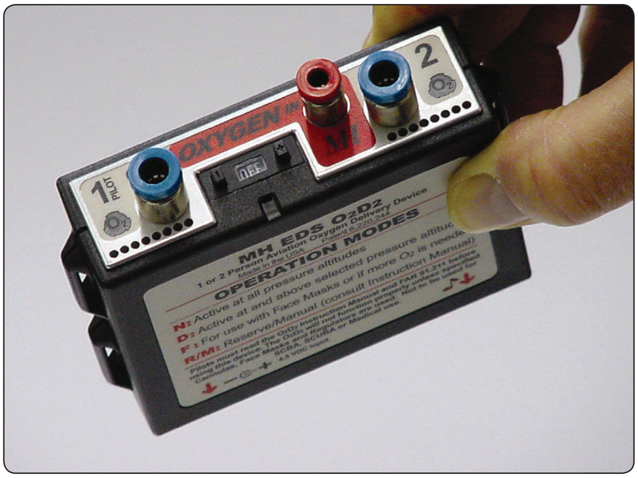


Figure 16-24. *A portable two-person electronic pulse-demand (EPD) oxygen regulating unit.*

electronic metering of oxygen has also been developed for passenger emergency oxygen use in airliners. *[Figure 16-25]*

Oxygen Plumbing and Valves

Tubing and fittings make up most of the oxygen system plumbing and connect the various components. Most lines are metal in permanent installations. High-pressure lines are usually stainless steel. Tubing in the low-pressure parts of the oxygen system is typically aluminum. Flexible plastic hosing is used deliver oxygen to the masks; its use is increasing in permanent installations to save weight.

Installed oxygen tubing is usually identified with color-coded tape applied to each end of the tubing, and at specified intervals along its length. The tape coding consists of a green band overprinted with the words "BREATHING OXYGEN" and a black rectangular symbol overprinted on a white background border strip. *[Figure 16-26]*

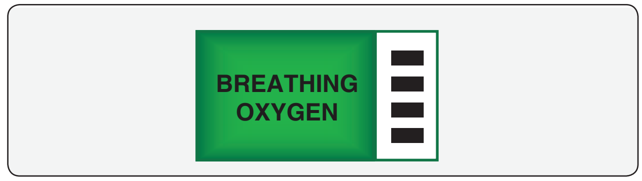


Figure 16-26. *Color-coded tape used to identify oxygen tubing.*

Tubing-to-tubing fittings in oxygen systems are often designed with straight threads to receive flared tube connections. Tubing-to-component fittings usually have straight threads on the tubing end and external pipe threads (tapered) on the other end for attachment to the component. The fittings are typically made of the same material as the tubing (i.e., aluminum or steel). Flared and flareless fittings are both used, depending on the system.

Five types of valves are commonly found in high-pressure gaseous oxygen systems: filler, check, shutoff, pressure reducer, and pressure relief. They function as they would in any other system with one exception: oxygen system shutoff valves are specifically designed to open slowly.

The ignition point for any substances is lower in pure oxygen than it is in air. When high-pressure oxygen is allowed to rush into a low-pressure area, its velocity could reach the speed of sound. If it encounters an obstruction (a valve seat, an elbow, a piece of contaminant, etc.), the oxygen compresses. With this compression, known as adiabatic compression (since it builds so quickly no heat is lost to its surroundings), comes high temperature. Under pressure, this high temperature exceeds the ignition point of the material the oxygen encounters and a fire or explosion results. A stainless-steel line, for example, would not normally burn and is used for carrying numerous fluids under high pressure. But under high pressure and temperature in the presence of 100 percent oxygen, even stainless steel can ignite.

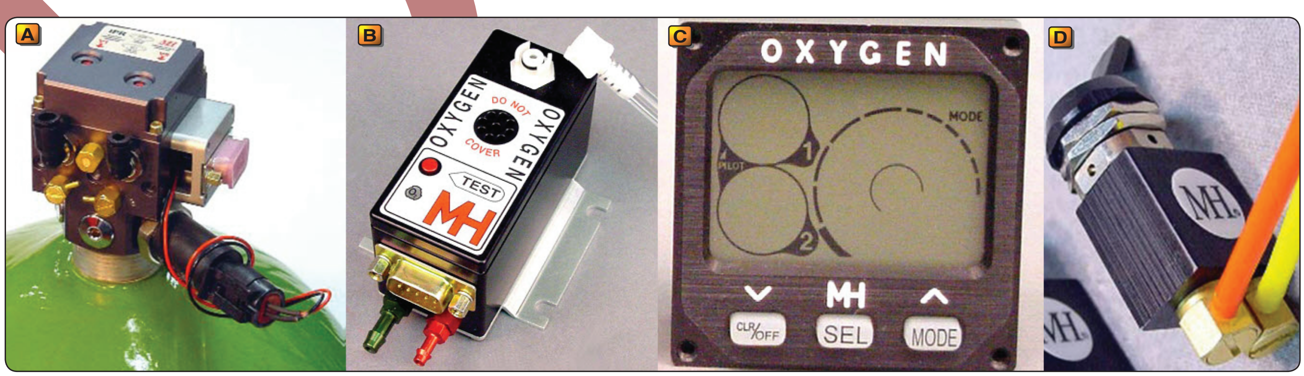


Figure 16-25. *The key components of a built-in electronic pulse demand oxygen metering system: (A) electronic regulator, (B) oxygen station distributer unit, (C) command/display unit, (D) emergency bypass switch.*

To combat this issue, all oxygen shutoff valves are slow, opening valves designed to decrease velocity. *[Figure 16-27]*

Additionally, technicians should always open all oxygen valves slowly. Keeping oxygen from rushing into a low-pressure area should be a major concern when working with high-pressure gaseous oxygen systems.

Oxygen cylinder valves and high-pressure systems are often provided with a relief valve should the desired pressure be exceeded. Often, the valve is ported to an indicating or blowout disk. This is located in a conspicuous place, such as the fuselage skin, where it can be seen during walk-around inspection. Most blowout disks are green. The absence of the green disk indicates the relief valve has opened, and the cause should be investigated before flight. *[Figure 16-28]*

Chemical Oxygen Systems

The two primary types of chemical oxygen systems are the portable type, much like a portable carry-on gaseous oxygen cylinder, and the fully integrated supplementary oxygen system used as backup on pressurized aircraft in case of pressurization failure. *[Figure 16-29]* This latter use of solid chemical oxygen generators is most common on airliners. The generators are stored in the overhead PSU attached to hoses and masks for every passenger on board the aircraft. When a depressurization occurs, or the flight crew activates a switch, a compartment door opens, and the masks and hoses fall out in front of the passengers. The action of pulling the mask down to a usable position actuates an electric current, or ignition hammer, that ignites the oxygen candle and initiates the flow of oxygen. Typically, 10 to 20 minutes of oxygen is available for each user. This is calculated to be enough time for the aircraft to descend to a safe altitude for unassisted breathing.

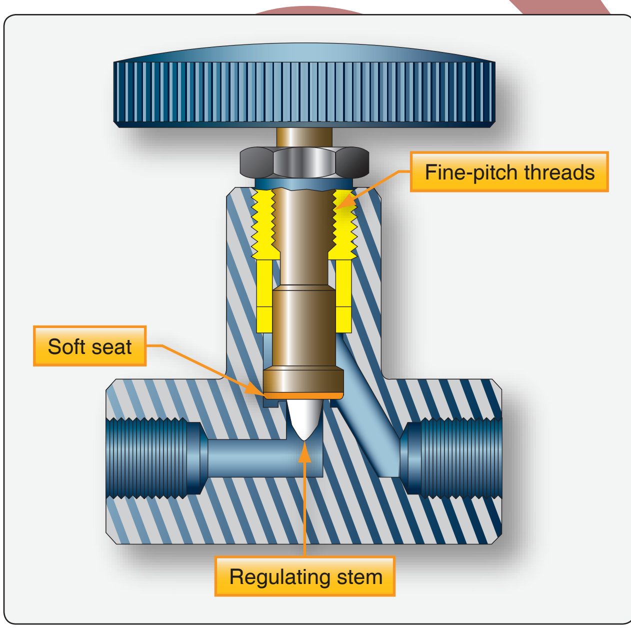


Figure 16-27. *This high-pressure oxygen system shutoff valve has fine-pitch threads and a regulating stem to slow the flow of oxygen through the valve. A soft valve seat is also included to assure the valve closes completely.*

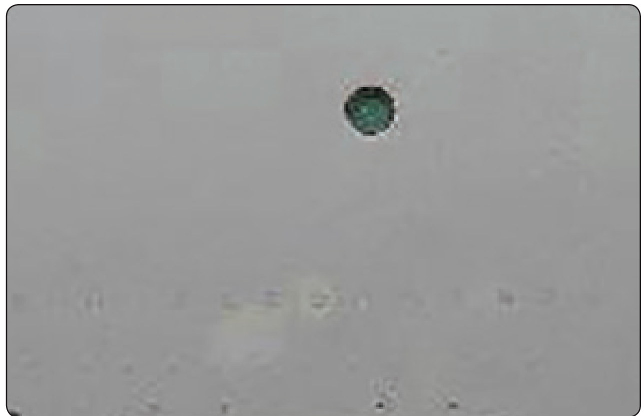


Figure 16-28. *An oxygen blowout plug on the side of the fuselage indicates when pressure relief has occurred and should be investigated.*

Chemical oxygen systems are unique in that they do not produce the oxygen until it is time to be used. This allows safer transportation of the oxygen supply with less maintenance. Chemical oxygen-generating systems also require less space and weigh less than gaseous oxygen systems supplying the same number of people. Long runs of tubing, fittings, regulators, and other components are avoided, as are heavy gaseous oxygen storage cylinders. Each passenger row grouping has its own fully independent chemical oxygen generator. The generators, which often weigh less than a pound, are insulated and can burn completely without getting hot. The size of the orifice opening in the hose-attach nipples regulates the continuous flow of oxygen to the users.

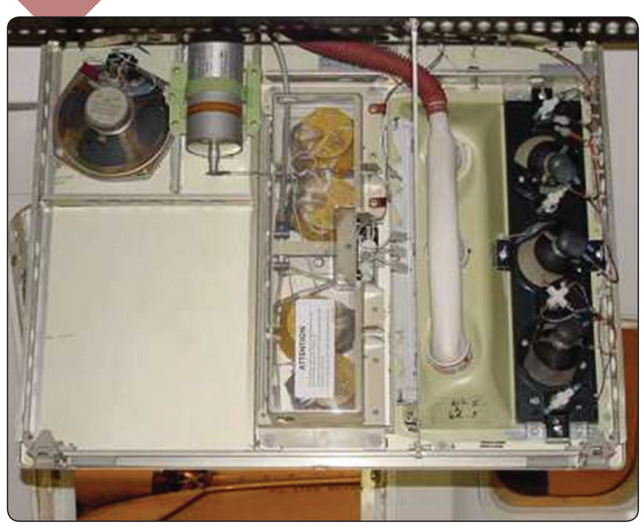


Figure 16-29. *An oxygen generator mounted in place in an overhead passenger service unit of an air transport category aircraft.*

LOX Systems

LOX systems are rarely used in civilian aviation. They may be encountered on former military aircraft now in the civilian fleet. As mentioned, the storage of LOX requires a special container system. The plumbing arrangement to convert the liquid to a usable gas is also unique. It basically consists of a controlled heat exchange assembly of tubing and valves. Overboard pressure relief is provided for excessive temperature situations. Once gaseous, the LOX system is the same as it is in any comparable gaseous oxygen delivery system. Use of pressure-demand regulators and masks is common. Consult the manufacturer's maintenance manual for further information if a LOX system is encountered.

Oxygen System Servicing

Servicing Gaseous Oxygen

Gaseous oxygen systems are prevalent in general, corporate, and airline aviation. The use of lightweight aluminum and composite storage cylinders has improved these simple and reliable life support systems. All gaseous oxygen systems require servicing and maintenance. Various procedures and requirements to perform these functions are covered in this section.

Leak Testing Gaseous Oxygen Systems

Leaks in a continuous-flow oxygen system may be difficult to detect because the system is open at the user end. Blocking the flow of oxygen allows pressure to build and leak check procedures can be followed that are similar to those used in the high-pressure sections of the systems. Detection of leaks should be performed with oxygen-safe leak check fluid. This is a soapy liquid free from elements that might react with pure oxygen or contaminate the system. As with leak detection on an inflated tire or tube assembly, the oxygen leak detection solution is applied to the outside of fittings and mating surfaces. The formation of bubbles indicates a leak. *[Figure 16-30]*

Figure 16-30. *Oxygen system leak check solution.*

Careful assembly of oxygen components and fittings without overtightening or undertightening is required. If a leak is found at a fitting, it should be checked for the proper torque. Tightening may not always stop the leak. If the fitting is torqued properly and a leak still exists, pressure must be released from the system and the fitting must be examined for flaws or contamination. If necessary, the fitting must be replaced. All system components, lines, and fittings must be replaced with the proper parts, which should be cleaned and inspected thoroughly before installation. Follow the manufacturer's instructions and repeat the leak check when completed.

Use caution when maintaining the high-pressure portion of a gaseous oxygen system. An open tank valve pressurizes the lines and components with up to 1,850 pounds per square inch (psi) of oxygen. Identify the high-pressure section of the system as that portion upstream of the reducer or regulator that has stainless steel tubing. Note that no attempt should be made to tighten a leaky oxygen fitting while the system is charging. The oxygen supply should be isolated in the cylinder and the system depressurized to reduce the consequences of a spark or to minimize spillage and injury should a complete fitting failure occur.

Draining an Oxygen System

The biggest factor in draining an oxygen system is safety. The oxygen must be released into the atmosphere without causing a fire, explosion, or hazard. Draining outside is highly recommended. The exact method of draining can vary. The basic procedure involves establishing a continuous flow in a safe area until the system is empty.

If the cylinder valve is operative, close the valve to isolate the oxygen supply in the cylinder. All that remains is to empty the lines and components. This can be done without disassembling the system by letting oxygen flow from the delivery point(s). If the environment is safe to receive the oxygen, positioning a demand-flow regulator to the emergency setting delivers a continuous flow of oxygen to the mask when plugged in. Hang the mask(s) out of a window while the system drains. Plug in all mask(s) to allow oxygen to drain from a continuous-flow oxygen system. Systems without check valves can be drained by opening the refill valve.

Filling an Oxygen System

Filling procedures for oxygen systems vary. Many general aviation aircraft are set up to simply replace an empty cylinder with one that is fully charged. This is also the case with a portable oxygen system. High performance and air transport category aircraft often have built-in oxygen systems that contain plumbing designed to refill gaseous oxygen cylinders while they are in place. A general discussion of the procedure to fill this type of installation follows.

Before charging any oxygen system, consult the aircraft manufacturer's maintenance manual. The type of oxygen to be used, safety precautions, equipment to be used, and the procedures for filling and testing the system must be observed. Several general precautions should also be observed when servicing a gaseous oxygen system. Oxygen valves should be opened slowly, and filling should proceed slowly to avoid overheating. The hose from the refill source to the oxygen fill valve on the aircraft should be purged of air before it is used to transfer oxygen into the system. Pressures should also be checked frequently while refilling.

Airline and fixed-base operator maintenance shops often use oxygen filler carts to service oxygen systems. These contain several large oxygen supply cylinders connected to the fill cart manifold. This manifold supplies a fill hose that attaches to the aircraft. Valves and pressure gauges allow awareness and control of the oxygen dispensing process. *[Figure 16-31]* Be sure all cylinders on the cart are aviator's breathing oxygen and that all cylinders contain at least 50 psi of oxygen pressure. Each cylinder should also be within its hydrostatic test date interval. After a cart cylinder has dispensed oxygen, the remaining pressure should be recorded. This is usually written on the outside of the cylinder with chalk or in a cylinder pressure log kept with the cart. As such, the technician can tell at a glance the status of each oxygen bottle.

No pump or mechanical device is used to transfer oxygen from the fill cart manifold to the aircraft system. Objects

Figure 16-31. *Typical oxygen servicing cart used to fill an aircraft system.*

under pressure flow from high pressure to low pressure. Thus, by connecting the cart to the aircraft and systematically opening oxygen cylinders with increasingly higher pressure, a slow increase in oxygen flow to the aircraft can be managed.

The following is a list of steps to safely fill an aircraft oxygen system from a typical oxygen refill cart.

1. Check hydrostatic dates on all cylinders, especially those that are to be filled on the aircraft. If a cylinder is out of date, remove and replace it with a specified unit that is serviceable.
2. Check pressures on all cylinders on the cart and in the aircraft. If pressure is below 50 psi, replace the cylinder(s). On the aircraft, this may require purging the system with oxygen when completed. Best practices dictate that any low-pressure or empty cylinder(s) on the cart should also be removed and replaced when discovered.
3. Take all oxygen handling precautions to ensure a safe environment around the aircraft.
4. Ground the refill cart to the aircraft.
5. Connect the cart hose from the cart manifold to the aircraft fill port. Purge the air from the refill hose with oxygen before opening the refill valve on the aircraft. Some hoses are equipped with purge valves to do this while the hose is securely attached to the aircraft. Other hoses need to be purged while attached to the refill fitting but not fully tightened.
6. Observe the pressure on the aircraft bottle to be filled. Open it. On the refill cart, open the cylinder with the closest pressure to the aircraft cylinder that exceeds it.
7. Open the aircraft oxygen system refill valve. Oxygen will flow from cart cylinder (manifold) into the aircraft cylinder.
8. When the cylinder pressures equalize, close the cylinder on the cart, and open the cart cylinder with the next highest pressure. Allow it to flow into the aircraft cylinder until the pressures equalize and flow ceases. Close the cart cylinder and proceed to the cart cylinder with the next highest pressure.
9. Continue the procedure in step 8 until the desired pressure in the aircraft cylinder is achieved.
10. Close the aircraft refill valve and close all cylinders on the cart.
11. The aircraft oxygen cylinder valve(s) should be left in the proper position for normal operations. Remotely mounted cylinders are usually left open.
12. Disconnect the refill line from the refill port on the aircraft. Cap or cover both.

13. Remove the grounding strap.

Temperature has a significant effect on the pressure of gaseous oxygen. Manufacturers typically supply a fill chart or a placard at the aircraft oxygen refill station to guide technicians in compensating for temperature/pressure variations. Technicians should consult the chart and fill cylinders to the maximum pressure listed for the prevailing ambient temperature. *[Figure 16-32]*

When it is hot, oxygen cylinders are filled to a higher pressure than 1,800 psi or 1,850 psi, the standard maximum pressure ratings of most high-pressure aircraft oxygen cylinders. This is allowable because at altitude the temperature and pressure of the oxygen can decrease significantly. Filling cylinders to temperature-compensated pressure values ensures a full supply of oxygen is available when needed. When filling cylinders on a cold day, compensation for temperature and pressure changes dictates that cylinders be filled to less than the maximum rated capacity to allow for pressure increases as temperature rises. Strict adherence to the temperature/pressure compensation chart values is mandatory to ensure safe storage of aircraft oxygen.

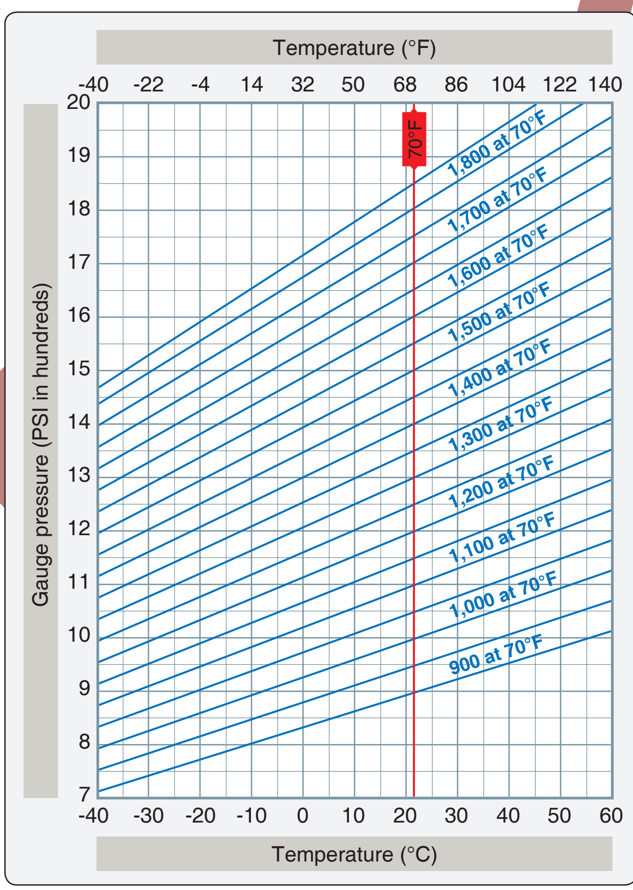


Figure 16-32. *A temperature-compensating pressure refill chart is used by the technician to ensure proper oxygen cylinder pressure in the aircraft system.*

Note that some aircraft have temperature compensation features built into the refill valve. After setting the ambient temperature on the valve dial, the valve closes when the correct amount of oxygen pressure has been established in the aircraft cylinder. A chart can be used to ensure proper servicing.

Purging an Oxygen System

The inside of an oxygen system becomes completely saturated with oxygen during use. This is desirable to deliver clean, odor-free oxygen to the users and to prevent corrosion caused by contamination. An oxygen system needs to be purged if it has been opened or depleted for more than 2 hours, or if it is suspected that the system has been contaminated. Purging is accomplished to evacuate contaminants and to restore oxygen saturation to the inside of the system

The main cause of contamination in an oxygen system is moisture. In very cold weather, the small amount of moisture contained in the breathing oxygen can condense. With repeated charging, a significant amount of moisture may collect. Additionally, systems that are opened contain the moisture from the air that has entered. Damp charging equipment, or poor refill procedures, can also introduce water into the system. Always follow manufacturer's instructions when performing maintenance, refilling, or purging an oxygen system.

Cumulative condensation in an oxygen system cannot be entirely avoided. Purging is needed periodically. The procedure for purging may vary somewhat with each aircraft model. Generally speaking, oxygen is run through a sound oxygen system for a number of minutes at a given pressure to perform the purging. This can be as little as 10 minutes at normal delivery pressure. Other systems may require up to 30 minutes of flow at an elevated pressure. Regardless, the removal of contaminants and the resaturation of the inside of the system with oxygen is the basis for purging. It is acceptable to use nitrogen, or dry air, to blow through lines and components when performing maintenance. However, a final purging with pure oxygen is required before the system is serviceable for use.

It is important to ensure storage cylinders are refilled if they are used during the purging process. Be certain that there are no open lines and all safety caps are installed before returning the aircraft to service.

Filling LOX Systems

The use of LOX in civilian aviation is rare. The most common and safest way to fill a LOX system is to simply exchange the storage unit for one that is full. However, filling LOX on the aircraft is possible.

A portable fill cart is used, and all of the same precautions must be observed as when servicing a high-pressure gaseous oxygen system. Additionally, protection from cold burns is necessary. Due to the amount of gaseous oxygen released during the process, refilling should be accomplished outside. The servicing cart is attached to the aircraft system through a fill valve. The buildup/vent valve on the LOX container assembly is placed in the vent position. The valve on the service cart is then opened. LOX flows into the aircraft system; some vaporizes and cools the entire setup. This gaseous oxygen flows overboard through the vent valve while the system fills. When a steady stream of LOX flows from the vent valve, the system is filled. The valve is then switched to the buildup position. The aircraft refill valve and cart supply valves are closed, and the hose is removed.

Note that back seated valves can freeze in the open position due to the low temperature involved while LOX is being transferred. Valves should be opened completely and then closed slightly so as to not be back seated.

Inspection of Masks and Hoses

The wide varieties of oxygen masks used in aviation require periodic inspection. Mask and hose integrity ensure effective delivery of oxygen to the user when it is needed. Sometimes this is in an emergency situation. Leaks, holes, and tears are not acceptable. Most discrepancies of this type are remedied by replacement of the damaged unit.

Some continuous-flow masks are designed for disposal after use. Be sure there is a mask for each potential user on board the aircraft. Masks designed to be reused should be clean, as well as functional. This reduces the danger of infection and prolongs the life of the mask. Various mild cleaners and antiseptics that are free of petroleum products can be used. A supply of individually wrapped alcohol swabs are often kept in the cockpit.

Built-in microphones should be operational. Donning straps and fittings should be in good condition and function so that the mask is held firm to the user's face. Note that the diameter of mask hoses in a continuous-flow system is quite a bit smaller than those used in a demand-flow system. This is because the inside diameter of the hose aids in controlling flow rate. Masks for each kind of system are made to only connect to the proper hose.

Smoke masks are required on transport aircraft and are used on some other aircraft as well. These cover the eyes, as well as the user's nose and mouth. Smoke masks are usually available within easy grasp of the crew members. They are used when the situation in the cockpit demands the increased level of protection offered. Smoke mask hoses plug into demand regulators in the same port used for regular demand type masks and operate in the same manner. Most include a built-in microphone. *[Figure 16-33]* Some portable oxygen systems are also fitted with smoke masks.

Replacing Tubing, Valves, and Fittings

The replacement of aircraft oxygen system tubing, valves, and fittings is similar to the replacement of the same components in other aircraft systems. There is, however, an added emphasis on cleanliness and compatible sealant use.

Any oxygen system component should be cleaned thoroughly before installation. Often tubing comes with leftover residue from the bending or flaring processes. Cleaning should be accomplished with nonpetroleum-based cleansers. Trichlorethylene, acetone, and similar cleaners can be used to flush new tubing. Tubing should be blown or baked dry before installation. Follow the manufacturer's procedures for cleaning oxygen system components.

Some oxygen components make use of tapered pipe fittings. This type of connection is usually sealed with the application of thread lubricant/sealant. Typical thread sealers are petroleum based and should not be used; only oxygen compatible thread lubricant/sealers should be used. Alternatively, Teflon® tape is also used on oxygen pipe fitting

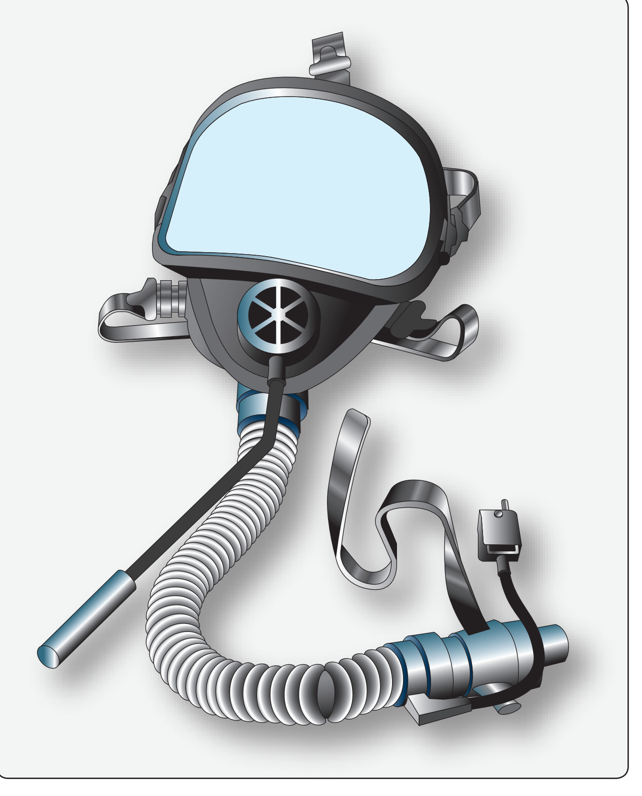


Figure 16-33. *Smoke masks cover the eyes as well as the nose and mouth of the user.*

connections. Be sure to begin wrapping the Teflon® tape at least two threads from the end of the fitting. This prevents any tape from coming loose and entering the oxygen system.

Prevention of Oxygen Fires or Explosions

Precautions must be observed when working with or around pure oxygen. It readily combines with other substances, some in a violent and explosive manner. As mentioned, it is extremely important to keep distance between pure oxygen and petroleum products. When allowed to combine, an explosion can result. Additionally, there are a variety of inspection and maintenance practices that should be followed to ensure safety when working with oxygen and oxygen systems. Care should be used and, as much as possible, maintenance should be done outside.

When working on an oxygen system, it is essential that the warnings and precautions given in the aircraft maintenance manual be carefully observed. Before any work is attempted, an adequate fire extinguisher should be on hand. Cordon off the area and post "NO SMOKING" placards. Ensure that all tools and servicing equipment are clean and avoid power on checks and use of the aircraft electrical system.

Oxygen System Inspection and Maintenance

When working around oxygen and oxygen systems, cleanliness enhances safety. Clean, grease-free hands, clothes, and tools are essential. A good practice is to use only tools dedicated for work on oxygen systems. There should be absolutely no smoking or open flames within a minimum of 50 feet of the work area. Always use protective caps and plugs when working with oxygen cylinders, system components, or plumbing. Do not use any kind of adhesive tape. Oxygen cylinders should be stored in a designated, cool, ventilated area in the hangar away from petroleum products or heat sources.

Oxygen system maintenance should not be accomplished until the valve on the oxygen supply cylinder is closed and pressure is released from the system. Fittings should be unscrewed slowly to allow any residual pressure to dissipate. All oxygen lines should be marked and should have at least 2 inches of clearance from moving parts, electrical wiring, and all fluid lines. Adequate clearance must also be provided from hot ducts and other sources that might heat the oxygen. A pressure and leak check must be performed each time the system is opened for maintenance. Do not use any lubricants, sealers, cleaners, etc., unless specifically approved for oxygen system use.

Aircraft Pressurization Systems

Pressure of the Atmosphere

The gases of the atmosphere (air), although invisible, have weight. A one square inch column of air stretching from sea level into space weighs 14.7 pounds. Therefore, it can be stated that the pressure of the atmosphere, or atmospheric pressure, at sea level is 14.7 psi. *[Figure 16-34]*

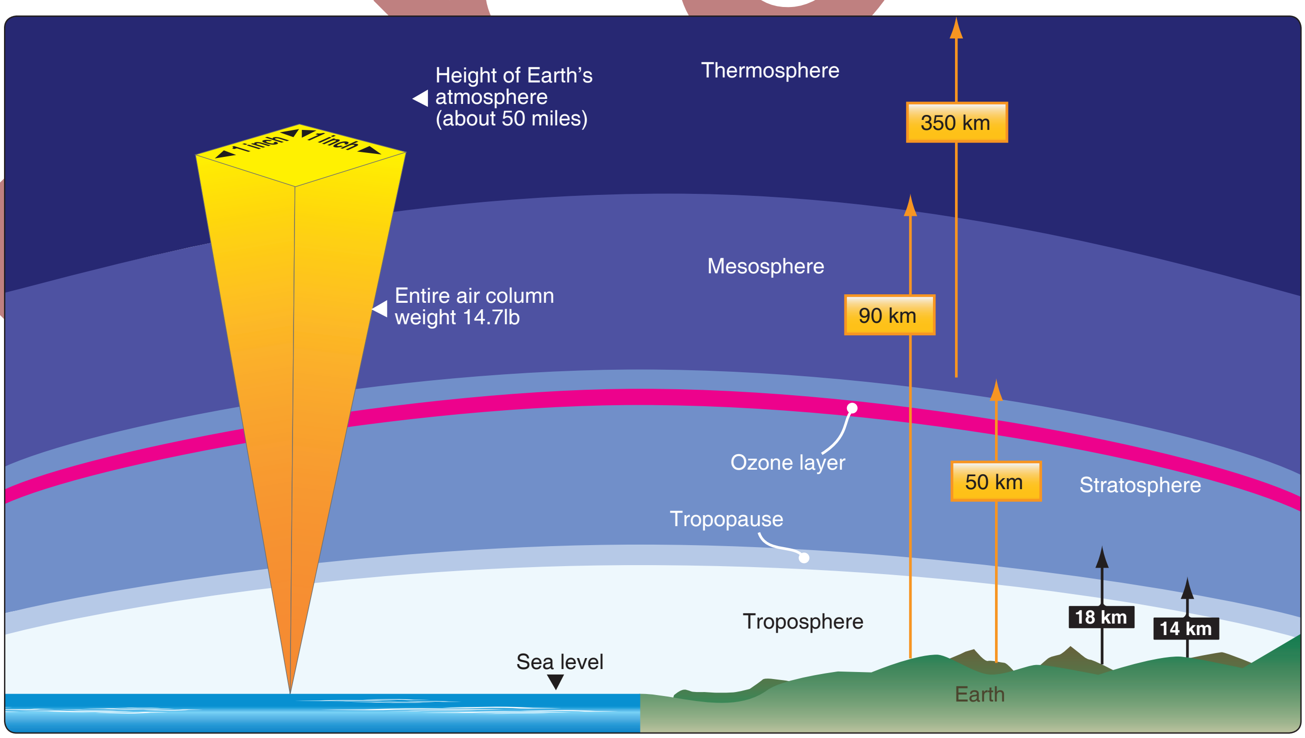


Figure 16-34. *The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.*

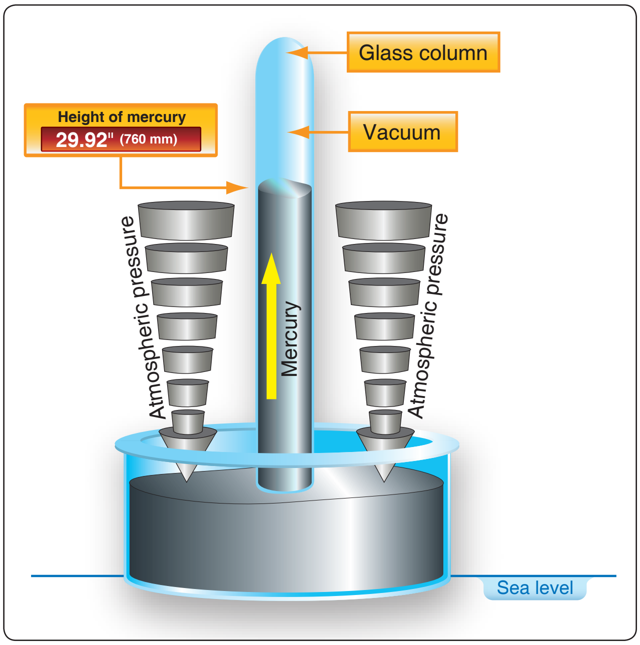


Figure 16-35. *The weight of the atmosphere pushes down on the mercury in the reservoir of a barometer, which causes mercury to rise in the column. At sea level, mercury is forced up into the column approximately 29.92 inches. Therefore, it is said that barometric pressure is 29.92 inches of mercury at sea level.*

Atmospheric pressure is also known as barometric pressure and is measured with a barometer. *[Figure 16-35]* Expressed in various ways, such as in inches of mercury or millimeters of mercury, these measurements come from observing the height of mercury in a column when air pressure is exerted on a reservoir of mercury into which the column is set. The column must be evacuated so air inside does not act against the mercury rising. A column of mercury 29.92 inches high weighs the same as a column of air that extends from sea level to the top of the atmosphere and has the same cross-section as the column of mercury.

Aviators often interchange references to atmospheric pressure between linear displacement (e.g., inches of mercury) and units of force (e.g., psi). Over the years, meteorology has shifted its use of linear displacement representation of atmospheric

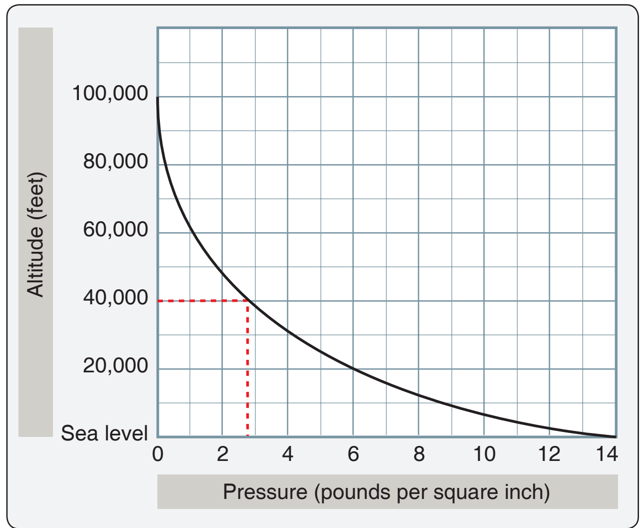


Figure 16-37. *Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40,000 feet, as the dotted lines show, the pressure is only 2.72 psi.*

pressure to units of force. However, the unit of force nearly universally used today to represent atmospheric pressure in meteorology is the hectopascal (hPa). A hectopascal is a metric (SI) unit that expresses force in newtons per square meter. 1,013.2 hPa is equal to 14.7 psi. *[Figure 16-36]*

Atmospheric pressure decreases with increasing altitude. The simplest explanation for this is that the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in *Figure 16-37.* The decrease in pressure is a rapid one and, at 50,000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value.

Temperature and Altitude

Temperature variations in the atmosphere are of concern to aviators. Weather systems produce changes in temperature near the earth's surface. Temperature also changes as altitude is increased. The troposphere is the lowest layer of the atmosphere. On average, it ranges from the earth's surface to about 38,000 feet above it. Over the poles, the troposphere extends to only 25,000–30,000 feet and, at the equator, it

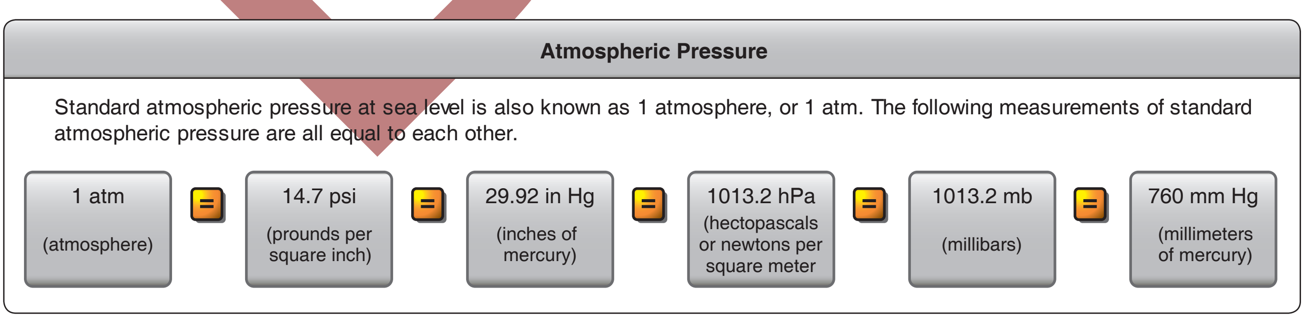


Figure 16-36. *Various equivalent representations of atmospheric pressure at sea level.*

may extend to around 60,000 feet. This oblong nature of the troposphere is illustrated in *Figure 16-38*.

Most civilian aviation takes place in the troposphere in which temperature decreases as altitude increases. The rate of change is somewhat constant at about –2 °C or –3.5 °F for every 1,000 feet of increase in altitude. The upper boundary of the troposphere is the tropopause. It is characterized as a zone of relatively constant temperature of –57 °C or –69 °F.

Above the tropopause lies the stratosphere. Temperature increases with altitude in the stratosphere to near 0 °C before decreasing again in the mesosphere, which lies above it. The stratosphere contains the ozone layer that protects the earth's inhabitants from harmful UV rays. Some civilian flights and numerous military flights occur in the stratosphere. *Figure 16-39* diagrams the temperature variations in different layers of the atmosphere.

When an aircraft is flown at high altitude, it burns less fuel for a given airspeed than it does for the same speed at a lower altitude. This is due to decreased drag that results from the reduction in air density. Bad weather and turbulence can also be avoided by flying in the relatively smooth air above storms and convective activity that occur in the lower troposphere. To take advantage of these efficiencies, aircraft are equipped with environmental systems to overcome extreme temperature and pressure levels. While supplemental oxygen and a means of staying warm suffice, aircraft pressurization and air conditioning systems have been developed to make high altitude flight more comfortable. *Figure 16-40* illustrates the temperatures and pressures at various altitudes in the atmosphere.

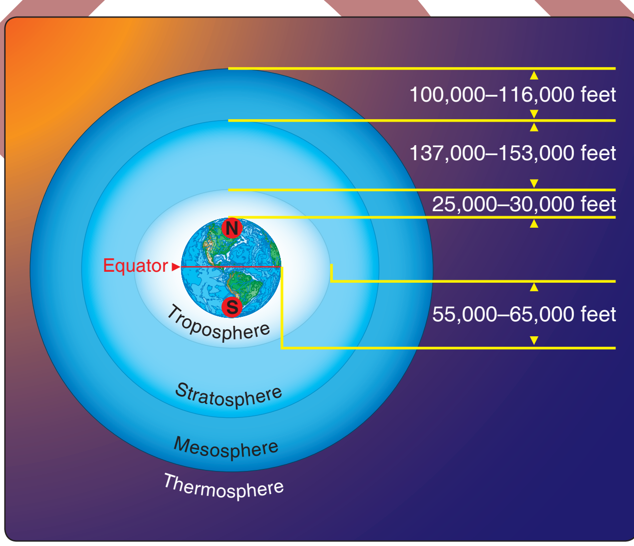


Figure 16-38. *The troposphere extends higher above the earth's surface at the equator than it does at the poles.*

Pressurization Terms

The following terms should be understood for the discussion of pressurization and cabin environmental systems that follows:

1. Cabin altitude—given the air pressure inside the cabin, the altitude on a standard day that has the same pressure as that in the cabin. Rather than saying the pressure inside the cabin is 10.92 psi, it can be said that the cabin altitude is 8,000 feet (MSL).
2. Cabin differential pressure—the difference between the air pressure inside the cabin and the air pressure outside the cabin. Cabin pressure (psi) – ambient pressure (psi) = cabin differential pressure (psid or Δ psi).
3. Cabin rate of climb—the rate of change of air pressure inside the cabin, expressed in feet per minute (fpm) of cabin altitude change.

Pressurization Issues

Pressurizing an aircraft cabin assists in making flight possible in the hostile environment of the upper atmosphere.

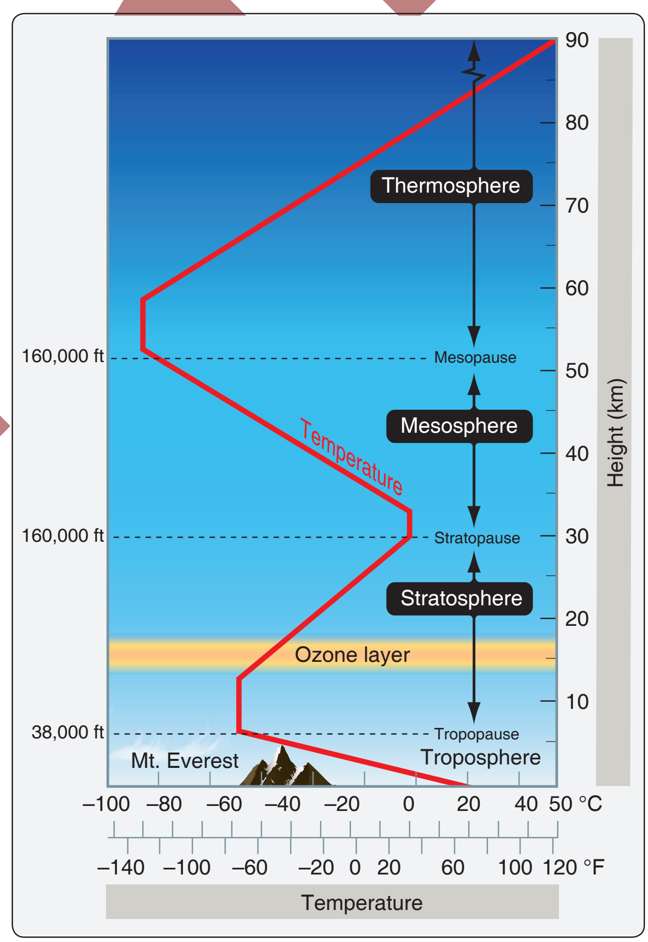


Figure 16-39. *The atmospheric layers with temperature changes depicted by the red line.*

Altitude	Pressure			Temperature	
feet	psi	hPa	in Hg	°F	°C
0	14.69	1013.2	29.92	59.0	15
1,000	14.18	977.2	28.86	55.4	13
2,000	13.66	942.1	27.82	51.9	11
3,000	13.17	908.1	26.82	48.3	9.1
4,000	12.69	875.1	25.84	44.7	7.1
5,000	12.23	843.1	24.90	41.2	5.1
6,000	11.77	812.0	23.98	37.6	3.1
7,000	11.34	781.8	23.09	34.0	1.1
8,000	10.92	752.6	22.23	30.5	–0.8
9,000	10.51	724.3	21.39	26.9	–2.8
10,000	10.10	696.8	20.58	23.3	–4.8
12,000	9.34	644.4	19.03	16.2	–8.8
14,000	8.63	595.2	17.58	9.1	–12.7
16,000	7.96	549.2	16.22	1.9	–16.7
18,000	7.34	506.0	14.94	–5.2	–29.7
20,000	6.76	465.6	13.75	–12.3	–24.6
22,000	6.21	427.9	12.64	–19.5	–28.6
24,000	5.70	392.7	11.60	–26.6	–32.5
26,000	5.22	359.9	10.63	–33.7	–36.5
28,000	4.78	329.3	9.72	–40.9	–40.5
30,000	4.37	300.9	8.89	–48.0	–44.4
32,000	3.99	274.5	8.11	–55.1	–48.4
34,000	3.63	250.0	7.38	–62.2	–52.4
36,000	3.30	227.3	6.71	–69.4	–56.3
38,000	3.00	206.5	6.10	–69.4	–56.5
40,000	2.73	187.5	5.54	–69.4	–56.5
45,000	2.14	147.5	4.35	–69.4	–56.5
50,000	1.70	116.0	3.42	–69.4	–56.5

Figure 16-40. *Cabin environmental systems establish conditions quite different from these found outside the aircraft.*

The degree of pressurization and the operating altitude of any aircraft are limited by critical design factors. A cabin pressurization system must accomplish several functions if it is to ensure adequate passenger comfort and safety. It must be capable of maintaining a cabin pressure altitude of approximately 8,000 feet or lower regardless of the cruising altitude of the aircraft. This is to ensure that passengers and crew have enough oxygen present at sufficient pressure to facilitate full blood saturation. A pressurization system must also be designed to prevent rapid changes of cabin pressure, which can be uncomfortable or injurious to passengers and crew. Additionally, a pressurization system should circulate air from inside the cabin to the outside at a rate that quickly eliminates odors and to remove stale air. Cabin air must also be heated or cooled on pressurized aircraft. Typically, these functions are incorporated into the pressurization source.

To pressurize, a portion of the aircraft designed to contain air at a pressure higher than outside atmospheric pressure must be sealed. A wide variety of materials facilitate this. Compressible seals around doors combine with various other seals, grommets, and sealants to essentially establish an air tight pressure vessel. This usually includes the cabin, flight compartment, and the baggage compartments. Air is then pumped into this area at a constant rate sufficient to raise the pressure slightly above that which is needed. Control is maintained by adjusting the rate at which the air is allowed to flow out of the aircraft.

A key factor in pressurization is the ability of the fuselage to withstand the forces associated with the increase in pressure inside the structure versus the ambient pressure outside. This differential pressure can range from 3.5 psi for a single-engine reciprocating aircraft, to approximately 9 psi on high performance jet aircraft. *[Figure 16-41]* If the weight of the aircraft structure were of no concern, this would not be a problem. Making an aircraft strong for pressurization, yet also light, has been an engineering challenge met over numerous years beginning in the 1930s. The development of jet aircraft and their ability to exploit low drag flight at higher altitude made the problem even more pronounced. Today, the proliferation of composite materials in aircraft structure continues this engineering challenge.

In addition to being strong enough to withstand the pressure differential between the air inside and the air outside the cabin, metal fatigue from repeated pressurization and depressurization weakens the airframe. Some early pressurized aircraft structures failed due to this and resulted in fatal accidents. The FAA's aging aircraft program was instituted to increase inspection scrutiny of older airframes that may show signs of fatigue due to the pressurization cycle.

Aircraft of any size may be pressurized. Weight considerations when making the fuselage strong enough to endure pressurization usually limit pressurization to high performance light aircraft and larger aircraft. A few pressurized single-engine reciprocating aircraft exist, as well as many pressurized single-engine turboprop aircraft.

Sources of Pressurized Air

The source of air to pressurize an aircraft varies mainly with engine type. Reciprocating aircraft have pressurization sources different from those of turbine-powered aircraft. Note that the compression of air raises its temperature. A means for keeping pressurization air cool enough is built into most pressurization systems. It may be in the form of a heat exchanger, using cold ambient air to modify the temperature of the air from the pressurization source. A full air cycle air conditioning system with expansion turbine may also be used. The latter provides the advantage of temperature control on the ground and at low altitudes where ambient air temperature may be higher than comfortable for the passengers and crew.

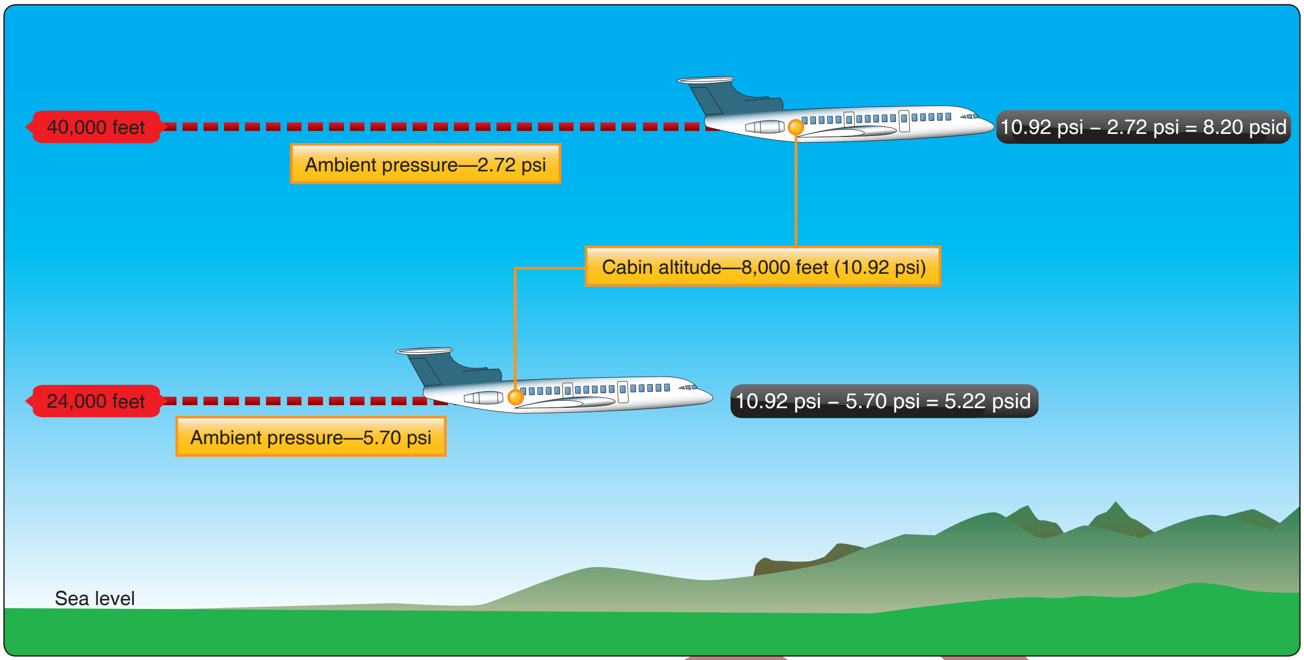


Figure 16-41. *Differential pressure (psid) is calculated by subtracting the ambient air pressure from the cabin air pressure.*

Reciprocating Engine Aircraft

There are three typical sources of air used to pressurize reciprocating aircraft: supercharger, turbocharger, and engine-driven compressor. Superchargers and turbochargers are installed on reciprocating engines to permit better performance at high altitude by increasing the quantity and pressure of the air in the induction system. Some of the air produced by each of these can be routed into the cabin to pressurize it.

A supercharger is mechanically driven by the engine. Despite engine performance increases due to higher induction system pressure, some of the engine output is utilized by the supercharger. Furthermore, superchargers have limited capability to increase engine performance. If supplying both the intake and the cabin with air, the engine performance ceiling is lower than if the aircraft were not pressurized. Superchargers must be located upstream of the fuel delivery to be used for pressurization. They are found on older reciprocating engine aircraft, including those with radial engines. *[Figures 16-42* and *16-43]*

Turbochargers, sometimes known as turbosuperchargers, are driven by engine exhaust gases. They are the most common source of pressurization on modern reciprocating engine aircraft. The turbocharger impeller shaft extends through the bearing housing to support a compression impeller in a separate housing. By using some of the turbocharger compressed air for cabin pressurization, less is available for the intake charge, resulting in lower overall engine performance. Nonetheless, the otherwise wasted exhaust gases are put to work in the turbocharger compressor, enabling high altitude flight with the benefits of low drag and weather avoidance in relative comfort and without the use of supplemental oxygen. *[Figures 16-44* and *16-45]*

Both superchargers and turbochargers are oil lubricated. The supercharger is part of the fuel intake system and the turbocharger is part of the exhaust system. As such, there is a risk of contamination of cabin air from oil, fuel, or exhaust fumes should a malfunction occur, a shortcoming of these pressurization sources.

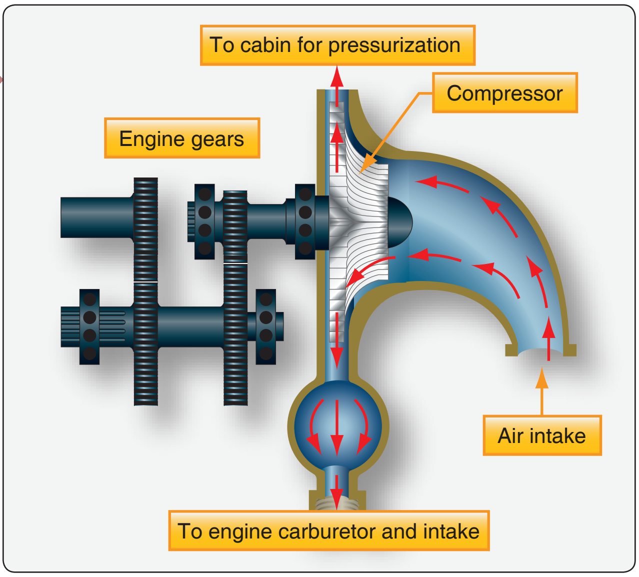


Figure 16-42. *A reciprocating engine supercharger can be used as a source of pressurization if it is upstream of carburetion.*

Figure 16-43. *The radial engine supercharger cannot be used since fuel is introduced before the supercharger impeller compresses the air.*

A third source of air for pressurizing the cabin in reciprocating aircraft is an engine driven compressor. Either belt driven or gear driven by the accessory drive, an independent, dedicated compressor for pressurization avoids some of the potential contamination issues of superchargers and turbochargers. The compressor device does, however, add significant weight. It also consumes engine output since it is engine driven.

The roots blower is used on older, large reciprocating engine aircraft. *[Figure 16-46]* The two lobes in this compressor do not touch each other or the compressor housing. As they rotate, air enters the space between the lobes and is compressed and delivered to the cabin for pressurization. Independent engine-driven centrifugal compressors can also be found on reciprocating engine aircraft. *[Figure 16-47]* A variable ratio gear drive system is used to maintain a constant rate of airflow during changes of engine rpm.

Near maximum operating altitude, the performance of any reciprocating engine and the pressurization compressor suffer. This is due to the reduced pressure of the air at altitude that supplies the intake of each. The result is difficulty in maintaining a sufficient volume of air to the engine intake to produce power, as well as to allow enough air to the fuselage for pressurization. These are the limiting factors for determining the design ceiling of most reciprocating aircraft, which typically does not exceed 25,000 feet. Turbine engine aircraft overcome these shortcomings, permitting them to fly at much higher altitudes.

Turbine Engine Aircraft

The main principle of operation of a turbine engine involves the compression of large amounts of air to be mixed with fuel and burned. Bleed air from the compressor section of the engine is relatively free of contaminants. As such, it is a great source of air for cabin pressurization. However, the volume of air for engine power production is reduced. The amount of air bled off for pressurization compared to the overall amount of air compressed for combustion is relatively small but should be minimized. Modern large-cabin turbofan engine aircraft contain recirculation fans to reuse up to 50 percent of the air in the cabin, maintaining high engine output.

There are different ways hot, high-pressure bleed air can be exploited. Smaller turbine aircraft, or sections of a large aircraft, may make use of a jet pump flow multiplier. With this device, bleed air is tapped off of the turbine engine's compressor section. It is ejected into a venturi jet pump mounted in air ducting that has one end open to the ambient air and the other end directed into the compartment to be

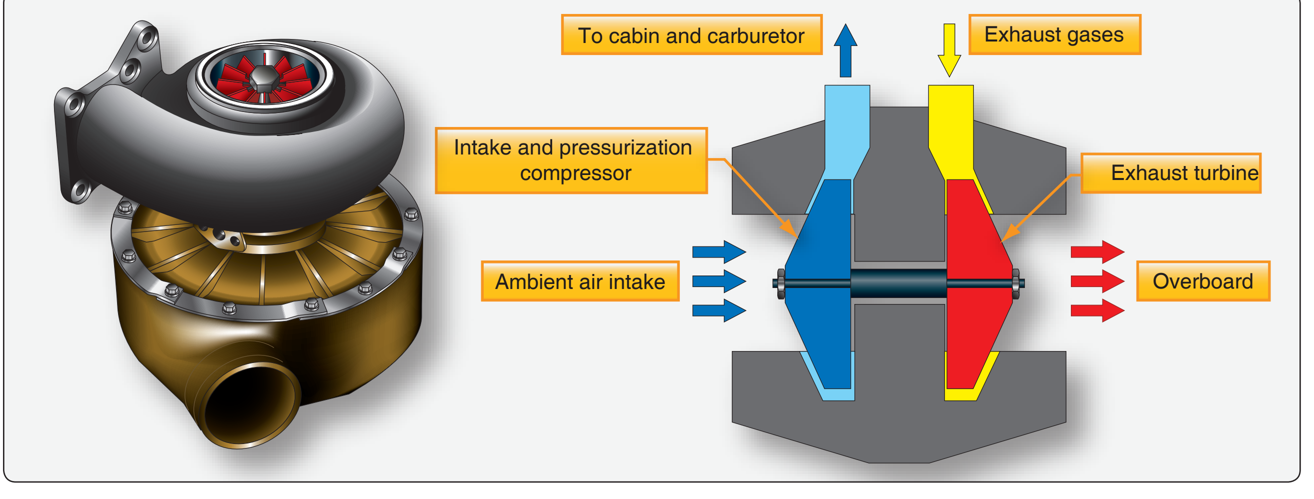


Figure 16-44. *A turbocharger used for pressurizing cabin air and engine intake air on a reciprocating engine aircraft.*

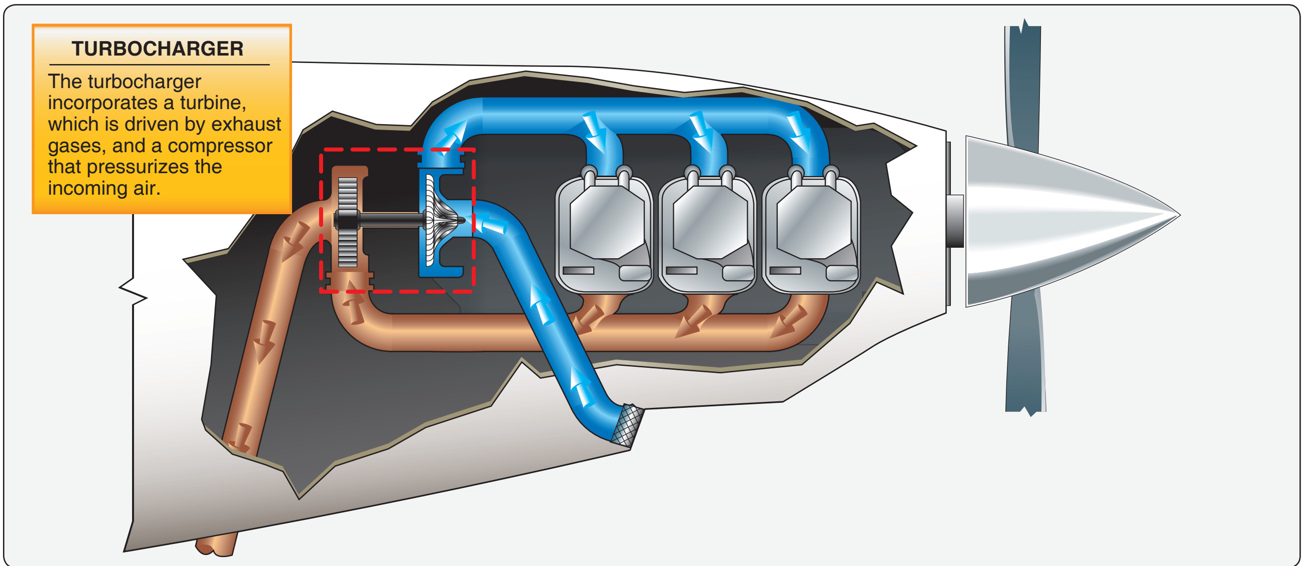


Figure 16-45. *A turbocharger installation on a reciprocating aircraft engine (top left side).*

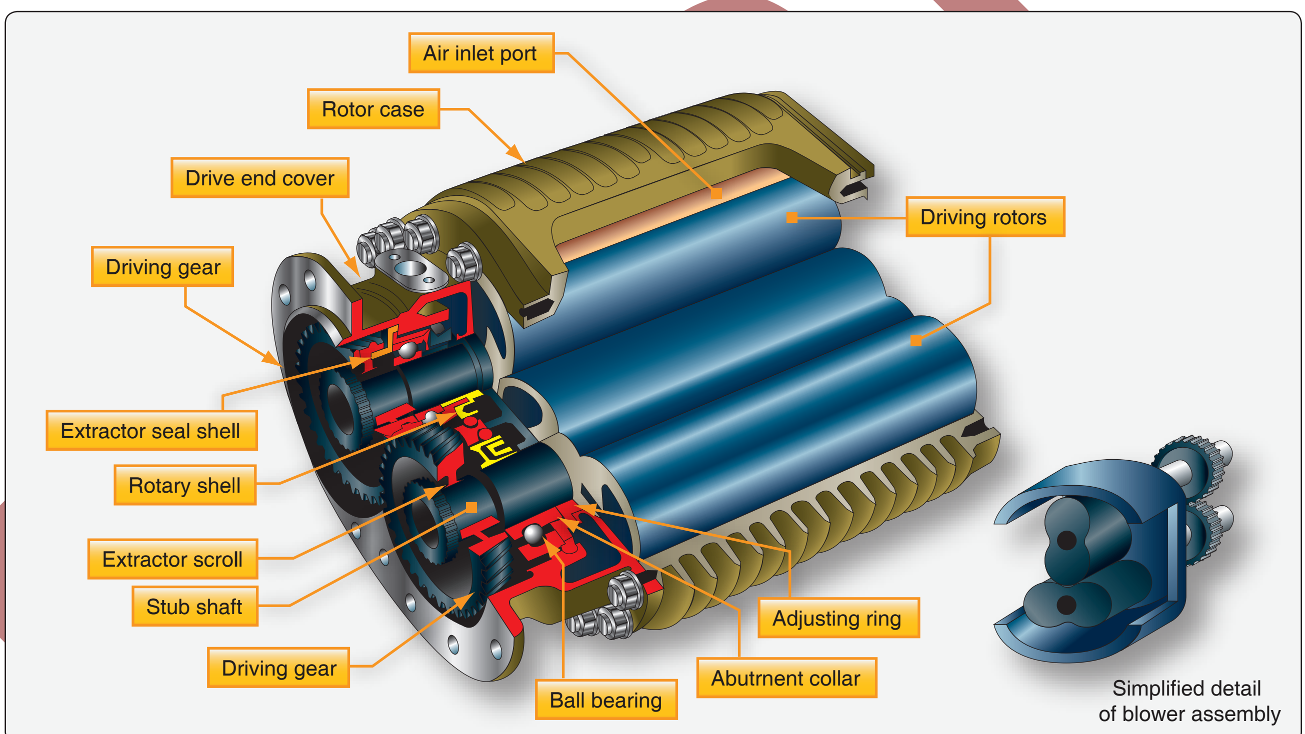


Figure 16-46. *A roots blower found on older pressurized aircraft is gear driven by the engine. It pressurizes air as the rotors rotate very close to each other without touching.*

pressurized. Due to the low pressure established in the venturi by the bleed air flow, air is drawn in from outside the aircraft. It mixes with the bleed air and is delivered to the pressure vessel to pressurize it. An advantage of this type of pressurization is the lack of moving parts. *[Figure 16-48]* A disadvantage is only a relatively small volume of space can be pressurized in this manner.

Another method of pressurizing an aircraft using turbine engine compressor bleed air is to have the bleed air drive a separate compressor that has an ambient air intake. A turbine turned by bleed air rotates a compressor impellor mounted on the same shaft. Outside air is drawn in and compressed. It is mixed with the bleed air outflow from the turbine and is sent to the pressure vessel. Turboprop aircraft often use this device, known as a turbocompressor. *[Figure 16-49]*

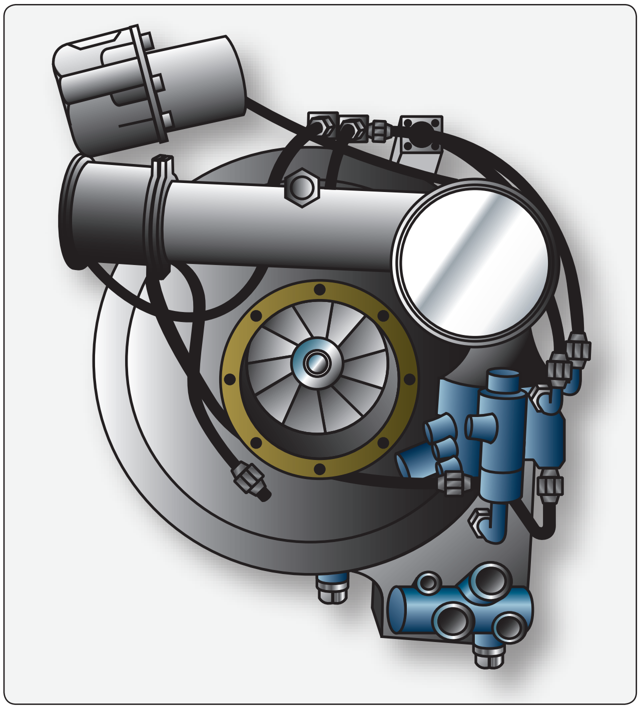


Figure 16-47. *A centrifugal cabin supercharger.*

The most common method of pressurizing turbine-powered aircraft is with an air cycle air conditioning and pressurization system. Bleed air is used, and through an elaborate system including heat exchangers, a compressor, and an expansion turbine, cabin pressurization and the temperature of the pressurizing air are precisely controlled. This air cycle system is discussed in greater detail in the air conditioning section of this chapter. *[Figure 16-50]*

Control of Cabin Pressure

Pressurization Modes

Aircraft cabin pressurization can be controlled via two different modes of operation. The first is the isobaric mode, which works to maintain cabin altitude at a single pressure despite the changing altitude of the aircraft. For example, the flight crew may select to maintain a cabin altitude of 8,000 feet (10.92 psi). In the isobaric mode, the cabin pressure is established at the 8,000-foot level and remains at this level, even as the altitude of the aircraft fluctuates.

The second mode of pressurization control is the constant differential mode, which controls cabin pressure to maintain a constant pressure difference between the air pressure inside the cabin and the ambient air pressure, regardless of aircraft altitude changes. The constant differential mode pressure differential is lower than the maximum differential pressure for which the airframe is designed, keeping the integrity of the pressure vessel intact.

When in isobaric mode, the pressurization system maintains the cabin altitude selected by the crew. This is the condition for normal operations. But when the aircraft climbs beyond a certain altitude, maintaining the selected cabin altitude may result in a differential pressure above that for which the airframe was designed. In this case, the mode of pressurization automatically switches from isobaric to constant differential mode. This occurs before the cabin's max differential pressure limit is reached. A constant differential pressure is then maintained, regardless of the selected cabin altitude.

In addition to the modes of operation described above, the rate of change of the cabin pressure, also known as the cabin rate of climb or descent, is also controlled. This can be done

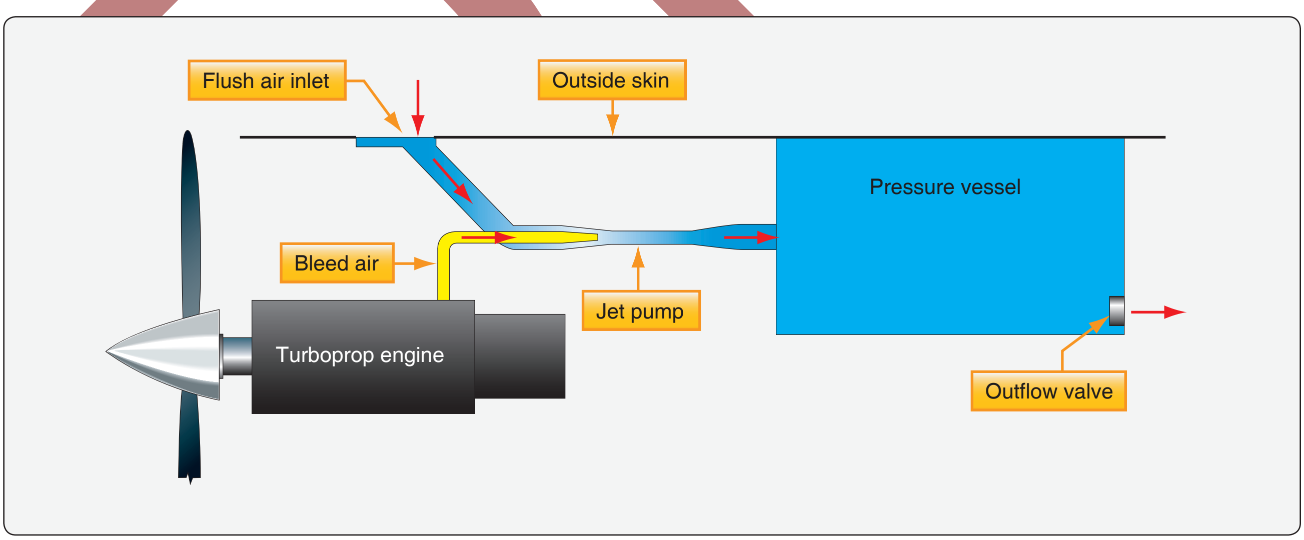


Figure 16-48. *A jet pump flow multiplier ejects bleed air into a venturi which draws air for pressurization from outside the aircraft.*

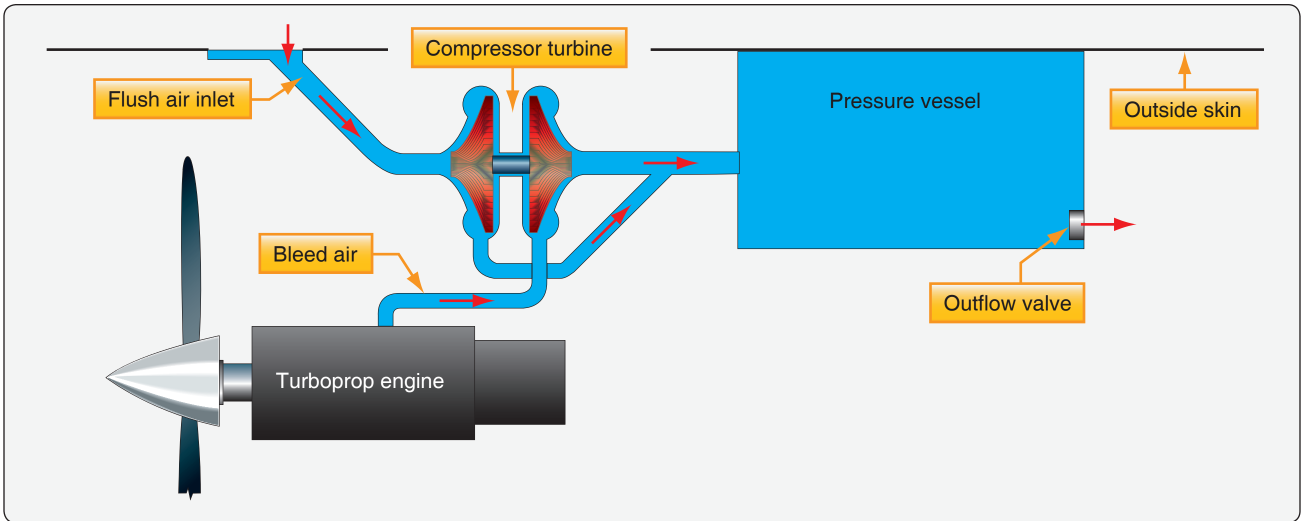


Figure 16-49. *A turbo compressor used to pressurize cabins mostly in turboprop aircraft.*

Figure 16-50. *An air cycle air conditioning system used to pressurize the cabin of a business jet.*

automatically or manually by the flight crew. Typical rates of change for cabin pressure are 300 to 500 fpm. Also, note that modes of pressurization may also refer to automatic versus standby versus manual operation of the pressurization system.

Cabin Pressure Controller

The cabin pressure controller is the device used to control the cabin air pressure. Older aircraft use strictly pneumatic means for controlling cabin pressure. Selections for the desired cabin altitude, rate of cabin altitude change, and barometric pressure setting are all made directly to the pressure controller from pressurization panel in the cockpit. *[Figure 16-51]*

Adjustments and settings on the pressure controller are the control input parameters for the cabin pressure regulator. The regulator controls the position of the outflow valve(s) normally located at the rear of the aircraft pressure vessel. Valve position determines the pressure level in the cabin.

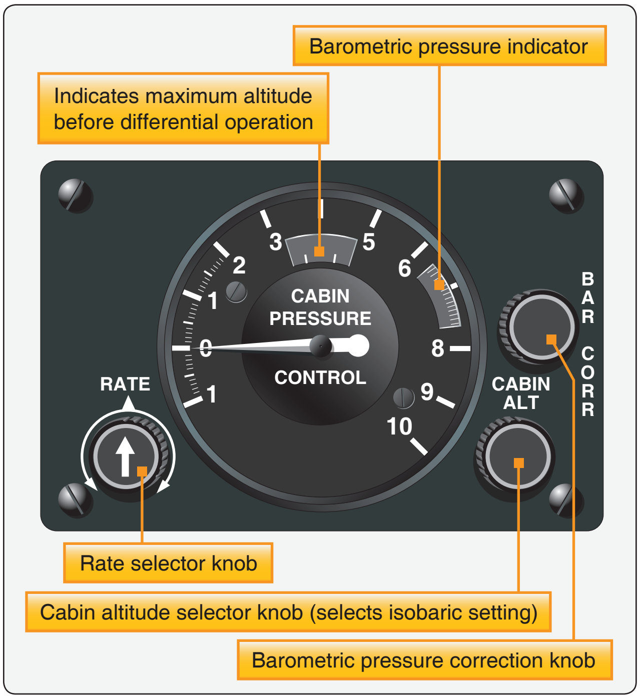


Figure 16-51. *A pressure controller for an all pneumatic cabin pressure control system.*

Modern aircraft often combine pneumatic, electric, and electronic control of pressurization. Cabin altitude, cabin rate of change, and barometric setting are made on the cabin pressure selector of the pressurization panel in the cockpit. Electric signals are sent from the selector to the cabin pressure controller, which functions as the pressure regulator. It is remotely located out of sight near the cockpit but inside the pressurized portion of the aircraft. The signals are converted from electric to digital and are used by the controller. Cabin pressure and ambient pressure are also input to the controller, as well as other inputs. *[Figure 16-52]*

Using this information, the controller, which is essentially a computer, supplies pressurization logic for various stages of a flight. On many small transport and business jets, the controller's electric output signal drives a torque motor in the primary outflow valve. This modulates pneumatic airflow through the valve, which positions the valve to maintain the pressurization schedule.

On many transport category aircraft, two cabin pressure controllers, or a single controller with redundant circuitry, are used. Located in the electronics equipment bay, they receive electric input from the panel selector, as well as ambient and cabin pressure input. Flight altitude and landing field altitude information are often the crew selection choices on the pressurization control panel. Cabin altitude, rate of climb, and barometric setting are automatic through built-in logic and communication with the ADC and the flight management

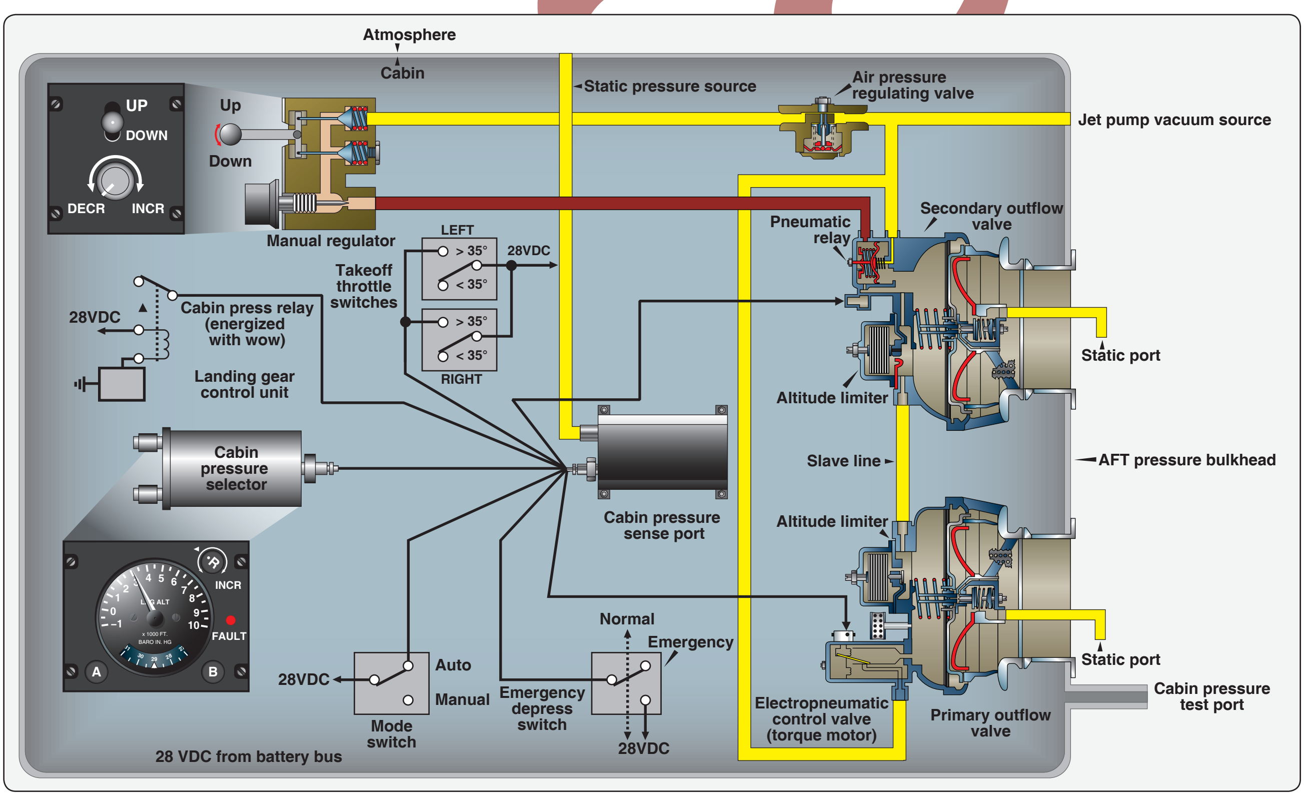


Figure 16-52. *The pressurization control system on many small transports and business jets utilizes a combination of electronic, electric, and pneumatic control elements.*

system (FMS). The controllers process the information and send electric signals to motors that directly position the outflow valve(s). *[Figure 16-53]*

Modern pressurization control is fully automatic once variable selections are made on the pressurization control panel if, in fact, there are any to be made. Entering or selecting a flight plan into the FMS of some aircraft automatically supplies the pressurization controller with the parameters needed to establish the pressurization schedule for the entire flight. No other input is needed from the crew.

All pressurization systems contain a manual mode that can override automatic control. This can be used in flight or on the ground during maintenance. The operator selects the manual mode on the pressurization control panel. A separate switch is used to position the outflow valve open or closed to control cabin pressure. The switch is visible in *Figure 16-53,* as well as a small gauge that indicates the position of the valve.

Cabin Air Pressure Regulator and Outflow Valve

Controlling cabin pressurization is accomplished through regulating the amount of air that flows out of the cabin. A cabin outflow valve opens, closes, or modulates to establish the amount of air pressure maintained in the cabin. Some outflow valves contain the pressure regulating and the valve mechanism in a single unit. They operate pneumatically in response to the settings on the cockpit pressurization panel that influence the balance between cabin and ambient air pressure. *[Figure 16-54]*

Pneumatic operation of outflow valves is common. It is simple, reliable, and eliminates the need to convert air pressure operating variables into some other form. Diaphragms, springs, metered orifices, jet pumps, bellows, and poppet valves are used to sense and manipulate cabin and ambient air pressures to correctly position the outflow valve without the use of electricity. Outflow valves that combine the use of electricity with pneumatic operation have all-pneumatic standby and manual modes, as shown in *Figure 16-52.*

The pressure regulating mechanism can also be found as a separate unit. Many air transport category aircraft have an outflow valve that operates electrically, using signals sent from a remotely located cabin air pressure controller that acts as the pressure regulator. The controller positions the valve(s) to achieve the settings on the cockpit pressurization panel selectors according to predetermined pressurization schedules. Signals are sent to electric motors to move the valve as needed. On transports, often AC motors are used with a redundant DC motor for standby or manual operations. *[Figure 16-55]*

Cabin Air Pressure Safety Valve Operation

Aircraft pressurization systems incorporate various features to limit human and structural damage should the system malfunction or become inoperative. A means for preventing overpressurization is incorporated to ensure the structural integrity of the aircraft if control of the pressurization system is lost. A cabin air safety valve is a pressure relief valve set to open at a predetermined pressure differential. It allows air to

Figure 16-53. *This pressurization panel from an 800 series Boeing 737 has input selections of flight altitude and landing altitude.*

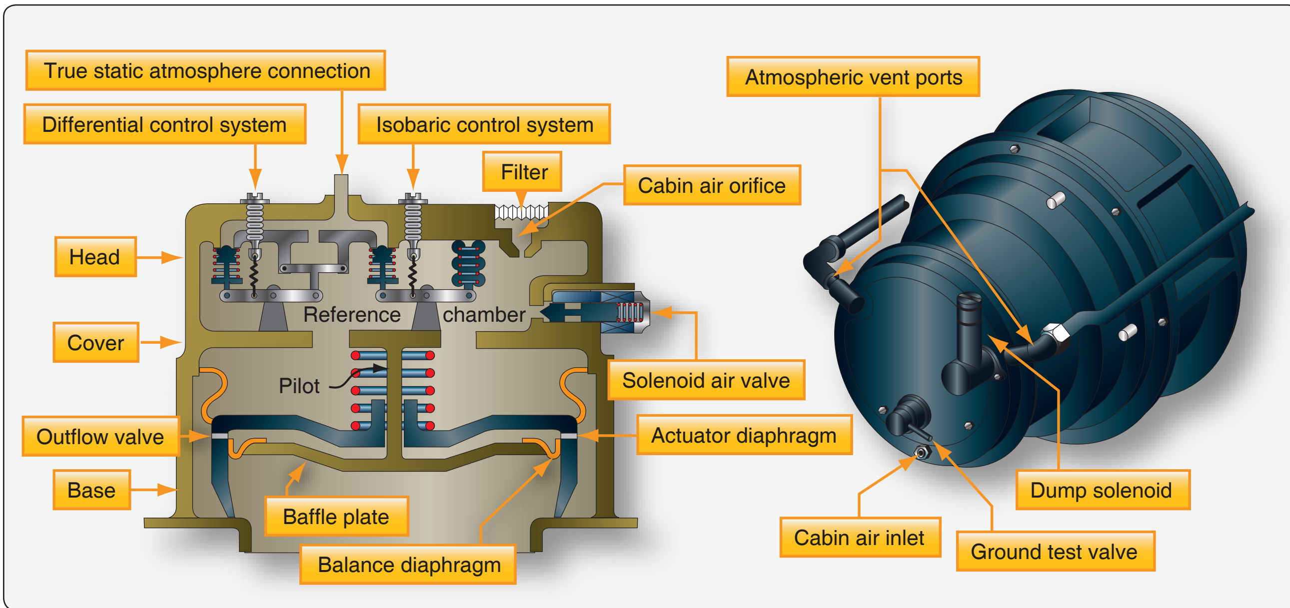


Figure 16-54. *An all-pneumatic cabin pressure regulator and outflow valve.*

flow from the cabin to prevent internal pressure from exceeding design limitations. *Figure 16-56* shows cabin air pressure safety valves on a large transport category aircraft. On most aircraft, safety valves are set to open between 8 and 10 psid.

Pressurization safety valves are used to prevent the over pressurization of the aircraft cabin. They open at a preset differential pressure and allow air to flow out of the cabin.

Figure 16-55. *This outflow valve on a transport category aircraft is normally operated by an ac motor controlled by a pressure controller in the electronics equipment bay. A second ac motor on the valve is use when in standby mode. A dc motor also on the valve is used for manual operation.*

Wide-body transport category aircraft cabins may have more than one cabin pressurization safety valve.

Some outflow valves incorporate the safety valve function into their design. This is common on some corporate jets when two outflow valves are used. One outflow valve operates as the primary and the other as a secondary. Both contain a pilot valve that opens when the pressure differential increases to a preset value. This, in turn, opens the outflow valve(s) to prevent further pressurization. The outflow valves shown in *Figure 16-52* operate in this manner.

Cabin altitude limiters are also used. These close the outflow valves when the pressure in the cabin drops well below the normal cabin altitude range, preventing a further

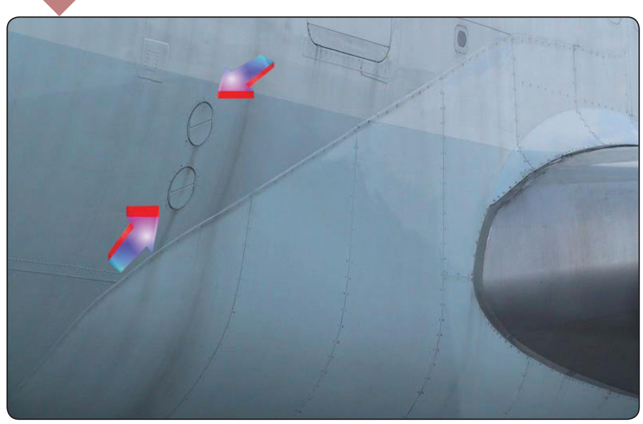


Figure 16-56. *Two pressurization safety valves are shown on a Boeing 747.*

increase in cabin altitude. Some limiter functions are built into the outflow valve(s). An example of this can be seen in *Figure 16-52*. Other limiters are independent bellows units that send input to the outflow valve or are part of the cabin pressurization controller logic.

A negative pressure relief valve is included on pressurized aircraft to ensure that air pressure outside the aircraft does not exceed cabin air pressure. The spring-loaded relief valve opens inward to allow ambient air to enter the cabin when this situation arises. Too much negative pressure can cause difficulty when opening the cabin door. If high enough, it could cause structural damage since the pressure vessel is designed for cabin pressure to be greater than ambient.

Some aircraft are equipped with pressurization dump valves. These essentially are safety valves that are operated automatically or manually by a switch in the cockpit. They are used to quickly remove air and air pressure from the cabin, usually in an abnormal, maintenance, or emergency situation.

Incorporation of an emergency pressurization mode is found on some aircraft. A valve opens when the air conditioning packs fail or emergency pressurization is selected from the cockpit. It directs a mixture of bleed air and ram air into the cabin. This combines with fully closed outflow valves to preserve some pressurization in the aircraft.

Pressurization Gauges

While all pressurization systems differ slightly, usually three cockpit indications, in concert with various warning lights and alerts, advise the crew of pressurization variables. They are the cabin altimeter, the cabin rate of climb or vertical speed indicator, and the cabin differential pressure indicator. These can be separate gauges or combined into one or two gauges. All are typically located on the pressurization panel, although sometimes they are elsewhere on the instrument panel. Outflow valve position indicator(s) are also common. *[Figure 16-57]* On modern aircraft equipped with digital aircraft monitoring systems with LCD displays, such as Engine Indicating and Crew Alerting System (EICAS) or Electronic Centralized Aircraft Monitor (ECAM), the pressurization panel may contain no gauges. The environmental control system (ECS) page of the monitoring system is selected to display similar information. Increased use of automatic redundancy and advanced operating logic simplifies operation of the pressurization system. It is almost completely automatic. The cabin pressurization panel remains in the cockpit primarily for manual control. *[Figure 16-58]*

Pressurization Operation

The normal mode of operation for most pressurization control systems is the automatic mode. A standby mode can also be

Figure 16-57. *This cabin pressurization gauge is a triple combination gauge. The long pointer operates identically to a vertical speed indicator with the same familiar scale on the left side of the gauge. It indicates the rate of change of cabin pressure. The orange PSI pointer indicates the differential pressure on the right side scale. The ALT indicator uses the same scale as the PSI pointer, but it indicates cabin altitude when ALT indicator moves against it.*

selected. This also provides automatic control of pressurization, usually with different inputs, a standby controller, or standby outflow valve operation. A manual mode is available should the automatic and standby modes fail. This allows the crew to directly position the outflow valve through pneumatic or electric control, depending on the system.

Coordination of all pressurization components during various flight segments is essential. A weight-on-wheels (WOW) switch attached to the landing gear and a throttle position switch are integral parts of many pressurization control systems. During ground operations and prior to takeoff, the WOW switch typically controls the position of the pressurization safety valve, which is held in the open position until the aircraft takes off. In an advanced system, the WOW switch may give input to the pressurization controller, which in turn controls the positions and operation of all pressurization components. In other systems, the WOW switch may directly control the safety valve or a pneumatic source valve that causes the safety valve to be held open until the source is cut at takeoff when the WOW switch opens.

Throttle position switches can be used to cause a smooth transition from an unpressurized cabin to a pressurized cabin. A partial closing of the outflow valve(s) when the WOW switch is closed (on the ground) and the throttles are advanced

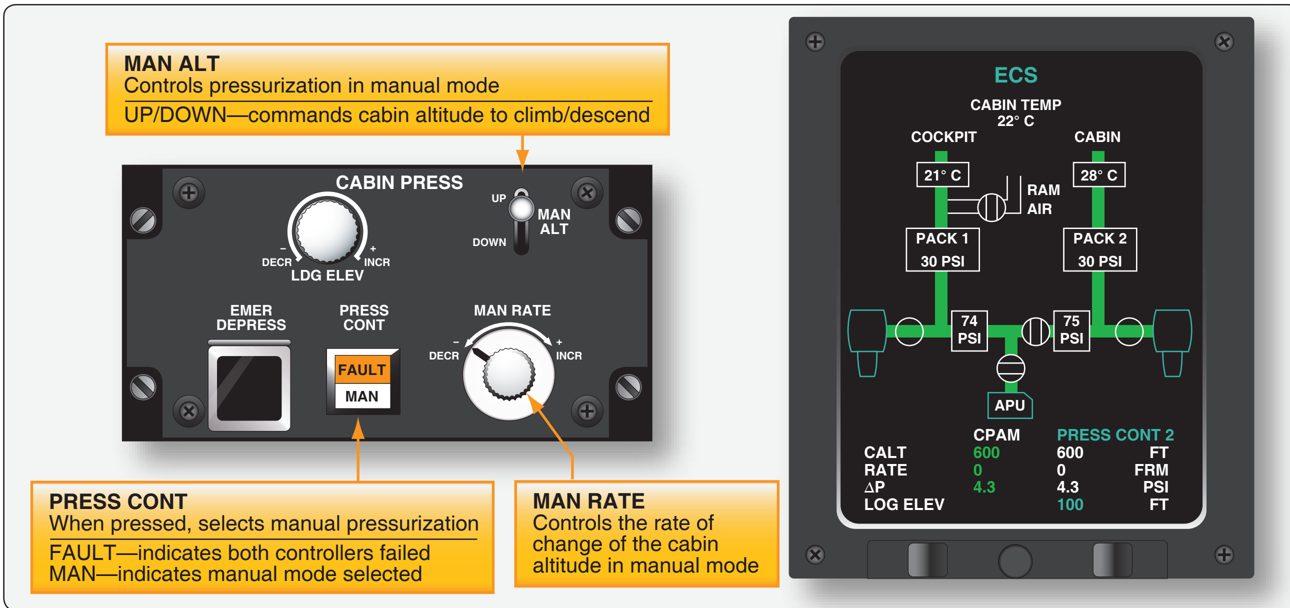


Figure 16-58. *The pressurization panel and environmental control system page on a Bombardier CRJ200 50 passenger jet have no gauges. Traditional pressurization data is presented in digital format at the bottom of the page.*

gradually initiates pressurization during rollout. At takeoff, the rate of climb and the pressurization schedule require the outflow valve(s) to fully close. Passengers do not experience a harsh sensation from the fully closed valves because the cabin has already begun to pressurize slightly.

Once in flight, the pressurization controller automatically controls the sequence of operation of the pressurization components until the aircraft lands. When the WOW switch closes again at landing, it opens the safety valve(s) and, in some aircraft, the outflow valve(s) makes pressurizing impossible on the ground in the automatic pressurization mode. Maintenance testing of the system is done in manual mode. This allows the technician to control the position of all valves from the cockpit panel.

Air Distribution

Distribution of cabin air on pressurized aircraft is managed with a system of air ducts leading from the pressurization source into and throughout the cabin. Typically, air is ducted to and released from ceiling vents, where it circulates and flows out floor-level vents. The air then flows aft through the baggage compartments and under the floor area. It exits the pressure vessel through the outflow valve(s) mounted low, on, or near the aft pressure bulkhead. The flow of air is nearly imperceptible. Ducting is hidden below the cabin floor and behind walls and ceiling panels depending on the aircraft and system design. Valves to select pressurization air source, ventilating air, temperature trim air, as well as in line fans and jet pumps to increase flow in certain areas of the cabin, are all components of the air distribution system. Temperature sensors, overheat switches, and check valves are also common.

On turbine-powered aircraft, temperature-controlled air from the air conditioning system is the air that is used to pressurize the cabin. The final regulation of the temperature of that air is sometimes considered part of the distribution system. Mixing air-conditioned air with bleed air in a duct or a mixing chamber allows the crew to select the exact temperature desired for the cabin. The valve for mixing is controlled in the cockpit or cabin by a temperature selector. Centralized manifolds from which air can be distributed are common. *[Figure 16-59]*

Large aircraft may be divided into zones for air distribution. Each zone has its own temperature selector and associated valve to mix conditioned and bleed air so that each zone can be maintain at a temperature independent of the others.

The air distribution system on most aircraft makes provisions for ducting and circulating cooling air to electronics equipment bays. It also contains a gasper air system. This is air ducted from the cold air manifold or duct to an overhead adjustable delivery nozzle at each passenger station. An inline fan controlled from the cockpit supplies a steady stream of gasper air that can be regulated or shut off with the delivery nozzle(s). *[Figure 16-60]*

When an aircraft is on the ground, operating the engines or the APU to provide air for air conditioning is expensive. It

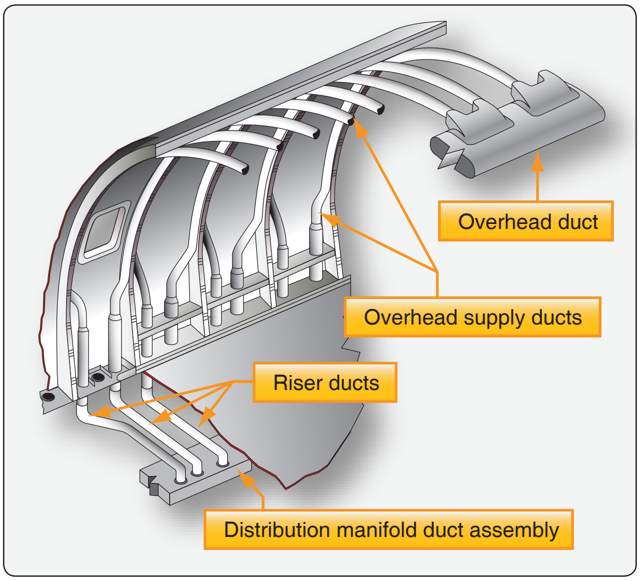


Figure 16-59. *Centralized manifolds from which air can be distributed are common.*

increases the time in service of these expensive components and expedites expensive mandatory overhauls that are performed at specified time intervals. Most high-performance, medium size, and larger turbine-powered aircraft are fitted with a receptacle in the air distribution system. To this a ground source of conditioned air can be connected via a ducting hose. The cabin can be heated or cooled through the aircraft's air distribution ducting using air from the ground source. This limits the operating time on the engines and APU. Once prefight checks and passenger boarding are completed, the ducting hose can be disconnected for taxi and flight. A check valve is used to prevent ground source air from flowing upstream into the air conditioning system. *[Figure 16-61]*

Cabin Pressurization Troubleshooting

While pressurization systems on different aircraft operate similarly with similar components, it cannot be assumed that they are the same. Even those systems constructed by a single manufacturer likely have differences when installed on different aircraft. It is important to check the aircraft manufacture's service information when troubleshooting the pressurization system. A fault, such as failure to pressurize or failure to maintain pressurization, can have many different causes. Adherence to the steps in a manufacturer's troubleshooting procedures is highly recommended to sequentially evaluate possible causes. Pressurization system test kits are available, or the aircraft can be pressurized by its normal sources during troubleshooting. A test flight may be required after maintenance.

Air Conditioning Systems

There are two types of air conditioning systems commonly used on aircraft. Air cycle air conditioning is used on most turbine-powered aircraft. It makes use of engine bleed air or APU pneumatic air during the conditioning process. Vapor cycle air conditioning systems are often used on reciprocating aircraft. This type system is similar to that found in homes and automobiles. Note that some turbine-powered aircraft also use vapor cycle air conditioning.

Air Cycle Air Conditioning

Air cycle air conditioning prepares engine bleed air to pressurize the aircraft cabin. The temperature and quantity of the air must be controlled to maintain a comfortable cabin environment at all altitudes and on the ground. The air cycle system is often called the air conditioning package or pack. It is usually located in the lower half of the fuselage or in the tail section of turbine-powered aircraft. *[Figure 16-62]*

System Operation

Even with the frigid temperatures experienced at high altitudes, bleed air is too hot to be used in the cabin without being cooled. It is let into the air cycle system and routed through a heat exchanger where ram air cools the bleed air. This cooled bleed air is directed into an air cycle machine. There, it is compressed before flowing through a secondary heat exchange that cools the air again with ram air. The bleed air then flows back into the air cycle machine where it drives an expansion turbine and cools even further. Water is then removed, and the air is mixed with bypassed bleed air for final temperature adjustment. It is sent to the cabin through the air distribution system. By examining the operation of each component in the air cycle process, a better understanding can be developed of how bleed air is conditioned for cabin use. Refer to *Figure 16-63,* which diagrams the air cycle air conditioning system of the Boeing 737.

Pneumatic System Supply

The air cycle air conditioning system is supplied with air by the aircraft pneumatic system. In turn, the pneumatic system is supplied by bleed air tap-offs on each engine compressor section or from the APU pneumatic supply. An external pneumatic air supply source may also be connected while the aircraft is stationary on the ground. In normal flight operations, a pneumatic manifold is supplied by the engine bleed air through the use of valves, regulators, and ducting. The air conditioning packs are supplied by this manifold as are other critical airframe systems, such as the anti-ice and hydraulic pressurization system.

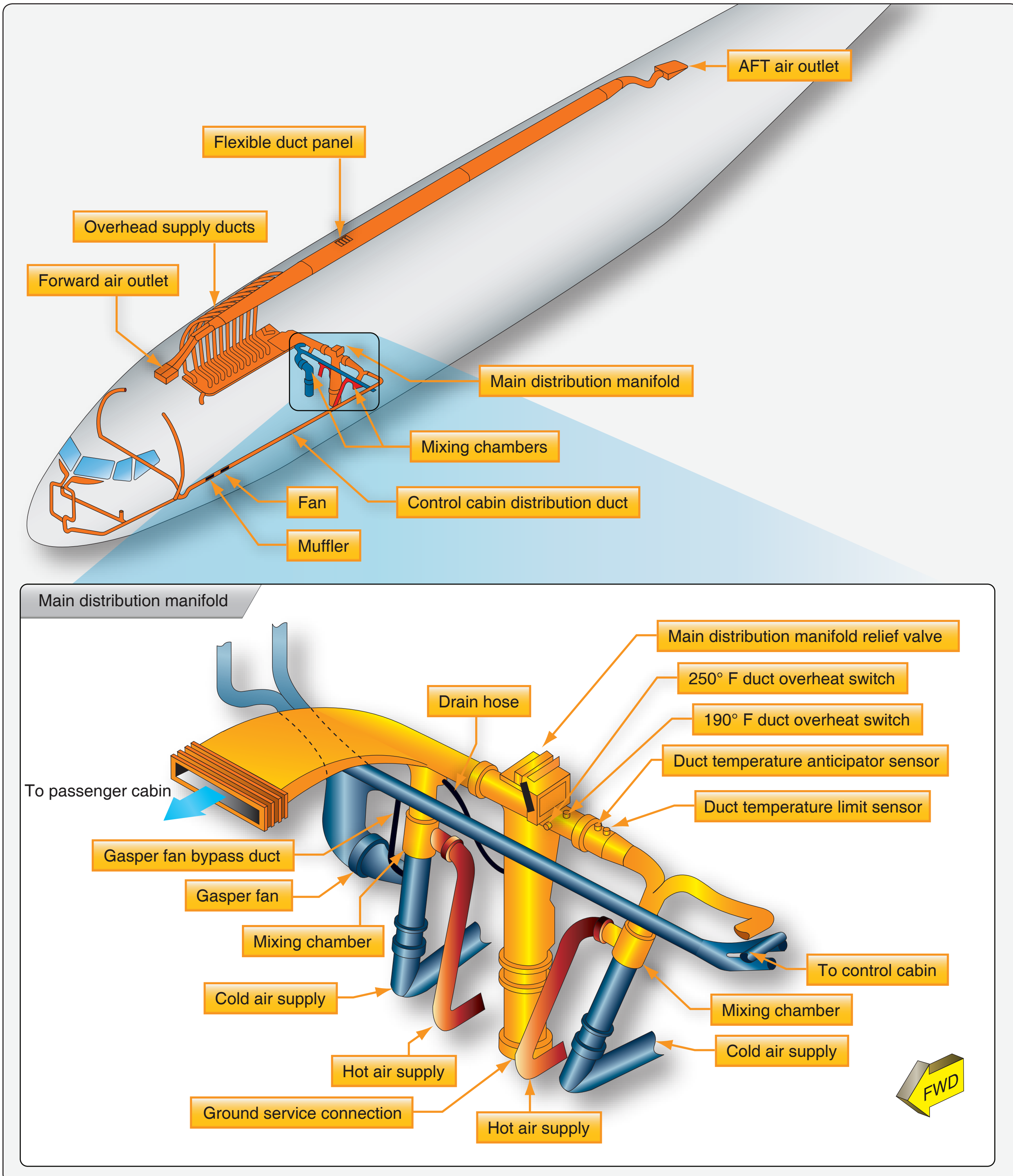


Figure 16-60. *The conditioned air distribution system on a Boeing 737. The main distribution manifold is located under the cabin floor. Riser ducts run horizontally then vertcally from the manifold to supply ducts, which follow the curvature of the fuselage carrying conditioned air to be released in the cabin.*

Figure 16-61. *A duct hose installed on this airliner distributes hot or cold air from a ground-based source throughout the cabin using the aircraft's own air distribution system ducting.*

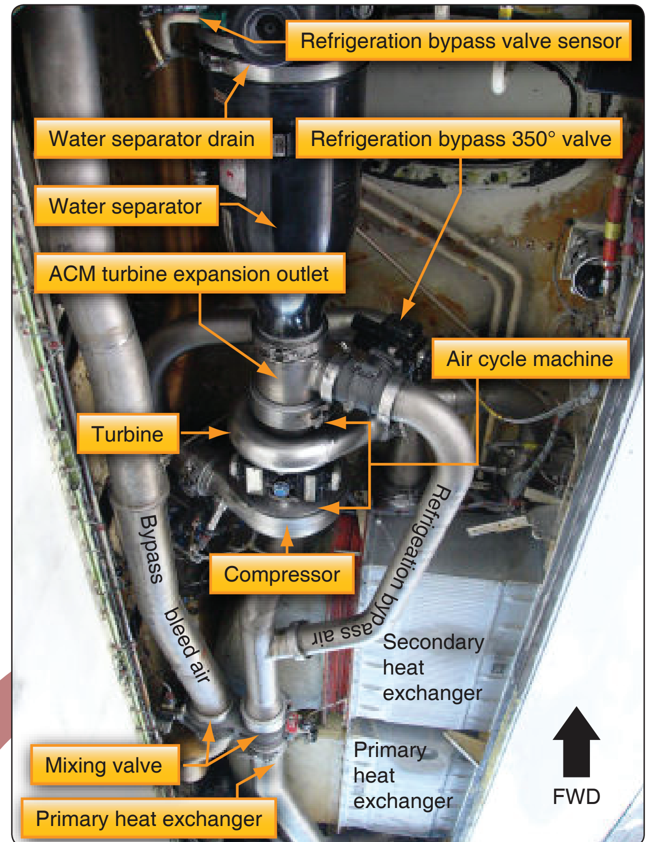


Figure 16-62. *Boeing 737 air cycle system. The photo is taken looking up into the air conditioning bay located in the lower fuselage on each side of the aircraft.*

Component Operation

Pack Valve

The pack valve is the valve that regulates bleed air from the pneumatic manifold into the air cycle air conditioning system. It is controlled with a switch from the air conditioning panel in the cockpit. Many pack valves are electrically controlled and pneumatically operated. Also known as the supply shutoff valve, the pack valve opens, closes, and modulates to allow the air cycle air conditioning system to be supplied with a designed volume of hot, pressurized air. *[Figure 16-64]* When an overheat or other abnormal condition requires that the air conditioning package be shut down, a signal is sent to the pack valve to close.

Bleed Air Bypass

A means for bypassing some of the pneumatic air supplied to the air cycle air conditioning system around the system is present on all aircraft. This warm bypassed air must be mixed with the cold air produced by the air cycle system so the air delivered to the cabin is a comfortable temperature. In the system shown in *Figure 16-58,* this is accomplished by the mixing valve. It simultaneously controls the flow of bypassed air and air to be cooled to meet the requirements of the auto temperature controller. It can also be controlled manually with the cabin temperature selector in manual mode. Other air cycle systems may refer to the valve that controls the air bypassed around the air cycle cooling system as a temperature control valve, trim air pressure regulating valve, or something similar.

Primary Heat Exchanger

Generally, the warm air dedicated to pass through the air cycle system first passes through a primary heat exchanger. It acts similarly to the radiator in an automobile. A controlled flow of ram air is ducted over and through the exchanger, which reduces the temperature of the air inside the system. *[Figure 16-65]* A fan draws air through the ram air duct when the aircraft is on the ground so that the heat exchange is possible when the aircraft is stationary. In flight, ram air doors are modulated to increase or decrease ram air flow to the exchanger according to the position of the wing flaps. During slow flight, when the flaps are extended, the doors are open. At higher speeds, with the flaps retracted, the doors move toward the closed position reducing the amount of ram air to the exchanger. Similar operation is accomplished with a valve on smaller aircraft. *[Figure 16-66]*

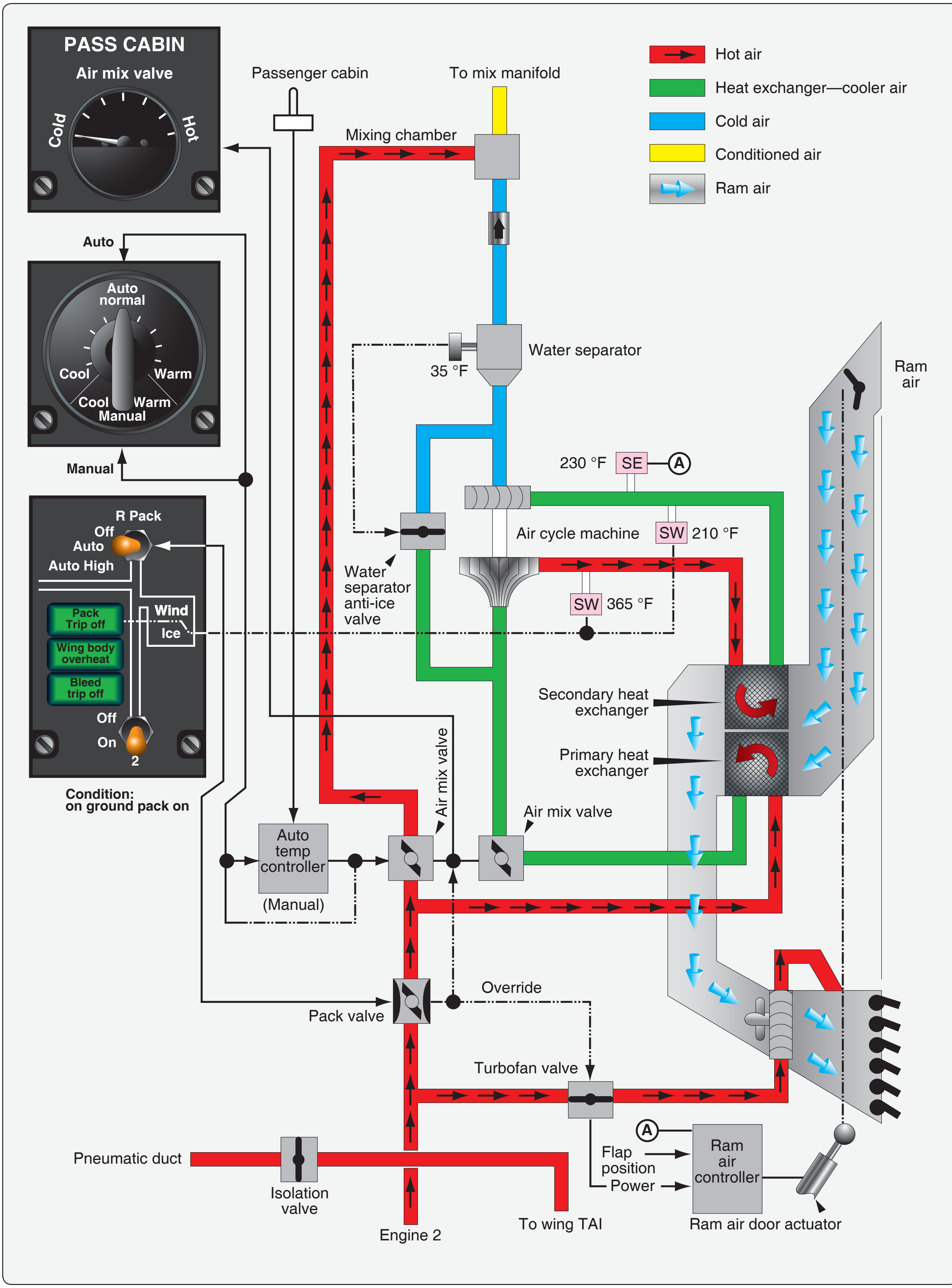


Figure 16-63. *The air cycle air conditioning system on a Boeing 737.*

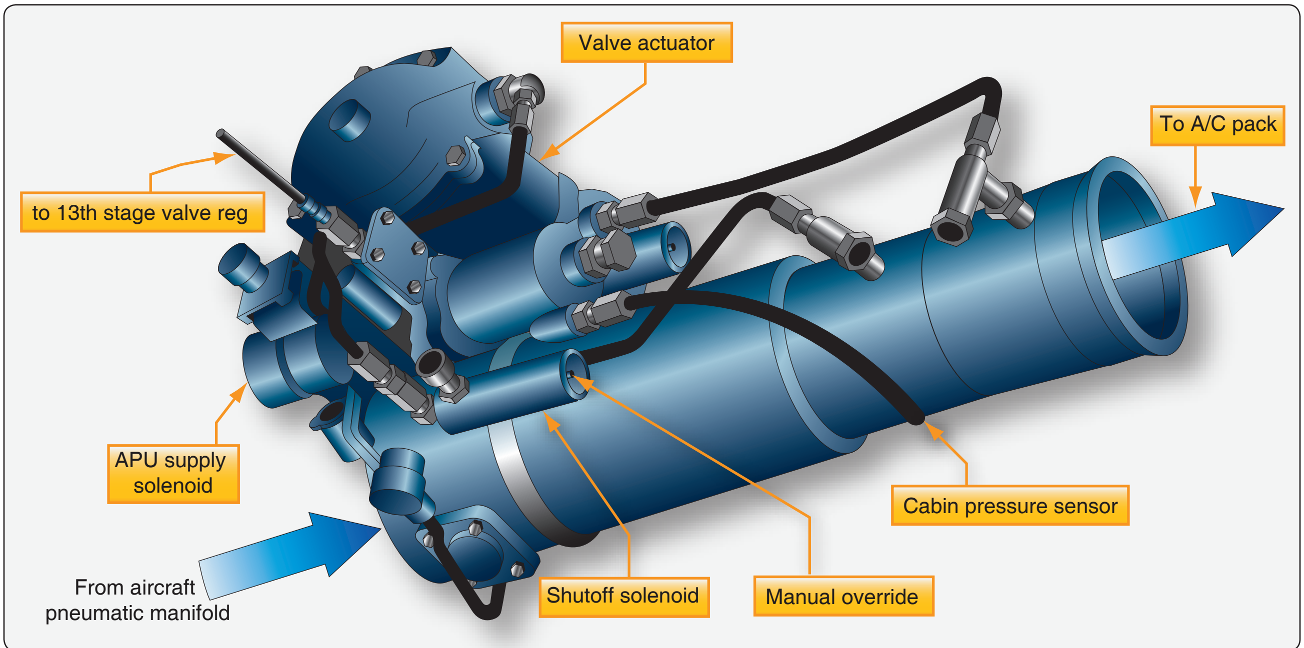


Figure 16-64. *This pack valve drawing illustrates the complexity of the valve, which opens, closes, and modulates. It is manually actuated from the cockpit and automatically responds to supply and air cycle system parameter inputs.*

Refrigeration Turbine Unit or Air Cycle Machine and Secondary Heat Exchanger

The heart of the air cycle air conditioning system is the refrigeration turbine unit, also known as the air cycle machine (ACM). It is comprised of a compressor that is driven by a turbine on a common shaft. System air flows from the primary heat exchanger into the compressor side of the ACM. As the air is compressed, its temperature rises. It is then sent to a secondary heat exchanger, similar to the primary heat exchanger located in the ram air duct. The elevated temperature of the ACM compressed air facilitates an easy exchange of heat energy to the ram air. The cooled system air, still under pressure from the continuous system air flow and the ACM compressor, exits the secondary heat exchanger. It is directed into the turbine side of the ACM. The steep blade pitch angle of the ACM turbine extracts more energy from the air as it passes through and drives the turbine. Once through,

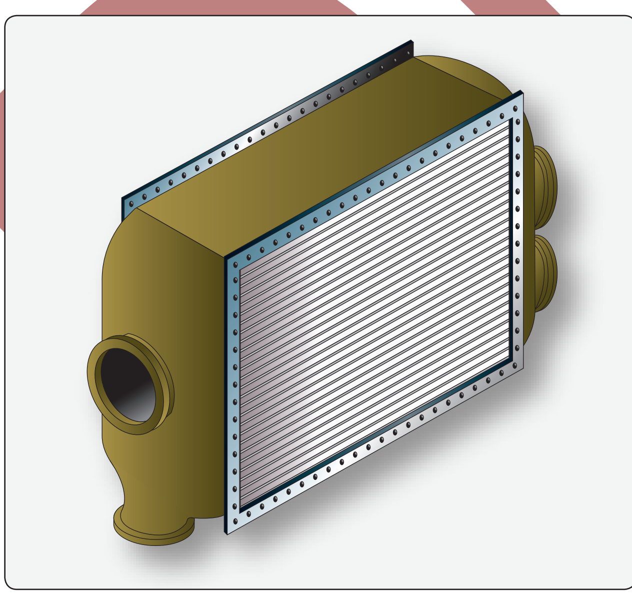


Figure 16-65. *The primary and secondary heat exchangers in an air cycle air conditioning system are of similar construction. They both cool bleed air when ram air passes over the exchanger coils and fins.*

Figure 16-66. *A ram air door controls the flow of air through the primary and secondary heat exchangers.*

the air is allowed to expand at the ACM outlet, cooling even further. The combined energy loss from the air first driving the turbine and then expanding at the turbine outlet lowers the system air temperature to near freezing. *[Figure 16-67]*

Water Separator

The cool air from the air cycle machine can no longer hold the quantity of water it could when it was warm. A water separator is used to remove the water from the saturated air before it is sent to the aircraft cabin. The separator operates with no moving parts. Foggy air from the ACM enters and is forced through a fiberglass sock that condenses and coalesces the mist into larger water drops. The convoluted interior structure of the separator swirls the air and water. The water collects on the sides of the separator and drains down and out of the unit, while the dry air passes through. A bypass valve is incorporated in case of a blockage. *[Figure 16-68]*

Refrigeration Bypass Valve

As mentioned, air exiting the ACM turbine expands and cools. It becomes so cold, it could freeze the water in the water separator, thus inhibiting or blocking airflow. A temperature sensor in the separator controls a refrigeration bypass valve designed to keep the air flowing through the water separator above freezing temperature. The valve is also identified by other names such as a temperature control valve, 35° valve, anti-ice valve, and similar. It bypasses warm air around the ACM when opened. The air is introduced into the expansion ducting, just upstream of the water separator, where it heats the air just enough to keep it from freezing. Thus, the refrigeration bypass valve regulates the temperature of the ACM discharge air so it does not freeze when passing through the water separator. This valve is visible in *Figure 16-62* and is diagrammed in the system in *Figure 16-63*.

All air cycle air conditioning systems use at least one ram air heat exchanger and an air cycle machine with expansion turbine to remove heat energy from the bleed air, but variations exist. An example of a system different from that described above is found on the McDonnell Douglas DC-10. Bleed air from the pneumatic manifold is compressed by the air cycle machine compressor before it flows to a single heat exchanger.

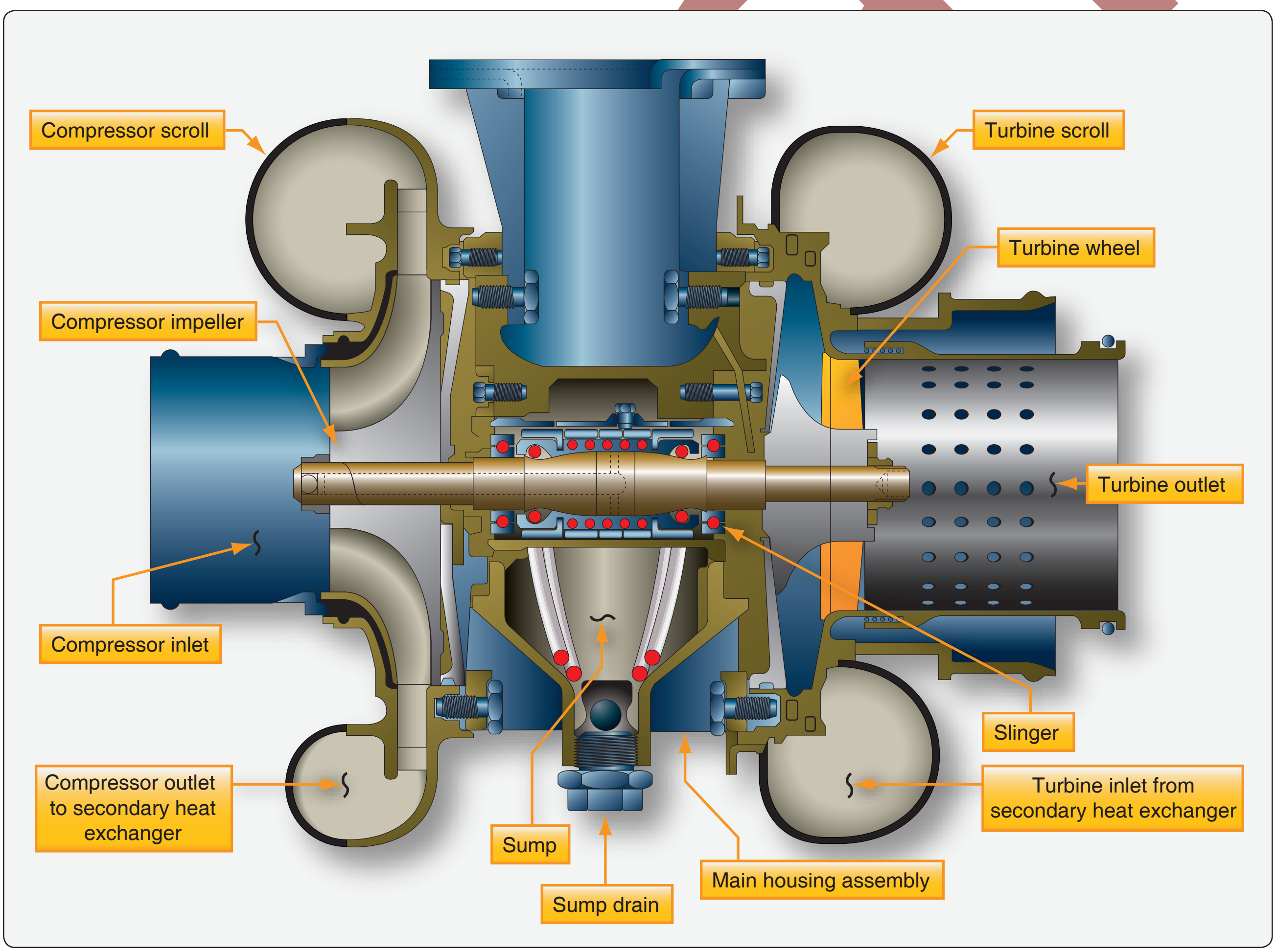


Figure 16-67. *A cutaway diagram of an air cycle machine. The main housing supports the single shaft to which the compressor and turbine are attached. Oil lubricates and cools the shaft bearings.*

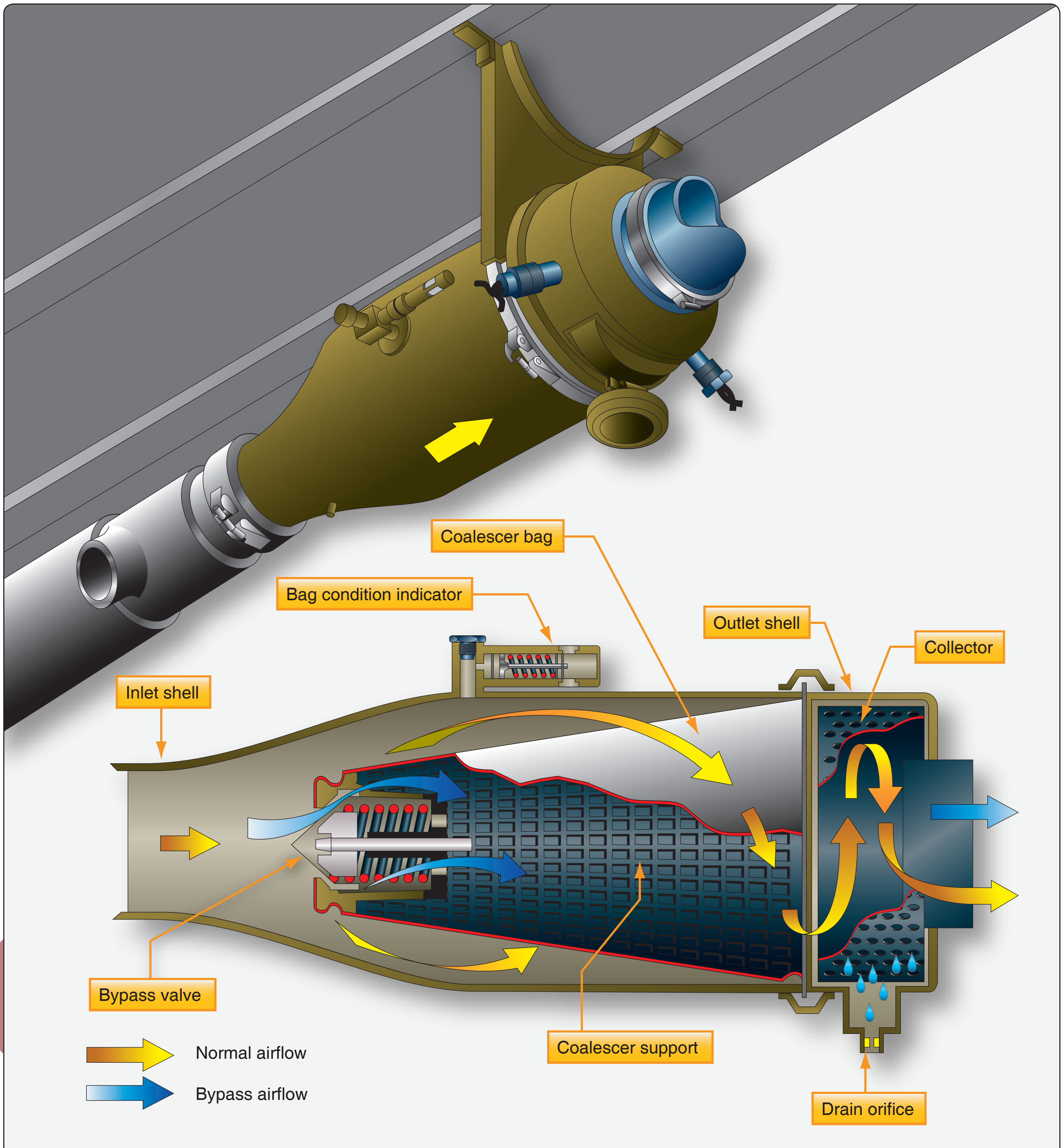


Figure 16-68. *A water separator coalesces and removes water by swirling the air/water mixture from ACM expansion turbine. Centrifugal force sends the water to the walls of the collector where it drains from the unit.*

Condensed water from the water separator is sprayed into the ram air at its entrance to the exchanger to draw additional heat from the compressed bleed air as the water evaporates. A trim air valve for each cabin zone mixes bypassed bleed air with conditioned air in response to individual temperature selectors for each zone. When cooling air demands are low, a turbine bypass valve routes some heat exchanger air directly to the conditioned air manifold. *[Figure 16-69]*

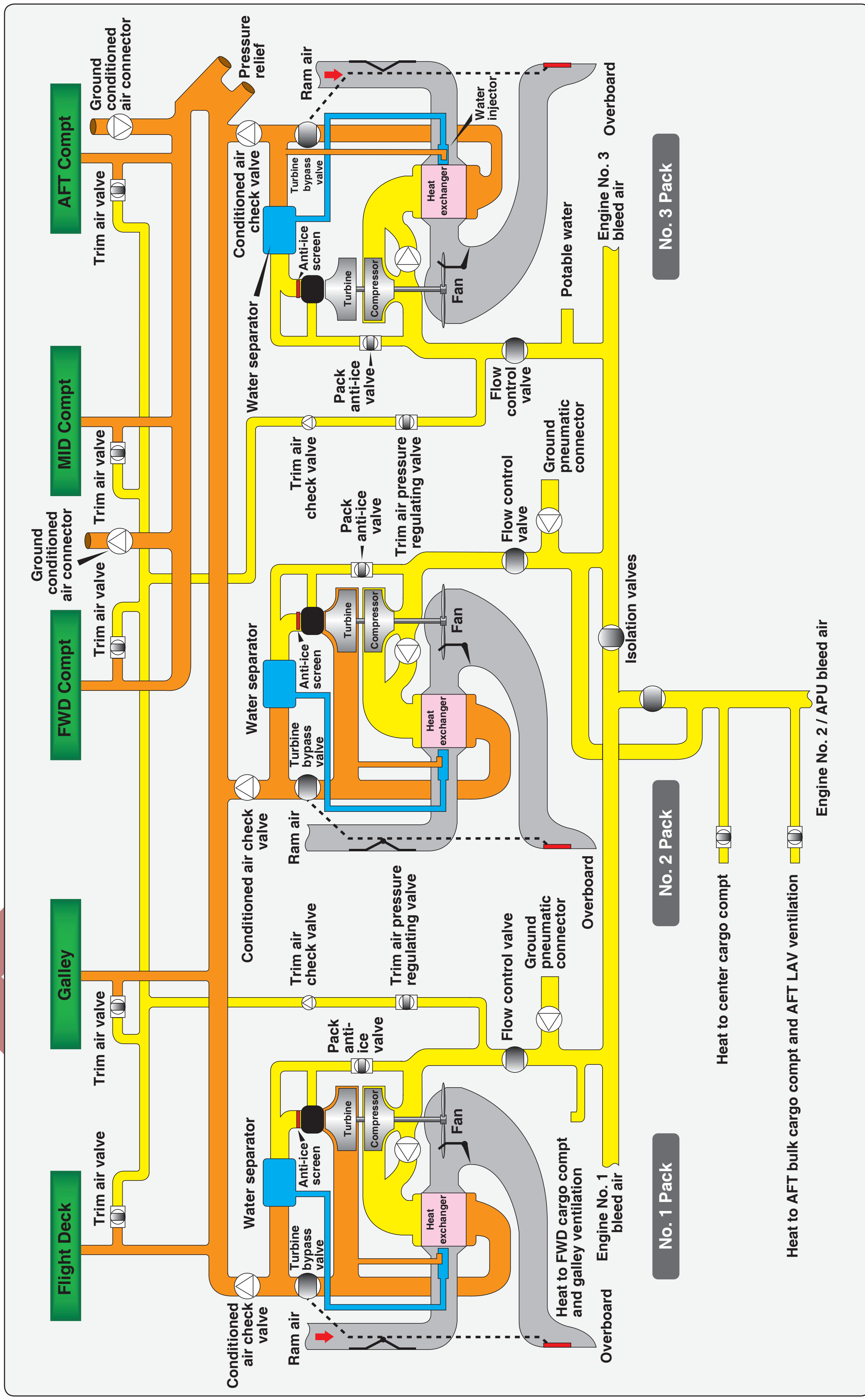


Figure 16-69. *The air cycle air conditioning system of a DC-10 transport category aircraft uses only one heat exchanger per ACM.*

Cabin Temperature Control System

Typical System Operation

Most cabin temperature control systems operate in a similar manner. Temperature is monitored in the cabin, cockpit, conditioned air ducts, and distribution air ducts. These values are input into a temperature controller, or temperature control regulator, normally located in the electronics bay. A temperature selector in the cockpit can be adjusted to input the desired temperature. *[Figure 16-70]* The temperature controller compares the actual temperature signals received from the various sensors with the desired temperature input. Circuit logic for the selected mode processes these input signals. An output signal is sent to a valve in the air cycle air conditioning system. This valve has different names depending on the aircraft manufacturer and design of the environmental control systems (i.e., mixing valve, temperature control valve, trim air valve). It mixes warm bleed air that bypassed the air cycle cooling process with the cold air produced by it. By modulating the valve in response to the signal from the temperature controller, air of the selected temperature is sent to the cabin through the air distribution system.

Cabin temperature pickup units and duct temperature sensors used in the temperature control system are thermistors. Their resistance changes as temperature changes. The temperature selector is a rheostat that varies its resistance as the knob is turned. In the temperature controller, resistances are compared in a bridge circuit. The bridge output feeds a temperature regulating function. An electric signal output is prepared and sent to the valve that mixes hot and cold air. On large aircraft with separate temperature zones, trim air modulating valves for each zone are used. The valves modulate to provide the correct mix required to match the selected temperature. Cabin, flight deck, and duct temperature sensors are strategically located to provide useful information to control cabin temperature. *[Figure 16-71]*

Vapor Cycle Air Conditioning

The absence of a bleed air source on reciprocating engine aircraft makes the use of an air cycle system impractical for conditioning cabin air. Vapor cycle air conditioning is used on most nonturbine aircraft that are equipped with air conditioning. However, it is not a source of pressurizing air as the air cycle system conditioned air is on turbine powered aircraft. The vapor cycle system only cools the cabin. If an aircraft equipped with a vapor cycle air conditioning system is pressurized, it uses one of the sources discussed in the pressurization section above. Vapor cycle air conditioning is a closed system used solely for the transfer of heat from inside the cabin to outside of the cabin. It can operate on the ground and in flight.

Theory of Refrigeration

Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapor cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapor. The vapor is compressed and becomes very hot. It is removed from the cabin where the very hot vapor refrigerant transfers its heat energy to the outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer. *[Figure 16-72]*

Heat is an expression of energy, typically measured by temperature. The higher the temperature of a substance, the more energy it contains. Heat always flows from hot to cold. These terms express the relative amount of energy present in two substances. They do not measure the absolute amount of heat present. Without a difference in energy levels, there is no transfer of energy (heat).

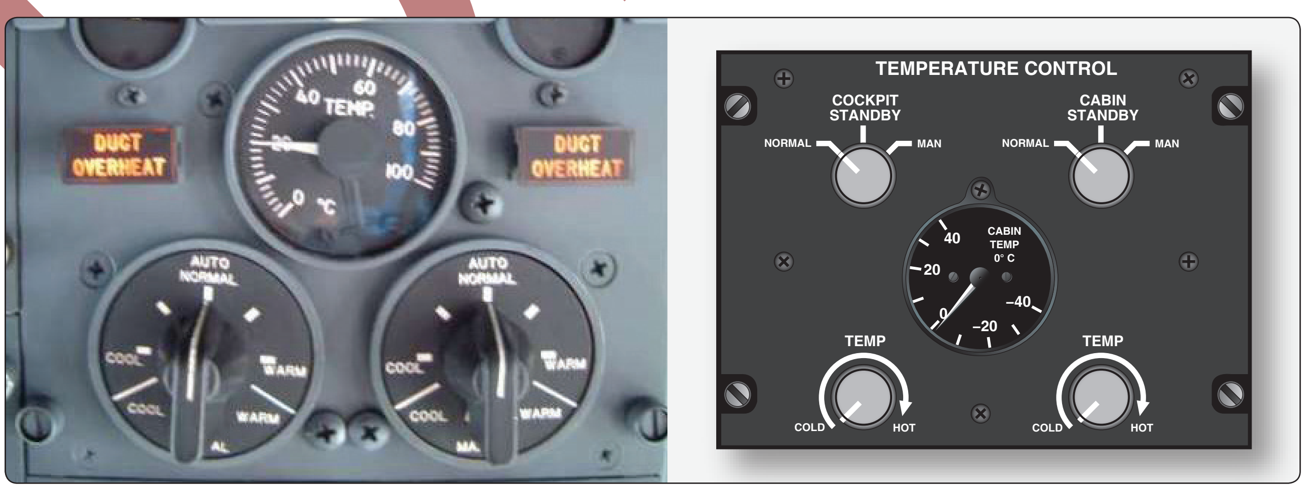


Figure 16-70. *Typical temperature selectors on a transport category aircraft temperature control panel in the cockpit (left) and a business jet (right). On large aircraft, temperature selectors may be located on control panels located in a particular cabin air distribution zone.*

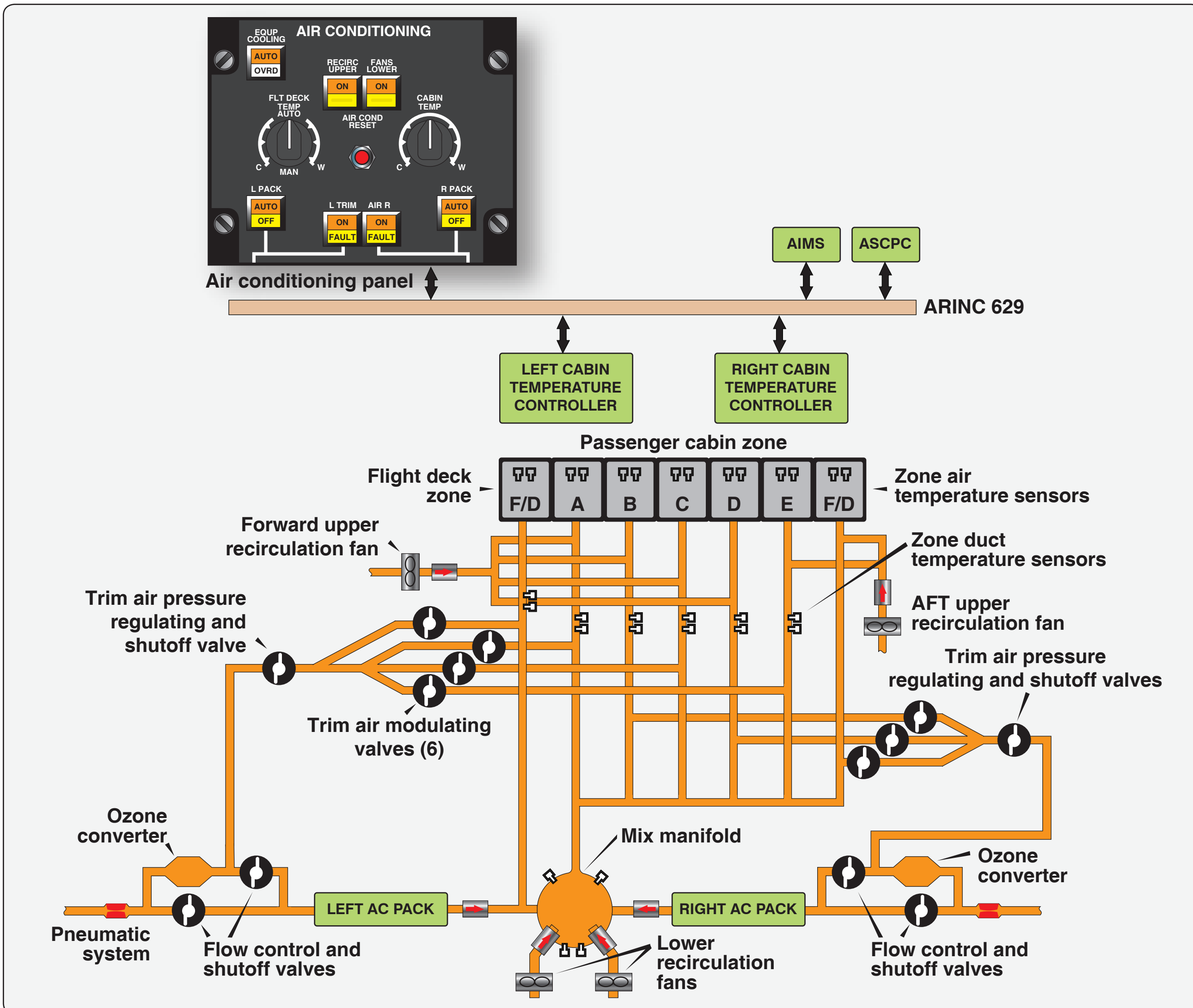


Figure 16-71. *The temperature control system of a Boeing 777 combines the use of zone and duct temperature sensors with trim air modulating valves for each zone. Redundant digital left and right cabin temperature controllers process temperature input signals from the sensors and temperature selectors on the cockpit panel and throughout the aircraft to modulate the valves.*

Adding heat to a substance does not always raise its temperature. When a substance changes state, such as when a liquid changes into a vapor, heat energy is absorbed. This is called latent heat. When a vapor condenses into a liquid, this heat energy is given off. The temperature of a substance remains constant during its change of state. All energy absorbed or given off, the latent heat, is used for the change process. Once the change of state is complete, heat added to a substance raises the temperature of the substance. After a substance changes state into a vapor, the rise in temperature of the vapor caused by the addition of still more heat is called superheat.

The temperature at which a substance changes from a liquid into a vapor when heat is added is known as its boiling point. This is the same temperature at which a vapor condenses into a liquid when heat is removed. The boiling point of any substance varies directly with pressure. When pressure on a liquid is increased, its boiling point increases, and when pressure on a liquid is decreased, its boiling point also decreases. For example, water boils at 212 °F at normal atmospheric temperature (14.7 psi). When pressure on liquid water is increased to 20 psi, it does not boil at 212 °F. More energy is required to overcome the increase in pressure. It boils at approximately 226.4 °F. The converse is also true. Water can also boil at a much lower temperature simply by reducing the pressure upon it. With only 10 psi of pressure upon liquid water, it boils at 194 °F. *[Figure 16-73]*

Vapor pressure is the pressure of the vapor that exists above a liquid that is in an enclosed container at any given temperature. The vapor pressure developed by various

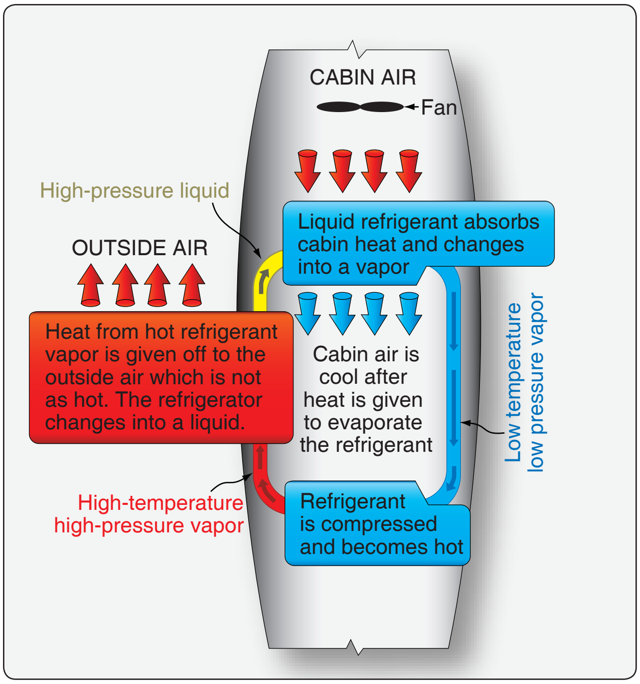


Figure 16-72. *In vapor cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapor and back again.*

substances is unique to each substance. A substance that is said to be volatile, develops high vapor pressure at standard day temperature (59 °F). This is because the boiling point of the substance is much lower. The boiling point of tetrafluoroethane (R134a), the refrigerant used in most aircraft vapor cycle air conditioning systems, is approximately –15 °F. Its vapor pressure at 59 °F is about 71 psi. The vapor pressure of any substance varies directly with temperature.

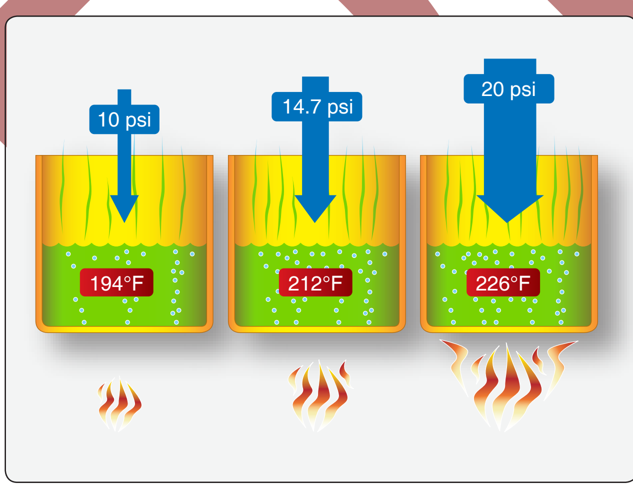


Figure 16-73. *Boiling point of water changes as pressure changes.*

Basic Vapor Cycle

Vapor cycle air conditioning is a closed system in which a refrigerant is circulated through tubing and a variety of components. The purpose is to remove heat from the aircraft cabin. While circulating, the refrigerant changes state. By manipulating the latent heat required to do so, hot air is replaced with cool air in the aircraft cabin.

To begin, R134a is filtered and stored under pressure in a reservoir known as a receiver dryer. The refrigerant is in liquid form. It flows from the receiver dryer through tubing to an expansion valve. Inside the valve, a restriction in the form of a small orifice blocks most of the refrigerant. Since it is under pressure, some of the refrigerant is forced through the orifice. It emerges as a spray of tiny droplets in the tubing downstream of the valve. The tubing is coiled into a radiator-type assembly known as an evaporator. A fan is positioned to blow cabin air over the surface of the evaporator. As it does, the heat in the cabin air is absorbed by the refrigerant, which uses it to change state from a liquid to a vapor. So much heat is absorbed that the cabin air blown by the fan across the evaporator cools significantly. This is the vapor cycle conditioned air that lowers the temperature in the cabin.

The gaseous refrigerant exiting the evaporator is drawn into a compressor. There, the pressure and the temperature of the refrigerant are increased. The high-pressure high-temperature gaseous refrigerant flows through tubing to a condenser. The condenser is like a radiator comprised of a great length of tubing with fins attached to promote heat transfer. Outside air is directed over the condenser. The temperature of the refrigerant inside is higher than the ambient air temperature, so heat is transferred from the refrigerant to the outside air. The amount of heat given off is enough to cool the refrigerant and to condense it back to a high-pressure liquid. It flows through tubing and back into the receiver dryer, completing the vapor cycle.

There are two sides to the vapor cycle air conditioning system. One accepts heat and is known as the low side. The other gives up heat and is known as the high side. The low and high refer to the temperature and pressure of the refrigerant. As such, the compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. *[Figure 16-74]* Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.

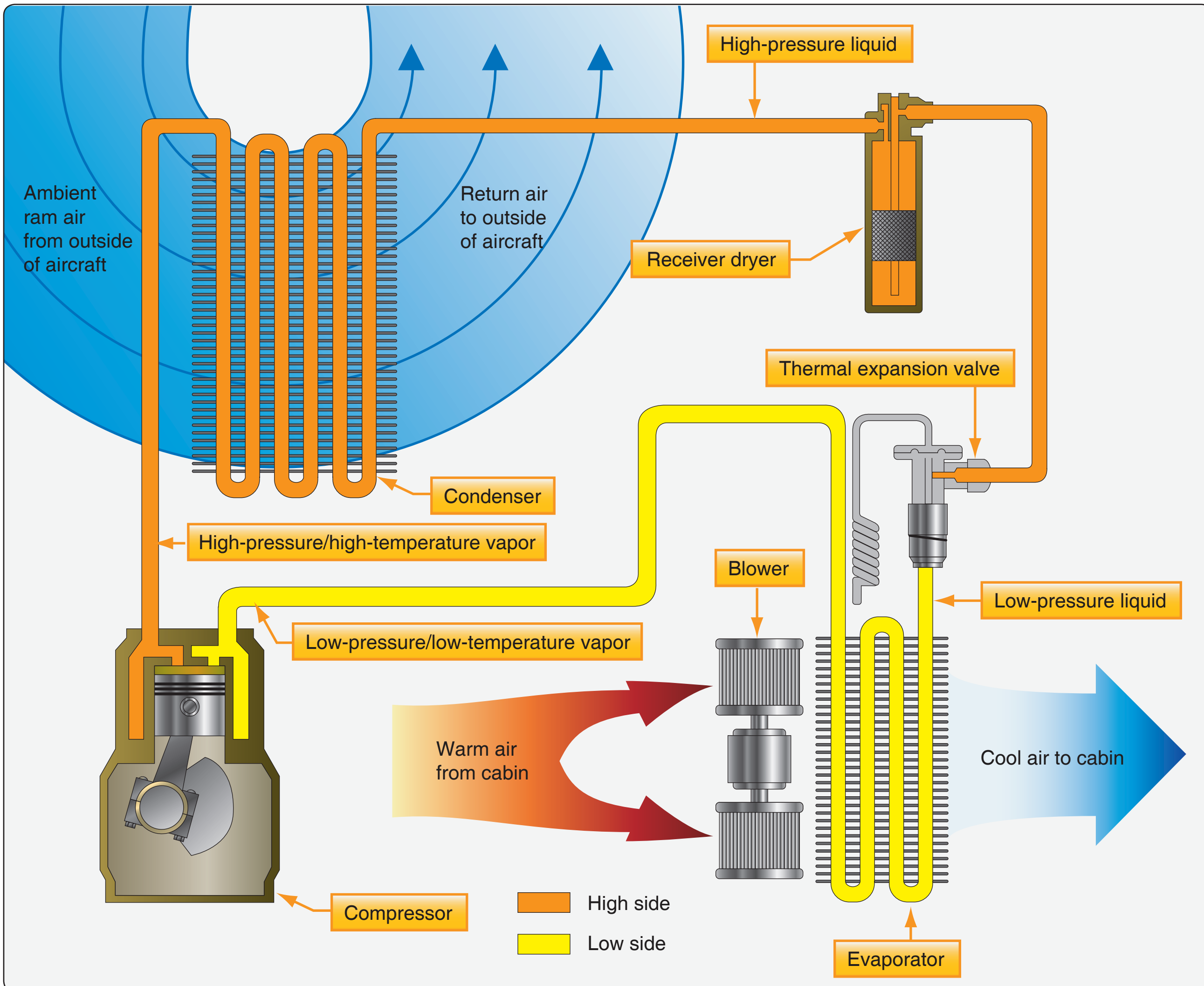


Figure 16-74. *A basic vapor cycle air conditioning system. The compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. This figure illustrates this division. Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.*

Vapor Cycle Air Conditioning System Components

By examining each component in the vapor cycle air conditioning system, greater insight into its function can be gained.

Refrigerant

For many years, dichlorodifluoromethane (R12) was the standard refrigerant used in aircraft vapor cycle air conditioning systems. Some of these systems remain in use today. R12 was found to have a negative effect on the environment; in particular, it degraded the earth's protective ozone layer. In most cases, it has been replaced by tetrafluoroethane (R134a), which is safer for the environment. R12 and R134a should not be mixed, nor should one be used in a system designed for the other. Possible damage to soft components, such as hoses and seals, could result causing leaks and or malfunction. Use only the specified refrigerant when servicing vapor cycle air conditioning systems. *[Figure 16-75]* R12 and R134a behave so similarly that the descriptions of the R134a vapor cycle air conditioning system and components in the following paragraphs also apply to an R12 system and its components.

R134a is a halogen compound (CF3CFH2). As mentioned, it has a boiling point of approximately –15 °F. It is not poisonous to inhale in small quantities, but it does displace oxygen. Suffocation is possible if breathed in mass quantity.

Regardless of manufacturer, refrigerants are sometimes called Freon®, which is a trade name owned by the Dupont Company. Caution should be used when handling any refrigerant. Because of the low boiling points, liquid

Figure 16-75. *A small can of R134a refrigerant used in vapor cycle air conditioning systems.*

refrigerants boil violently at typical atmospheric temperatures and pressure. They rapidly absorb heat energy from all surrounding matter. If a drop lands on skin, it freezes, resulting in a burn. Similar tissue damage can result if a drop gets in one's eye. Gloves and other skin protection, as well as safety goggles, are required when working with refrigerant.

Receiver Dryer

The receiver dryer acts as the reservoir of the vapor cycle system. It is located downstream of the condenser and upstream of the expansion valve. When it is very hot, more refrigerant is used by the system than when temperatures are moderate. Extra refrigerant is stored in the receiver dryer for this purpose.

Liquid refrigerant from the condenser flows into the receiver dryer. Inside, it passes through filters and a desiccant material. The filters remove any foreign particles that might be in the system. The desiccant captures any water in the refrigerant. Water in the refrigerant causes two major problems. First, the refrigerant and water combine to form an acid. If left in contact with the inside of the components and tubing, the acid deteriorates the materials from which these are made. The second problem with water is that it could form ice and block the flow of refrigerant around the system, rendering it inoperative. Ice is particularly a problem if it forms at the orifice in the expansion valve, which is the coldest point in the cycle.

Occasionally, vapor may find its way into the receiver dryer, such as when the gaseous refrigerant does not completely change state to a liquid in the condenser. A stand tube is used to remove refrigerant from the receiver dryer. It runs to the bottom of the unit to ensure liquid is withdrawn and forwarded to the expansion valve. At the top of the stand tube, a sight glass allows the technician to see the refrigerant. When enough refrigerant is present in the system, liquid flows in the sight glass. If low on refrigerant, any vapor present in the receiver dryer may be sucked up the stand tube causing bubbles to be visible in the sight glass. Therefore, bubbles in the sight glass indicate that the system needs to have more refrigerant added. *[Figure 16-76]*

Expansion Valve

Refrigerant exits the receiver dryer and flows to the expansion valve. The thermostatic expansion valve has an adjustable orifice through which the correct amount of refrigerant is

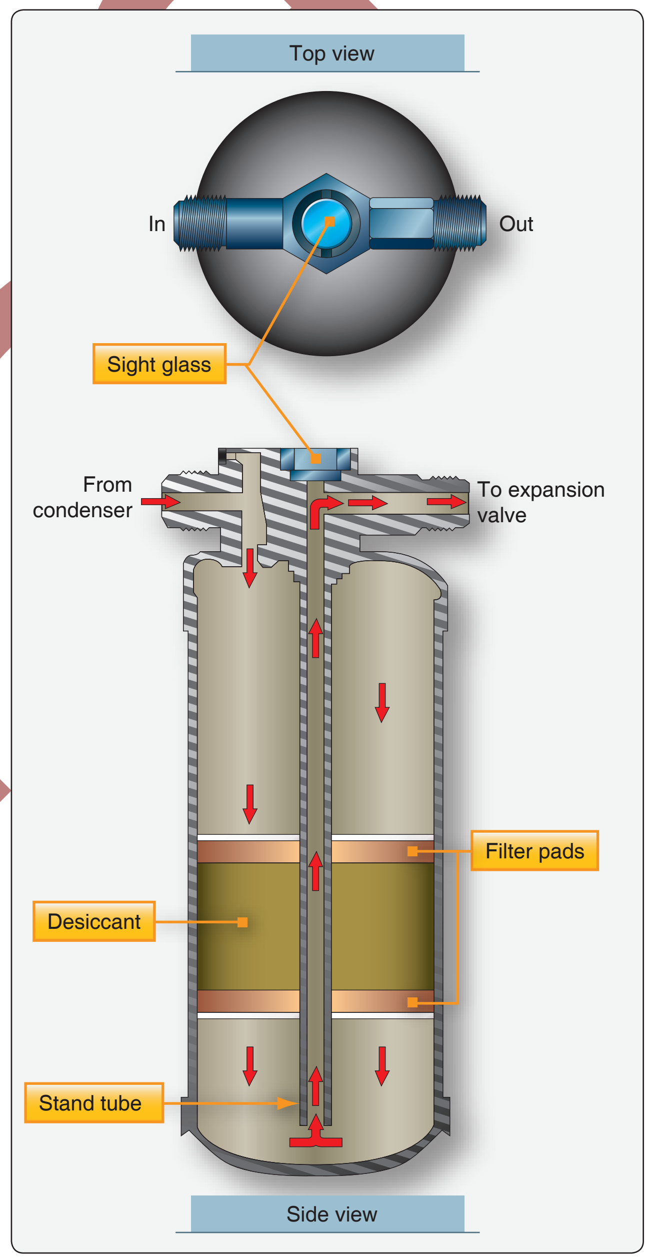


Figure 16-76. *A receiver dryer acts as reservoir and filter in a vapor cycle system. Bubbles viewed in the sight glass indicate the system is low on refrigerant and needs to be serviced.*

metered to obtain optimal cooling. This is accomplished by monitoring the temperature of the gaseous refrigerant at the outlet of the next component in the cycle, the evaporator. Ideally, the expansion valve should only let the amount of refrigerant spray into the evaporator that can be completely converted to a vapor.

The temperature of the cabin air to be cooled determines the amount of refrigerant the expansion valve should spray into the evaporator. Only so much is needed to completely change the state of the refrigerant from a liquid to a vapor. Too little causes the gaseous refrigerant to be superheated by the time it exits the evaporator. This is inefficient. Changing the state of the refrigerant from liquid to vapor absorbs much more heat than adding heat to already converted vapor (superheat). The cabin air blowing over the evaporator will not be cooled sufficiently if superheated vapor is flowing through the evaporator. If too much refrigerant is released by the expansion valve into the evaporator, some of it remains liquid when it exits the evaporator. Since it next flows to the compressor, this could be dangerous. The compressor is designed to compress only vapor. If liquid is drawn in and attempts are made to compress it, the compressor could break, since liquids are essentially incompressible.

The temperature of superheated vapor is higher than liquid refrigerant that has not totally vaporized. A coiled capillary tube with a volatile substance inside is located at the evaporator outlet to sense this difference. Its internal pressure increases and decreases as temperature changes. The coiled end of the tube is closed and attached to the evaporator outlet. The other end terminates in the area above a pressure diaphragm in the expansion valve. When superheated refrigerant vapor reaches the coiled end of the tube, its elevated temperature increases the pressure inside the tube and in the space above the diaphragm. This increase in pressure causes the diaphragm to overcome spring tension in the valve. It positions a needle valve that increases the amount of refrigerant released by the valve. The quantity of refrigerant is increased so that the refrigerant only just evaporates, and the refrigerant vapor does not superheat.

When too much liquid refrigerant is released by the expansion valve, low-temperature liquid refrigerant arrives at the outlet of the evaporator. The result is low pressure inside the temperature bulb and above the expansion valve diaphragm. The superheat spring in the valve moves the needle valve toward the closed position, reducing the flow of refrigerant into the evaporator as the spring overcomes the lower pressure above the diaphragm. [*Figure 16-77*]

Vapor cycle air conditioning systems that have large evaporators experience significant pressure drops while

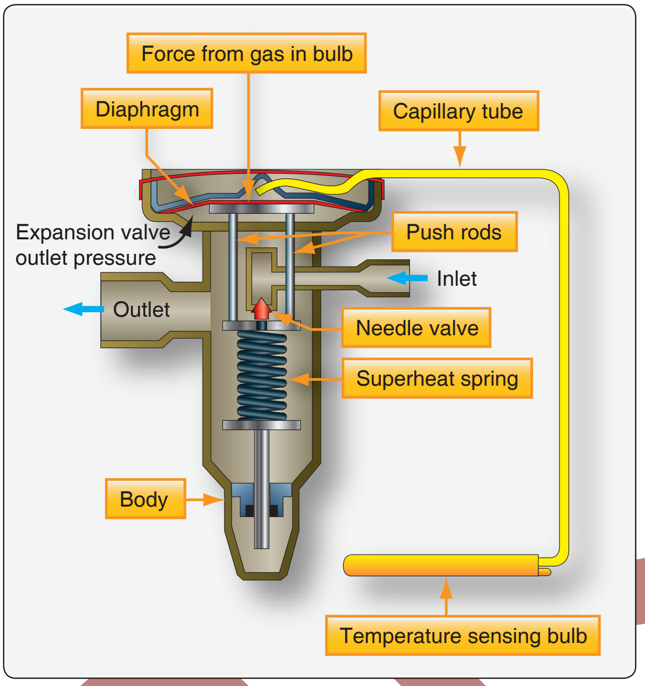


Figure 16-77. *An internally equalized expansion valve.*

refrigerant is flowing through them. Externally equalized expansion valves use a pressure tap from the outlet of the evaporator to help the superheat spring balance the diaphragm. This type of expansion valve is easily recognizable by the additional small-diameter line that comes from the evaporator into the valve (2 total). Better control of the proper amount of refrigerant allowed through the valve is attained by considering both the temperature and pressure of the evaporator refrigerant. [*Figure 16-78*]

Evaporator

Most evaporators are constructed of copper or aluminum tubing coiled into a compact unit. Fins are attached to increase surface area, facilitating rapid heat transfer between the cabin air blown over the outside of the evaporator with a fan and the refrigerant inside. The expansion valve located at the evaporator inlet releases high-pressure, high-temperature liquid refrigerant into the evaporator. As the refrigerant absorbs heat from the cabin air, it changes into a low-pressure vapor. This is discharged from the evaporator outlet to the next component in the vapor cycle system, the compressor. The temperature and pressure pickups that regulate the expansion valve are located at the evaporator outlet.

The evaporator is situated in such a way that cabin air is pulled to it by a fan. The fan blows the air over the evaporator and discharges the cooled air back into the cabin. [*Figure 16-79*] This discharge can be direct when the evaporator is located in a cabin wall. A remotely located evaporator may require ducting

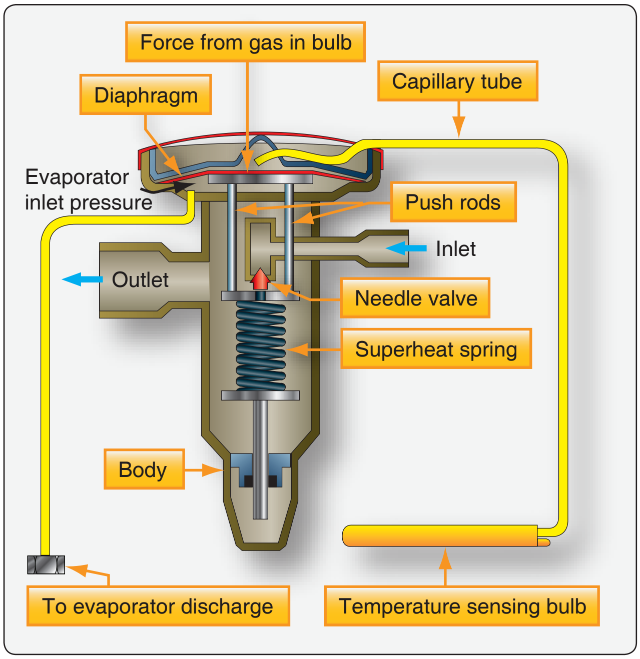


Figure 16-78. *An externally equalized expansion valve uses evaporator discharge temperature and pressure to regulate the amount of refrigerant passing through the valve and into the evaporator.*

from the cabin to the evaporator and from the evaporator back into the cabin. Sometimes the cool air produced may be introduced into an air distribution system where it can blow directly on the occupants through individual delivery vents. In this manner, the entire vapor cycle air conditioning system may be located fore or aft of the cabin. A multiposition fan switch controlled by the pilot is usually available. *Figure 16-80* diagrams the vapor cycle air conditioning system in a Cessna Mustang very light jet. It has two evaporators that share in the cooling, with outlets integrated into a distribution

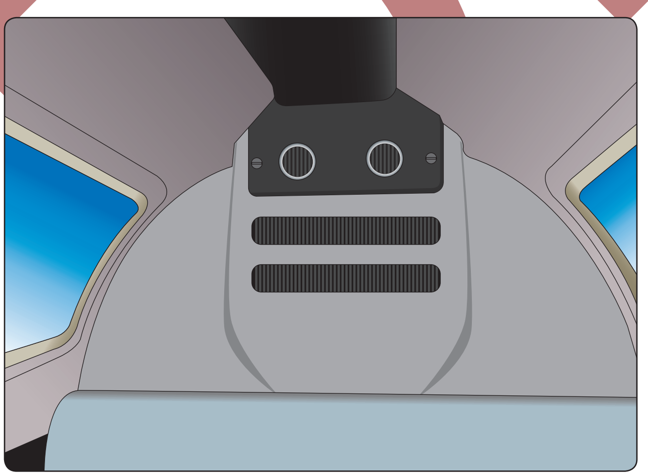


Figure 16-79. *The evaporator of this aircraft's vapor cycle air conditioning system is visible in the forward cabin sidewall behind the right rudder pedal.*

system and cockpit mounted switches for the fans, as well as engaging and disengaging the system.

When cabin air is cooled by flowing over the evaporator, it can no longer retain the water that it could at higher temperature. As a result, it condenses on the outside of the evaporator and needs to be collected and drained overboard. Pressurized aircraft may contain a valve in the evaporator drain line that opens only periodically to discharge the water, to maintain pressurization. Fins on the evaporator must be kept from being damaged, which could inhibit airflow. The continuous movement of warm cabin air around the fins keeps condensed water from freezing. Ice on the evaporator reduces the efficiency of the heat exchange to the refrigerant.

Compressor

The compressor is the heart of the vapor cycle air conditioning system. It circulates the refrigerant around the vapor cycle system. It receives low-pressure, low-temperature refrigerant vapor from the outlet of the evaporator and compresses it. As the pressure is increased, the temperature also increases. The refrigerant temperature is raised above that of the outside air temperature. The refrigerant then flows out of the compressor to the condenser where it gives off the heat to the outside air.

The compressor is the dividing point between the low side and the high side of the vapor cycle system. Often it is incorporated with fittings or has fittings in the connecting lines to it that are designed to service the system with refrigerant. Access to the low and high sides of the system are required for servicing, which can be accomplished with fitting upstream and downstream of the compressor.

Modern compressors are either engine driven or driven by an electric motor. Occasionally, a hydraulically driven compressor is used. A typical engine-driven compressor, similar to that found in an automobile, is located in the engine nacelle and operated by a drive belt off of the engine crankshaft. An electromagnetic clutch engages when cooling is required, which causes the compressor to operate. When cooling is sufficient, power to the clutch is cut, and the drive pulley rotates but the compressor does not. [*Figure 16-81*]

Dedicated electric motor-driven compressors are also used on aircraft. Use of an electric motor allows the compressor to be located nearly anywhere on the aircraft, since wires can be run from the appropriate bus to the control panel and to the compressor. [*Figure 16-82*] Hydraulically-driven compressors are also able to be remotely located. Hydraulic lines from the hydraulic manifold are run through a switch-activated solenoid to the compressor. The solenoid allows fluid to the compressor or bypasses it. This controls the operation of the hydraulically driven compressor.

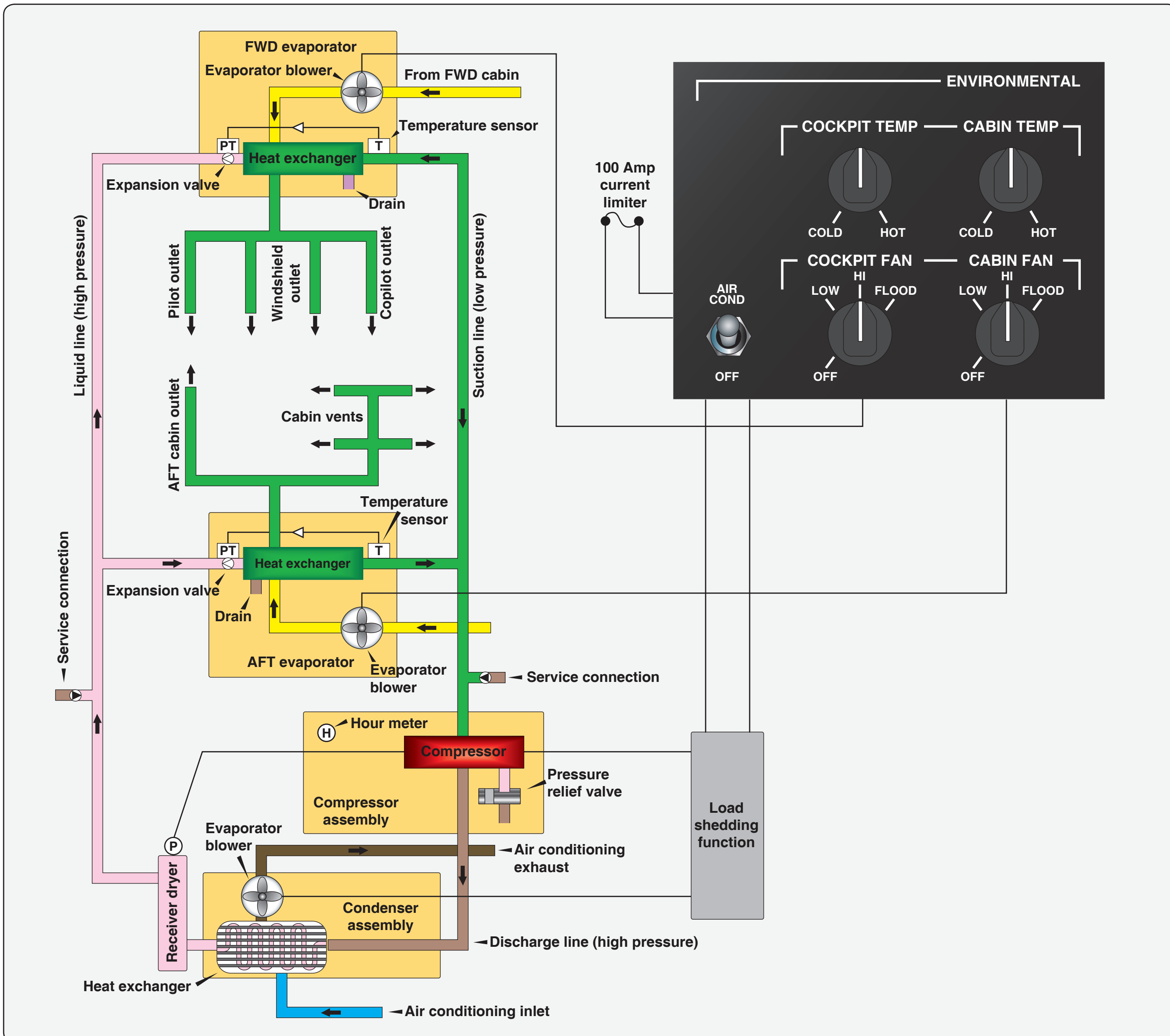


Figure 16-80. *The vapor cycle air conditioning system on a Cessna Mustang has two evaporators, one for the cockpit and one for the cabin. Each evaporator assembly contains the evaporator, a blower, a thermal expansion valve and the temperature feedback line fromthe outlet of the evaporator to the expansion valve.*

Regardless of how the vapor cycle air conditioning compressor is driven, it is usually a piston type pump. It requires use of a lightweight oil to lubricate and seal the unit. The oil is entrained by the refrigerant and circulates with it around the system. The crankcase of the compressor retains a supply of the oil, the level of which can be checked and adjusted by the technician. Valves exist on some compressor installations that can be closed to isolate the compressor from the remainder of the vapor cycle system while oil servicing takes place.

Condenser

The condenser is the final component in the vapor cycle. It is a radiator-like heat exchanger situated so that outside air flows over it and absorbs heat from the high-pressure, high-temperature refrigerant received from the compressor. A fan is usually included to draw the air through the compressor during ground operation. On some aircraft, outside air is ducted to the compressor. On others, the condenser is lowered into the airstream from the fuselage via a hinged panel. Often, the panel is controlled by a switch on the throttle levers. It is set to retract the compressor and streamline the fuselage when full power is required. *[Figure 16-83]*

The outside air absorbs heat from the refrigerant flowing through the condenser. The heat loss causes the refrigerant to change state back into a liquid. The high-pressure liquid refrigerant then leaves the condenser and flows to the receiver dryer. A properly engineered system that is

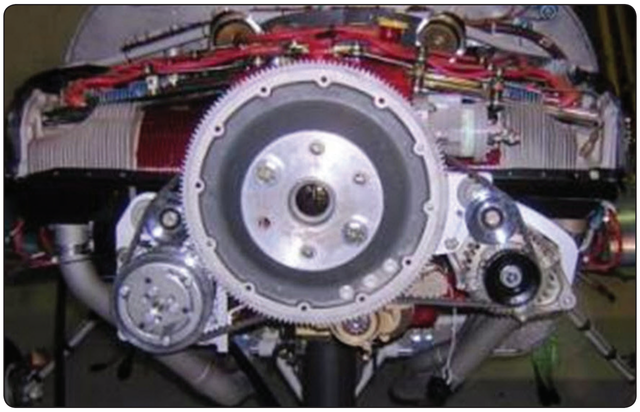


Figure 16-81. *A typical belt drive engine driven compressor. The electromagnetic clutch pulley assembly in the front starts and stops the compressor depending on cooling demand.*

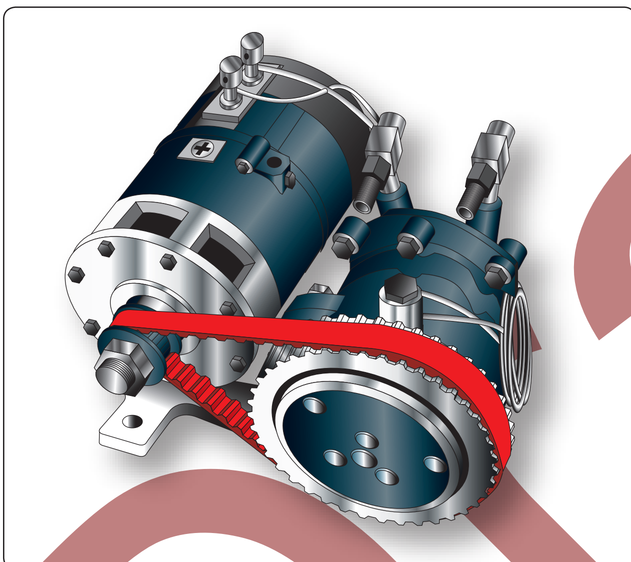


Figure 16-82. *Examples of electric motor driven vapor cycle air conditioning compressors.*

functioning normally fully condenses all the refrigerant flowing through the condenser.

Service Valves

All vapor cycle air conditioning systems are closed systems; however, access is required for servicing. This is accomplished through the use of two service valves. One valve is located in the high side of the system and the other in the low side. A common type of valve used on vapor cycle systems that operate with R12 refrigerant is the Schrader valve. It is similar to the valve used to inflate tires. *[Figure 16-84]* A central valve core seats and unseats by depressing a stem attached to it. A pin in the servicing hose fitting is designed to do this when screwed onto the valve's exterior threads. All aircraft service valves should be capped when not in use.

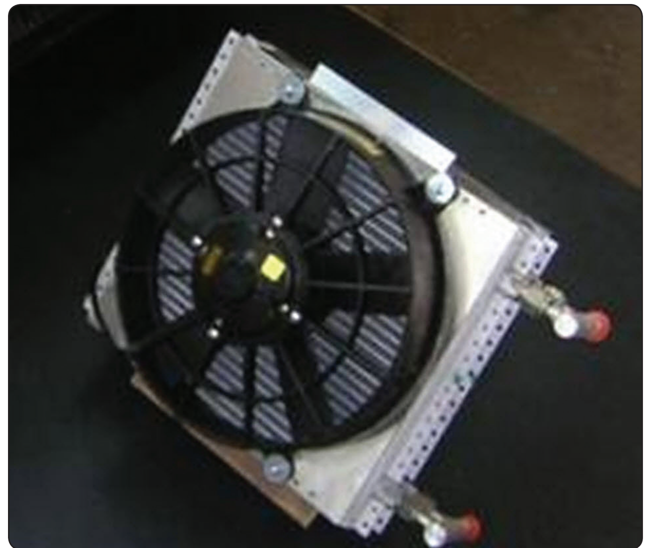


Figure 16-83. *A vapor cycle air conditioning condenser assembly with an integral fan used to pull outside air through the unit during ground operation.*

R134a systems use valves that are very similar to the Schrader valve in function, operation, and location. As a safety device to prevent inadvertent mixing of refrigerants, R134a valve fittings are different from Schrader valve fittings and do not attach to Schrader valve threads. The R134a valve fittings are a quick-disconnect type.

Another type of valve called a compressor isolation valve is used on some aircraft. It serves two purposes. Like

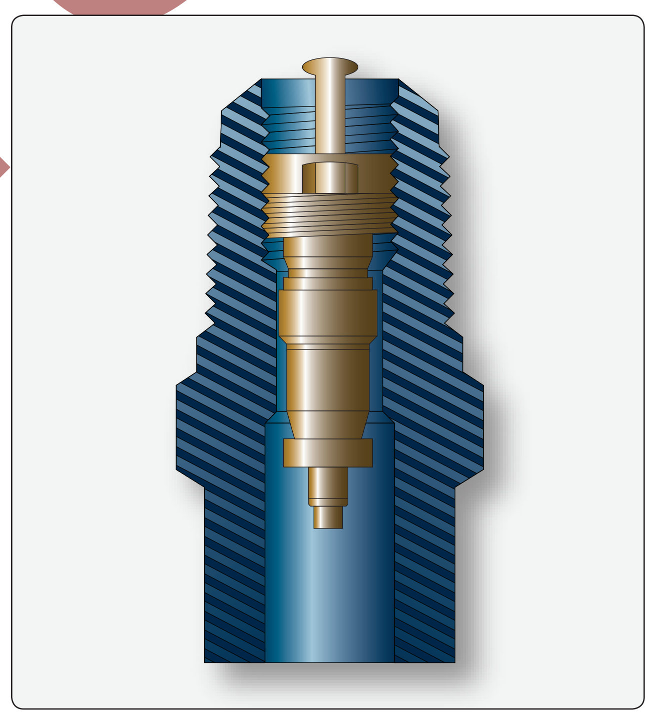


Figure 16-84. *Cross-section of an R12 refrigerant service valve.*

the Schrader valve, it permits servicing the system with refrigerant. It also can isolate the compressor so the oil level can be checked and replenished without opening the entire system and losing the refrigerant charge. These valves are usually hard mounted to the inlet and outlet of the compressor.

A compressor isolation valve has three positions. When fully open, it back seats and allows the normal flow of refrigerant in the vapor cycle. When fully closed or front seated, the valve isolates the compressor from the rest of the system and servicing with oil, or even replacement of the compressor, is possible without losing the refrigerant charge. When in an intermediate position, the valve allows access to the system for servicing. The system can be operated with the valve in this position but should be back seated for normal operation. The valve handle and service port should be capped when servicing is complete. *[Figure 16-85]*

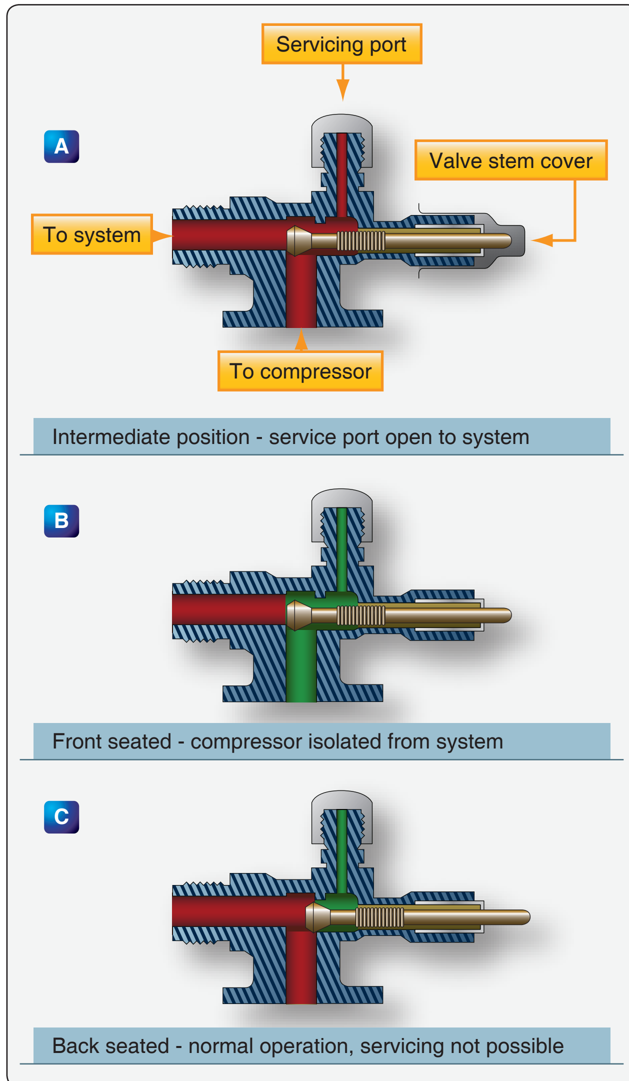


Figure 16-85. *Compressor isolation valves isolate the compressor for maintenance or replacement. They also allow normal operation and servicing of the vapor cycle air conditioning system with refrigerant.*

Vapor Cycle Air Conditioning Servicing Equipment

Special servicing equipment is used to service vapor cycle air conditioning systems. The U.S. Environmental Protection Agency (EPA) has declared it illegal to release R12 refrigerant into the atmosphere. Equipment has been designed to capture the refrigerant during the servicing process. Although R134a does not have this restriction, it is illegal in some locations to release it to the atmosphere, and it may become universally so in the near future. It is good practice to capture all refrigerants for future use, rather than to waste them or to harm the environment by releasing them into the atmosphere. Capturing the refrigerant is a simple process designed into the proper servicing equipment. The technician should always be vigilant to use the approved refrigerant for the system being serviced and should follow all manufacturer's instruction.

Manifold Set, Gauges, Hoses, and Fittings

In the past, the main servicing device for vapor cycle air conditioning systems was the manifold set. It contains three hose fittings, two O-ring sealed valves, and two gauges. It is essentially a manifold into which the gauges, fittings, and valves are attached. The valves are positioned to connect or isolate the center hose with either fitting.

Hoses attach to the right and left manifold set fittings and the other ends of those hoses attach to the service valves in the vapor cycle system. The center fitting also has a hose attached to it. The other end of this hose connects to either a refrigerant supply or a vacuum pump, depending on the servicing function to be performed. All servicing operations are performed by manipulating the valves. *[Figure 16-86]*

The gauges on the manifold set are dedicated—one for the low side of the system and the other for the high side. The low-pressure gauge is a compound gauge that indicates pressures above or below atmospheric pressure (0-gauge pressure). Below atmospheric pressure, the gauge is scaled in inches of mercury down to 30 inches. This is to indicate vacuum. 29.92 inches equals an absolute vacuum (absolute zero air pressure). Above atmospheric pressure, gauge pressure is read in psi. The scale typically ranges from 0 to 60 psi, although some gauges extend up to 150 psi. The high-pressure gauge usually has a range from zero up to about 500 psi gauge pressure. It does not indicate vacuum (pressure lower than atmospheric). These gauges and their scales can be seen in *Figure 16-87*.

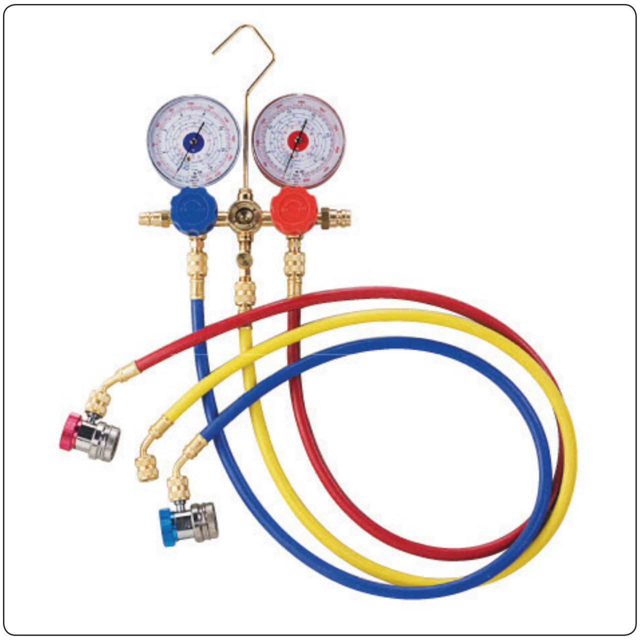


Figure 16-86. *A basic manifold set for servicing a vapor cycle air conditioning system.*

The low-pressure gauge is connected on the manifold directly to the low side fitting. The high-pressure gauge connects directly to the high side fitting. The center fitting of the manifold can be isolated from either of the gauges or the high and low service fittings by the hand valves. When these valves are turned fully clockwise, the center fitting is isolated. If the low-pressure valve is opened (turned counterclockwise), the center fitting is opened to the low-pressure gauge and the low side service line. The same is true for the high side when the high-pressure valve is opened. *[Figure 16-87]*

Special hoses are attached to the fittings of the manifold valve for servicing the system. The high-pressure charging hose is usually red and attaches to the service valve located in the high side of the system. The low-pressure hose, usually blue, attaches to the service valve that is located in the low side of the system. The center hose attaches to the vacuum pump for evacuating the system, or to the refrigerant supply for charging the system. Proper charging hoses for the refrigerant specific service valves must be used. When not using the manifold set, be sure the hoses are capped to prevent moisture from contaminating the valves.

Full Service Refrigerant Recovery, Recycling, Evacuation, and Recharging Units

Regulations that require capture of all vapor cycle refrigerant have limited the use of the manifold set. It can still be used to charge a system. The refrigerant container is attached to the center hose and the manifold set valves are manipulated to allow flow into the low or high side of the system as required. But, emptying a system of refrigerant requires a service

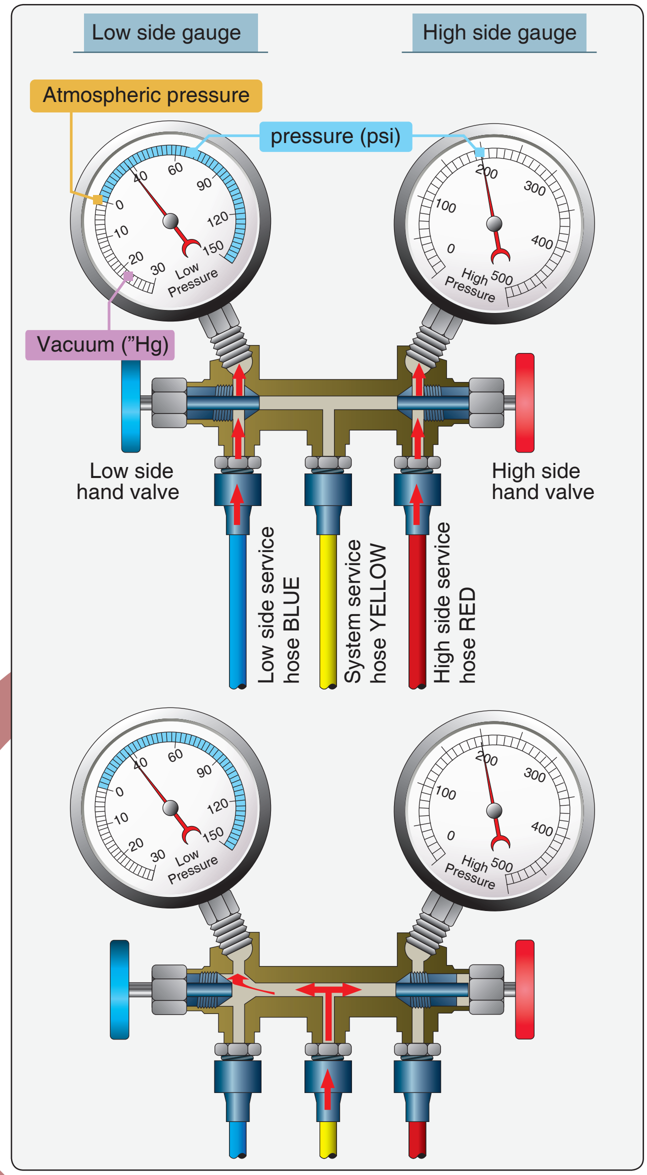


Figure 16-87. *The internal workings of a manifold set with the center fitting isolated (top). Opening a valve connects the center hose to that side of the system and the gauge (bottom).*

unit made to collect it. Allowing the refrigerant to flow into a collection container attached to the center hose will not capture the entire refrigerant charge, as the system and container pressures equalize above atmospheric pressure. An independent compressor and collection system is required.

Modern refrigeration recharging and recovery units are available to perform all of the servicing functions required for vapor cycle air conditioning systems. These all-in-one service carts have the manifold set built into the unit. As such, the logic for using a manifold set still applies. Integral solenoid valves, reservoirs, filters, and smart controls allow the entire servicing procedure to be controlled from the unit panel once the high side and low side services hoses are connected. A built-in compressor enables complete system refrigerant purging. A built-in vacuum pump performs system evacuation. A container and recycling filters for the refrigerant and the lubricating oil allow total recovery and recycling of these fluids. The pressure gauges used on the service unit panel are the same as those on a manifold set. Top-of-the-line units have an automatic function that performs all of the servicing functions sequentially and automatically once the hoses are hooked up to the vapor cycle air conditioning system and the system quantity of refrigerant has been entered. *[Figure 16-88]*

Refrigerant Source

R134a comes in containers measured by the weight of the refrigerant they hold. Small 12-ounce to 2½-pound cans are common for adding refrigerant. Larger 30- and 50-pound cylinders equipped with shutoff valves are often used to charge an evacuated system, and they are used in shops that service vapor cycle systems frequently. *[Figure 16-89]* These larger cylinders are also used in the full servicing carts described above. The amount of refrigerant required for any system is measured in pounds. Check the manufacturer's service data and charge the system to the level specified using only the approved refrigerant from a known source.

Vacuum Pumps

Vacuum pumps used with a manifold set, or as part of a service cart, are connected to the vapor cycle system so that the system pressure can be reduced to a near total vacuum. The reason for doing this is to remove all of the water in the system. As mentioned, water can freeze, causing system malfunction and can also combine with the refrigerant to create corrosive compounds.

Once the system has been purged of its refrigerant and it is at atmospheric pressure, the vacuum pump is operated. It gradually reduces the pressure in the system. As it does, the boiling point of any water in the system is also reduced. Water boils off or is vaporized under the reduced pressure and is pulled from the system by the pump, leaving the system moisture free to be recharged with refrigerant. *[Figure 16-90]* The strength and efficiency of vacuum pumps varies as does the amount of time to hold the system at reduced pressure specified by manufacturers. Generally, the best-established vacuum is held for 15–30 minutes to ensure all water is removed from the system. Follow the manufacturer's instructions when evacuating a vapor cycle air conditioning system. *[Figure 16-91]*

Leak Detectors

Even the smallest leak in a vapor cycle air conditioning system can cause a loss of refrigerant. When operating normally, little or no refrigerant escapes. A system that requires the addition of refrigerant should be suspected of having a leak. Electronic leak detectors are safe, effective

Figure 16-88. *A modern refrigerant recovery/recycle/charging service unit. Electronic control of solenoid activated valves combine with a built-in system for recovering, recycling, and recharging. A built-in vacuum pump and heated refrigerant reservoir are also included.*

Figure 16-89. *A 30 pound R134a refrigerant container with dual fittings. The fitting controlled by the blue valve wheel opens to the vapor space above the liquid refrigerant for connection to the low side of the vapor cycle system. The fitting controlled by the red valve wheel draws liquid refrigerant from the bottom of the cylinder through a stand tube. This fitting is connected to the system high side. On containers without dual fittings, the container must be inverted to deliver liquid refrigerant through a connected hose.*

Inches of vacuum on low side gauge (inches Hg)	Temperature at which water boils (°F)	Absolute pressure (psi)
0	212	14.696
4.92	204.98	12.279
9.23	194	10.152
15.94	176	6.866
20.72	158	4.519
24.04	140	2.888
26.28	122	1.788
27.75	104	1.066
28.67	86	0.614
28.92	80.06	0.491
29.02	75.92	0.442
29.12	71.96	0.393
29.22	69.08	0.344
29.32	64.04	0.295
29.42	59	0.246
29.52	53.06	0.196
29.62	44.96	0.147
29.74	32	0.088
29.82	21.02	0.0049
29.87	6.08	0.00245
29.91	–23.98	0.00049

Figure 16-90. *When the temperature is low, a greater amount of vacuum is needed to boil off and remove any water in the vapor cycle system.*

devices used to find leaks. There are many types available that are able to detect extremely small amounts of escaped refrigerant. The detector is held close to component and hose connections where most leaks occur. Audible and visual alarms signal the presence of refrigerant. A detector specified for the type of refrigerant in the system should be chosen. A good leak detector is sensitive enough to detect leaks that would result in less than ½ ounce of refrigerant to be lost per year. *[Figure 16-92]*

Other leak detection methods exist. A soapy solution can also be applied to fittings and inspected for the formation of bubbles indicating a leak. Special leak detection dyes compatible for use with refrigerant can be injected into the vapor cycle system and can be seen when they are forced out at a leak. Many of these are made to be visible under UV light. Occasionally, a leak can be detected upon close visual inspection. Oil in the system can be forced out of a leak, leaving a visible residue that is usually on the bottom side of a leaky fitting. Old hoses may become slightly porous and leak a significant amount of refrigerant over time. Because of the length and area through which the refrigerant is lost, this type of leak may be difficult to detect, even with leak detecting methods. Visibly deteriorated hoses should be replaced.

System Servicing

Vapor cycle air conditioning systems can give many hours of reliable, maintenance-free service. Periodic visual inspections, tests, and refrigerant level and oil level checks may be all that is required for some time. Follow the manufacturer's instructions for inspection criteria and intervals.

Figure 16-91. *A vacuum pump is used to lower the pressure in the vapor cycle air conditioning system. This reduces the boiling point of water in the system, which vaporizes and is drawn out by the pump.*

Figure 16-92. *This electronic infrared leak detector can detect leaks that would lose less than ¼ ounce of refrigerant per year.*

Visual Inspection

All components of any vapor cycle system should be checked to ensure they are secure. Be vigilant for any damage, misalignment, or visual signs of leakage. The evaporator and condenser fins should be checked to ensure they are clean, unobstructed, and not folded over from an impact. Dirt and inhibited airflow through the fins can prevent effective heat exchange to and from the refrigerant. Occasionally, these units can be washed. Since the condenser often has ram air ducted to it or extends into the airstream, check for the presence of debris that may restrict airflow. Hinged units should be checked for security and wear. The mechanism to extend and retract the unit should function as specified, including the throttle position switch present on many systems. It is designed to cut power to the compressor clutch and retract the condenser at full power settings. Condensers may also have a fan to pull air over them during ground operation. It should be checked to ensure it functions correctly. *[Figure 16-93]*

Be sure the capillary temperature feedback sensor to the expansion valve is securely attached to the evaporator outlet. Also, check the security of the pressure sensor and thermostat sensor if the system has them. The evaporator should not have ice on the outside. This prevents proper heat exchange to the refrigerant from the warm cabin air blown over the unit. The fan blower should be checked to ensure it rotates freely. Depending on the system, it should run whenever the cooling switch is selected and should change speeds as the selector is rotated to more or less cooling. Sometimes systems low on refrigerant can cause ice on the evaporator,

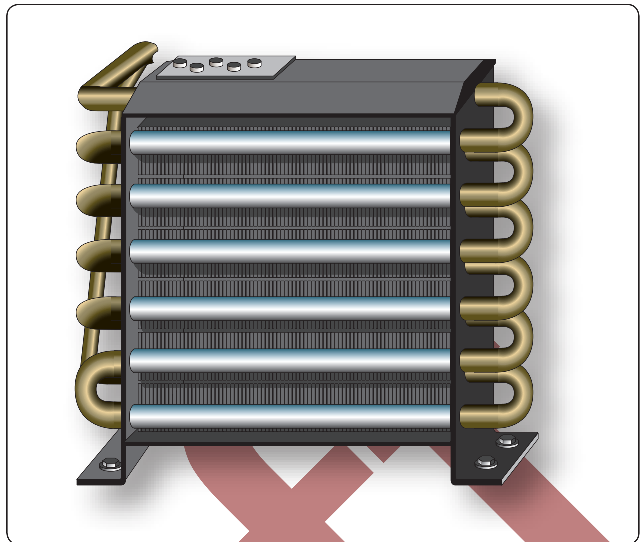


Figure 16-93. *Damaged fins on a condenser.*

as can a faulty expansion valve or feedback control line. Ice formation anywhere on the outside of a vapor cycle air conditioning system should be investigated for cause and corrected. *[Figure 16-94]*

Security and alignment of the compressor is critical and should be checked during inspection. Belt-driven compressors need to have proper belt tension to function properly. Check the manufacturer's data for information on how to determine the condition and tension of the belt, as well as how to make adjustments. Oil level should be sufficient. Typically, ¼ ounce of oil is added for each pound of refrigerant added to the system. When changing a component, additional oil may need to be added to replace that which is trapped in the replaced unit. Always use the oil specified in the manufacturer's maintenance manual.

Leak Test

As mentioned under the leak detector section above, leaks in a vapor cycle air conditioning system must be discovered and repaired. The most obvious sign of a possible leak is a low refrigerant level. Bubbles present in the sight glass of the receiver dryer while the system is operating indicate more refrigerant is needed. A system check for a leak may be in order. Note that vapor cycle systems normally lose a small amount of refrigerant each year. No action is needed if this amount is within limits.

Occasionally, all of the refrigerant escapes from the system. No bubbles are visible in the sight glass, but the complete lack of cooling indicates the refrigerant has leaked out. To locate the leak point, the system needs to be partially charged with refrigerant so leak detection methods can be employed.

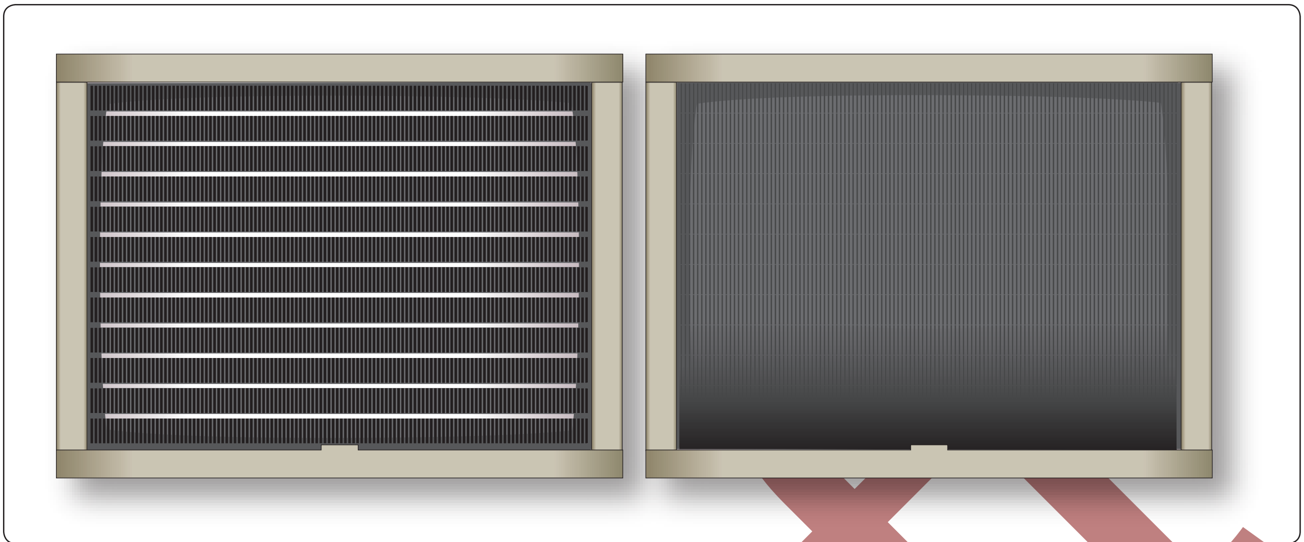


Figure 16-94. *Ice on the evaporator coils is cause for investigation. It prevents proper heat exchange to the refrigerant.*

About 50 psi of refrigerant in the high and low sides should be sufficient for a leak check. By introducing the refrigerant into the high side, pressure indicated on the low side gauge verifies the orifice in the expansion valve is not clogged. When all refrigerant is lost due to a leak, the entire system should be checked. Each fitting and connection should be inspected visually and with a leak detector.

When a vapor cycle air conditioning system loses all of its refrigerant charge, air may enter the system. Water may also enter since it is in the air. This means that a full system evacuation must be performed after the leak is found and repaired. By establishing only a 50-psi charge in a depleted system, the leak(s) becomes detectable, but time and refrigerant are not wasted prior to evacuation. System evacuation is discussed below.

Performance Test

Verification of proper operation of a vapor cycle air conditioning system is often part of a performance test. This involves operating the system and checking parameters to ensure they are in the normal range. A key indication of performance is the temperature of the air that is cooled by the evaporator. This can be measured at the air outflow from the evaporator or at a nearby delivery duct outlet. An ordinary thermometer should read 40–50 °F, with the controls set to full cold after the system has been allowed to operate for a few minutes. Manufacturer's instructions include information on where to place the thermometer and the temperature range that indicates acceptable performance.

Pressures can also be observed to indicate system performance. Typically, low side pressure in a vapor cycle system operating normally is 10–50 psi, depending on ambient temperature. High side pressure is between 125 and 250 psi, again, depending on ambient temperature and the design of the system. All system performance tests are performed at a specified engine rpm (stable compressor speed) and involve a period of time to stabilize the operation of the vapor cycle. Consult the manufacturer's instructions for guidance.

Feel Test

A quick reference field test can be performed on a vapor cycle air conditioning system to gauge its health. In particular, components and lines in the high side (from the compressor to the expansion valve) should be warm or hot to the touch. The lines on both sides of the receiver dryer should be the same temperature. Low side lines and the evaporator should be cool. Ice should not be visible on the outside of the system. If any discrepancies exist, further investigation is needed. On hot, humid days, the cooling output of the vapor cycle system may be slightly compromised due to the volume of water condensing on the evaporator.

Purging the System

Purging the system means emptying it of its refrigerant charge. Since the refrigerant must be captured, a service cart with this capability should be used. By connecting the hoses to the high side and low side service valves and selecting recover, cart solenoid valves position so that a system purging compressor pumps the refrigerant out of the vapor cycle system and into a recovery tank.

Vapor cycle systems must be properly purged before opening for maintenance or component replacement. Once opened, precautions should be taken to prevent contaminants from entering the system. When suspicion exists that the system has been contaminated, such as when a component has catastrophically failed, it can be flushed clean. Special fluid flush formulated for vapor cycle air conditioning systems should be used. The receiver dryer is removed from the system for flushing and a new unit is installed, as it contains fresh filters. Follow the aircraft manufacturer's instructions.

Checking Compressor Oil

The compressor is a sealed unit in the vapor cycle system that is lubricated with oil. Any time the system is purged, it is an opportunity to check the oil quantity in the compressor crankcase. This is often done by removing a filler plug and using a dip stick. Oil quantity should be maintained within the proper range using oil recommended by the manufacturer. Be certain to replace the filler plug after checking or adding oil. *[Figure 16-95]*

Evacuating the System

Only a few drops of moisture can contaminate a vapor cycle air conditioning system. If this moisture freezes in the expansion valve, it could completely block the refrigerant flow. Water is removed from the system by evacuation. Anytime the system refrigerant charge falls below atmospheric pressure, the refrigerant is lost, or the system is opened, it must be evacuated before recharging.

Evacuating a vapor cycle air conditioning system is also known as pumping down the system. A vacuum pump is

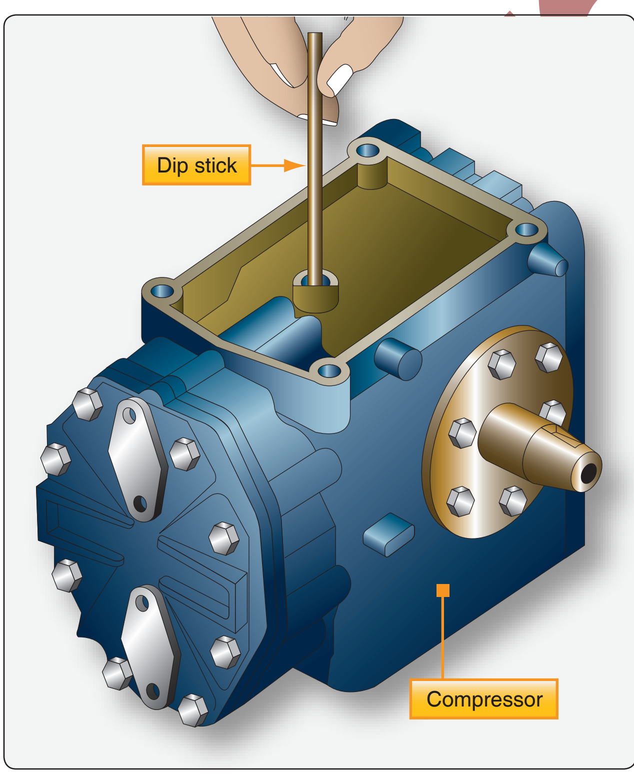


Figure 16-95. *Checking the compressor oil when the system is open.*

connected and pressure inside the system is reduced to vaporize any water that may exist. Continued operation of the vacuum pump draws the water vapor from the system. A typical pump used for evacuating an air conditioning system can reduce system pressure to about 29.62 "Hg (gauge pressure). At this pressure, water boils at 45 °F. Operate the vacuum pump to achieve the recommended gauge pressure. Hold this vacuum for as long as the manufacturer specifies.

As long as a vapor cycle air conditioning system retains a charge higher than atmospheric pressure, any leak forces refrigerant out of the system. The system pressure prevents air (and water vapor) from entering. Therefore, it is permissible to recharge or add refrigerant to a system that has not dropped below atmospheric pressure without evacuating the system.

Charging the System

Charging capacity of a vapor cycle air conditioning system is measured by weight. The aircraft manufacturer's maintenance manual specifies this amount and the amount and type of oil to be put into the system when filling. Pre-weighing the refrigerant or setting the refrigerant weight into the servicing cart input ensures the system is filled to capacity.

Charging a vapor cycle air conditioning system should be undertaken immediately after evacuation of the system is completed. With the hoses still connected to the high and low side service valves, selecting charge on the service cart panel positions solenoid operated valves so that the refrigerant supply is available. First, refrigerant is released into the high side of the system. Observe the low side gauge. When the low side gauge begins to indicate pressure, it is known that refrigerant is passing through the tiny orifice in the expansion valve. As pressure builds in the high side, the flow of refrigerant into the system stops.

To complete the charge of the system, refrigerant needs to be drawn in by the compressor. A major concern is to avoid damage to the compressor by having liquid refrigerant enter the compressor inlet. After the initial release of refrigerant into the high side, the high side service valve is closed, and the remaining charge is made through the low side service valve. The engine is started and run at a specified rpm, usually a high idle speed. Full cool is selected on the air conditioning control panel in the cockpit. As the compressor operates, it draws vapor into the low side until the correct weighed amount of refrigerant is in the system. Charging is completed with a full performance test.

Charging with a manifold set is accomplished in the same way. The manifold center hose is connected to the refrigerant source that charges the system. After opening the valve on the container (or puncturing the seal on a small can), the center hose connection on the manifold set should be loosened to allow air in the hose to escape. Once the air is bled out of the hose, the refrigerant can enter the system through whichever service valve is opened. The sequence is the same as above and all manufacturer instructions should be followed.

Oil quantity added to the system is specified by the manufacturer. Refrigerant premixed with oil is available and may be permissible for use. This eliminates the need to add oil separately. Alternately, the amount of oil to be put into the system can be selected on the servicing cart. Approximately ¼ ounce of oil for each pound of refrigerant is a standard amount; however, follow the manufacturer's specifications.

Technician Certification

The EPA requires certification of technicians that work with vapor cycle air conditioning refrigerant and equipment to ensure safe compliance with current regulations. Aircraft technicians can obtain certification or can refer vapor cycle air conditioning work to shops that specialize in this work.

Aircraft Heaters

Bleed Air Systems

Temperatures at high altitudes in which aircraft operate can be well below 0 °F. Combined with seasonally cold temperatures, this makes heating the cabin more than just a luxury. Pressurized aircraft that use air cycle air conditioning systems mix bleed air with cold air produced by the air cycle machine expansion turbine to obtain warm air for the cabin. This is discussed in the section that covers air cycle air conditioning in this chapter. Aircraft not equipped with air cycle air conditioning may be heated by one of a few possible methods.

Some turbine-powered aircraft not equipped with air cycle systems still make use of engine compressor bleed air to heat the cabin. Various arrangements exist. The bleed air is mixed with ambient air, or cabin return air, and distributed throughout the aircraft via ducting. The mixing of air can be done in a variety of ways. Mixing air valves, flow control valves, shutoff valves, and other various control valves are controlled by switches in the cockpit. One STC'd bleed air heat system uses mini-ejectors in helicopter cabins to combine bleed air with cabin air. All of these bleed air heating systems are simple and function well, as long as the valves, ducting, and controls are in operational condition.

Electric Heating Systems

Occasionally, an electric heating device is used to heat the aircraft. Electricity flowing through a heating element makes the element warm. A fan to blow air over the elements and into the cabin is used to transfer the heat. Other floor or sidewall elements simply radiate heat to warm the cabin.

Electric heating element heaters require a significant amount of the aircraft's generator output, which is better dedicated to the operation of other electrical devices. For this reason, they are not very common. However, their use on the ground when powered by a ground electrical power source preheats the cabin before passengers board and does not tax the electrical system.

Exhaust Shroud Heaters

Most single-engine light aircraft use exhaust shroud heating systems to heat the cabin. Ambient air is directed into a metal shroud, or jacket, that encases part of the engine's exhaust system. The air is warmed by the exhaust and directed through a firewall heater valve into the cabin. This simple solution requires no electrical or engine power and it makes use of heat that would otherwise be wasted. *[Figures 16-96 and 16-97]*

A major concern of exhaust shroud heat systems is the possibility that exhaust gases could contaminate the cabin air. Even the slightest crack in an exhaust manifold could send enough carbon monoxide into the cabin to be fatal. Strict inspection procedures are in place to minimize this threat. Most involve pressurizing the exhaust system with air, while inspecting for leaks with a soapy solution. Some require the exhaust to be removed and pressurized while submerged under water to detect any leaks. Frequency of exhaust heat leak detection can be every 100 hours.

Occasionally, the exhaust system is slightly modified in a shroud heat configuration. For example, an exhaust muffler may have numerous welded studs attached, which increase heat transfer to the cabin air. Each weld point is a location for a potential leak. *[Figure 16-98]*

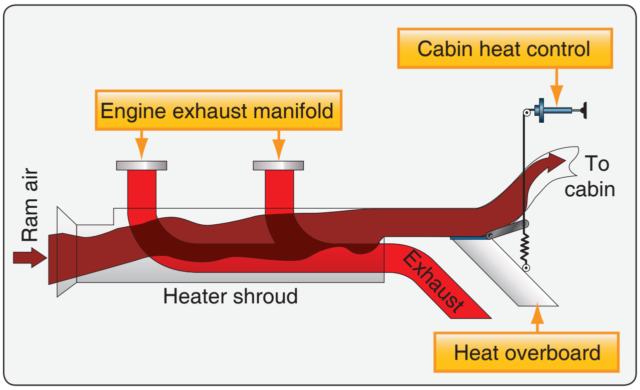


Figure 16-96. *The basic arrangement of an aircraft exhaust shroud heater.*

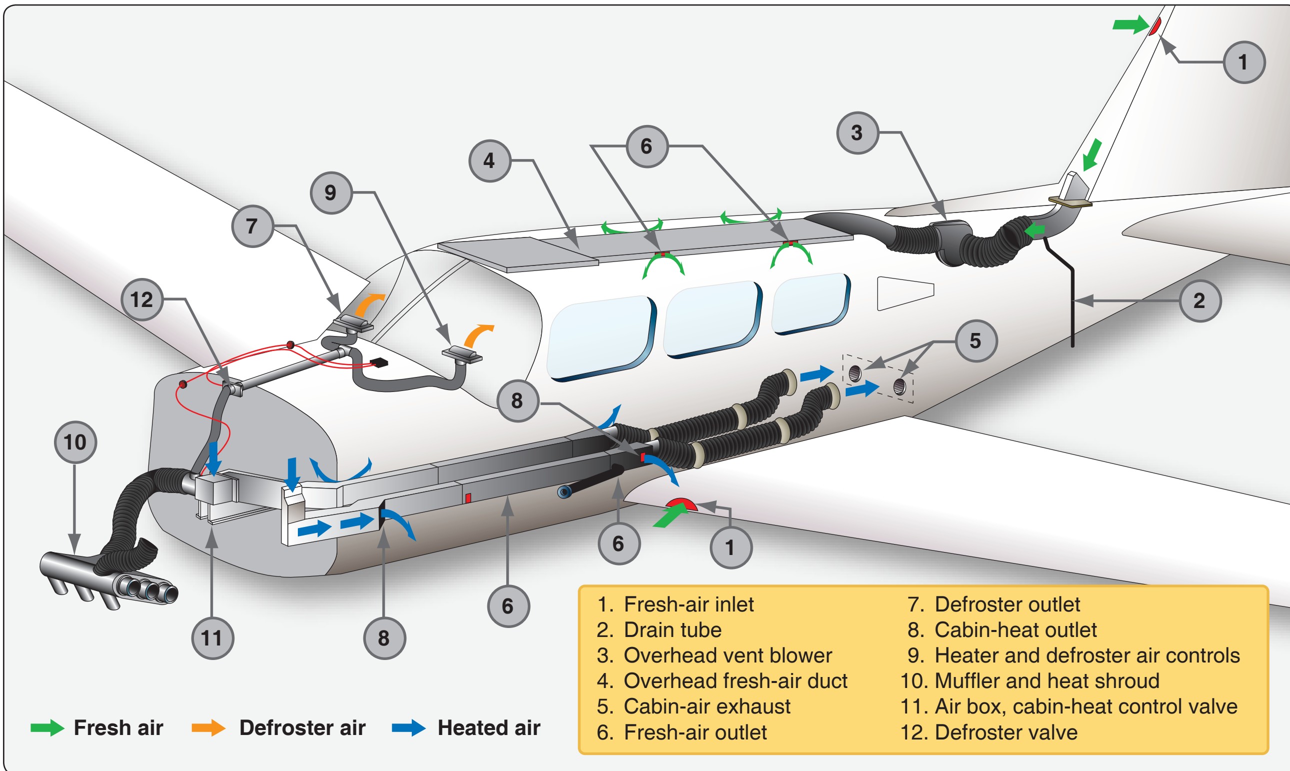


Figure 16-97. *The environmental system of a single-engine Piper aircraft with an exhaust shroud heating system.*

Regardless of age or condition, aircraft with exhaust shroud heating systems should contain a carbon monoxide detection device in the cockpit.

Combustion Heaters

An aircraft combustion heater is used on many small to medium sized aircraft. It is a heat source independent from the aircraft's engine(s), although it does use fuel from the aircraft's main fuel system. Combustion heaters are manufactured by a few different companies that supply the aviation industry. Most are similar to the description that follows. The most up to date units have electronic ignition and temperature control switches.

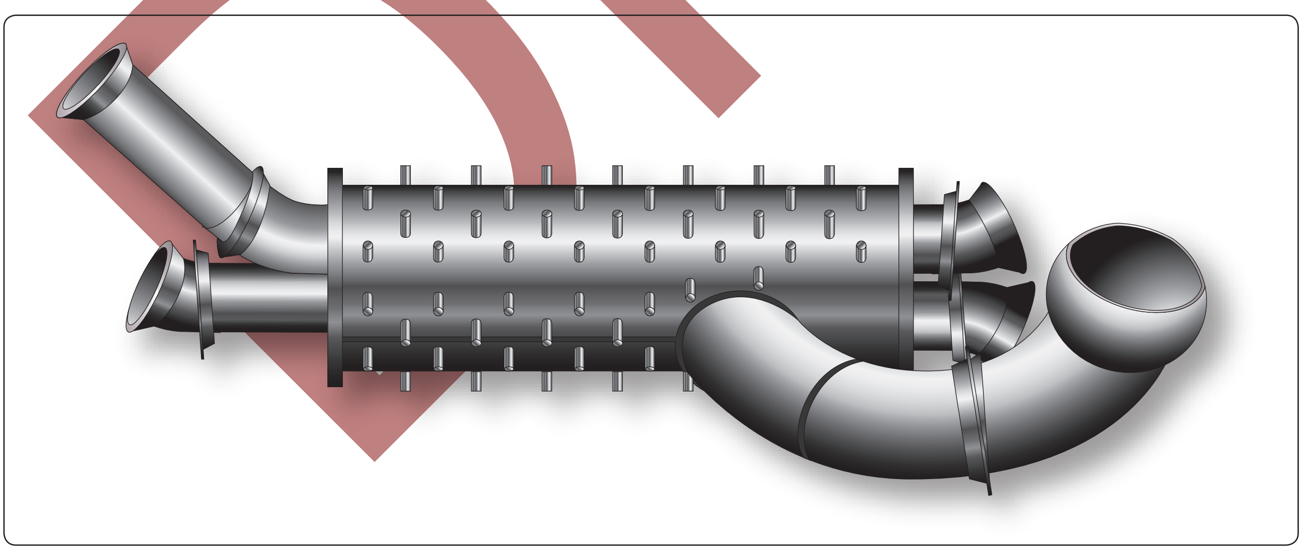


Figure 16-98. *An exhaust manifold with its shroud removed showing numerous welded studs used to increase heat transfer from the exhaust to the ambient air going to the cabin.*

Combustion heaters are similar to exhaust shroud heaters in that ambient air is heated and sent to the cabin. The source of heat in this case is an independent combustion chamber located inside the cylindrical outer shroud of the heater unit. The correct amount of fuel and air are ignited in the air-tight inner chamber. The exhaust from combustion is funneled overboard. Ambient air is directed between the combustion chamber and the outer shroud. It absorbs the combustion heat by convection and is channeled into the cabin. *[Figure 16-99]* Refer to *Figure 16-100* for the following descriptions of the combustion heater subsystems and heater operation.

Combustion Air System

The air used in the combustion process is ambient air scooped from outside the aircraft, or from the compartment in which the combustion heater is mounted. A blower ensures that the correct quantity and pressure of air are sent into the chamber.

Some units have regulators or a relief valve to ensure these parameters. The combustion air is completely separate from the air that is warmed and sent into the cabin.

Ventilating Air System

Ventilating air is the name of the air that is warmed and sent into the cabin. Typically, it comes into the combustion heater through a ram air intake. When the aircraft is on the ground, a ventilating air fan controlled by a landing gear squat switch operates to draw in the air. Once airborne, the fan ceases to operate as the ram air flow is sufficient. Ventilating air passes between the combustion chamber and the outer shroud of the combustion heater where it is warmed and sent to the cabin.

Figure 16-99. *A modern combustion heater.*

Fuel System

As mentioned, fuel for the combustion heater is drawn from an aircraft fuel tank. A constant pressure fuel pump with relief valve pulls the fuel through a filter. A main solenoid valve downstream delivers the fuel to the unit. The solenoid is controlled by the cabin heater switch in the cockpit and three safety switches located on the combustion heater. The first safety switch is a duct limit switch that keeps the valve closed should the unit not have enough ventilating airflow to keep it within the correct operating temperature range. The second is a pressure switch that must sense pressure from the combustion air fan to allow the solenoid to open. Fuel

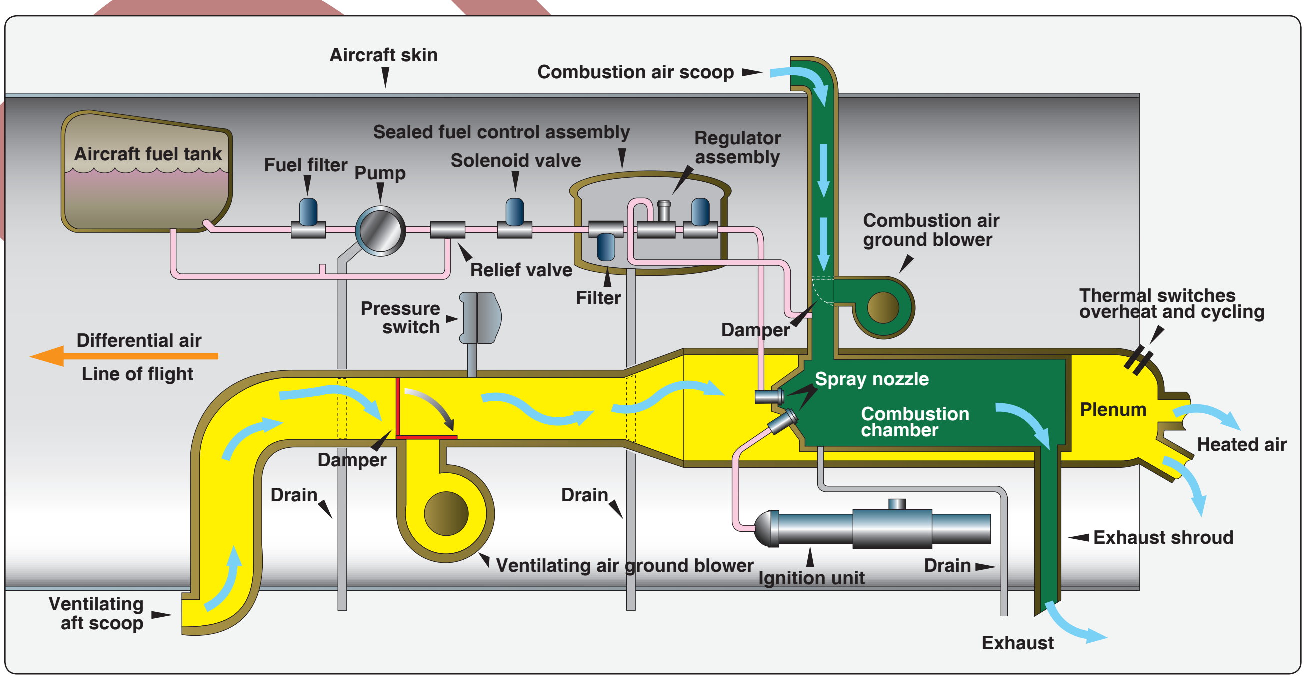


Figure 16-100. *A diagram of a typical combustion heater and its components.*

is delivered to the combustion chamber only if there is air there with which it can be mixed. Finally, an overheat switch also controls the main fuel supply solenoid. When an over temperature condition occurs, it closes the solenoid to stop the supply of fuel.

A secondary solenoid is located downstream of the main fuel supply solenoid. It is part of a fuel control unit that also houses a pressure regulator and an additional fuel filter. The valve opens and closes on command from the combustion heater thermostat. During normal operation, the heater cycles on and off by opening and closing this solenoid at the entrance to the combustion chamber. When opened, fuel flows through a nozzle that sprays it into the combustion chamber. *[Figure 16-100]*

Ignition System

Most combustion heaters have an ignition unit designed to receive aircraft voltage and step it up to fire a spark plug located in the combustion chamber. Older combustion heaters use vibrator-type ignition units. Modern units have electronic ignition. *[Figure 16-101]* The ignition is continuous when activated. This occurs when the heater switch is placed in the ON position in the cockpit, and the combustion air blower builds sufficient air pressure in the combustion chamber. Use of the proper spark plug for the combustion heater is essential. Check the manufacturer's approved data. *[Figure 16-102]*

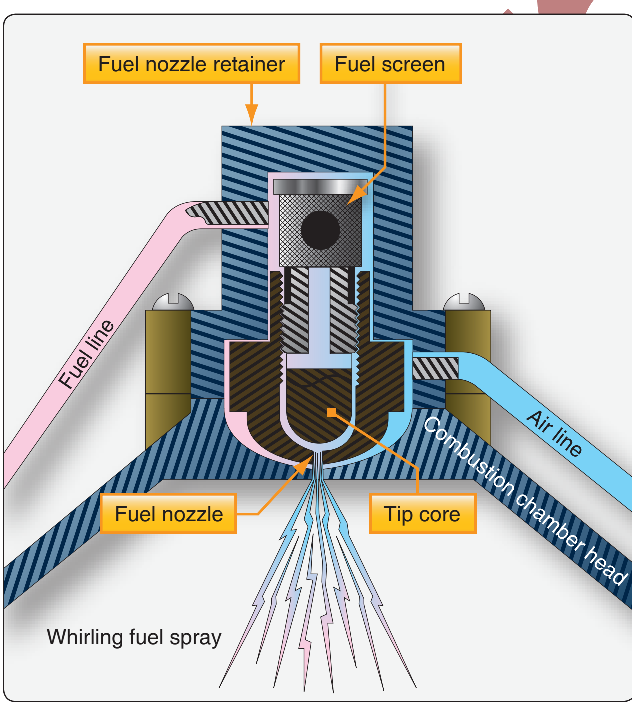


Figure 16-101. *The fuel nozzle located at the end of the combustion chamber sprays aircraft fuel, which is lit by a continuous sparking ignition system spark plug.*

Controls

The combustion heater controls consist of a cabin heat switch and a thermostat. The cabin heat switch starts the fuel pump, opens the main fuel supply solenoid, and turns on the combustion air fan, as well as the ventilating air fan if the aircraft is on the ground. When the combustion air fan builds pressure, it allows the ignition unit to start. The thermostat sends power to open the fuel control solenoid when heat is needed. This triggers combustion in the unit and heat is delivered to the cabin. When the preselected temperature is reached, the thermostat cuts power to the fuel control solenoid and combustion stops. Ventilating air continues to circulate and carry heat away. When the temperature level falls to that below which the thermostat is set, the combustion heater cycles on again.

Safety Features

Various automatic combustion heater controls prevent operation of the heater when dangerous conditions exist. As stated, a duct limit switch cuts off fuel to the heater when there is not enough airflow to keep the heater duct below a preset temperature. This is usually caused by a lack of ventilating air flow. An overheat switch set at a higher temperature than the duct limit switch guards against overheat of any kind. It is designed to cut fuel to the combustion heater before an unwanted fire occurs. When this switch activates, a light is illuminated in the cockpit and the heater cannot be restarted until maintenance determines the cause. Some heaters contain a circuit to prevent fuel from being delivered to the combustion chamber if the ignition system is not working.

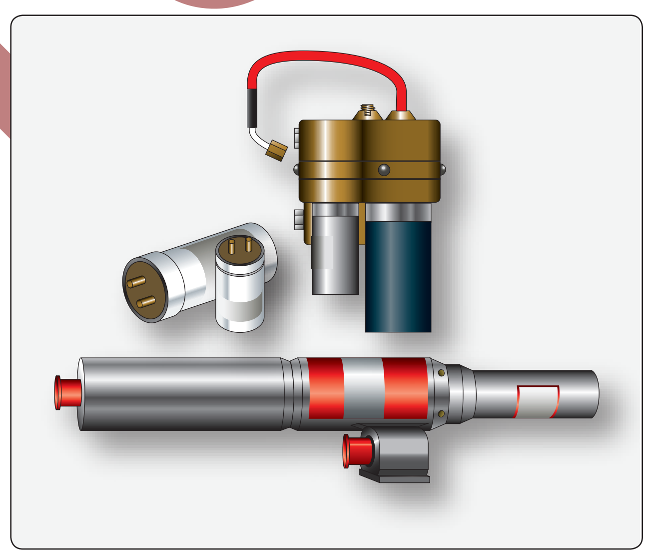


Figure 16-102. *Examples of ignition units used on combustion heaters.*

Maintenance and Inspection

Maintenance of combustion heaters consists of routine items, such as cleaning filters, checking spark plug wear, and ensuring inlets are not plugged. All maintenance and inspection of combustion heaters should be accomplished in accordance with the aircraft manufacturer's instructions. Combustion heater manufacturers also produce maintenance guidelines that should be followed. Intervals between the performance of maintenance items and the time between overhauls must be followed to help ensure a properly functioning heater is available when it is needed.

Inspection of the combustion heater should be performed on schedule as provided by the manufacturer or whenever a malfunction is suspected. Inlets and outlets should be clear. All controls should be checked for freedom of operation and function. Close observation for any sign of fuel leaks or cracks in the combustion chamber and/or shroud should be made. All components should be secure. An operational check can also be made. Follow the manufacturer's inspection criteria to ensure the combustion heater is in airworthy condition.

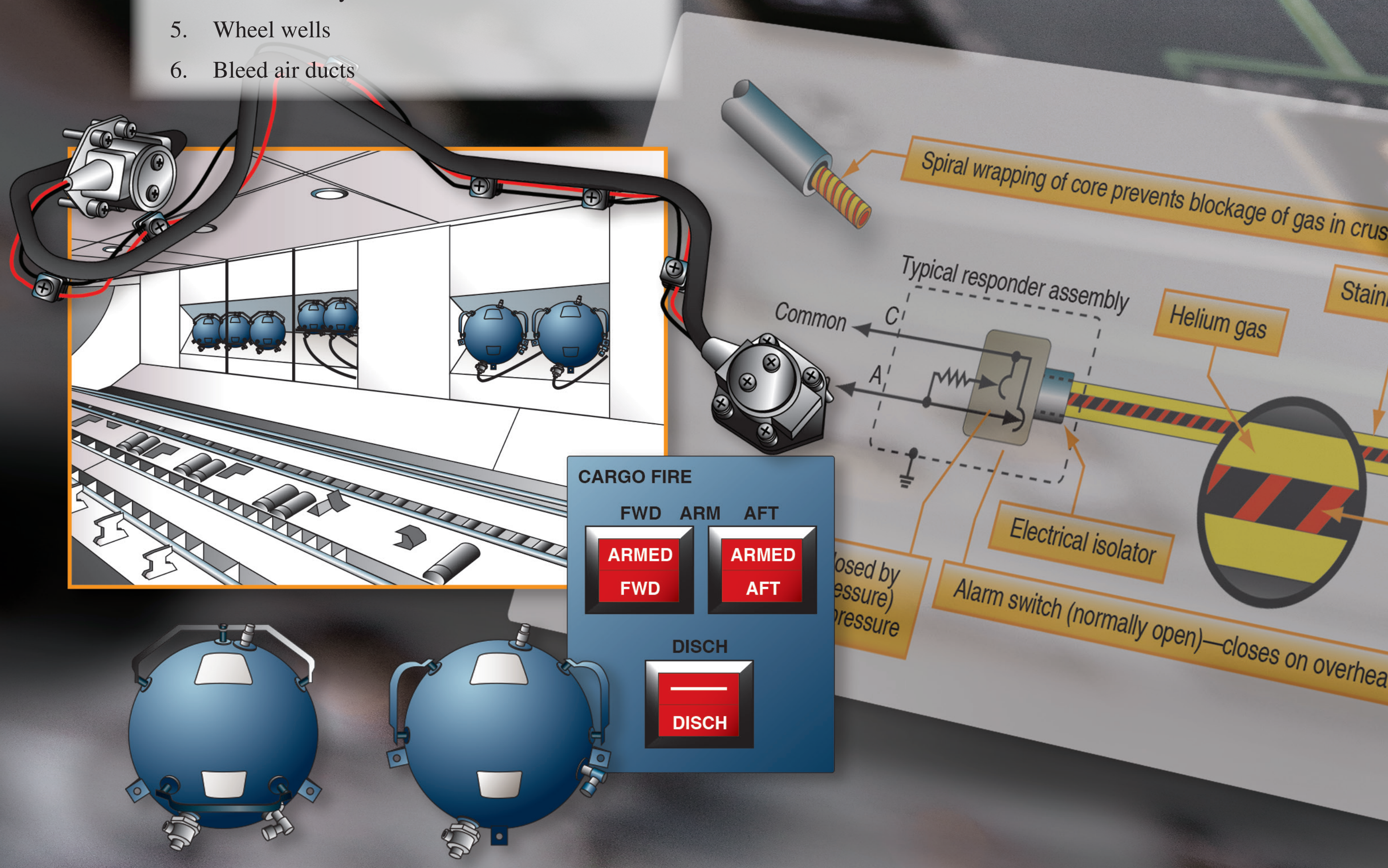
Chapter 17

Fire Protection Systems

Introduction

Because fire is one of the most dangerous threats to an aircraft, the potential fire zones of modern multiengine aircraft are protected by a fixed fire protection system. A fire zone is an area, or region, of an aircraft designed by the manufacturer to require fire detection and/or fire extinguishing equipment and a high degree of inherent fire resistance. The term "fixed" describes a permanently installed system in contrast to any type of portable fire extinguishing equipment, such as a hand-held Halon or water fire extinguisher. A complete fire protection system on modern aircraft, and on many older aircraft, includes a fire detection system and a fire extinguishing system. Typical zones on aircraft that have a fixed fire detection and/or fire extinguisher system are:

1. Engines and auxiliary power unit (APU)
2. Cargo and baggage compartments
3. Lavatories on transport aircraft
4. Electronic bays
5. Wheel wells
6. Bleed air ducts



To detect fires or overheat conditions, detectors are placed in the various zones to be monitored. Fires are detected in reciprocating engine and small turboprop aircraft using one or more of the following:

1. Overheat detectors
2. Rate-of-temperature-rise detectors
3. Flame detectors
4. Observation by crewmembers

In addition to these methods, other types of detectors are used in aircraft fire protection systems but are seldom used to detect engine fires. For example, smoke detectors are better suited to monitor areas where materials burn slowly or smolder, such as cargo and baggage compartments. Other types of detectors in this category include carbon monoxide detectors and chemical sampling equipment capable of detecting combustible mixtures that can lead to accumulations of explosive gases.

The complete aircraft fire protection systems of most large turbine-engine aircraft incorporate several of these different detection methods.

1. Rate-of-temperature-rise detectors
2. Radiation sensing detectors
3. Smoke detectors
4. Overheat detectors
5. Carbon monoxide detectors
6. Combustible mixture detectors
7. Optical detectors
8. Observation by crew or passengers

The types of detectors most commonly used for fast detection of fires are the rate-of-rise, optical sensor, pneumatic loop, and electric resistance systems.

Classes of Fires

The following classes of fires that are likely to occur onboard aircraft, as defined in the U.S. National Fire Protection Association (NFPA) Standard 10, Standard for Portable Fire Extinguishers, 2007 Edition, are:

1. Class A—fires involving ordinary combustible materials, such as wood, cloth, paper, rubber, and plastics.
2. Class B—fires involving flammable liquids, petroleum oils, greases, tars, oil-based paints, lacquers, solvents, alcohols, and flammable gases.
3. Class C—fires involving energized electrical equipment in which the use of an extinguishing media that is electrically nonconductive is important.
4. Class D—fires involving combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.

Requirements for Overheat and Fire Protection Systems

Fire protection systems on current-production aircraft do not rely on observation by crew members as a primary method of fire detection. An ideal fire detector system includes as many of the following features as possible:

1. No false warnings under any flight or ground condition.
2. Rapid indication of a fire and accurate location of the fire.
3. Accurate indication that a fire is out.
4. Indication that a fire has re-ignited.
5. Continuous indication for duration of a fire.
6. Means for electrically testing the detector system from the aircraft cockpit.
7. Resists damage from exposure to oil, water, vibration, extreme temperatures, or handling.
8. Light in weight and easily adaptable to any mounting position.
9. Circuitry that operates directly from the aircraft power system without inverters.
10. Minimum electrical current requirements when not indicating a fire.
11. Cockpit light that illuminates, indicating the location of the fire, and with an audible alarm system.
12. A separate detector system for each engine.

Fire Detection/Overheat Systems

A fire detection system should signal the presence of a fire. Units of the system are installed in locations where there are greater possibilities of a fire. Three detector system types in common use are the thermal switch, thermocouple, and the continuous loop.

Thermal Switch System

A number of detectors, or sensing devices, are available. Many older-model aircraft still operating have some type of thermal switch system or thermocouple system. A thermal switch system has one or more lights energized by the aircraft power system and thermal switches that control operation of the light(s). These thermal switches are heat-sensitive units that complete electrical circuits at a certain temperature. They are connected in parallel with each other but in series with the indicator lights. *[Figure 17-1]* If the temperature rises above a set value in any one section of the circuit, the thermal switch closes, completing the light circuit to indicate a fire or overheat condition. No set number of thermal switches is required; the exact number is usually determined by the aircraft manufacturer. On some installations, all the thermal detectors are connected to one light; on others, there may be one thermal switch for each indicator light.

Some warning lights are push-to-test lights. The bulb is tested by pushing it in to check an auxiliary test circuit. The circuit shown in *Figure 17-1* includes a test relay. With the relay contact in the position shown, there are two possible paths for current flow from the switches to the light. This is an additional safety feature. Energizing the test relay completes a series circuit and checks all the wiring and the light bulb. Also included in the circuit shown in *Figure 17-1* is a dimming relay. By energizing the dimming relay, the circuit is altered to include a resistor in series with the light. In some installations, several circuits are wired through the dimming relay, and all the warning lights may be dimmed at the same time.

Thermocouple System

The thermocouple fire warning system operates on an entirely different principle from the thermal switch system. A thermocouple depends on the rate of temperature rise and does not give a warning when an engine slowly overheats or a short circuit develops. The system consists of a relay box, warning lights, and thermocouples. The wiring system of these units may be divided into the following circuits:

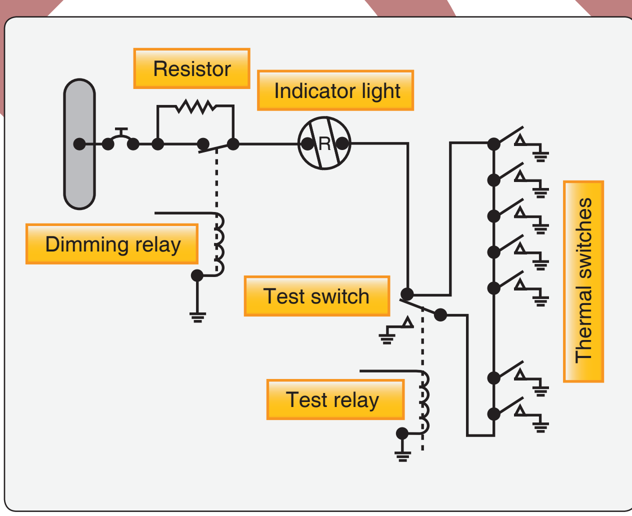


Figure 17-1. *Thermal switch fire circuit.*

1. Detector circuit
2. Alarm circuit
3. Test circuit

These circuits are shown in *Figure 17-2*. The relay box contains two relays, the sensitive relay and the slave relay, and the thermal test unit. Such a box may contain from one to eight identical circuits, depending on the number of potential fire zones. The relays control the warning lights. In turn, the thermocouples control the operation of the relays. The circuit consists of several thermocouples in series with each other and with the sensitive relay.

The thermocouple is constructed of two dissimilar metals, such as chromel and constantan. The point at which these metals are joined and exposed to the heat of a fire is called a hot junction. There is also a reference junction enclosed in a dead air space between two insulation blocks. A metal cage surrounds the thermocouple to give mechanical protection without hindering the free movement of air to the hot junction. If the temperature rises rapidly, the thermocouple produces a voltage because of the temperature difference between the reference junction and the hot junction. If both junctions are heated at the same rate, no voltage results. In the engine compartment, there is a normal, gradual rise in temperature from engine operation; because it is gradual, both junctions heat at the same rate and no warning signal is given. If there is a fire, however, the hot junction heats more rapidly than the reference junction. The ensuing voltage causes a current to flow within the detector circuit. Any time the current is greater than 4 milliamperes (0.004 ampere), the sensitive relay closes. This completes a circuit from the aircraft power system to the coil of the slave relay. The slave relay then closes and completes the circuit to the warning light to give a visual fire warning.

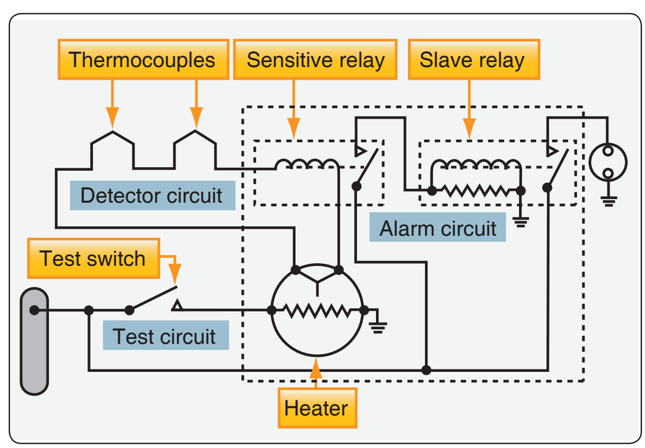


Figure 17-2. *Thermocouple fire warning circuit.*

The total number of thermocouples used in individual detector circuits depends on the size of the fire zones and the total circuit resistance, which usually does not exceed 5 ohms. As shown in *Figure 17-2,* the circuit has two resistors. The resistor connected across the slave relay terminals absorbs the coil's self-induced voltage to prevent arcing across the points of the sensitive relay. The contacts of the sensitive relay are so fragile that they burn, or weld, if arcing is permitted.

When the sensitive relay opens, the circuit to the slave relay is interrupted and the magnetic field around its coil collapses. The coil then gets a voltage through self-induction but, with the resistor across the coil terminals, there is a path for any current flow as a result of this voltage, eliminating arcing at the sensitive relay contacts.

Continuous-Loop Systems

Transport aircraft almost exclusively use continuous thermal sensing elements for powerplant and wheel well protection. These systems offer superior detection performance and coverage, and they have the proven ruggedness to survive in the harsh environment of modern turbofan engines.

A continuous-loop detector or sensing system permits more complete coverage of a fire hazard area than any of the spot-type temperature detectors. Two widely used types of continuous-loop systems are the thermistor type detectors, such as the Kidde and the Fenwal systems, and the pneumatic pressure detector, such as the Lingberg system. (Lindberg system is also known as Systron-Donner and, more recently, Meggitt Safety Systems.)

Fenwal System

The Fenwal system uses a slender Inconel tube packed with thermally sensitive eutectic salt and a nickel wire center conductor. *[Figure 17-3]* Lengths of these sensing elements are connected in series to a control unit. The elements may be of equal or varying length and of the same or different temperature settings. The control unit, operating directly from the power source, impresses a small voltage on the sensing elements. When an overheat condition occurs at any point along the element length, the resistance of the eutectic salt within the sensing element drops sharply, causing current to flow between the outer sheath and the center conductor. This current flow is sensed by the control unit, which produces a signal to actuate the output relay and activate the alarms. When the fire has been extinguished or the critical temperature lowered below the set point, the Fenwal system automatically returns to standby alert, ready to detect any subsequent fire or overheat condition. The Fenwal system may be wired to employ a loop circuit. In this case, should an open circuit occur, the system still signals fire or overheat. If multiple open circuits occur, only that section between breaks becomes inoperative.

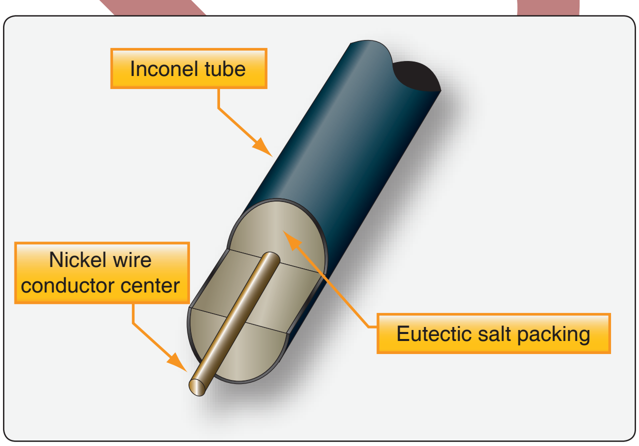


Figure 17-3. *Fenwal sensing element.*

Kidde System

In the Kidde continuous-loop system, two wires are imbedded in an inconel tube filled with a thermistor core material. *[Figure 17-4]* Two electrical conductors go through the length of the core. One conductor has a ground connection to the tube, and the other conductor connects to the fire detection control unit. As the temperature of the core increases, electrical resistance to the ground decreases. The fire detection control unit monitors this resistance. If the resistance decreases to the overheat set point, an overheat indication occurs in the flight deck. Typically, a 10-second time delay is incorporated for the overheat indication. If the resistance decreases more to the fire set point, a fire warning occurs. When the fire or overheat condition is gone, the resistance of the core material increases to the reset point and the flight deck indications disappear. The rate of change of resistance identifies an electrical short or a fire. The resistance decreases more quickly with an electrical short than with a fire. In some aircraft, in addition to fire and overheat detection, the Kidde continuous-loop system can supply nacelle temperature data to the airplane condition monitoring function of the aircraft in-flight monitoring system (AIMS).

Sensing Element

The resistance of a sensor varies inversely as it is heated; as sensor temperature is increased, its resistance decreases. Each sensor is composed of two wires embedded in thermistor material that is encased in a heavy wall inconel tube for high strength at elevated temperatures. The electrical connectors at each end of the sensor are ceramic insulated. The inconel tubes are shrouded in a perforated stainless-steel tube and supported by Teflon-impregnated asbestos bushings at intervals. The shroud protects the sensor from breakage due to vibration, abrasion against airplane structure, and damage from maintenance activity.

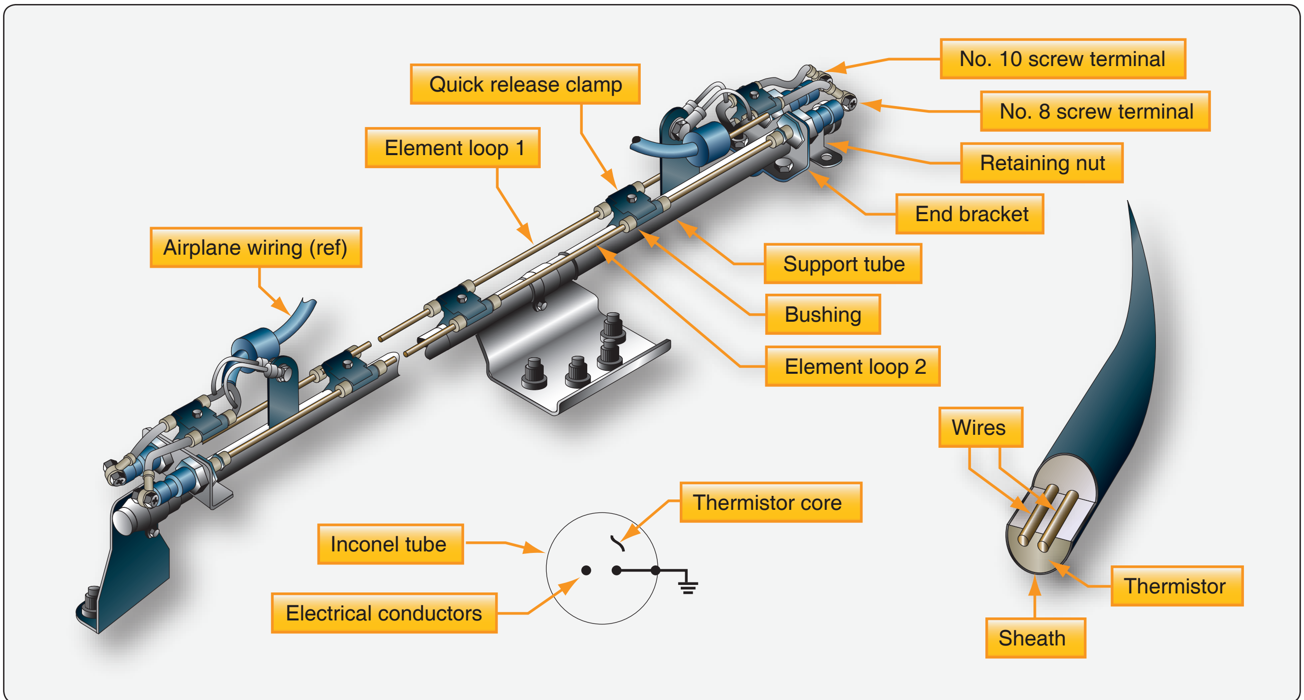


Figure 17-4. *Kidde continuous-loop system.*

The resistance of a sensor also varies inversely with its length, the increments of length being resistances in parallel. The heating of a short length of sensor out of a given length requires that the short length be heated above the temperature alarm point, so the total resistance of the sensor decreases to the alarm point. This characteristic permits integration of all temperatures throughout the length of the installation rather than sensing only the highest local temperature. The two wires encased within the thermistic material of each inconel tube form a variable resistance network between themselves, between the detector wire and the inconel tube, and between each adjacent incremental length of sensor. These variable resistance networks are monitored by the application of 28 volts direct current (DC) to the detector wire from the detector control unit.

Combination Fire and Overheat Warning

The analog signal from the thermistor-sensing element permits the control circuits to be arranged to give a two-level response from the same sensing element loop. The first is an overheat warning at a temperature level below the fire warning indicating a general engine compartment temperature rise, such as would be caused by leakage of hot bleed air or combustion gas into the engine compartment. It could also be an early warning of fire and would alert the crew to appropriate action to reduce the engine compartment temperature. The second-level response is at a level above that attainable by a leaking hot gas and is the fire warning.

Temperature Trend Indication

The analog signal produced by the sensing element loop as its temperature changes is converted to signals suitable for flight deck display to indicate engine bay temperature increases from normal. A comparison of the readings from each loop system also provides a check on the condition of the fire detection system, because the two loops should normally read alike.

System Test

The integrity of the continuous-loop fire detection system may be tested by actuating a test switch in the flight deck that switches one end of the sensing element loop from its control circuit to a test circuit built into the control unit, which simulates the sensing element resistance change due to fire. *[Figure 17-5]* If the sensing element loop is unbroken, the resistance detected by the control circuit is that of the simulated fire, and the alarm is activated. The test demonstrates, in addition to the continuity of the sensing element loop, the integrity of the alarm indicator circuit and the proper functioning of the control circuits. The thermistic properties of the sensing element remain unchanged for the life of the element (no irreversible changes take place when heated); the element functions properly as long as it is electrically connected to the control unit.

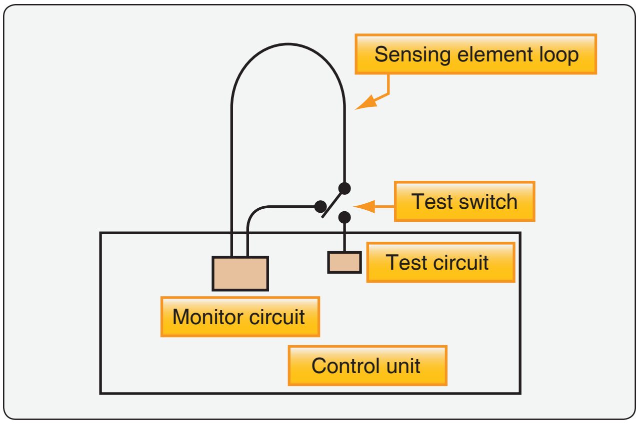


Figure 17-5. *Continuous loop fire detection system test circuit.*

Fault Indication

Provision is made in the control unit to output a fault signal which activates a fault indicator whenever the short discriminator circuit detects a short in the sensing element loop. This is a requirement for transport category aircraft because such a short disables the fire detection system.

Dual-Loop Systems

Dual-loop systems are two complete basic fire detection systems with their output signals connected so that both must signal to result in a fire warning. This arrangement, called AND logic, results in greatly increased reliability against false fire warnings from any cause. Should one of the two loops be found inoperative at the preflight integrity test, a cockpit selector switch disconnects that loop and allows the signal from the other loop alone to activate the fire warning. Since the single operative loop meets all fire detector requirements, the aircraft can be safely dispatched and maintenance deferred to a more convenient time. However, should one of the two loops become inoperative in flight and a fire subsequently occur, the fire signaling loop activates a cockpit fault signal that alerts the flight crew to select single-loop operation to confirm the possible occurrence of fire.

Automatic Self-Interrogation

Dual-loop systems automatically perform the loop switching and decision-making function required of the flight crew upon appearance of the fault indication in the cockpit, a function called automatic self-interrogation. Automatic self-interrogation eliminates the fault indication and assures the immediate appearance of the fire indication should fire occur while at least one loop of the dual-loop system is operative. Should the control circuit from a single-loop signal fire, the self-interrogation circuit automatically tests the functioning of the other loop. If it tests operative, the circuit suppresses the fire signal because the operative loop would have signaled if a fire existed. If, however, the other loop tests inoperative, the circuit outputs a fire signal. The interrogation and decision takes place in milliseconds, so that no delay occurs if a fire actually exists.

Support Tube Mounted Sensing Elements

For those installations where it is desired to mount the sensing elements on the engine, and in some cases, on the aircraft structure, the support tube mounted element solves the problem of providing sufficient element support points and greatly facilitates the removal and reinstallation of the sensing elements for engine or system maintenance.

Most modern installations use the support tube concept of mounting sensing elements for better maintainability, as well as increased reliability. The sensing element is attached to a prebent stainless steel tube by closely spaced clamps and bushings, where it is supported from vibration damage and protected from pinching and excessive bending. The support tube-mounted elements can be furnished with either single or dual sensing elements.

Being prebent to the designed configuration assures its installation in the aircraft precisely in its designed location, where it has the necessary clearance to be free from the possibility of the elements chafing against engine or aircraft structure. The assembly requires only a few attachment points and, should its removal for engine maintenance be necessary, it is quickly and easily accomplished. Should the assembly require repair or maintenance, it is easily replaced with another assembly, leaving the repair for the shop. Should a sensing element be damaged, it is easily replaced in the assembly.

Fire Detection Control Unit (Fire Detection Card)

The control unit for the simplest type of system typically contains the necessary electronic resistance monitoring and alarm output circuits housed in a hermetically sealed aluminum case fitted with a mounting bracket and electrical connector. For more sophisticated systems, control modules are employed that contain removable control cards with circuitry for individual hazard areas and/or unique functions. In the most advanced applications, the detection system circuitry controls all aircraft fire protection functions, including fire detection and extinguishing for engines, APUs, cargo bays, and bleed-air systems.

Pressure Type Sensor Responder Systems

Some smaller turboprop aircraft are outfitted with pneumatic single point detectors. The design of these detectors is based on the principles of gas laws. The sensing element consists of a closed, helium-filled tube connected at one end to a responder assembly. As the element is heated, the gas pressure inside the tube increases until the alarm threshold is reached. At this point, an internal switch closes and reports an alarm to the cockpit. Continuous fault monitoring is included. This type of sensor is designed as a single-sensor detection system and does not require a control unit.

Pneumatic Continuous-Loop Systems

The pneumatic continuous-loop systems are also known by their manufacturers' names Lindberg, Systron-Donner, and Meggitt Safety Systems. These systems are used for engine fire detection of transport type aircraft and have the same function as the Kidde system; however, they work on a different principle. They are typically used in a dual-loop design to increase reliability of the system.

The pneumatic detector has two sensing functions. It responds to an overall average temperature threshold and to a localized discrete temperature increase caused by impinging flame or hot gasses. Both the average and discrete temperature are factory set and are not field adjustable. *[Figure 17-6]*

Averaging Function

The fire/overheat detector serves as a fixed-volume device filled with helium gas. The helium gas pressure inside the detector increases in proportion to the absolute temperature and operates a pressure diaphragm that closes an electrical contact, actuating the alarm circuit. The pressure diaphragm within the responder assembly serves as one side of the electrical alarm contact and is the only moving part in the detector. The alarm switch is preset at an average temperature. Typical temperature ranges for average temperature settings are 200 °F (93 °C) to 850 °F (454 °C).

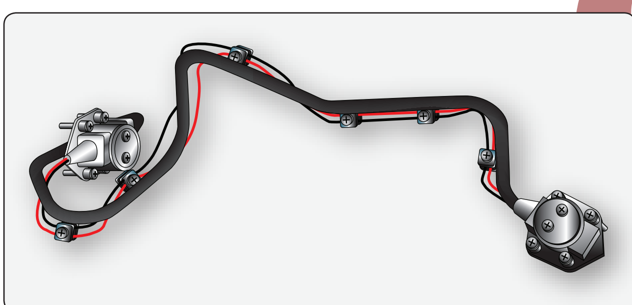


Figure 17-6. *Pneumatic dual fire/overheat detector assembly.*

Discrete Function

The fire/overheat detector's sensor tube also contains a hydrogen-filled core material. *[Figure 17-7]* Large quantities of hydrogen gas are released from the detector core whenever a small section of the tube is heated to the preset discrete temperature or higher. The core outgassing increases the pressure inside the detector and actuates the alarm switch. Both the averaging and discrete functions are reversible. When the sensor tube is cooled, the average gas pressure is lowered, and the discrete hydrogen gas returns to the core material. The reduction of internal pressure allows the alarm switch to return to its normal position, opening the electrical alarm circuit.

Figure 17-8 shows a typical aircraft fire detection system in which a control module monitors two loops of up to four pneumatic detectors each, connected in parallel. The control module responds directly to an alarm condition and continuously monitors the wiring and integrity of each loop. The normally open alarm switch closes upon an overheat or fire condition, causing a short circuit between terminals A and C. During normal operation, a resistance value is maintained across the terminals by a normally closed integrity switch. Loss of sensor gas pressure opens the integrity switch, creating an open circuit across the terminals of the faulted detector. In addition to the pressure-activated alarm switch, there is a second integrity switch in the detector that is held

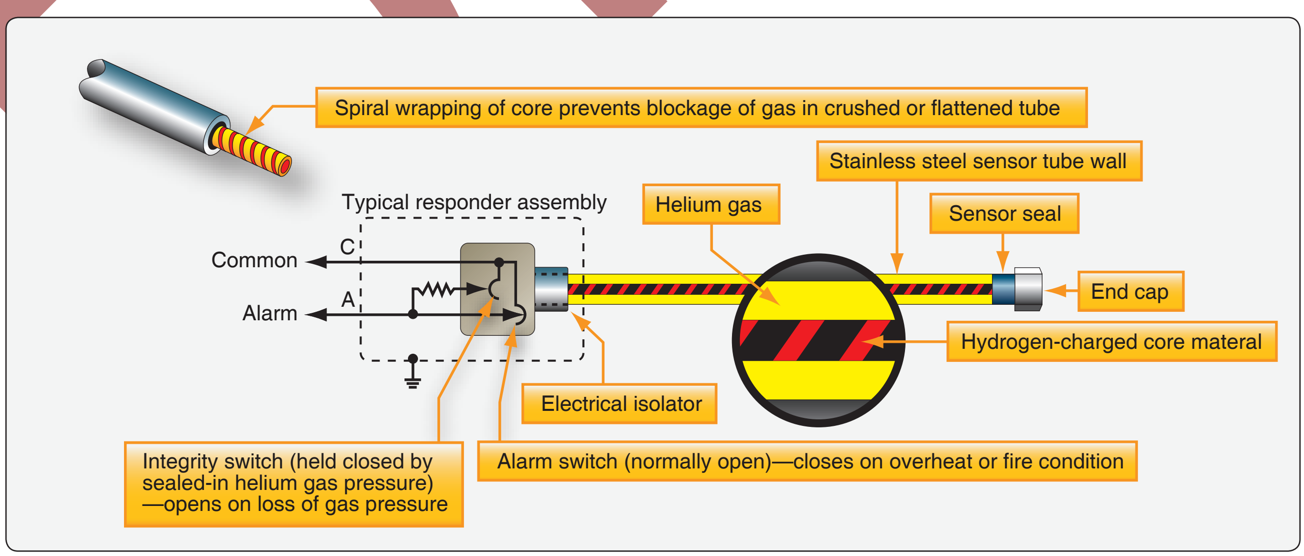


Figure 17-7. *Pneumatic pressure loop detector system.*

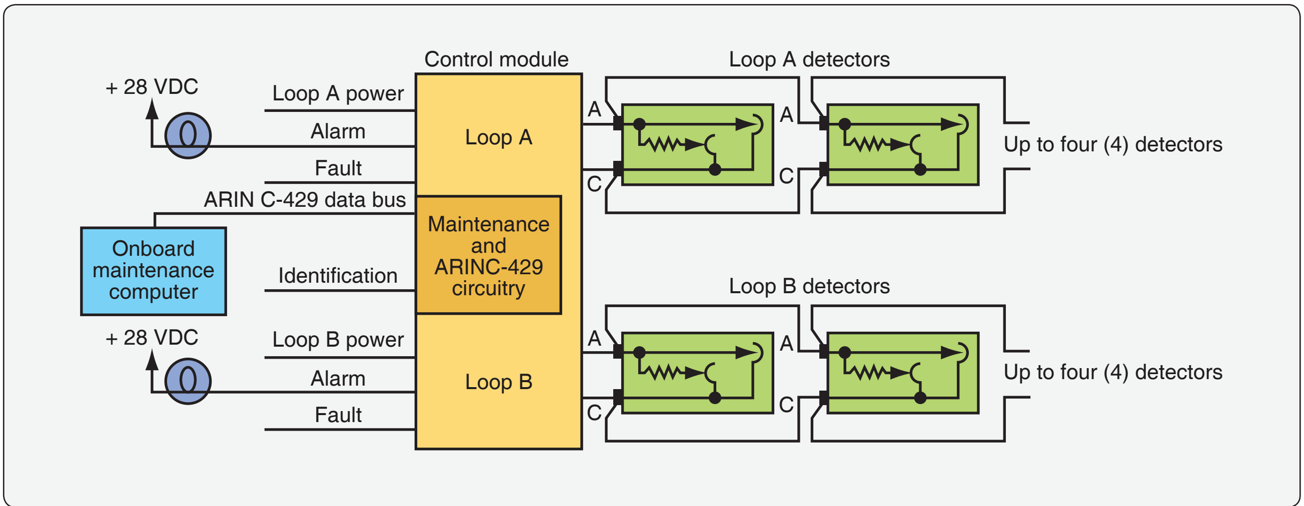


Figure 17-8. *Aircraft detection system control module.*

closed by the averaging gas pressure at all temperatures down to –65 °F (–54 °C). If the detector should develop a leak, the loss of gas pressure would allow the integrity switch to open and signal a lack of detector integrity. The system then does not operate during test.

Fire Zones

Powerplant compartments are classified into zones based on the airflow through them.

1. Class A zone—area of heavy airflow past regular arrangements of similarly shaped obstructions. The power section of a reciprocating engine is usually of this type.
2. Class B zone—area of heavy airflow past aerodynamically clean obstructions. Included in this type are heat exchanger ducts, exhaust manifold shrouds, and areas where the inside of the enclosing cowling or other closure is smooth, free of pockets, and adequately drained so leaking flammables cannot puddle. Turbine engine compartments may be considered in this class if engine surfaces are aerodynamically clean and all airframe structural formers are covered by a fireproof liner to produce an aerodynamically clean enclosure surface.
3. Class C zone—area of relatively low airflow. An engine accessory compartment separated from the power section is an example of this type of zone.
4. Class D zone—area of very little or no airflow. These include wing compartments and wheel wells where little ventilation is provided.
5. Class X zone—area of heavy airflow and of unusual construction, making uniform distribution of the extinguishing agent very difficult. Areas containing deeply recessed spaces and pockets between large structural formers are of this type. Tests indicate agent requirements to be double those for Class A zones.

Smoke, Flame, and Carbon Monoxide Detection Systems

Smoke Detectors

A smoke detection system monitors the lavatories and cargo baggage compartments for the presence of smoke, which is indicative of a fire condition. Smoke detection instruments that collect air for sampling are mounted in the compartments in strategic locations. A smoke detection system is used where the type of fire anticipated is expected to generate a substantial amount of smoke before temperature changes are sufficient to actuate a heat detection system. Two common types used are light refraction and ionization.

Light Refraction Type

The light refraction type of smoke detector contains a photoelectric cell that detects light refracted by smoke particles. Smoke particles refract the light to the photoelectric cell and, when it senses enough change in the amount of light, it creates an electrical current that sets off a warning light. This type of smoke detector is referred to as a photoelectrical device.

Ionization Type

Some aircraft use an ionization type smoke detector. The system generates an alarm signal (both horn and indicator) by detecting a change in ion density due to smoke in the cabin. The system is connected to the 28-volt DC electrical power supplied from the aircraft. Alarm output and sensor sensitive checks are performed simply with the test switch on the control panel.

Flame Detectors

Optical sensors, often referred to as flame detectors, are designed to alarm when they detect the presence of prominent, specific radiation emissions from hydrocarbon flames. The two types of optical sensors available are infrared (IR) and ultraviolet (UV), based on the specific emission wavelengths that they are designed to detect. IR-based optical flame detectors are used primarily on light turboprop aircraft and helicopter engines. These sensors have proven to be very dependable and economical for these applications.

When radiation emitted by the fire crosses the airspace between the fire and the detector, it impinges on the detector front face and window. The window allows a broad spectrum of radiation to pass into the detector where it strikes the sensing device filter. The filter allows only radiation in a tight waveband centered on 4.3 micrometers in the IR band to pass on to the radiation-sensitive surface of the sensing device. The radiation striking the sensing device minutely raises its temperature causing small thermoelectric voltages to be generated. These voltages are fed to an amplifier whose output is connected to various analytical electronic processing circuits. The processing electronics are tailored exactly to the time signature of all known hydrocarbon flame sources and ignores false alarm sources, such as incandescent lights and sunlight. Alarm sensitivity level is accurately controlled by a digital circuit. *[Figure 17-9]*

Carbon Monoxide Detectors

Carbon monoxide is a colorless, odorless gas that is a byproduct of incomplete combustion. Its presence in the breathing air of human beings can be deadly. To ensure crew and passenger safety, carbon monoxide detectors are used in aircraft cabins and cockpits. They are most often found on reciprocating engine aircraft with exhaust shroud heaters and on aircraft equipped with a combustion heater. Turbine bleed air, when used for heating the cabin, is tapped off of the engine upstream of the combustion chamber. Therefore, no threat of carbon monoxide presence is posed.

Carbon monoxide gas is found in varying degrees in all smoke and fumes of burning carbonaceous substances. Exceedingly small amounts of the gas are dangerous if inhaled. A concentration of as little as 2 parts in 10,000 may produce headache, mental dullness, and physical lethargy within a few hours. Prolonged exposure or higher concentrations may cause death.

There are several types of carbon monoxide detectors. Electronic detectors are common. Some are panel mounted and others are portable. Chemical color-change types are also common. These are mostly portable. Some are simple buttons, cards, or badges that have a chemical applied to the surface. Normally, the color of the chemical is tan. In the presence of carbon monoxide, the chemical darkens to grey or even black. The transition time required to change color is inversely related to the concentration of CO present. At 50 parts per million, the indication is apparent within 15 to 30 minutes. A concentration of 100 parts per million changes the color of the chemical in as little as 2–5 minutes. As concentration increases or duration of exposure is prolonged, the color evolves from grey to dark grey to black. If contaminated, installing a new indicating element allows a carbon monoxide portable test unit to be returned to service.

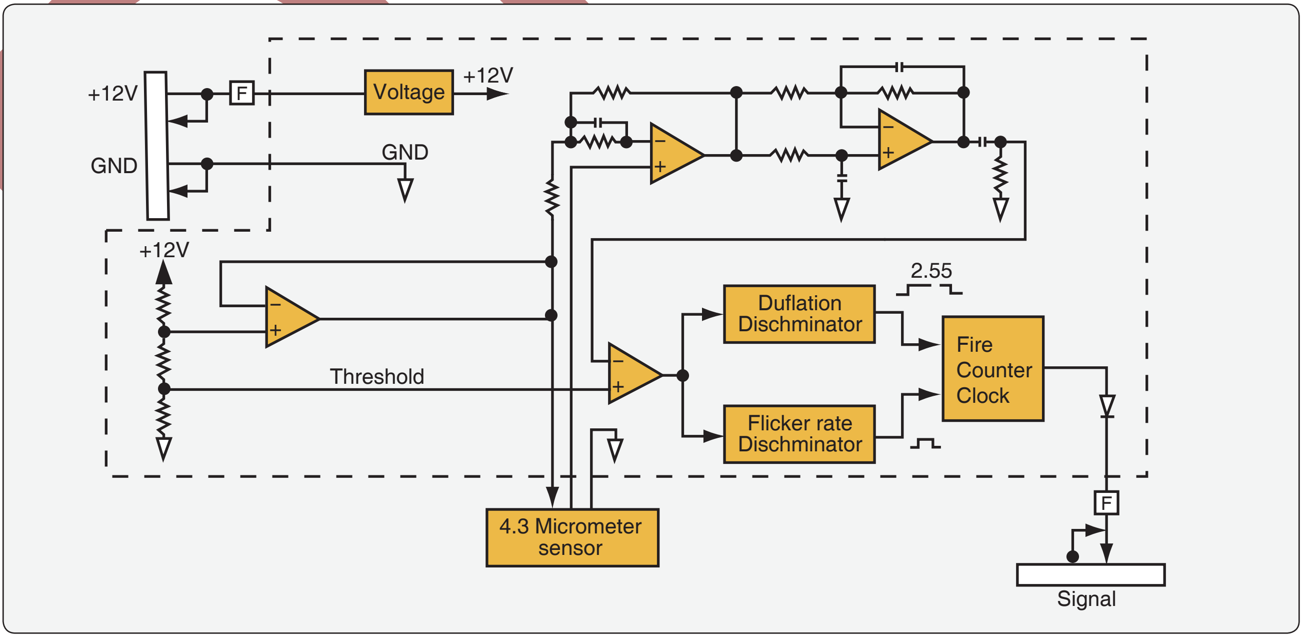


Figure 17-9. *Infrared (IR) based optical flame detector.*

Extinguishing Agents and Portable Fire Extinguishers

There must be at least one hand held, portable fire extinguisher for use in the pilot compartment that is located within easy access of the pilot while seated. There must be at least one hand held fire extinguisher located conveniently in the passenger compartment of each airplane accommodating more than 6 and less than 30 passengers. Each extinguisher for use in a personnel compartment must be designed to minimize the hazard of toxic gas concentrations. The number of portable, hand held fire extinguishers for transport aircraft is shown in *Figure 17-10.*

Halogenated Hydrocarbons

For over 45 years, halogenated hydrocarbons (Halons) have been practically the only fire extinguishing agents used in civil transport aircraft. However, Halon is an ozone depleting and global warming chemical, and its production has been banned by international agreement. Although Halon usage has been banned in some parts of the world, aviation has been granted an exemption because of its unique operational and fire safety requirements. Halon has been the fire extinguishing agent of choice in civil aviation because it is extremely effective on a per unit weight basis over a wide range of aircraft environmental conditions. It is a clean agent (no residue), electrically nonconducting, and has relatively low toxicity.

Two types of Halons are employed in aviation: Halon 1301($CBrF_3$) a total flooding agent, and Halon 1211 ($CBrClF_2$) a streaming agent. Class A, B, or C fires are appropriately controlled with Halons. However, do not use Halons on a class D fire. Halon agents may react vigorously with the burning metal.

NOTE: While Halons are still in service and are appropriate agents for these classes of fires, the production of these ozone depleting agents has been restricted. Although not required, consider replacing Halon extinguishers with Halon replacement extinguishers when discharged. Halon replacement agents found to be compliant to date include the halocarbons HCFC Blend B, HFC-227ea, and HFC-236fa.

Passenger capacity	No. of extinguishers
7 through 30	1
31 through 60	2
61 through 200	3
201 through 300	4
301 through 400	5
401 through 500	6
501 through 600	7
601 through 700	8

Figure 17-10. *Hand held fire extinguisher requirement for transport aircraft.*

Inert Cold Gases

Carbon dioxide (CO_2) is an effective extinguishing agent. It is most often used in fire extinguishers that are available on the ramp to fight fires on the exterior of the aircraft, such as engine or APU fires. CO_2 has been used for many years to extinguish flammable fluid fires and fires involving electrical equipment. It is noncombustible and does not react with most substances. It provides its own pressure for discharge from the storage vessel, except in extremely cold climates where a booster charge of nitrogen may be added to winterize the system. Normally, CO_2 is a gas, but it is easily liquefied by compression and cooling. After liquification, CO_2 remains in a closed container as both liquid and gas. When CO_2 is then discharged to the atmosphere, most of the liquid expands to gas. Heat absorbed by the gas during vaporization cools the remaining liquid to –110 °F, and it becomes a finely divided white solid, dry ice snow.

Carbon dioxide is about 1½ times as heavy as air, which gives it the ability to replace air above burning surfaces and maintain a smothering atmosphere. CO_2 is effective as an extinguishing agent primarily because it dilutes the air and reduces the oxygen content so that combustion is no longer supported. Under certain conditions, some cooling effect is also realized. CO_2 is considered only mildly toxic, but it can cause unconsciousness and death by suffocation if the victim is allowed to breathe CO_2 in fire extinguishing concentrations for 20 to 30 minutes. CO_2 is not effective as an extinguishing agent on fires involving chemicals containing their own oxygen supply, such as cellulose nitrate (used in some aircraft paints). Also, fires involving magnesium and titanium cannot be extinguished by CO_2.

Dry Powders

Class A, B, or C fires can be controlled by dry chemical extinguishing agents. The only all purpose (Class A, B, C rating) dry chemical powder extinguishers contain mono-ammonium phosphate. All other dry chemical powders have a Class B, C U.S – UL fire rating only. Dry powder chemical extinguishers best control class A, B, and C fire but their use is limited due to residual residue and clean up after deployment.

Water

Class A type fires are best controlled with water by cooling the material below its ignition temperature and soaking the material to prevent re-ignition.

Cockpit and Cabin Interiors

All materials used in the cockpit and cabin must conform to strict standards to prevent fire. In case of a fire, several types of portable fire extinguishers are available to fight the fire. The most common types are Halon 1211 and water.

Extinguisher Types

Portable fire extinguishers are used to extinguish fires in the cabin or flight deck. *Figure 17-11* shows a Halon fire extinguisher used in a general aviation aircraft. The Halon extinguishers are used on electrical and flammable liquid fires. Some transport aircraft also use water fire extinguisher for use on non-electrical fires.

The following is a list of extinguishing agents and the type (class) fires for which each is appropriate.

1. Water—class A. Water cools the material below its ignition temperature and soaks it to prevent reignition.
2. Carbon dioxide—class B or C. CO_2 acts as a blanketing agent. NOTE: CO_2 is not recommended for hand-held extinguishers for internal aircraft use.
3. Dry chemicals—class A, B, or C. Dry chemicals are the best control agents for these types of fires.
4. Halons—only class A, B, or C.
5. Halocarbon clean agents—only class A, B, or C.
6. Specialized dry powder—class D. (Follow the recommendations of the extinguisher's manufacturer because of the possible chemical reaction between the burning metal and the extinguishing agent.)

The following hand-held extinguishers are unsuitable as cabin or cockpit equipment.

- CO_2
- Dry chemicals (due to the potential for corrosion damage to electronic equipment, the possibility of visual obscuration if the agent were discharged into the flight deck area, and the cleanup problems from their use)
- Specialized dry powder (it is suitable for use in ground operations)

Installed Fire Extinguishing Systems

Transport aircraft have fixed fire extinguishing systems installed in:

1. Turbine engine compartments
2. APU compartments
3. Cargo and baggage compartments
4. Lavatories

CO_2 Fire Extinguishing Systems

Older aircraft with reciprocating engines used CO_2 as an extinguishing agent, but all newer aircraft designs with turbine engines use Halon or equivalent extinguishing agent, such as halocarbon clean agents.

Halogenated Hydrocarbons Fire Extinguishing Systems

The fixed fire extinguisher systems used in most engine fire and cargo compartment fire protection systems are designed to dilute the atmosphere with an inert agent that does not support combustion. Many systems use perforated tubing or discharge nozzles to distribute the extinguishing agent. High rate of discharge (HRD) systems use open-end tubes to deliver a quantity of extinguishing agent in 1 to 2 seconds. The most common extinguishing agent still used today is Halon 1301 because of its effective firefighting capability and relatively low toxicity (UL classification Group 6). Noncorrosive Halon 1301 does not affect the material it contacts and requires no cleanup when discharged. Halon 1301 is the current extinguishing agent for commercial

Figure 17-11. *Portable fire extinguisher.*

aircraft, but a replacement is under development. Halon 1301 cannot be produced anymore because it depletes the ozone layer. Halon 1301 will be used until a suitable replacement is developed. Some military aircraft use HCL-125 and the Federal Aviation Administration (FAA) is testing HCL-125 for use in commercial aircraft.

Containers

Fire extinguisher containers (HRD bottles) store a liquid halogenated extinguishing agent and pressurized gas (typically nitrogen). They are normally manufactured from stainless steel. Depending upon design considerations, alternate materials are available, including titanium. Containers are also available in a wide range of capacities. They are produced under Department of Transportation (DOT) specifications or exemptions. Most aircraft containers are spherical in design, which provides the lightest weight possible. However, cylindrical shapes are available where space limitations are a factor. Each container incorporates a temperature/pressure sensitive safety relief diaphragm that prevents container pressure from exceeding container test pressure in the event of exposure to excessive temperatures. *[Figures 17-12* and *17-13]*

Figure 17-12. *Built-in non-portable fire extinguisher containers (HRD bottles) on an airliner.*

Discharge Valves

Discharge valves are installed on the containers. A cartridge (squib) and frangible disk-type valve are installed in the outlet of the discharge valve assembly. Special assemblies having solenoid-operated or manually-operated seat-type

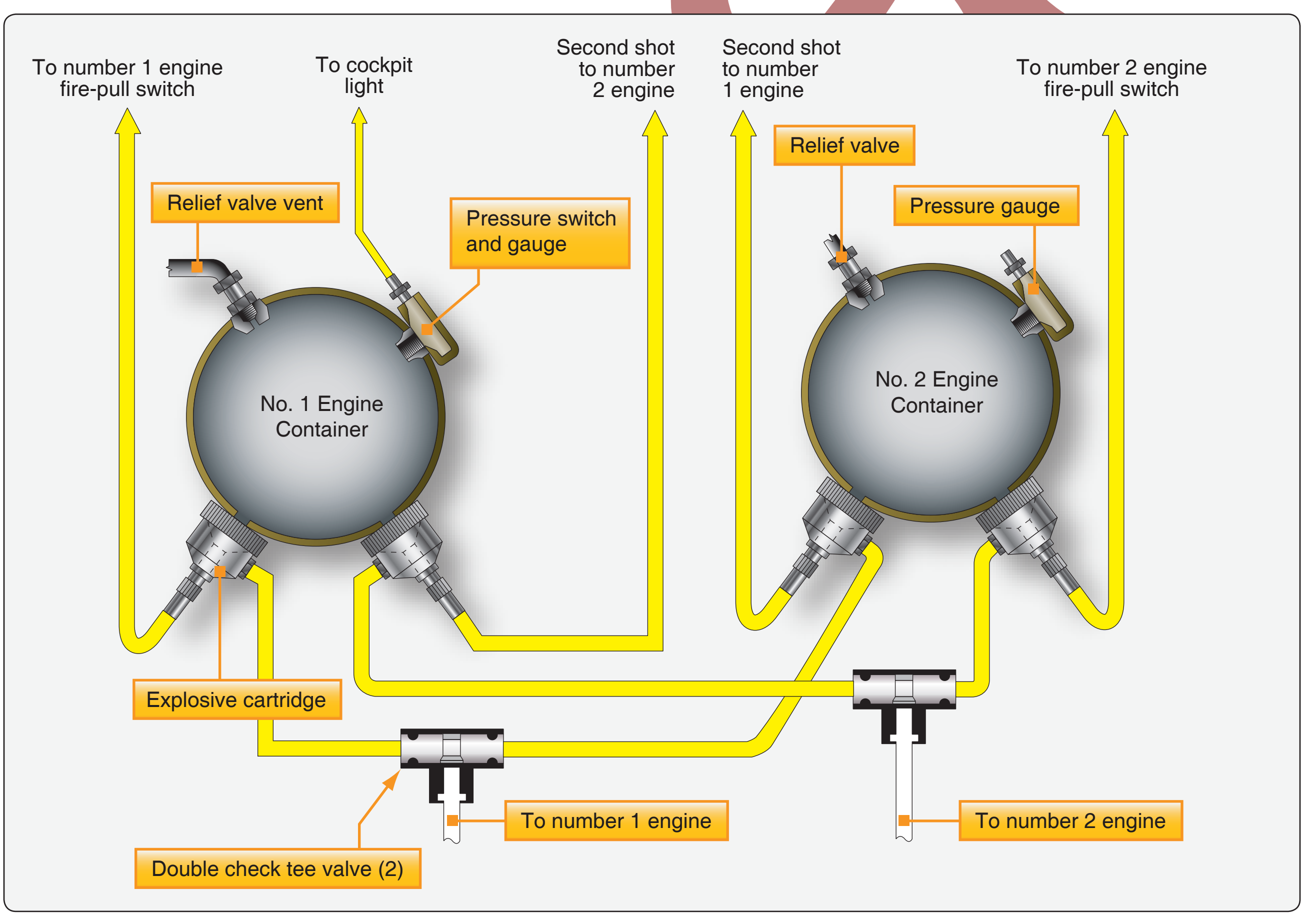


Figure 17-13. *Diagram of fire extinguisher containers (HRD bottles).*

valves are also available. Two types of cartridge disk-release techniques are used. Standard release-type uses a slug driven by explosive energy to rupture a segmented closure disc. For high temperature or hermetically sealed units, a direct explosive impact-type cartridge is used that applies fragmentation impact to rupture a prestressed corrosion resistant steel diaphragm. Most containers use conventional metallic gasket seals that facilitate refurbishment following discharge. *[Figure 17-14]*

Pressure Indication

A wide range of diagnostics is utilized to verify the fire extinguisher agent charge status. A simple visual indication gauge is available, typically a helical bourdon-type indicator that is vibration resistant. *[Figure 17-13]* A combination gauge switch visually indicates actual container pressure and also provides an electrical signal if container pressure is lost, precluding the need for discharge indicators. A ground checkable diaphragm-type low-pressure switch is commonly used on hermetically sealed containers. The Kidde system has a temperature compensated pressure switch that tracks the container pressure variations with temperatures by using a hermetically sealed reference chamber.

Two-Way Check Valve

Two-way check valves are required in a two-shot system to prevent the extinguisher agent from a reserve container from backing up into the previous emptied main container. Valves are supplied with either MS-33514 or MS-33656 fitting configurations.

Discharge Indicators

Discharge indicators provide immediate visual evidence of container discharge on fire extinguishing systems. Two kinds of indicators can be furnished: thermal and discharge. Both types are designed for aircraft and skin mounting. *[Figure 17-15]*

Figure 17-15. *Discharge indicators.*

Thermal Discharge Indicator (Red Disk)

The thermal discharge indicator is connected to the fire container relief fitting and ejects a red disk to show when container contents have dumped overboard due to excessive heat. The agent discharges through the opening left when the disk blows out. This gives the flight and maintenance crews an indication that the fire extinguisher container needs to be replaced before next flight.

Yellow Disk Discharge Indicator

If the flight crew activates the fire extinguisher system, a yellow disk is ejected from the skin of the aircraft fuselage. This is an indication for the maintenance crew that the fire extinguishing system was activated by the flight crew, and the fire extinguishing container needs to be replaced before next flight.

Fire Switch

The engine and APU fire switches are typically installed on the center overhead panel or center console in the flight deck. *[Figure 17-16]* When an engine fire switch is activated, the

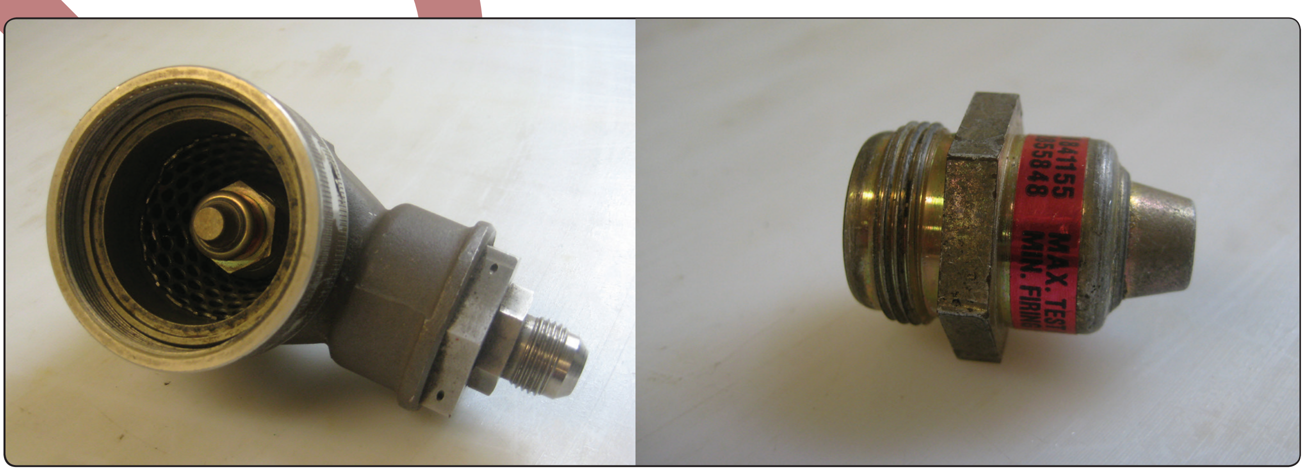


Figure 17-14. *Discharge valve (left) and cartridge, or squib (right).*

following happens: the engine stops because the fuel control shuts off, the engine is isolated from the aircraft systems, and the fire extinguishing system is activated. Some aircraft use fire switches that need to be pulled and turned to activate the system, while others use a push-type switch with a guard. To prevent accidental activation of the fire switch, a lock is installed that releases the fire switch only when a fire has been detected. This lock can be manually released by the flight crew if the fire detection system malfunctions. *[Figure 17-17]*

Cargo Fire Detection

Transport aircraft need to have the following provisions for each cargo or baggage compartment:

1. The detection system must provide a visual indication to the flight crew within 1 minute after the start of a fire.
2. The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased.
3. There must be means to allow the crew to check, in flight, the functioning of each fire detector circuit.

Cargo Compartment Classification

Class A

A Class A cargo or baggage compartment is one in which the presence of a fire would be easily discovered by a crewmember while at his or her station and each part of the compartment is easily accessible in flight.

Class B

A Class B cargo, or baggage compartment, is one in which there is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher. When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent enters any compartment occupied by the crew or passengers. There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

Class C

A Class C cargo, or baggage compartment, is one not meeting the requirements for either a Class A or B compartment but in which:

1. There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.
2. There is an approved built-in fire extinguishing or suppression system controllable from the cockpit.

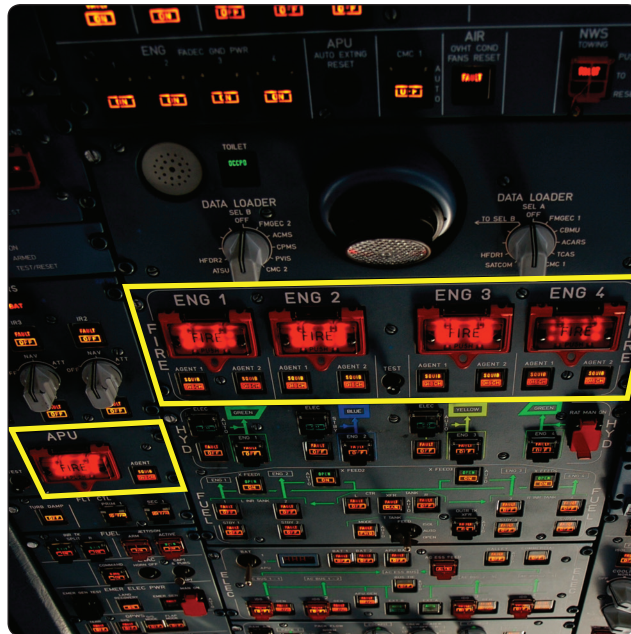


Figure 17-16. *Engine and APU fire switches on the cockpit center overhead panel.*

3. There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by the crew or passengers.
4. There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

Class E

Class E cargo compartment is one on airplanes used only for the carriage of cargo and in which:

1. There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station.
2. The controls for shutting off the ventilating airflow to, or within, the compartment are accessible to the flight crew in the crew compartment.
3. There are means to exclude hazardous quantities of smoke, flames, or noxious gases from the flight crew compartment.
4. The required crew emergency exits are accessible under any cargo loading condition.

Cargo and Baggage Compartment Fire Detection and Extinguisher System

The cargo compartment smoke detection system gives warnings in the flight deck if there is smoke in a cargo compartment. *[Figure 17-18]* Each compartment is equipped

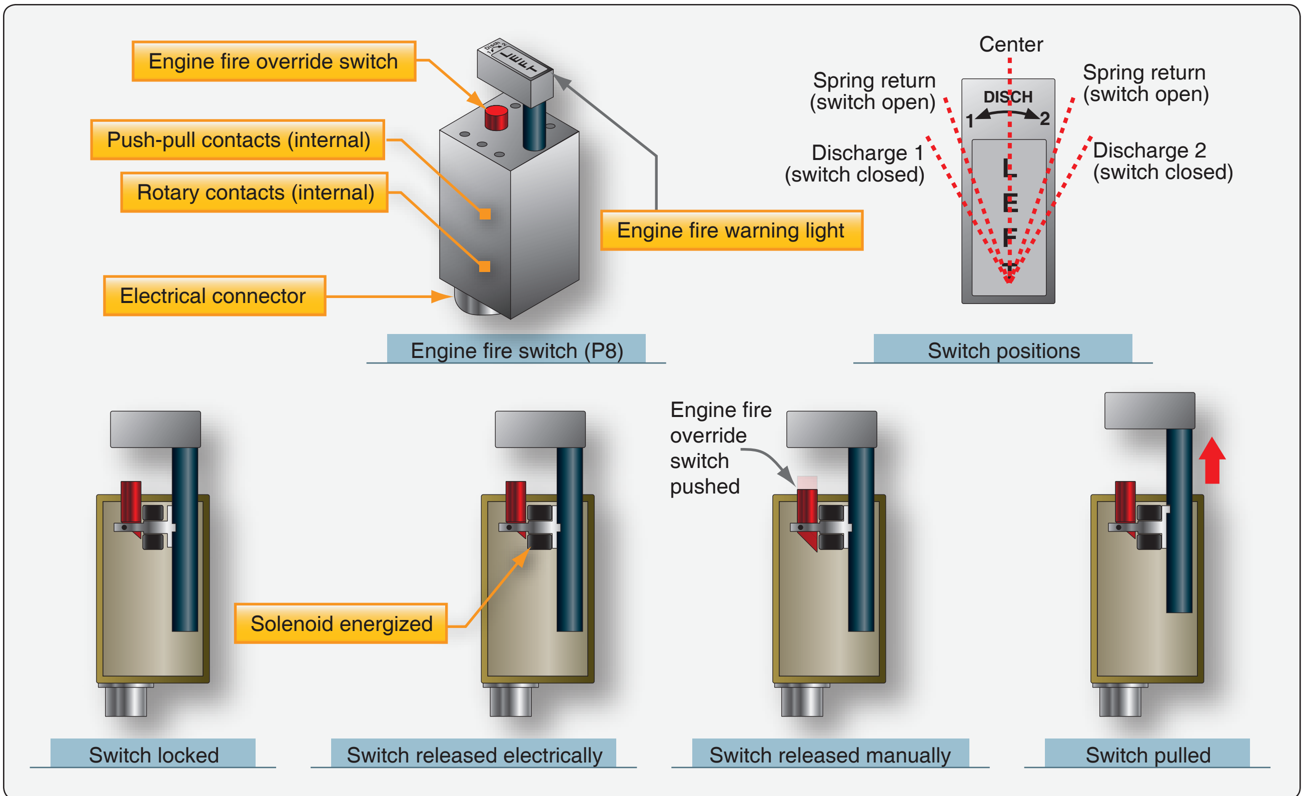


Figure 17-17. *Engine fire switch operation.*

with a smoke detector. The smoke detectors monitor air in the cargo compartments for smoke. The fans bring air from the cargo compartment into the smoke detector. Before the air goes in the smoke detector, in-line water separators remove condensation and heaters increase the air temperature. *[Figure 17-19]*

Smoke Detector System

The optical smoke detector consists of source light emitting diodes (LEDs), intensity monitor photodiodes, and scatter detector photodiodes. Inside the smoke detection chamber, air flows between a source (LED) and a scatter detector photodiode. Usually, only a small amount of light from the LED gets to the scatter detector. If the air has smoke in it, the smoke particles reflect more light on the scatter detector. This causes an alarm signal. The intensity monitor photodiode makes sure that the source LED is on and keeps the output of the source LED constant. This configuration also finds contamination of the LED and photodiodes. A defective diode, or contamination, causes the detector to change to

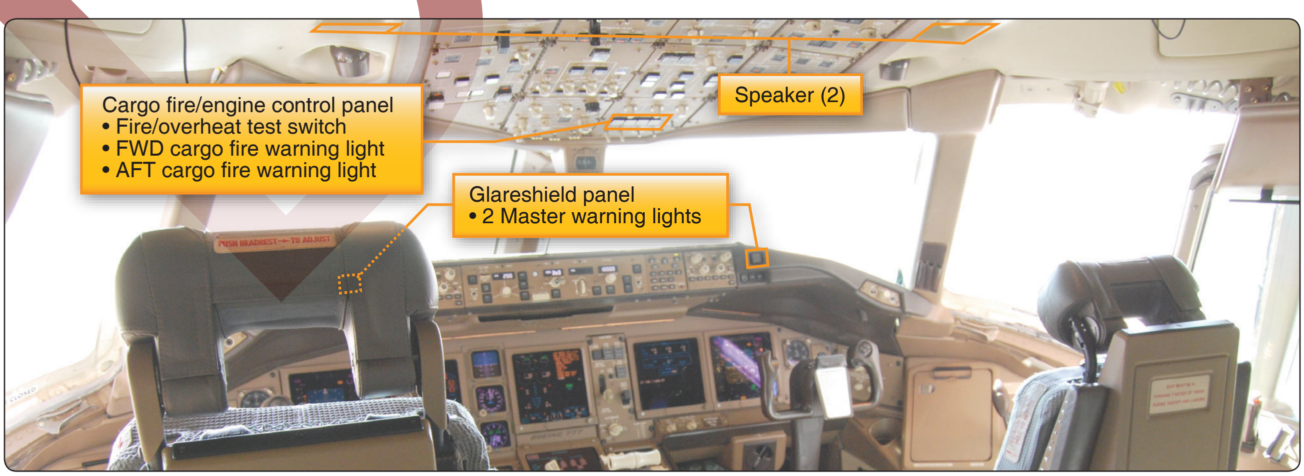


Figure 17-18. *Cargo fire detection warning.*

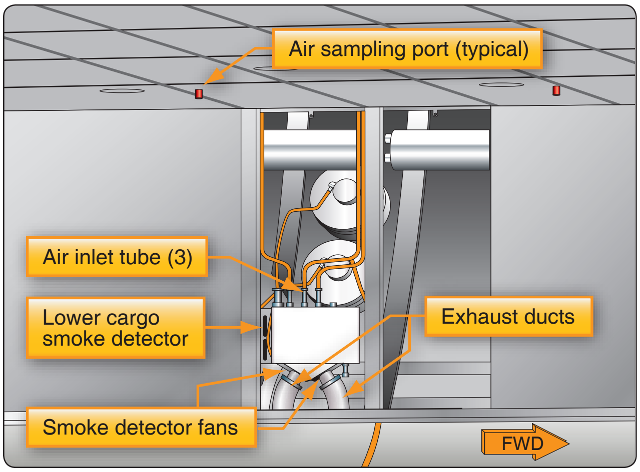


Figure 17-19. *Smoke detector installation.*

the other set of diodes. The detector sends a fault message.

The smoke detector has multiple sampling ports. The fans draw air from the sampling ports through a water separator and a heater unit to the smoke detector. *[Figure 17-20]*

Cargo Compartment Extinguishing System

The cargo compartment extinguishing system is activated by the flight crew if the smoke detectors detect smoke in the cargo compartment. Some aircraft are outfitted with two types of fire extinguisher containers. The first system is the dump system that releases the extinguishing agent directly when the cargo fire discharge switch is activated. This action extinguishes the fire.

The second system is the metered system. After a time delay, the metered bottles discharge slowly and at a controlled rate through the filter regulator. Halon from the metered bottles replaces the extinguishing agent leakage. This keeps the correct concentration of extinguishing agent in the cargo compartment to keep the fire extinguished for 180 minutes.

The fire extinguishing bottles contain Halon 1301 or equivalent fire extinguishing agent pressurized with nitrogen. Tubing connects the bottles to discharge nozzles in the cargo compartment ceilings.

The extinguishing bottles are outfitted with squibs. The squib is an electrically operated explosive device. It is adjacent to a bottle diaphragm that can break. The diaphragm normally seals the pressurized bottle. When the cargo discharge switch is activated, the squib fires and the explosion breaks the diaphragm. Nitrogen pressure inside the bottle pushes the Halon through the discharge port into the cargo compartment. When the bottle discharges, a pressure switch is activated that sends an indication to the flight deck that a bottle has been discharged. Flow control valves are incorporated if the bottles can be discharged in multiple compartments. The flow control valves direct the extinguishing agent to the selected cargo compartment. *[Figure 17-21]*

The following indications occur in the cockpit if there is smoke in a cargo compartment:

- Master warning lights come on.
- Fire warning aural operates.
- A cargo fire warning message shows.
- Cargo fire warning light comes on.

The master warning lights and fire warning aural are prevented from operating during part of the takeoff operation.

Lavatory Smoke Detectors

Airplanes that have a passenger capacity of 20 or more are equipped with a smoke detector system that monitors the lavatories for smoke. Smoke indications provide a warning light in the cockpit or provide a warning light or audible warning at the lavatory and at flight attendant stations that would be readily detected by a flight attendant. Each lavatory must have a built-in fire extinguisher that discharges

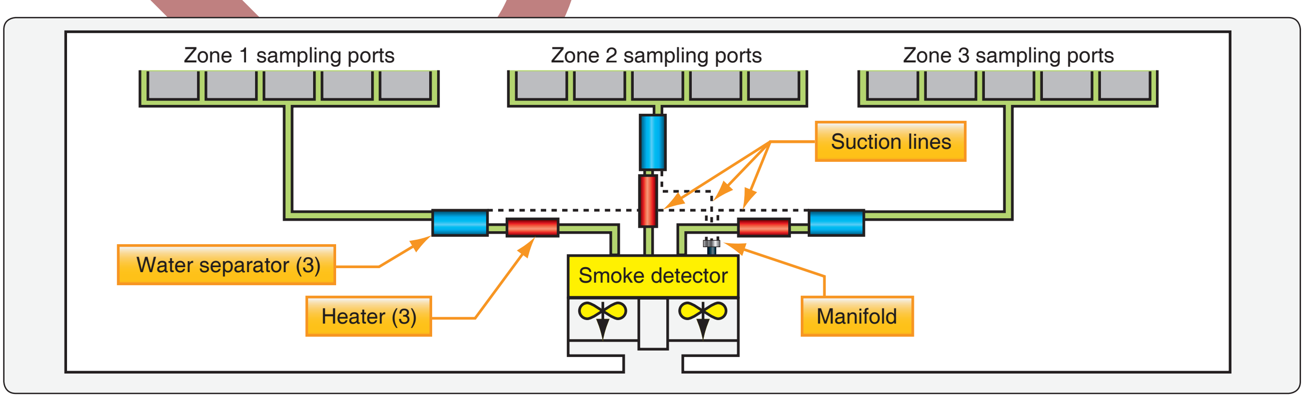


Figure 17-20. *Smoke detector system.*

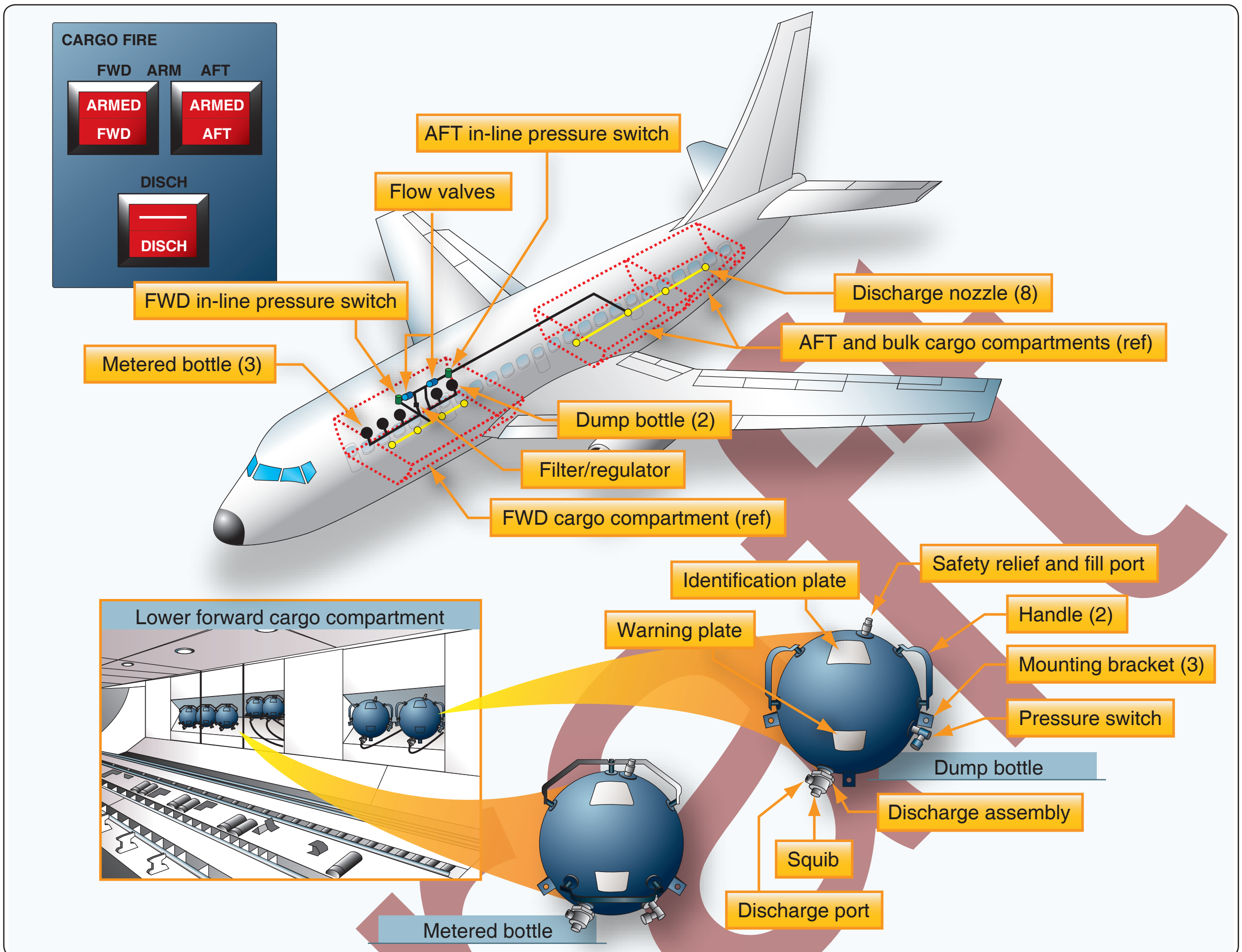


Figure 17-21. *Cargo and baggage compartment extinguishing system.*

automatically. The smoke detector is located in the ceiling of the lavatory. *[Figure 17-22]*

Lavatory Smoke Detector System

Refer to *Figure 17-23*. The lavatory smoke detector is powered by the 28-volt DC left/right main DC bus. If there is smoke in the sensing chamber of the smoke detector, the alarm LED (red) comes on. The timing circuit makes an intermittent ground. The warning horn and lavatory call light operate intermittently. The smoke detection circuit makes a ground for the relay. The energized relay makes a ground signal for the overhead electronics unit (OEU) in the central monitoring systems (CMS). This interface gives these indications: lavatory master call light flashes, cabin system control panel (CSCP) and cabin area control panel (CACP) pop-up window shows, and the lavatory call chime operates. Push the lavatory call reset switch or the smoke detector interrupt switch to cancel the smoke indications. If there is still smoke in the lavatory, the alarm LED (red) stays on. All smoke indications go away automatically when the smoke is gone.

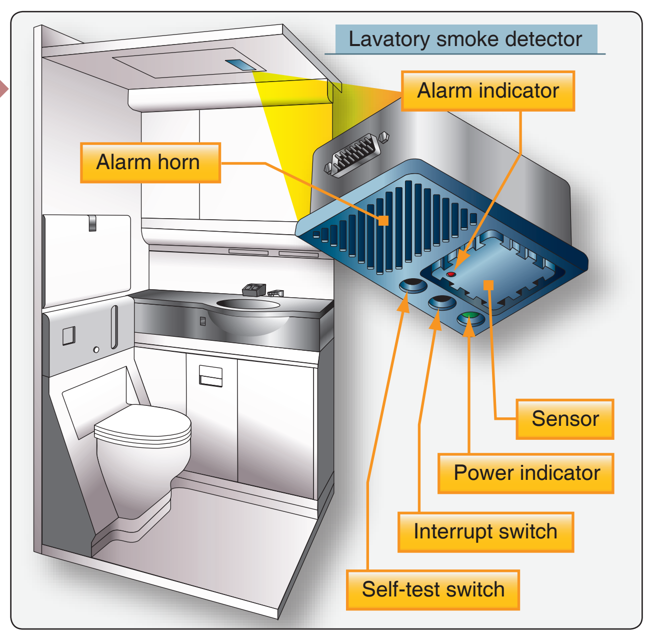


Figure 17-22. *Lavatory smoke detector diagram.*

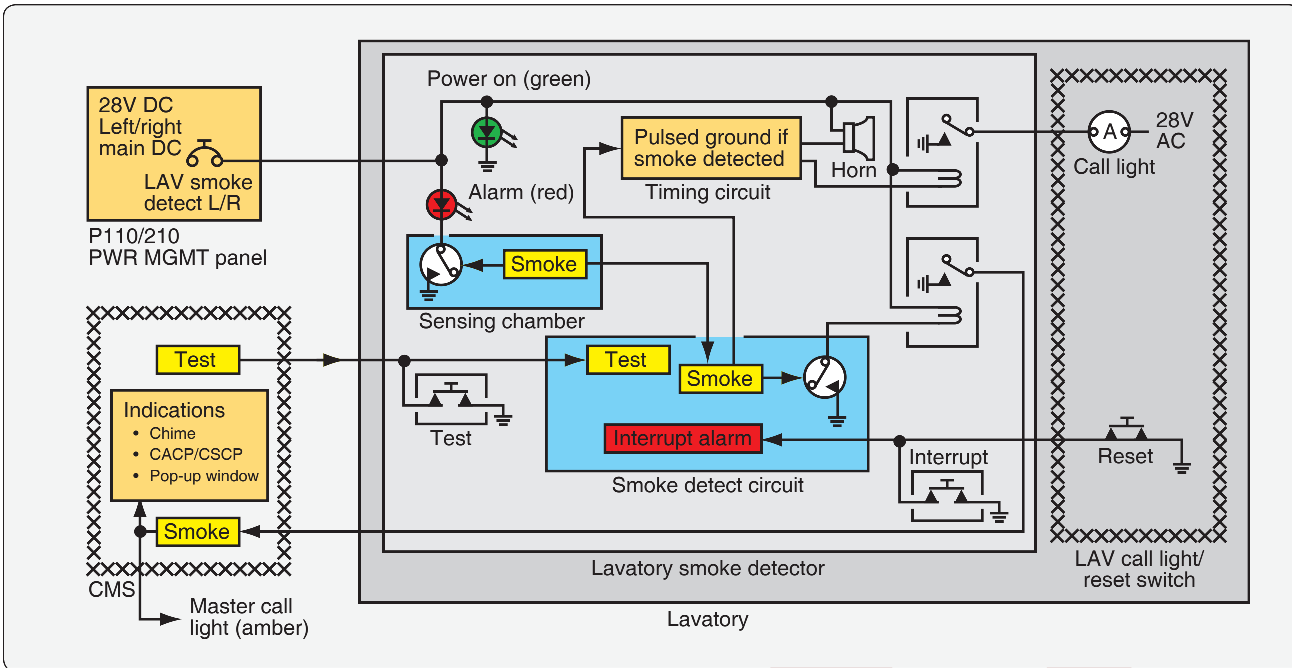


Figure 17-23. *Lavatory smoke detector diagram.*

Lavatory Fire Extinguisher System

The lavatory compartment is outfitted with a fire extinguisher bottle to extinguish fires in the waste compartment. The fire extinguisher is a bottle with two nozzles. The bottle contains pressurized Halon 1301 or equivalent fire extinguishing agent. When the temperature in the waste compartment reaches approximately 170 °F, the solder that seals the nozzles melt and the Halon is discharged. Weighing the bottle is often the only way to determine if the bottle is empty or full. *[Figure 17-24]*

Fire Detection System Maintenance

Fire detector sensing elements are located in many high-activity areas around aircraft engines. Their location, together with their small size, increases the chance of damage to the sensing elements during maintenance. General maintenance of a fire detection system typically includes the inspection and servicing of damaged sections, containment of loose material that could short detector terminals, correcting connection joints and shielding, and replacement of damaged sensing elements. An inspection and maintenance program for all types of continuous-loop systems should include the following visual checks.

Note: These procedures are examples and should not be used to replace the applicable manufacturer's instructions.

Sensing elements of a continuous-loop system should be inspected for the following:

1. Cracked or broken sections caused by crushing or squeezing between inspection plates, cowl panels, or engine components.
2. Abrasion caused by rubbing of the element on cowling, accessories, or structural members.

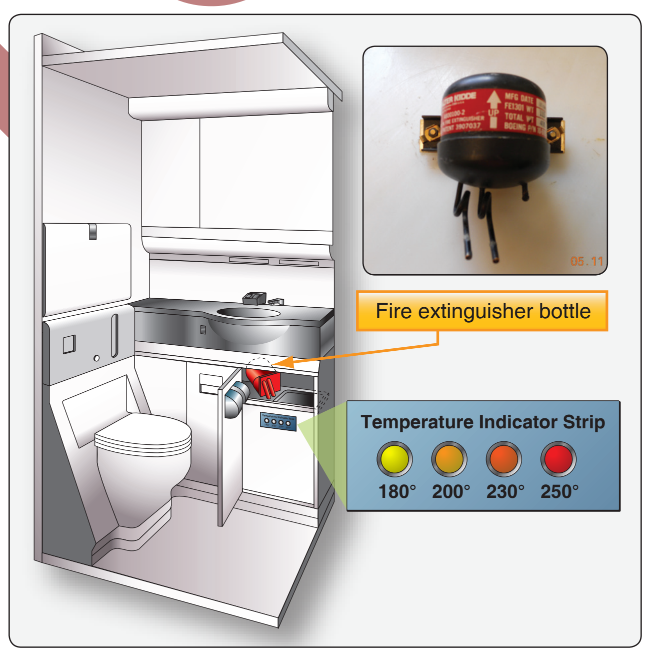


Figure 17-24. *Lavatory fire extinguishing bottle.*

3. Pieces of safety wire, or other metal particles, that may short the spot-detector terminals.
4. Condition of rubber grommets in mounting clamps that may be softened from exposure to oils or hardened from excessive heat.
5. Dents and kinks in sensing element sections. Limits on the element diameter, acceptable dents and kinks, and degree of smoothness of tubing contour are specified by manufacturers. No attempt should be made to straighten any acceptable dent or kink, since stresses may be set up that could cause tubing failure. *[Figure 17-25]*

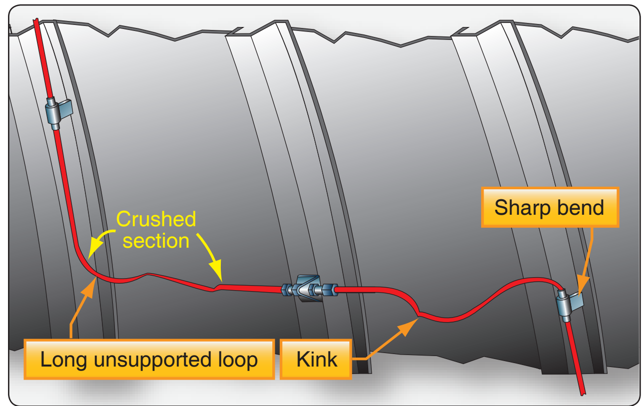


Figure 17-25. *Sensing element defects.*

6. Nuts at the end of the sensing elements should be inspected for tightness and safety wire. *[Figure 17-26]* Loose nuts should be retorqued to the value specified by the manufacturer's instructions. Some types of sensing element connection joints require the use of copper crush gaskets. These should be replaced any time a connection is separated.

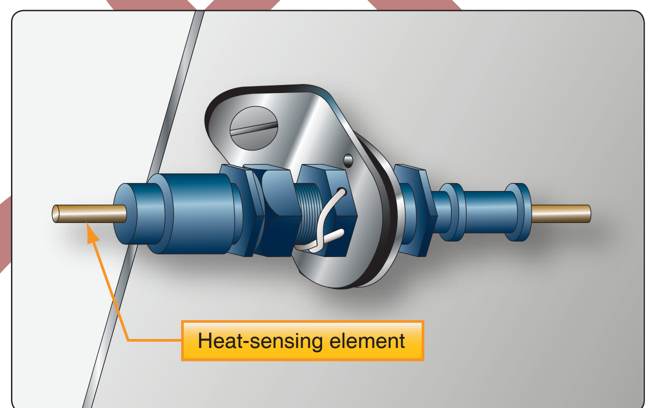


Figure 17-26. *Connector joint fitting attached to the structure.*

7. If shielded flexible leads are used, they should be inspected for fraying of the outer braid. The braided sheath is made up of many fine metal strands woven into a protective covering surrounding the inner insulated wire. Continuous bending of the cable or rough treatment can break these fine wires, especially those near the connectors.
8. Sensing element routing and clamping should be inspected carefully. *[Figure 17-27]* Long, unsupported sections may permit excessive vibration that can cause breakage. The distance between clamps on straight runs, usually about 8 to 10 inches, is specified by each manufacturer. At end connectors, the first support clamp usually is located about 4 to 6 inches from the end connector fittings. In most cases, a straight run of one inch is maintained from all connectors before a bend is started, and an optimum bend radius of 3 inches is normally adhered to.

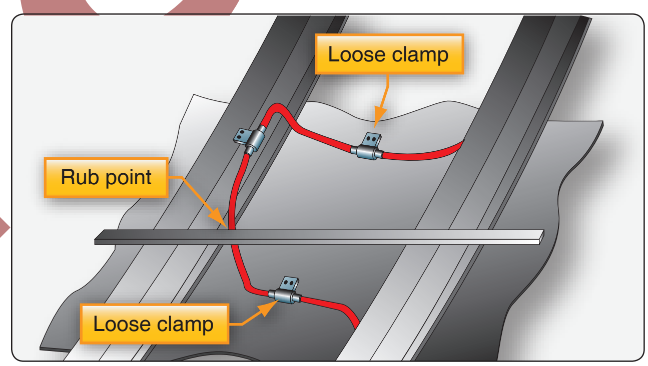


Figure 17-27. *Rubbing interference.*

9. Interference between a cowl brace and a sensing element can cause rubbing. This interference may cause wear and short the sensing element.
10. Grommets should be installed on the sensing element so that both ends are centered on its clamp. The split end of the grommet should face the outside of the nearest bend. Clamps and grommets should fit the element snugly. *[Figure 17-28]*

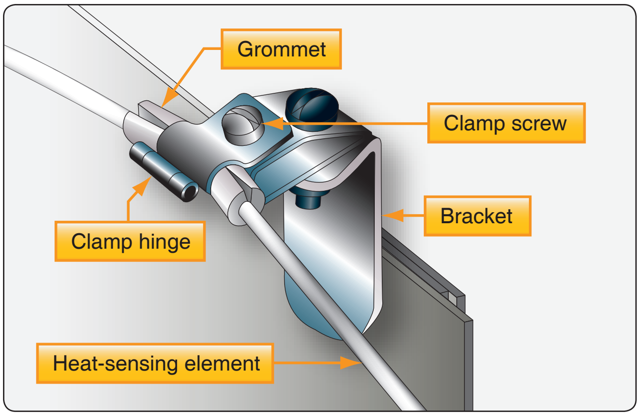


Figure 17-28. *Inspection of fire detector loop clamp.*

Fire Detection System Troubleshooting

The following troubleshooting procedures represent the most common difficulties encountered in engine fire detection systems:

1. Intermittent alarms are most often caused by an intermittent short in the detector system wiring. Such shorts may be caused by a loose wire that occasionally touches a nearby terminal, a frayed wire brushing against a structure, or a sensing element rubbing against a structural member long enough to wear through the insulation. Intermittent faults often can be located by moving wires to recreate the short.
2. Fire alarms and warning lights can occur when no engine fire or overheat condition exists. Such false alarms can be most easily located by disconnecting the engine sensing loop connections from the control unit. If the false alarm ceases when the engine sensing loop is disconnected, the fault is in the disconnected sensing loop, which should be examined for areas that have been bent into contact with hot parts of the engine. If no bent element can be found, the shorted section can be located by isolating the connecting elements consecutively around the entire loop.
3. Kinks and sharp bends in the sensing element can cause an internal wire to short intermittently to the outer tubing. The fault can be located by checking the sensing element with an ohm meter while tapping the element in the suspected areas to produce the short.
4. Moisture in the detection system seldom causes a false fire alarm. If, however, moisture does cause an alarm, the warning persists until the contamination is removed, or boils away, and the resistance of the loop returns to its normal value.
5. Failure to obtain an alarm signal when the test switch is actuated may be caused by a defective test switch or control unit, the lack of electrical power, inoperative indicator light, or an opening in the sensing element or connecting wiring. When the test switch fails to provide an alarm, the continuity of a two-wire sensing loop can be determined by opening the loop and measuring the resistance. In a single-wire, continuous-loop system, the center conductor should be grounded.

Fire Extinguisher System Maintenance

Regular maintenance of fire extinguisher systems typically includes such items as the inspection and servicing of fire extinguisher bottles (containers), removal and reinstallation of cartridge and discharge valves, testing of discharge tubing for leakage, and electrical wiring continuity tests. The following paragraphs contain details of some of the most typical maintenance procedures.

Container Pressure Check

Fire extinguisher containers are checked periodically to determine that the pressure is between the prescribed minimum and maximum limits. Changes of pressure with ambient temperatures must also fall within prescribed limits. The graph shown in *Figure 17-29* is typical of the pressure-temperature curve graphs that provide maximum and minimum gauge readings. If the pressure does not fall within the graph limits, the extinguisher container is replaced.

Discharge Cartridges

The service life of fire extinguisher discharge cartridges is calculated from the manufacturer's date stamp, which is usually placed on the face of the cartridge. The cartridge service life recommended by the manufacturer is usually in terms of years. Cartridges are available with a service life of 5 years or more. To determine the unexpired service life of a discharge cartridge, it is usually necessary to remove

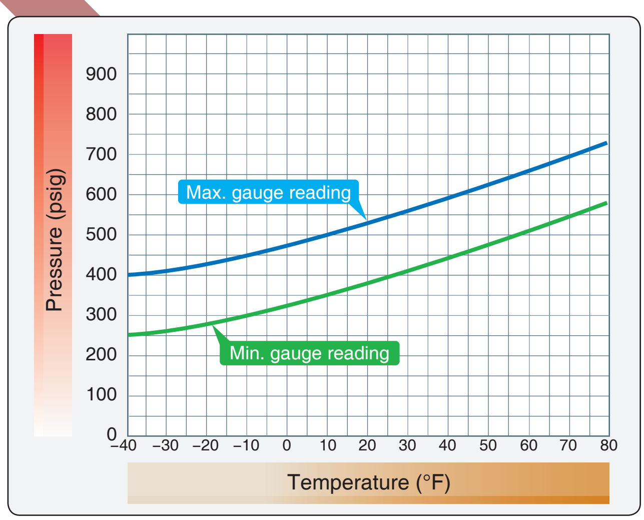


Figure 17-29. *Fire extinguisher container pressure-temperature chart.*

the electrical leads and discharge line from the plug body, which can then be removed from the extinguisher container.

Agent Containers

Care must be taken in the replacement of cartridge and discharge valves. Most new extinguisher containers are supplied with their cartridge and discharge valve disassembled. Before installation on the aircraft, the cartridge must be assembled properly in the discharge valve and the valve connected to the container, usually by means of a swivel nut that tightens against a packing ring gasket. *[Figure 17-30]*

If a cartridge is removed from a discharge valve for any reason, it should not be used in another discharge valve assembly, since the distance the contact point protrudes may vary with each unit. Thus, continuity might not exist if a used plug that had been indented with a long contact point were installed in a discharge valve with a shorter contact point.

Note: The preceding material in this chapter has been largely of a general nature dealing with the principles involved and general procedures to be followed. When actually performing maintenance, always refer to the applicable maintenance manuals and other related publications pertaining to a particular aircraft.

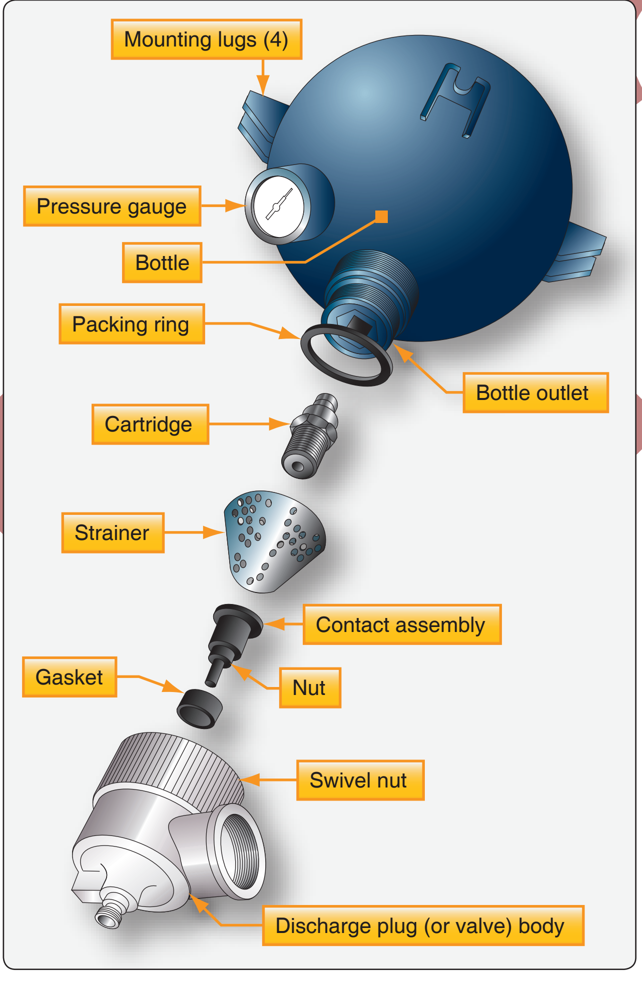


Figure 17-30. *Components of fire extinguisher container.*

Fire Prevention

Leaking fuel, hydraulic, deicing, or lubricating fluids can be sources of fire in an aircraft. This condition should be noted, and corrective action taken when inspecting aircraft systems. Minute pressure leaks of these fluids are particularly dangerous for they quickly produce an explosive atmospheric condition. Carefully inspect fuel tank installations for signs of external leaks. With integral fuel tanks, the external evidence may occur at some distance from where the fuel is actually escaping. Many hydraulic fluids are flammable and should not be permitted to accumulate in the structure. Sound-proofing and lagging materials may become highly flammable if soaked with oil of any kind. Any leakage or spillage of flammable fluid in the vicinity of combustion heaters is a serious fire risk, particularly if any vapor is drawn into the heater and passes over the hot combustion chamber.

Oxygen system equipment must be kept absolutely free from traces of oil or grease, since these substances spontaneously ignite when in contact with oxygen under pressure. Oxygen servicing cylinders should be clearly marked so they cannot be mistaken for cylinders containing air or nitrogen, as explosions have resulted from this error during maintenance operations.

Glossary

Aborted takeoff. A takeoff that is terminated prematurely when it is determined that some condition exists that makes takeoff or further flight dangerous.

Absolute pressure. Pressure measured from zero pressure or a vacuum.

Absolute pressure regulator. A valve used in a pneumatic system at the pump inlet to regulate the compressor inlet air pressure to prevent excessive speed variation and/or overspeeding of the compressor.

Absolute zero. The point at which all molecular motion ceases. Absolute zero is –460 °F and –273 °C.

Accumulator. A hydraulic component that consists of two compartments separated by a movable component, such as a piston, diaphragm, or bladder. One compartment is filled with compressed air or nitrogen, and the other is filled with hydraulic fluid and is connected into the system pressure manifold. An accumulator allows an incompressible fluid to be stored under pressure by the force produced by a compressible fluid. Its primary purposes are to act as a shock absorber in the system, and to provide a source of additional hydraulic power when heavy demands are placed on the system.

Actuator. A fluid power device that changes fluid pressure into mechanical motion.

ADC. Air data computer.

ADF. Automatic direction finder.

ADI. Attitude director indicator.

Advancing blade. The blade on a helicopter rotor whose tip is moving in the same direction the helicopter is moving.

Adverse yaw. A condition of flight at the beginning of a turn in which the nose of an airplane momentarily yaws in the opposite direction from the direction in which the turn is to be made.

Aerodynamic drag. The total resistance to the movement of an object through the air. Aerodynamic drag is composed of both induced drag and parasite drag. See induced drag and parasite drag.

Aerodynamic lift. The force produced by air moving over a specially shaped surface called an airfoil. Aerodynamic lift acts in a direction perpendicular to the direction the air is moving.

Aeronautical Radio Incorporated (ARINC). A corporation whose principal stockholders are the airlines. Its function is to operate certain communication links between airliners in flight and the airline ground facilities. ARINC also sets standards for communication equipment used by the airlines.

Aging. A change in the characteristics of a material with time. Certain aluminum alloys do not have their full strength when they are first removed from the quench bath after they have been heat-treated, but they gain this strength after a few days by the natural process of aging.

Agonic line. A line drawn on an aeronautical chart along which there is no angular difference between the magnetic and geographic north poles.

Air carrier. An organization or person involved in the business of transporting people or cargo by air for compensation or hire.

Air-cycle cooling system. A system for cooling the air in the cabin of a turbojet-powered aircraft. Compressor bleed air passes through two heat exchangers where it gives up some of its heat; then, it drives an expansion turbine where it loses still more of its heat energy as the turbine drives a compressor. When the air leaves the turbine, it expands and its pressure and temperature are both low.

Aircraft communication addressing and reporting system (ACARS). A two-way communication link between an airliner in flight and the airline's main ground facilities. Data is collected in the aircraft by digital sensors and is transmitted to the ground facilities. Replies from the ground may be printed out so the appropriate flight crewmember can have a hard copy of the response.

Airfoil. Any surface designed to obtain a useful reaction, or lift, from air passing over it.

Airspeed indicator. A flight instrument that measures the pressure differential between the pitot, or ram, air pressure, and the static pressure of the air surrounding the aircraft. This differential pressure is shown in units of miles per hour, knots, or kilometers per hour.

Airworthiness Directive (AD note). Airworthiness Directives (ADs) are legally enforceable rules issued by the FAA in accordance with 14 CFR part 39 to correct an unsafe condition in a product. 14 CFR part 39 defines a product as an aircraft, aircraft engine, propeller, or appliance.

Alclad. A registered trade name for clad aluminum alloy.

Alodine. The registered trade name for a popular conversion coating chemical used to produce a hard, airtight, oxide film on aluminum alloy for corrosion protection.

Alphanumeric symbols. Symbols made up of all of the letters in our alphabet, numerals, punctuation marks, and certain other special symbols.

Alternator. An electrical generator that produces alternating current. The popular DC alternator used on light aircraft produces three-phase AC in its stator windings. This AC is changed into DC by a six-diode, solid-state rectifier before it leaves the alternator.

Altimeter setting. The barometric pressure at a given location corrected to mean (average) sea level.

Altitude engine. A reciprocating engine whose rated sea-level takeoff power can be produced to an established higher altitude.

Alumel. An alloy of nickel, aluminum, manganese, and silicon that is the negative element in a thermocouple used to measure exhaust gas temperature.

Ambient pressure. The pressure of the air surrounding a person or an object.

Ambient temperature. The temperature of the air surrounding a person or an object.

American wire gauge. The system of measurement of wire size used in aircraft electrical systems.

Amphibian. An airplane with landing gear that allows it to operate from both water and land surfaces.

Amplifier. An electronic circuit in which a small change in voltage or current controls a much larger change in voltage or current.

Analog electronics. Electronics in which values change in a linear fashion. Output values vary in direct relationship to changes of input values.

Analog-type indicator. An electrical meter that indicates values by the amount a pointer moves across a graduated numerical scale.

Aneroid. The sensitive component in an altimeter or barometer that measures the absolute pressure of the air. The aneroid is a sealed, flat capsule made of thin corrugated disks of metal soldered together and evacuated by pumping all of the air out of it. Evacuating the aneroid allows it to expand or collapse as the air pressure on the outside changes.

Angle of attack. The acute angle formed between the chord line of an airfoil and the direction of the air that strikes the airfoil.

Angle of attack indicator. An instrument that measures the angle between the local airflow around the direction detector and the fuselage reference plane.

Angle of incidence. The acute angle formed between the chord line of an airfoil and the longitudinal axis of the aircraft on which it is mounted.

Annual rings. The rings that appear in the end of a log cut from a tree. The number of annual rings per inch gives an indication of the strength of the wood. The more rings there are and the closer they are together, the stronger the wood. The pattern of alternating light and dark rings is caused by the seasonal variations in the growth rate of the tree. A tree grows quickly in the spring and produces the light-colored, less dense rings. The slower growth during the summer, or latter part of the growing season, produces the dark-colored, denser rings.

Annunciator panel. A panel of warning lights in plain sight of the pilot. These lights are identified by the name of the system they represent and are usually covered with colored lenses to show the meaning of the condition they announce.

Anodizing. The electrolytic process in which a hard, airtight, oxide film is deposited on aluminum alloy for corrosion protection.

Antenna. A special device used with electronic communication and navigation systems to radiate and receive electromagnetic energy.

Anti-ice system. A system that prevents the formation of ice on an aircraft structure.

Anti-icing additive. A chemical added to the turbine-engine fuel used in some aircraft. This additive mixes with water that condenses from the fuel and lowers its freezing temperature so it will not freeze and block the fuel filters. It also acts as a biocidal agent and prevents the formation of microbial contamination in the tanks.

Antidrag wire. A structural wire inside a Pratt truss airplane wing between the spars. Antidrag wires run from the rear spar inboard, to the front spar at the next bay outboard. Antidrag wires oppose the forces that try to pull the wing forward.

Antiservo tab. A tab installed on the trailing edge of a stabilator to make it less sensitive. The tab automatically moves in the same direction as the stabilator to produce an aerodynamic force that tries to bring the surface back to a streamline position. This tab is also called an antibalance tab.

Antiskid brake system. An electrohydraulic system in an airplane's power brake system that senses the deceleration rate of every main landing gear wheel. If any wheel decelerates too rapidly, indicating an impending skid, pressure to that brake is released and the wheel stops decelerating. Pressure is then reapplied at a slightly lower value.

Antitear strip. Strips of aircraft fabric laid under the reinforcing tape before the fabric is stitched to an aircraft wing.

Arbor press. A press with either a mechanically or hydraulically operated ram used in a maintenance shop for a variety of pressing functions.

Arcing. Sparking between a commutator and brush or between switch contacts that is caused by induced current when a circuit is broken.

Area. The number of square units in a surface.

Aspect ratio. The ratio of the length, or span, of an airplane wing to its width, or chord. For a nonrectangular wing, the aspect ratio is found by dividing the square of the span of the wing by its area. Aspect Ratio = span^2 ÷ area.

Asymmetrical airfoil. An airfoil section that is not the same on both sides of the chord line.

Asymmetrical lift. A condition of uneven lift produced by the rotor when a helicopter is in forward flight. Asymmetrical lift is caused by the difference between the airspeed of the advancing blade and that of the retreating blade.

Attenuate. To weaken, or lessen the intensity of, an activity.

Attitude indicator. A gyroscopic flight instrument that gives the pilot an indication of the attitude of the aircraft relative to its pitch and roll axes. The attitude indicator in an autopilot is in the sensing system that detects deviation from a level-flight attitude.

Augmenter tube. A long, stainless steel tube around the discharge of the exhaust pipes of a reciprocating engine. Exhaust gases flow through the augmenter tube and produce a low pressure that pulls additional cooling air through the engine compartment. Heat may be taken from the augmenter tubes and directed through the leading edges of the wings for thermal anti-icing.

Autoclave. A pressure vessel inside of which air can be heated to a high temperature and pressure raised to a high value. Autoclaves are used in the composite manufacturing industry to apply heat and pressure for curing resins.

Autogyro. A heavier-than-air rotor-wing aircraft sustained in the air by rotors turned by aerodynamic forces rather than by engine power. When the name Autogyro is spelled with a capital A, it refers to a specific series of machines built by Juan de la Cierva or his successors.

Autoignition system. A system on a turbine engine that automatically energizes the igniters to provide a relight if the engine should flame out.

Automatic adjuster. A subsystem in an aircraft disk brake that compensates for disk or lining wear. Each time the brakes are applied, the automatic adjuster is reset for zero clearance, and when the brakes are released, the clearance between the disks or the disk and lining is returned to a preset value. A malfunctioning automatic adjuster in a multiple-disk brake can cause sluggish and jerky operation.

Automatic flight control system (AFCS). The full system of automatic flight control that includes the autopilot, flight director, horizontal situation indicator, air data sensors, and other avionics inputs.

Automatic pilot (autopilot). An automatic flight control device that controls an aircraft about one or more of its three axes. The primary purpose of an autopilot is to relieve the pilot of the control of the aircraft during long periods of flight.

Autosyn system. A synchro system used in remote indicating instruments. The rotors in an Autosyn system are two-pole electromagnets, and the stators are delta-connected, three-phase, distributed-pole windings in the stator housings. The rotors in the transmitters and indicators are connected in parallel and are excited with 26-volt, 400-Hz AC. The rotor in the indicator follows the movement of the rotor in the transmitter.

Auxiliary power unit (APU). A small turbine or reciprocating engine that drives a generator, hydraulic pump, and air pump. The APU is installed in the aircraft and is used to supply electrical power, compressed air, and hydraulic pressure when the main engines are not running.

Aviation snips. Compound-action hand shears used for cutting sheet metal. Aviation snips come in sets of three. One pair cuts to the left, one pair cuts to the right, and the third pair of snips cuts straight.

Aviator's oxygen. Oxygen that has had almost all of the water and water vapor removed from it.

Avionics. The branch of technology that deals with the design, production, installation, use, and servicing of electronic equipment mounted in aircraft.

Azimuth. A horizontal angular distance, measured clockwise from a fixed reference direction to an object.

Back course. The reciprocal of the localizer course for an ILS (Instrument Landing System). When flying a back-course approach, the aircraft approaches the instrument runway from the end on which the localizer antennas are installed.

Backhand welding. Welding in which the torch is pointed away from the direction the weld is progressing.

Backplate (brake component). A floating plate on which the wheel cylinder and the brake shoes attach on an energizing-type brake.

Backup ring. A flat leather or Teflon ring installed in the groove in which an O-ring or T-seal is placed. The backup ring is on the side of the seal away from the pressure, and it prevents the pressure extruding the seal between the piston and the cylinder wall.

Balance cable. A cable in the aileron system of an airplane that connects to one side of each aileron. When the control wheel is rotated, a cable from the cockpit pulls one aileron down and relaxes the cable going to the other aileron. The balance cable pulls the other aileron up.

Balance panel. A flat panel hinged to the leading edge of some ailerons that produces a force which assists the pilot in holding the ailerons deflected. The balance panel divides a chamber ahead of the aileron in such a way that when the aileron is deflected downward, for example, air flowing over its top surface produces a low pressure that acts on the balance panel and causes it to apply an upward force to the aileron leading edge.

Balance tab. An adjustable tab mounted on the trailing edge of a control surface to produce a force that aids the pilot in moving the surface. The tab is automatically actuated in such a way it moves in the direction opposite to the direction the control surface on which it is mounted moves.

Balanced actuator. A linear hydraulic or pneumatic actuator that has the same area on each side of the piston.

Banana oil. Nitrocellulose dissolved in amyl acetate, so named because it smells like bananas.

Bank (verb). The act of rotating an aircraft about its longitudinal axis.

Barometric scale. A small window in the dial of a sensitive altimeter in which the pilot sets the barometric pressure level from which the altitude shown on the altimeter is measured. This window is sometimes called the "Kollsman" window. base. The electrode of a bipolar transistor between the emitter and the collector. Varying a small flow of electrons moving into or out of the base controls a much larger flow of electron between the emitter and the collector.

Base. The electrode of a bipolar transistor between the emitter and the collector. Varying a small flow of electrons moving into or out of the base controls a much larger flow of electrons between the emitter and the collector.

Bead (tire component). The high-strength carbon-steel wire bundles that give an aircraft tire its strength and stiffness where it mounts on the wheel.

Bead seat area. The flat surface on the inside of the rim of an aircraft wheel on which the bead of the tire seats.

Bearing strength (sheet metal characteristic). The amount of pull needed to cause a piece of sheet metal to tear at the points at which it is held together with rivets. The bearing strength of a material is affected by both its thickness and the diameter of the rivet.

Beehive spring. A hardened-steel, coil-spring retainer used to hold a rivet set in a pneumatic rivet gun. This spring gets its name from its shape. It screws onto the end of the rivet gun and allows the set to move back and forth, but prevents it being driven from the gun.

Bend allowance. The amount of material actually used to make a bend in a piece of sheet metal. Bend allowance depends upon the thickness of the metal and the radius of the bend, and is normally found in a bend allowance chart.

Bend radius. The radius of the inside of a bend.

Bend tangent line. A line made in a sheet metal layout that indicates the point at which the bend starts.

Bernoulli's principle. The basic principle that explains the relation between kinetic energy and potential energy in fluids that are in motion. When the total energy in a column of moving fluid remains constant, any increase in the kinetic energy of the fluid (its velocity) results in a corresponding decrease in its potential energy (its pressure).

Bezel. The rim that holds the glass cover in the case of an aircraft instrument.

Bias-cut surface tape. A fabric tape in which the threads run at an angle of 45° to the length of the tape. Bias-cut tape may be stretched around a compound curve such as a wing tip bow without wrinkling.

Bilge area. A low portion in an aircraft structure in which water and contaminants collect. The area under the cabin floorboards is normally called the bilge.

Bipolar transistor. A solid-state component in which the flow of current between its emitter and collector is controlled by a much smaller flow of current into or out of its base. Bipolar transistors may be of either the NPN or PNP type.

BITE. Built-in test equipment.

Blade track. The condition of a helicopter rotor in which each blade follows the exact same path as the blade ahead of it.

Black box. A term used for any portion of an electrical or electronic system that can be removed as a unit. A black box does not have to be a physical box.

Bladder-type fuel cell. A plastic-impregnated fabric bag supported in a portion of an aircraft structure so that it forms a cell in which fuel is carried.

Bleeder. A material such as glass cloth or mat that is placed over a composite lay-up to absorb the excess resin forced out of the ply fibers when pressure is applied.

Bleeding dope. Dope whose pigments are soluble in the solvents or thinners used in the finishing system. The color will bleed up through the finished coats.

Bleeding of brakes. The maintenance procedure of removing air entrapped in hydraulic fluid in the brakes. Fluid is bled from the brake system until fluid with no bubbles flows out.

Blimp. A cigar-shaped, nonrigid lighter-than-air flying machine.

Blush. A defect in a lacquer or dope finish caused by moisture condensing on the surface before the finish dries. If the humidity of the air is high, the evaporation of the solvents cools the air enough to cause the moisture to condense. The water condensed from the air mixes with the lacquer or dope and forms a dull, porous, chalky-looking finish called blush. A blushed finish is neither attractive nor protective.

Bonding. The process of electrically connecting all isolated components to the aircraft structure. Bonding provides a path for return current from electrical components, and a low-impedance path to ground to minimize static electrical charges. Shock-mounted components have bonding braids connected across the shock mounts.

Boost pump. An electrically driven centrifugal pump mounted in the bottom of the fuel tanks in large aircraft. Boost pumps provide a positive flow of fuel under pressure to the engine for starting and serve as an emergency backup in the event an engine-driven pump should fail. They are also used to transfer fuel from one tank to another and to pump fuel overboard when it is being dumped. Boost pumps prevent vapor locks by holding pressure on the fuel in the line to the engine-driven pump. Centrifugal boost pumps have a small agitator propeller on top of the impeller to force vapors from the fuel before it leaves the tank.

Boundary layer. The layer of air that flows next to an aerodynamic surface. Because of the design of the surface and local surface roughness, the boundary layer often has a random flow pattern, sometimes even flowing in a direction opposite to the direction of flight. A turbulent boundary layer causes a great deal of aerodynamic drag.

Bourdon tube. A pressure-indicating mechanism used in most oil pressure and hydraulic pressure gages. It consists of a sealed, curved tube with an elliptical cross section. Pressure inside the tube tries to straighten it, and as it straightens, it moves a pointer across a calibrated dial. Bourdon-tube pressure gauges are used to measure temperature by measuring the vapor pressure in a sealed container of a volatile liquid, such as methyl chloride, whose vapor pressure varies directly with its temperature.

Brazing. A method of thermally joining metal parts by wetting the surface with a molten nonferrous alloy. When the molten material cools and solidifies, it holds the pieces together. Brazing materials melt at a temperature higher than 800 °F, but lower than the melting temperature of the metal on which they are used.

British thermal unit (BTU). The amount of heat energy needed to raise the temperature of one pound of pure water 1 °F.

Bucking bar. A heavy steel bar with smooth, hardened surfaces, or faces. The bucking bar is held against the end of the rivet shank when it is driven with a pneumatic rivet gun, and the shop head is formed against the bucking bar.

Buffeting. Turbulent movement of the air over an aerodynamic surface.

Bulb angle. An L-shaped metal extrusion having an enlarged, rounded edge that resembles a bulb on one of its legs.

Bulkhead. A structural partition that divides the fuselage of an aircraft into compartments, or bays.

Bungee shock cord. A cushioning material used with the nonshock absorbing landing gears installed on older aircraft. Bungee cord is made up of many small rubber bands encased in a loose-woven cotton braid.

Burnish (verb). To smooth the surface of metal that has been damaged by a deep scratch or gouge. The metal piled up at the edge of the damage is pushed back into the damage with a smooth, hard steel burnishing tool.

Burr. A sharp rough edge of a piece of metal left when the metal was sheared, punched, or drilled.

Bus. A point within an electrical system from which the individual circuits get their power.

Buttock line. A line used to locate a position to the right or left of the center line of an aircraft structure.

Butyl. Trade name for a synthetic rubber product made by the polymerization of isobutylene. Butyl withstands such potent chemicals as phosphate ester-base (Skydrol) hydraulic fluids.

Cage (verb). To lock the gimbals of a gyroscopic instrument so it will not be damaged by abrupt flight maneuvers or rough handling.

Calendar month. A measurement of time used by the FAA for inspection and certification purposes. One calendar month from a given day extends from that day until midnight of the last day of that month.

Calibrated airspeed (CAS). Indicated airspeed corrected for position error. See position error.

Calorie. The amount of heat energy needed to raise the temperature of one gram of pure water 1 °C.

Canted rate gyro. A rate gyro whose gimbal axis is tilted so it can sense rotation of the aircraft about its roll axis as well as its yaw axis.

Camber (wheel alignment). The amount the wheels of an aircraft are tilted, or inclined, from the vertical. If the top of the wheel tilts outward, the camber is positive. If the top of the wheel tilts inward, the camber is negative.

Canard. A horizontal control surface mounted ahead of the wing to provide longitudinal stability and control.

Cantilever wing. A wing that is supported by its internal structure and requires no external supports. The wing spars are built in such a way that they carry all the bending and torsional loads.

Cap strip. The main top and bottom members of a wing rib. The cap strips give the rib its aerodynamic shape.

Capacitance-type fuel quantity measuring system. A popular type of electronic fuel quantity indicating system that has no moving parts in the fuel tank. The tank units are cylindrical capacitors, called probes, mounted across the tank, from top to bottom. The dielectric between the plates of the probes is either fuel or the air above the fuel, and the capacitance of the probe varies with the amount of fuel in the tank. The indicator is a servo-type instrument driven by the amplified output of a capacitance bridge.

Capillary tube. A soft copper tube with a small inside diameter. The capillary tube used with vapor-pressure thermometer connects the temperature sensing bulb to the Bourdon tube. The capillary tube is protected from physical damage by enclosing it in a braided metal wire jacket.

Carbon monoxide detector. A packet of chemical crystals mounted in the aircraft cockpit or cabin where they are easily visible. The crystals change their color from yellow to green when they are exposed to carbon monoxide.

Carbon-pile voltage regulator. A type of voltage regulator used with high-output DC generators. Field current is controlled by varying the resistance of a stack of thin carbon disks. This resistance is varied by controlling the amount the stack is compressed by a spring whose force is opposed by the pull of an electromagnet. The electromagnet's strength is proportional to the generator's output voltage.

Carburizing flame. An oxyacetylene flame produced by an excess of acetylene. This flame is identified by a feather around the inner cone. A carburizing flame is also called a reducing flame.

Carcass (tire component). The layers of rubberized fabric that make up the body of an aircraft tire.

Case pressure. A low pressure that is maintained inside the case of a hydraulic pump. If a seal becomes damaged, hydraulic fluid will be forced out of the pump rather than allowing air to be drawn into the pump.

Cathode-ray tube (CRT). A display tube used for oscilloscopes and computer video displays. An electron gun emits a stream of electrons that is attracted to a positively charged inner surface of the face of the tube. Acceleration and focusing grids speed the movement of the electrons and shape the beam into a pinpoint size. Electrostatic or electromagnetic forces caused by deflection plates or coils move the beam over the face of the tube. The inside surface of the face of the tube is treated with a phosphor material that emits light when the beam of electrons strikes it.

Cavitation. A condition that exist in a hydraulic pump when there is not enough pressure in the reservoir to force fluid to the inlet of the pump. The pump picks up air instead of fluid.

CDI. Course deviation indicator.

CDU. Control display unit.

Center of gravity. The location on an aircraft about which the force of gravity is concentrated.

Center of lift. The location of the chord line of an airfoil at which all the lift forces produced by the airfoil are considered to be concentrated.

Center of pressure. The point on the chord line of an airfoil where all of the aerodynamic forces are considered to be concentrated.

Centering cam. A cam in the nose-gear shock strut that causes the piston to center when the strut fully extends. When the aircraft takes off and the strut extends, the wheel is straightened in its fore-and-aft position so it can be retracted into the wheel well.

Charging stand (air conditioning service equipment). A handy and compact arrangement of air conditioning servicing equipment. A charging stand contains a vacuum pump, a manifold gauge set, and a method of measuring and dispensing the refrigerant.

Chatter. A type of rapid vibration of a hydraulic pump caused by the pump taking in some air along with the hydraulic fluid.

Check (wood defect). Longitudinal cracks that extend across a log's annual rings.

Check valve. A hydraulic or pneumatic system component that allows full flow of fluid in one direction but blocks all flow in the opposite direction.

Chemical oxygen candle system. An oxygen system used for emergency or backup use. Solid blocks of material that release oxygen when they are burned are carried in special fireproof fixtures. When oxygen is needed, the candles are ignited with an integral igniter, and oxygen flows into the tubing leading to the masks.

Chevron seal. A form of one-way seal used in some fluid-power actuators. A chevron seal is made of a resilient material whose cross section is in the shape of the letter V. The pressure being sealed must be applied to the open side of the V.

Chromel. An alloy of nickel and chromium used as the positive element in a thermocouple for measuring exhaust gas temperature.

Circle. A closed plane figure with every point an equal distance from the center. A circle has the greatest area for its circumference of any enclosed shape.

Circuit breaker. An electrical component that automatically opens a circuit any time excessive current flows through it. A circuit breaker may be reset to restore the circuit after the fault causing the excessive current has been corrected.

Clad aluminum. A sheet of aluminum alloy that has a coating of pure aluminum rolled on one or both of its surfaces for corrosion protection.

Clamp-on ammeter. An electrical instrument used to measure current without opening the circuit through which it is flowing. The jaws of the ammeter are opened, slipped over the current-carrying wire, and then clamped shut. Current flowing through the wire produces a magnetic field which induces a voltage in the ammeter that is proportional to the amount of current.

Cleco fastener. A patented spring-type fastener used to hold metal sheets in position until they can be permanently riveted together.

Close-quarter iron. A small hand-held iron with an accurately calibrated thermostat. This iron is used for heat-shrinking polyester fabrics in areas that would be difficult to work with a large iron.

Closed angle. An angle formed in sheet metal that has been bent more than 90°.

Closed assembly time. The time elapsing between the assembly of glued joints and the application of pressure.

Closed-center hydraulic system. A hydraulic system in which the selector valves are installed in parallel with each other. When no unit is actuated, fluid circulates from the pump back to the reservoir without flowing through any of the selector valves.

Closed-center selector valve. A type of flow-control valve used to direct pressurized fluid into one side of an actuator, and at the same time, direct the return fluid from the other side of the actuator to the fluid reservoir. Closed-center selector valves are connected in parallel between the pressure manifold and the return manifold.

Coaxial. Rotating about the same axis. Coaxial rotors of a helicopter are mounted on concentric shafts in such a way that they turn in opposite directions to cancel torque.

Coaxial cable. A special type of electrical cable that consists of a central conductor held rigidly in the center of a braided outer conductor. Coaxial cable, commonly called coax, is used for attaching radio receivers and transmitters to their antenna.

Coefficient of drag. A dimensionless number used in the formula for determining induced drag as it relates to the angle of attack.

Coefficient of lift. A dimensionless number relating to the angle of attack used in the formula for determining aerodynamic lift.

Coin dimpling. A process of preparing a hole in sheet metal for flush riveting. A coining die is pressed into the rivet hole to form a sharp-edged depression into which the rivet head fits.

Collective pitch control. The helicopter control that changes the pitch of all of the rotor blades at the same time. Movement of the collective pitch control increases or decreases the lift produced by the entire rotor disk.

Collodion. Cellulose nitrate used as a film base for certain aircraft dopes.

Combustion heater. A type of cabin heater used in some aircraft. Gasoline from the aircraft fuel tanks is burned in the heater.

Compass fluid. A highly refined, water-clear petroleum product similar to kerosene. Compass fluid is used to dampen the oscillations of magnetic compasses.

Compass rose. A location on an airport where an aircraft can be taken to have its compasses "swung." Lines are painted on the rose to mark the magnetic directions in 30° increments.

Compass swinging. A maintenance procedure that minimizes deviation error in a magnetic compass. The aircraft is aligned on a compass rose, and the compensating magnets in the compass case are adjusted so the compass card indicates the direction marked on the rose. After the deviation error is minimized on all headings, a compass correction card is completed and mounted on the instrument panel next to the compass.

Compensated fuel pump. A vane-type, engine-driven fuel pump that has a diaphragm connected to the pressure regulating valve. The chamber above the diaphragm is vented to the carburetor upper deck where it senses the pressure of the air as it enters the engine. The diaphragm allows the fuel pump to compensate for altitude changes and keeps the carburetor inlet fuel pressure a constant amount higher than the carburetor inlet air pressure.

Compensator port (brake system component). A small hole between a hydraulic brake master cylinder and the reservoir. When the brakes are released, this port is uncovered and the fluid in the master cylinder is vented to the reservoir. When the brake is applied, the master-cylinder piston covers the compensator port and allows pressure in the line to the brake to build up and apply the brakes. When the brake is released, the piston uncovers the compensator port. If any fluid has been lost from the brake, the reservoir will refill the master cylinder. A restricted compensator port will cause the brakes to drag or will cause them to be slow to release.

Composite. Something made up of different materials combined in such a way that the characteristics of the resulting material are different from those of any of the components.

Compound curve. A curve formed in more than one plane. The surface of a sphere is a compound curve.

Compound gauge (air conditioning servicing equipment). A pressure gauge used to measure the pressure in the low side of an air conditioning system. A compound gauge is calibrated from zero to 30 inches of mercury vacuum, and from zero to about 150-psi positive gauge pressure.

Compressibility effect. The sudden increase in the total drag of an airfoil in transonic flight caused by formation of shock waves on the surface.

Compression failure. A type of structural failure in wood caused by the application of too great a compressive load. A compression failure shows up as a faint line running at right angles to the grain of the wood.

Compression strut. A heavy structural member, often in the form of a steel tube, used to hold the spars of a Pratt truss airplane wing apart. A compression strut opposes the compressive loads between the spars arising from the tensile loads produced by the drag and antidrug wires.

Compression wood. A defect in wood that causes it to have a high specific gravity and the appearance of an excessive growth of summerwood. In most species, there is little difference between the color of the springwood and the summerwood. Any material containing compression wood is unsuited for aircraft structural use and must be rejected.

Compressor (air conditioning system component). The component in a vapor-cycle cooling system in which the low-pressure refrigerant vapors, after they leave the evaporator, are compressed to increase both their temperature and pressure before they pass into the condenser. Some compressors are driven by electric motors, others by hydraulic motors and, in the case of most light airplanes, are belt driven from the engine.

Concave surface. A surface that is curved inward. The outer edges are higher than the center.

Condenser (air conditioning system component). The component in a vapor-cycle cooling system in which the heat taken from the aircraft cabin is given up to the ambient air outside the aircraft.

Conductor (electrical). A material that allows electrons to move freely from one atom to another within the material.

Coning angle. The angle formed between the plane of rotation of a helicopter rotor blade when it is producing lift and a line perpendicular to the rotor shaft. The degree of the coning angle is determined by the relationship between the centrifugal force acting on the blades and the aerodynamic lift produced by the blades.

Constant (mathematical). A value used in a mathematical computation that is the same every time it is used. For example, the relationship between the length of the circumference of a circle and the length of its diameter is a constant, 3.1416. This constant is called by the Greek name of Pi (π).

Constant differential mode (cabin pressurization). The mode of pressurization in which the cabin pressure is maintained a constant amount higher than the outside air pressure. The maximum differential pressure is determined by the structural strength of the aircraft cabin.

Constant-displacement pump. A fluid pump that moves a specific volume of fluid each time it rotates; the faster the pump turns, the more fluid it moves. Some form of pressure regulator or relief valve must be used with a constant-displacement pump when it is driven by an aircraft engine.

Constant-speed drive (CSD). A special drive system used to connect an alternating current generator to an aircraft engine. The drive holds the generator speed (and thus its frequency) constant as the engine speed varies.

Constantan. A copper-nickel alloy used as the negative lead of a thermocouple for measuring the cylinder head temperature of a reciprocating engine.

Contactor (electrical component). A remotely actuated, heavy-duty electrical switch. Contactors are used in an aircraft electrical system to connect the battery to the main bus.

Continuity tester. A troubleshooting tool that consists of a battery, a light bulb, and test leads. The test leads are connected to each end of the conductor under test, and if the bulb lights up, there is continuity. If it does not light up, the conductor is open.

Continuous Airworthiness Inspection Program. An inspection program that is part of a continuous airworthiness maintenance program approved for certain large airplanes (to which 14 CFR Part 125 is not applicable), turbojet multi-engine airplanes, turbopropeller-powered multi-engine airplanes, and turbine-powered rotorcraft.

Continuous-duty solenoid. A solenoid-type switch designed to be kept energized by current flowing through its coil for an indefinite period of time. The battery contactor in an aircraft electrical system is a continuous-duty solenoid. Current flows through its coil all the time the battery is connected to the electrical system.

Continuous-flow oxygen system. A type of oxygen system that allows a metered amount of oxygen to continuously flow into the mask. A rebreather-type mask is used with a continuous-flow system. The simplest form of continuous-flow oxygen system regulates the flow by a calibrated orifice in the outlet to the mask, but most systems use either a manual or automatic regulator to vary the pressure across the orifice proportional to the altitude being flown.

Continuous-loop fire-detection system. A fire-detection system that uses a continuous loop of two conductors separated with a thermistor-type insulation. Under normal temperature conditions, the thermistor material is an insulator; but if it is exposed to a fire, the thermistor changes into a conductor and completes the circuit between the two conductors, initiating a fire warning.

Control horn. The arm on a control surface to which the control cable or push-pull rod attaches to move the surface.

Control stick. The type of control device used in some airplanes. A vertical stick in the flight deck controls the ailerons by side-to-side movement and the elevators by fore-and-aft movement.

Control yoke. The movable column on which an airplane control wheel is mounted. The yoke may be moved in or out to actuate the elevators, and the control wheel may be rotated to actuate the ailerons.

Controllability. The characteristic of an aircraft that allows it to change its flight attitude in response to the pilot's movement of the flight deck controls.

Conventional current. An imaginary flow of electricity that is said to flow from the positive terminal of a power source, through the external circuit to its negative terminal. The arrowheads in semiconductor symbols point in the direction of conventional current flow.

Converging duct. A duct, or passage, whose cross-sectional area decreases in the direction of fluid flow.

Conversion coating. A chemical solution used to form an airtight oxide or phosphate film on the surface of aluminum or magnesium parts. The conversion coating prevents air from reaching the metal and keeps it from corroding.

Convex surface. A surface that is curved outward. The outer edges are lower than the center.

Coriolis effect. The change in rotor blade velocity to compensate for a change in the distance between the center of mass of the rotor blade and the axis rotation of the blade as the blades flap in flight.

Cornice brake. A large shop tool used to make straight bends across a sheet of metal. Cornice brakes are often called leaf brakes.

Corrugated metal. Sheets of metal that have been made more rigid by forming a series of parallel ridges or waves in its surface.

Cotter pin. A split metal pin used to safety a castellated or slotted nut on a bolt. The pin is passed through the hole in the shank of the bolt and the slots in the nut, and the ends of the pin are spread to prevent it backing out of the hole.

Countersinking. Preparation of a rivet hole for a flush rivet by beveling the edges of the holes with a cutter of the correct angle.

Coverite surface thermometer. A small surface-type bimetallic thermometer that calibrates the temperature of an iron used to heat-shrink polyester fabrics.

Crabbing. Pointing the nose of an aircraft into the wind to compensate for wind drift.

Crazing. A form of stress-caused damage that occurs in a transparent thermoplastic material. Crazing appears as a series of tiny, hair-like cracks just below the surface of the plastic.

Critical Mach number. The flight Mach number at which there is the first indication of supersonic airflow over any part of the aircraft structure.

Cross coat. A double coat of aircraft finishing material in which the second coat is sprayed at right angles to the first coat, before the solvents have evaporated from the first coat.

Cross-feed valve (fuel system component). A valve in a fuel system that allows any of the engines of a multi-engine aircraft to draw fuel from any fuel tank. Cross-feed systems are used to allow a multi-engine aircraft to maintain a balanced fuel condition.

Cross-flow valve. An automatic flow-control valve installed between the gear-up and gear-down lines of the landing gear of some large airplanes. When the landing gear is released from its uplocks, its weight causes it to fall faster than the hydraulic system can supply fluid to the gear-down side of the actuation cylinder. The cross-flow valve opens and directs fluid from the gear-up side into the gear-down side. This allows the gear to move down with a smooth motion.

CRT. Cathode-ray tube.

Cryogenic liquid. A liquid which boils at temperatures of less than about 110 °F (–163 °C) at normal atmospheric pressures.

Cuno filter. The registered trade name for a particular style of edge-type fluid filter. Cuno filters are made up of a stack of thin metal disks that are separated by thin scraper blades. Contaminants collect on the edge of the disks, and they are periodically scraped out and allowed to collect in the bottom of the filter case for future removal.

Current. A general term used for electrical flow. See conventional current.

Current limiter. An electrical component used to limit the amount of current a generator can produce. Some current limiters are a type of slow-blow fuse in the generator output. Other current limiters reduce the generator output voltage if the generator tries to put out more than its rated current.

Cusp. A pointed end.

Cyclic pitch control. The helicopter control that allows the pilot to change the pitch of the rotor blades individually, at a specific point in their rotation. The cyclic pitch control allows the pilot to tilt the plane of rotation of the rotor disk to change the direction of lift produced by the rotor.

Dacron. The registered trade name for a cloth woven from polyester fibers.

Damped oscillation. Oscillation whose amplitude decreases with time.

Database. A body of information that is available on any particular subject.

Data bus. A wire or group of wires that are used to move data within a computer system.

Debooster valve. A valve in a power brake system between the power brake control valve and the wheel cylinder. This valve lowers the pressure of the fluid going to the brake and increases its volume. A debooster valve increases the smoothness of brake application and aids in rapid release of the brakes.

Decay. The breakdown of the structure of wood fibers. Wood that shows any indication of decay must be rejected for use in aircraft structure.

Decomposition. The breakdown of the structure of wood fibers. Wood that shows any indication of decay must be rejected for use in aircraft structure.

Deciduous. A type of tree that sheds its foliage at the end of the growing season. Hardwoods come from deciduous trees.

Dedicated computer. A small digital computer, often built into an instrument or control device that contains a built-in program that causes it to perform a specific function.

Deep-vacuum pump. A vacuum pump capable of removing almost all of the air from a refrigeration system. A deep-vacuum pump can reduce the pressure inside the system to a few microns of pressure.

Deflator cap. A cap for a tire, strut, or accumulator air valve that, when screwed onto the valve, depresses the valve stem and allows the air to escape safely through a hole in the side of the cap.

Deicer system. A system that removes ice after it has formed on an aircraft.

Delamination. The separation of the layers of a laminated material.

Delivery air duct check valve. An isolation valve at the discharge side of the air turbine that prevents the loss of pressurization through a disengaged cabin air compressor.

Delta airplane. An airplane with a triangular-shaped wing. This wing has an extreme amount of sweepback on its leading edge, and a trailing edge that is almost perpendicular to the longitudinal axis of the airplane.

Delta connection (electrical connection). A method of connecting three electrical coils into a ring or, as they are drawn on a schematic diagram as a triangle, a delta (D).

Denier. A measure of the fineness of the yarns in a fabric.

Density altitude. The altitude in standard air at which the density is the same as that of the existing air.

Density ratio (σ). The ratio of the density of the air at a given altitude to the density of the air at sea level under standard conditions.

Derated (electrical specification). Reduction in the rated voltage or current of an electrical component. Derating is done to extend the life or reliability of the device.

Desiccant (air conditioning component). A drying agent used in an air conditioning system to remove water from the refrigerant. A desiccant is made of silica-gel or some similar material.

Detent. A spring-loaded pin or tab that enters a hole or groove when the device to which it is attached is in a certain position. Detents are used on a fuel valve to provide a positive means of identifying the fully on and fully off position of the valve.

Detonation. An explosion, or uncontrolled burning of the fuel-air mixture inside the cylinder of a reciprocating engine. Detonation occurs when the pressure and the temperature inside the cylinder become higher than the critical pressure and temperature of the fuel. Detonation is often confused with preignition.

Deviation error. An error in a magnetic compass caused by localized magnetic fields in the aircraft. Deviation error, which is different on each heading, is compensated by the technician "swinging" the compass. A compass must be compensated so the deviation error on any heading is no greater than 10 degrees.

Dewar bottle. A vessel designed to hold liquefied gases. It has double walls with the space between being evacuated to prevent the transfer of heat. The surfaces in the vacuum area are made heat-reflective.

Differential aileron travel. Aileron movement in which the upward-moving aileron deflects a greater distance than the one moving downward. The up aileron produces parasite drag to counteract the induced drag caused by the down aileron. Differential aileron travel is used to counteract adverse yaw.

Differential pressure. The difference between two pressures. An airspeed indicator is a differential-pressure gauge. It measures the difference between static air pressure and pitot air pressure.

Differential-voltage reverse-current cutout. A type of reverse-current cutout switch used with heavy-duty electrical systems. This switch connects the generator to the electrical bus when the generator voltage is a specific amount higher than the battery voltage.

Digital multimeter. An electrical test instrument that can be used to measure voltage, current, and resistance. The indication is in the form of a liquid crystal display in discrete numbers.

Dihedral. The positive angle formed between the lateral axis of an airplane and a line that passes through the center of the wing or horizontal stabilizer. Dihedral increases the lateral stability of an airplane.

Diluter-demand oxygen system. A popular type of oxygen system in which the oxygen is metered to the mask, where it is diluted with cabin air by an airflow-metering aneroid assembly which regulates the amount of air allowed to dilute the oxygen on the basis of cabin altitude. The mixture of oxygen and air flows only when the wearer of the mask inhales. The percentage of oxygen in the air delivered to the mask is regulated, on the basis of altitude, by the regulator. A diluter-demand regulator has an emergency position which allows 100 percent oxygen to flow to the mask, by-passing the regulating mechanism.

Dipole antenna. A half wavelength, center-fed radio antenna. The length of each of the two arms is approximately one fourth of the wavelength of the center frequency for which the antenna is designed.

Dirigible. A large, cigar-shaped, rigid, lighter-than-air flying machine. Dirigibles are made of a rigid truss structure covered with fabric. Gas bags inside the structure contain the lifting gas, which is either helium or hydrogen.

Disc area (helicopter specification). The total area swept by the blades of a helicopter main rotor.

Divergent oscillation. Oscillation whose amplitude increases with time.

Diverging duct. A duct, or passage, whose cross-sectional area increases in the direction of fluid flow.

DME. Distance measuring equipment.

Dope proofing. The treatment of a structure to be covered with fabric to keep the solvents in the dope from softening the protective coating on the structure.

Dope roping. A condition of aircraft dope brushed onto a surface in such a way that it forms a stringy, uneven surface rather than flowing out smoothly.

Double-acting actuator (hydraulic system component). A linear actuator moved in both directions by fluid power.

Double-acting hand pump (hydraulic system component). A hand-operated fluid pump that moves fluid during both strokes of the pump handle.

Doubler. A piece of sheet metal used to strengthen and stiffen a repair in a sheet metal structure.

Downtime. Any time during which an aircraft is out of commission and unable to be operated.

Downwash. Air forced down by aerodynamic action below and behind the wing of an airplane or the rotor of a helicopter. Aerodynamic lift is produced when the air is deflected downward. The upward force on the aircraft is the same as the downward force on the air.

Drag (helicopter rotor blade movement). Fore-and-aft movement of the tip of a helicopter rotor blade in its plane of rotation.

Dragging brakes. Brakes that do not fully release when the brake pedal is released. The brakes are partially applied all the time, which causes excessive lining wear and heat.

Drag wire. A structural wire inside a Pratt truss airplane wing between the spars. Drag wires run from the front spar inboard, to the rear spar at the next bay outboard. Drag wires oppose the forces that try to drag the wing backward.

Drill motor. An electric or pneumatic motor that drives a chuck that holds a twist drill. The best drill motors produce high torque, and their speed can be controlled.

Drip stick. A fuel quantity indicator used to measure the fuel level in the tank when the aircraft is on the ground. The drip stick is pulled down from the bottom of the tank until fuel drips from its opened end. This indicates that the top of the gauge inside the tank is at the level of the fuel. Note the number of inches read on the outside of the gauge at the point it contacts the bottom of the tank, and use a drip stick table to convert this measurement into gallons of fuel in the tank.

Dry air pump. An engine-driven air pump which used carbon vanes. Dry pumps do not use any lubrication, and the vanes are extremely susceptible to damage from the solid airborne particles. These pumps must be operated with filters in their inlet so they will take in only filtered air.

Dry ice. Solidified carbon dioxide. Dry ice sublimates, or changes from a solid directly into a gas, at a temperature of –110 °F (–78.5 °C).

Dry rot. Decomposition of wood fibers caused by fungi. Dry rot destroys all strength in the wood.

Ductility. The property of a material that allows it to be drawn into a thin section without breaking.

Dummy load (electrical load). A noninductive, high-power, 50-ohm resistor that can be connected to a transmission line in place of the antenna. The transmitter can be operated into the dummy load without transmitting any signal.

Duralumin. The name for the original alloy of aluminum, magnesium, manganese, and copper. Duralumin is the same as the modern 2017 aluminum alloy.

Dutch roll. An undesirable, low-amplitude coupled oscillation about both the yaw and roll axes that affects many swept wing airplanes. Dutch roll is minimized by the use of a yaw damper.

Dutchman shears. A common name for compound-action sheet metal shears.

Dynamic pressure (q). The pressure a moving fluid would have if it were stopped. Dynamic pressure is measured in pounds per square foot.

Dynamic stability. The stability that causes an aircraft to return to a condition of straight and level flight after it has been disturbed from this condition. When an aircraft is disturbed from the straight and level flight, its static stability starts it back in the correct direction; but it overshoots, and the corrective forces are applied in the opposite direction. The aircraft oscillates back and forth on both sides of the correct condition, with each oscillation smaller than the one before it. Dynamic stability is the decreasing of these restorative oscillations.

EADI. Electronic Attitude Director Indicator.

ECAM. Electronic Centralized Aircraft Monitor.

Eccentric brushing. A special bushing used between the rear spar of certain cantilever airplane wings and the wing attachment fitting on the fuselage. The portion of the bushing that fits through the hole in the spar is slightly offset from that which passes through the holes in the fitting. By rotating the bushing, the rear spar may be moved up or down to adjust the root incidence of the wing.

Eddy current damping (electrical instrument damping). Decreasing the amplitude of oscillations by the interaction of magnetic fields. In the case of a vertical-card magnetic compass, flux from the oscillating permanent magnet produces eddy currents in a damping disk or cup. The magnetic flux produced by the eddy currents opposes the flux from the permanent magnet and decreases the oscillations.

Edge distance. The distance between the center of a rivet hole and the edge of the sheet of metal.

EFIS. Electronic Flight Instrument System.

EHSI. Electronic Horizontal Situation Indicator.

EICAS. Engine Indicating and Crew Alerting System.

Ejector. A form of jet pump used to pick up a liquid and move it to another location. Ejectors are used to ensure that the compartment in which the boost pumps are mounted is kept full of fuel. Part of the fuel from the boost pump flowing through the ejector produces a low pressure that pulls fuel from the main tank and forces it into the boostpump sump area.

Elastic limit. The maximum amount of tensile load, in pounds per square inch, a material is able to withstand without being permanently deformed.

Electromotive force (EMF). The force that causes electrons to move from one atom to another within an electrical circuit. Electromotive force is an electrical pressure, and it is measured in volts.

Electron current. The actual flow of electrons in a circuit. Electrons flow from the negative terminal of a power source through the external circuit to its positive terminal. The arrowheads in semiconductor symbols point in the direction opposite to the flow of electron current.

ELT (emergency locator transmitter). A self-contained radio transmitter that automatically begins transmitting on the emergency frequencies any time it is triggered by a severe impact parallel to the longitudinal axis of the aircraft.

Elevator downspring. A spring in the elevator control system that produces a mechanical force that tries to lower the elevator. In normal flight, this spring force is overcome by the aerodynamic force from the elevator trim tab. But in slow flight with an aft CG position, the trim tab loses its effectiveness and the downspring lowers the nose to prevent a stall.

Elevons. Movable control surfaces on the trailing edge of a delta wing or a flying wing airplane. These surfaces operate together to serve as elevators, and differentially to act as ailerons.

EMI. Electromagnetic interference.

Empennage. The tail section of an airplane.

Enamel. A type of finishing material that flows out to form a smooth surface. Enamel is usually made of a pigment suspended in some form of resin. When the resin cures, it leaves a smooth, glossy protective surface.

Energizing brake. A brake that uses the momentum of the aircraft to increase its effectiveness by wedging the shoe against the brake drum. Energizing brakes are also called servo brakes. A single-servo brake is energizing only when moving in the forward direction, and a duo-servo brake is energizing when the aircraft is moving either forward or backward.

Epoxy. A flexible, thermosetting resin that is made by polymerization of an epoxide. Epoxy has wide application as a matrix for composite materials and as an adhesive that bonds many different types of materials. It is noted for its durability and its chemical resistance.

Equalizing resistor. A large resistor in the ground circuit of a heavy-duty aircraft generator through which all of the generator output current flows. The voltage drop across this resistor is used to produce the current in the paralleling circuit that forces the generators to share the electrical load equally.

Ethylene dibromide. A chemical compound added to aviation gasoline to convert some of the deposits left by the tetraethyl lead into lead bromides. These bromides are volatile and will pass out of the engine with the exhaust gases.

Ethylene glycol. A form of alcohol used as a coolant for liquid-cooled engines and as an anti-icing agent.

Eutectic material. An alloy or solution that has the lowest possible melting point.

Evacuation (air conditioning servicing procedure). A procedure in servicing vapor-cycle cooling systems. A vacuum pump removes all the air from the system. Evacuation removes all traces of water vapor that could condense out, freeze, and block the system.

Evaporator (air conditioning component). The component in a vapor-cycle cooling system in which heat from the aircraft cabin is absorbed into the refrigerant. As the heat is absorbed, the refrigerant evaporates, or changes from a liquid into a vapor. The function of the evaporator is to lower the cabin air temperature.

Expander-tube brake. A brake that uses hydraulic fluid inside a synthetic rubber tube around the brake hub to force rectangular blocks of brake-lining material against the rotating brake drum. Friction between the brake drum and the lining material slows the aircraft.

Expansion wave. The change in pressure and velocity of a supersonic flow of air as it passes over a surface which drops away from the flow. As the surface drops away, the air tries to follow it. In changing its direction, the air speeds up to a higher supersonic velocity and its static pressure decreases. There is no change in the total energy as the air passes through an expansion wave, and so there is no sound as there is when air passes through a shock wave.

Extruded angle. A structural angle formed by passing metal heated to its plastic state through specially shaped dies.

FAA Form 337. The FAA form that must be filled in and submitted to the FAA when a major repair or major alteration has been completed.

Federal Aviation Administration Flight Standards District Office (FAA FSDO). An FAA field office serving an assigned geographical area staffed with Flight Standards personnel who serve the aviation industry and the general public on matters relating to certification and operation of air carrier and general aviation aircraft.

Fading of brakes. The decrease in the amount of braking action that occurs with some types of brakes that are applied for a long period of time. True fading occurs with overheated drum-type brakes. As the drum is heated, it expands in a bell-mouthed fashion. This decreases the amount of drum in contact with the brake shoes and decreases the braking action. A condition similar to brake fading occurs when there is an internal leak in the brake master cylinder. The brakes are applied, but as the pedal is held down, fluid leaks past the piston, and the brakes slowly release.

Fairing. A part of a structure whose primary purpose is to produce a smooth surface or a smooth junction where two surfaces join.

Fairlead. A plastic or wooden guide used to prevent a steel control cable rubbing against an aircraft structure.

FCC. Federal Communications Commission.

FCC. Flight Control Computer.

Feather (helicopter rotor blade movement). Rotation of a helicopter rotor blade about its pitch-change axis.

Ferrous metal. Any metal that contains iron and has magnetic characteristics.

Fiber stop nut. A form of a self-locking nut that has a fiber insert crimped into a recess above the threads. The hole in the insert is slightly smaller than the minor diameter of the threads. When the nut is screwed down over the bolt threads, the opposition caused by the fiber insert produces a force that prevents vibration loosening the nut.

File. A hand-held cutting tool used to remove a small amount of metal with each stroke.

Fill threads. Threads in a piece of fabric that run across the width of the fabric, interweaving with the warp threads. Fill threads are often called woof, or weft, threads.

Fillet. A fairing used to give shape but not strength to an object. A fillet produces a smooth junction where two surfaces meet.

Finishing tape. Another name for surface tape. See surface tape.

Fishmouth splice. A type of splice used in a welded tubular structure in which the end of the tube whose inside diameter is the same as the outside diameter of the tube being spliced is cut in the shape of a V, or a fishmouth, and is slipped over the smaller tube welded. A fishmouth splice has more weld area than a butt splice and allows the stresses from one tube to transfer into the other tube gradually.

Fire pull handle. The handle in an aircraft flight deck that is pulled at the first indication of an engine fire. Pulling this handle removes the generator from the electrical system, shuts off the fuel and hydraulic fluid to the engine, and closes the compressor bleed air valve. The fire extinguisher agent discharge switch is uncovered, but it is not automatically closed.

Fire zone. A portion of an aircraft designated by the manufacturer to require fire-detection and/or fire-extinguishing equipment and a high degree of inherent fire resistance.

Fitting. An attachment device that is used to connect components to an aircraft structure.

Fixed fire-extinguishing system. A fire-extinguishing system installed in an aircraft.

Flameout. A condition in the operation of a gas turbine engine in which the fire in the engine unintentionally goes out.

Flap (aircraft control). A secondary control on an airplane wing that changes its camber to increase both its lift and its drag.

Flap (helicopter rotor blade movement). Up-and-down movement of the tip of a helicopter rotor blade.

Flap overload valve. A valve in the flap system of an airplane that prevents the flaps being lowered at an airspeed which could cause structural damage. If the pilot tries to extend the flaps when the airspeed is too high, the opposition caused by the air flow will open the overload valve and return the fluid to the reservoir.

Flash point. The temperature to which a material must be raised for it to ignite, but not continue to burn, when a flame is passed above it.

Flat pattern layout. The pattern for a sheet metal part that has the material used for each flat surface, and for all of the bends, marked out with bend-tangent lines drawn between the flats and bend allowances.

Flight controller. The component in an autopilot system that allows the pilot to maneuver the aircraft manually when the autopilot is engaged.

Fluid. A form of material whose molecules are able to flow past one another without destroying the material. Gases and liquids are both fluids.

Fluid power. The transmission of force by the movement of a fluid. The most familiar examples of fluid power systems are hydraulic and pneumatic systems.

Flutter. Rapid and uncontrolled oscillation of a flight control surface on an aircraft that is caused by a dynamically unbalanced condition.

Fly-by-wire. A method of control used by some modern aircraft in which control movement or pressures exerted by the pilot are directed into a digital computer where they are input into a program tailored to the flight characteristics of the aircraft. The computer output signal is sent to actuators at the control surfaces to move them the optimum amount for the desired maneuver.

Flying boat. An airplane whose fuselage is built in the form of a boat hull to allow it to land and takeoff from water. In the past, flying boats were a popular form of large airplane.

Flying wing. A type of heavier-than-air aircraft that has no fuselage or separate tail surfaces. The engines and useful load are carried inside the wing, and movable control surfaces on the trailing edge provide both pitch and roll control.

Foot-pound. A measure of work accomplished when a force of 1 pound moves an object a distance of 1 foot.

Force. Energy brought to bear on an object that tends to cause motion or to change motion.

Forehand welding. Welding in which the torch is pointed in the direction the weld is progressing.

Form drag. Parasite drag caused by the form of the object passing through the air.

Former. An aircraft structural member used to give a fuselage its shape.

FMC. Flight Management Computer.

Forward bias. A condition of operation of a semiconductor device such as a diode or transistor in which a positive voltage is connected to the P-type material and a negative voltage to the N-type material.

FPD. Freezing point depressant.

Fractional distillation. A method of separating the various components from a physical mixture of liquids. The material to be separated is put into a container and its temperature is increased. The components having the lowest boiling points boil off first and are condensed. Then, as the temperature is further raised, other components are removed. Kerosene, gasoline, and other petroleum products are obtained by fractional distillation of crude oil.

Frangible. Breakable, or easily broken.

Freon. The registered trade name for a refrigerant used in a vapor-cycle air conditioning system.

Frise aileron. An aileron with its hinge line set back from the leading edge so that when it is deflected upward, part of the leading edge projects below the wing and produces parasite drag to help overcome adverse yaw.

Full-bodied. Not thinned.

Fully articulated rotor. A helicopter rotor whose blades are attached to the hub in such a way that they are free to flap, drag, and feather. See each of these terms.

Frost. Ice crystal deposits formed by sublimation when the temperature and dew point are below freezing.

Fuel-flow transmitter. A device in the fuel line between the engine-driven fuel pump and the carburetor that measures the rate of flow of the fuel. It converts this flow rate into an electrical signal and sends it to an indicator in the instrument panel.

Fuel jettison system. A system installed in most large aircraft that allows the flight crew to jettison, or dump, fuel to lower the gross weight of the aircraft to its allowable landing weight. Boost pumps in the fuel tanks move the fuel from the tank into a fuel manifold. From the fuel manifold, it flows away from the aircraft through dump chutes is each wing tip. The fuel jettison system must be so designed and constructed that it is free from fire hazards.

Fuel totalizer. A fuel quantity indicator that gives the total amount of fuel remaining on board the aircraft on one instrument. The totalizer adds the quantities of fuel in all of the tanks.

Fungus (plural: fungi). Any of several types of plant life that include yeasts, molds, and mildew.

Fusible plugs. Plugs in the wheels of high-performance airplanes that use tubeless tires. The centers of the plugs are filled with a metal that melts at a relatively low temperature. If a takeoff is aborted and the pilot uses the brakes excessively, the heat transferred into the wheel will melt the center of the fusible plugs and allow the air to escape from the tire before it builds up enough pressure to cause an explosion.

Gauge (rivet). The distance between rows of rivets in a multirow seam. Gauge is also called transverse pitch.

Gauge pressure. Pressure referenced from the existing atmospheric pressure.

Galling. Fretting or pulling out chunks of a surface by sliding contact with another surface or body.

Gasket. A seal between two parts where there is no relative motion.

Gear-type pump. A constant-displacement fluid pump that contains two meshing large-tooth spur gears. Fluid is drawn into the pump as the teeth separate and is carried around the inside of the housing with teeth and is forced from the pump when the teeth come together.

Generator. A mechanical device that transforms mechanical energy into electrical energy by rotating a coil inside a magnetic field. As the conductors in the coil cut across the lines of magnetic flux, a voltage is generated that causes current to flow.

Generator series field. A set of heavy field windings in a generator connected in a series with the armature. The magnetic field produced by the series windings is used to change the characteristics of the generator.

Generator shunt field. A set of field windings in a generator connected in parallel with the armature. Varying the amount of current flowing in the shunt field windings controls the voltage output of the generator.

Gerotor pump. A form of constant-displacement gear pump. A gerotor pump uses an external-tooth spur gear that rides inside of and drives an internal-tooth rotor gear. There is one more tooth space inside the rotor than there are teeth on the drive gear. As the gears rotate, the volume of the space between two of the teeth on the inlet side of the pump increases, while the volume of the space between the two teeth on the opposite side of the pump decreases.

GHz (gigahertz). 1,000,000,000 cycles per second.

Gimbal. A support that allows a gyroscope to remain in an upright condition when its base is tilted.

Glass cockpit. An aircraft instrument system that uses a few cathode-ray-tube displays to replace a large number of mechanically actuated instruments.

Glaze ice. Ice that forms when large drops of water strike a surface whose temperature is below freezing. Glaze ice is clear and heavy.

Glide slope. The portion of an ILS (Instrument Landing System) that provides the vertical path along which an aircraft descends on an instrument landing.

Goniometer. Electronic circuitry in an ADF system that uses the output of a fixed loop antenna to sense the angle between a fixed reference, usually the nose of the aircraft, and the direction from which the radio signal is being received.

Gram. The basic unit of weight or mass in the metric system. One gram equals approximately 0.035 ounce.

Graphite. A form of carbon. Structural graphite is used in composite structure because of its strength and stiffness.

Greige (pronounced "gray"). The unshrunk condition of a polyester fabric as it is removed from the loom.

Ground effect. The increased aerodynamic lift produced when an airplane or helicopter is flown nearer than half wing span or rotor span to the ground. This additional lift is caused by an effective increase in angle of attack without the accompanying increase in induced drag, which is caused by the deflection of the downwashed air.

Ground. The voltage reference point in an aircraft electrical system. Ground has zero electrical potential. Voltage values, both positive and negative, are measured from ground. In the United Kingdom, ground is spoken of as "earth."

Ground-power unit (GPU). A service component used to supply electrical power to an aircraft when it is being operated on the ground.

Guncotton. A highly explosive material made by treating cotton fibers with nitric and sulfuric acids. Guncotton is used in making the film base of nitrate dope.

Gusset. A small plate attached to two or more members of a truss structure. A gusset strengthens the truss.

Gyro (gyroscope). The sensing device in an autopilot system. A gyroscope is a rapidly spinning wheel with its weight concentrated around its rim. Gyroscopes have two basic characteristics that make them useful in aircraft instruments: rigidity in space and precession. See rigidity in space and precession.

Gyroscopic precession. The characteristic of a gyroscope that causes it to react to an applied force as though the force were applied at a point 90° in the direction of rotation from the actual point of application. The rotor of a helicopter acts in much the same way as a gyroscope and is affected by gyroscopic precession.

Halon 1211. A halogenated hydrocarbon fire-extinguishing agent used in many HRD fire-extinguishing systems for powerplant protection. The technical name for Halon 1211 is bromochlorodifluoromethane.

Halon 1301. A halogenated hydrocarbon fire-extinguishing agent that is one of the best for extinguishing cabin and powerplant fires. It is highly effective and is the least toxic of the extinguishing agents available. The technical name for Halon 1301 is bromotrifluoromethane.

Hangar rash. Scrapes, bends, and dents in an aircraft structure caused by careless handling.

Hardwood. Wood from a broadleaf tree that sheds its leaves each year.

Heading indicator. A gyroscopic flight instrument that gives the pilot an indication of the heading of the aircraft.

Heat exchanger. A device used to exchange heat from one medium to another. Radiators, condensers, and evaporators are all examples of heat exchangers. Heat always moves from the object or medium having the greatest level of heat energy to a medium or object having a lower level.

Helix. A screw-like, or spiral, curve.

Hertz. One cycle per second.

Holding relay. An electrical relay that is closed by sending a pulse of current through the coil. It remains closed until the current flowing through its contacts is interrupted.

Homebuilt aircraft. Aircraft that are built by individuals as a hobby rather than by factories as commercial products. Homebuilt, or amateur-built, aircraft are not required to meet the stringent requirements imposed on the manufacture of FAA-certified aircraft.

Horsepower. A unit of mechanical power that is equal to 33,000 foot-pounds of work done in 1 minute, or 550 foot-pounds of work done in 1 second.

Hot dimpling. A process used to dimple, or indent, the hole into which a flush rivet is to be installed. Hot dimpling is done by clamping the metal between heating elements and forcing the dies through the holes in the softened metal. Hot dimpling prevents hard metal from cracking when it is dimpled.

Hot-wire cutter. A cutter used to shape blocks of Styrofoam. The wire is stretched tight between the arms of a frame and heated by electrical current. The hot wire melts its way through the foam.

HRD. High-rate-discharge.

HSI. Horizontal situation indicator.

Hydraulic actuator. The component in a hydraulic system that converts hydraulic pressure into mechanical force. The two main types of hydraulic actuators are linear actuators (cylinders and pistons) and rotary actuators (hydraulic motors).

Hydraulic fuse. A type of flow control valve that allows a normal flow of fluid in the system but, if the flow rate is excessive, or if too much fluid flows for normal operation, the fuse will shut off all further flow.

Hydraulic motor. A hydraulic actuator that converts fluid pressure into rotary motion. Hydraulic motors have an advantage in aircraft installations over electric motors, because they can operate in a stalled condition without the danger of a fire.

Hydraulic power pack. A small, self-contained hydraulic system that consists of a reservoir, pump, selector valves, and relief valves. The power pack is removable from the aircraft as a unit to facilitate maintenance and service.

Hydraulics. The system of fluid power which transmits force through an incompressible fluid.

Hydrocarbon. An organic compound that contains only carbon and hydrogen. The vast majority of fossil fuels, such as gasoline and turbine-engine fuel, are hydrocarbons.

Hydroplaning. A condition that exists when a high-speed airplane is landed on a water-covered runway. When the brakes are applied, the wheels lock up and the tires skid on the surface of the water in much the same way a water ski rides on the surface. Hydroplaning develops enough heat in a tire to ruin it.

Hydrostatic test. A pressure test used to determine the serviceability of high-pressure oxygen cylinders. The cylinders are filled with water and pressurized to 5⁄3 of their working pressure. Standard-weight cylinders (DOT 3AA) must by hydrostatically tested every five years, and lightweight cylinders (DOT 3HT) must be tested every three years.

Hypersonic speed. Speed of greater than Mach 5 (5 times the speed of sound).

Hyperbolic navigation. Electronic navigation systems that determine aircraft location by the time difference between reception of two signals. Signals from two stations at different locations will be received in the aircraft at different times. A line plotted between two stations along which the time difference is the same forms a hyperbola.

Hypoxia. A physiological condition in which a person is deprived of the needed oxygen. The effects of hypoxia normally disappear as soon as the person is able to breathe air containing sufficient oxygen.

ICAO. The International Civil Aeronautical Organization.

Icebox rivet. A solid rivet made of 2017 or 2024 aluminum alloy. These rivets are too hard to drive in the condition they are received from the factory, and must be heat-treated to soften them. They are heated in a furnace and then quenched in cold water. Immediately after quenching they are soft, but within a few hours at room temperature they become quite hard. The hardening can be delayed for several days by storing them in a subfreezing icebox and holding them at this low temperature until they are to be used.

IFR. Instrument flight rules.

Inch-pound. A measure of work accomplished when a force of 1 pound moves an object a distance of 1 inch.

Indicated airspeed (IAS). The airspeed as shown on an airspeed indicator with no corrections applied.

Induced current. Electrical current produced in a conductor when it is moved through or crossed by a magnetic field.

Induced drag. Aerodynamic drag produced by an airfoil when it is producing lift. Induced drag is affected by the same factors that affect induced lift.

Induction time. The time allowed an epoxy or polyurethane material between its initial mixing and its application. This time allows the materials to begin their cure.

Infrared radiation. Electromagnetic radiation whose wavelengths are longer than those of visible light.

Ingot. A large block of metal that was molded as it was poured from the furnace. Ingots are further processed into sheets, bars, tubes, or structural beams.

INS. Inertial Navigation System.

Inspection Authorization (IA). An authorization that may be issued to an experienced aviation maintenance technician who holds both an Airframe and Powerplant rating. It allows the holder to conduct annual inspections and to approve an aircraft or aircraft engine for return to service after a major repair or major alteration.

Integral fuel tank. A fuel tank which is formed by sealing off part of the aircraft structure and using it as a fuel tank. An integral wing tank is called a "wet wing." Integral tanks are used because of their large weight saving. The only way of repairing an integral fuel tank is by replacing damaged sealant and making riveted repairs, as is done with any other part of the aircraft structure.

Interference drag. Parasite drag caused by air flowing over one portion of the airframe interfering with the smooth flow of air over another portion.

Intermittent-duty solenoid. A solenoid-type switch whose coil is designed for current to flow through it for only a short period of time. The coil will overheat if current flows through it too long.

IRS. Inertial Reference System.

IRU. Inertial Reference Unit.

Iso-octane. A hydrocarbon, C_8H_{18}, which has very high critical pressure and temperature. Iso-octane is used as the high reference for measuring the antidetonation characteristics of a fuel.

Isobaric mode. The mode of pressurization in which the cabin pressure is maintained at a constant value regardless of the outside air pressure.

Isogonic line. A line drawn on an aeronautical chart along which the angular difference between the magnetic and geographic north poles is the same.

Isopropyl alcohol. A colorless liquid used in the manufacture of acetone and its derivatives and as a solvent and anti-icing agent.

Jackscrew. A hardened steel rod with strong threads cut into it. A jackscrew is rotated by hand or with a motor to apply a force or to lift an object.

Jet pump. A special venturi in a line carrying air from certain areas in an aircraft that need an augmented flow of air through them. High-velocity compressor bleed air is blown into the throat of a venturi where it produces a low pressure that pulls air from the area to which it is connected. Jet pumps are often used in the lines that pull air through galleys and toilet areas.

Joggle. A small offset near the edge of a piece of sheet metal. It allows one sheet of metal to overlap another sheet while maintaining a flush surface.

Jointer. A woodworking power tool used to smooth edges of a piece of wood.

K-factor. A factor used in sheet metal work to determine the setback for other than a 90° bend. Setback = K · (bend radius + metal thickness). For bends of less than 90°, the value of K is less than 1; for bends greater than 90°, the value of K is greater than 1.

Kevlar. A patented synthetic aramid fiber noted for its flexibility and light weight. It is to a great extent replacing fiberglass as a reinforcing fabric for composite construction.

Key (verb). To initiate an action by depressing a key or a button.

kHz (kilohertz). 1,000 cycles per second.

Kick-in pressure. The pressure at which an unloading valve causes a hydraulic pump to direct its fluid into the system manifold.

Kick-out pressure. The pressure at which an unloading valve shuts off the flow of fluid into the system pressure manifold and directs it back to the reservoir under a much reduced pressure.

Kilogram. One thousand grams.

Kinetic energy. Energy that exists because of motion.

Knot (wood defect). A hard, usually round section of a tree branch embedded in a board. The grain of the knot is perpendicular to the grain of the board. Knots decrease the strength of the board and should be avoided where strength is needed.

Knot (measure of speed). A speed measurement that is equal to one nautical mile per hour. One knot is equal to 1.15 statute mile per hour.

Kollsman window. The barometric scale window of a sensitive altimeter. See barometric scale.

Koroseal lacing. A plastic lacing material available in round or rectangular cross sections and used for holding wire bundles and tubing together. It holds tension on knots indefinitely and is impervious to petroleum products.

Kraft paper. A tough brown wrapping paper, like that used for paper bags.

Lacquer. A finishing material made of a film base, solvents, plasticizers, and thinners. The film base forms a tough film over the surface when it dries. The solvents dissolve the film base so it can be applied as a liquid. The plasticizers give the film base the needed resilience, and the thinners dilute the lacquer so it can be applied with a spray gun. Lacquer is sprayed on the surface as a liquid, and when the solvents and thinners evaporate, the film base remains as a tough decorative and protective coating.

Landing gear warning system. A system of lights used to indicate the condition of the landing gear. A red light illuminates when any of the gears are in an unsafe condition; a green light shows when all of the gears are down and locked, and no light is lit when the gears are all up and locked. An aural warning system is installed that sounds a horn if any of the landing gears are not down and locked when the throttles are retarded for landing.

Laminar flow. Airflow in which the air passes over the surface in smooth layers with a minimum of turbulence.

Laminated wood. A type of wood made by gluing several pieces of thin wood together. The grain of all pieces runs in the same direction.

Latent heat. Heat that is added to a material that causes a change in its state without changing its temperature.

Lateral axis. An imaginary line, passing through the center of gravity of an airplane, and extending across it from wing tip to wing tip.

Lay-up. The placement of the various layers of resin-impregnated fabric in the mold for a piece of laminated composite material.

L/D ratio. A measure of efficiency of an airfoil. It is the ratio of the lift to the total drag at a specified angle of attack.

Left-right indicator. The course-deviation indicator used with a VOR navigation system.

Lightning hole. A hole cut in a piece of structural material to get rid of weight without losing any strength. A hole several inches in diameter may be cut in a piece of metal at a point where the metal is not needed for strength, and the edges of the hole are flanged to give it rigidity. A piece of metal with properly flanged lightning holes is more rigid than the metal before the holes were cut.

Linear actuator. A fluid power actuator that uses a piston moving inside a cylinder to change pressure into linear, or straight-line, motion.

Linear change. A change in which the output is directly proportional to the input.

Loadmeter. A current meter used in some aircraft electrical systems to show the amount of current the generator or alternator is producing. Loadmeters are calibrated in percent of the generator rated output.

Localizer. The portion of an ILS (Instrument Landing System) that directs the pilot along the center line of the instrument runway.

Lodestone. A magnetized piece of natural iron oxide.

Logic flow chart. A type of graphic chart that can be made up for a specific process or procedure to help follow the process through all of its logical steps.

Longitudinal axis. An imaginary line, passing through the center of gravity of an airplane, and extending lengthwise through it from nose to tail.

Longitudinal stability. Stability of an aircraft along its longitudinal axis and about its lateral axis. Longitudinal stability is also called pitch stability.

LORAN A. Long Range Aid to Navigation. A hyperbolic navigation system that operates with frequencies of 1,950 kHz, 1,850 kHz, and 1,900 kHz.

LORAN C. The LORAN system used in aircraft. It operates on a frequency of 100 kHz.

LRU. Line replaceable unit.

Lubber line. A reference on a magnetic compass and directional gyro that represents the nose of the aircraft. The heading of the aircraft is shown on the compass card opposite the lubber line.

Mach number. A measurement of speed based on the ratio of the speed of the aircraft to the speed of sound under the same atmospheric conditions. An airplane flying at Mach 1 is flying at the speed of sound.

Magnetic bearing. The direction to or from a radio transmitting station measured relative to magnetic north.

Major alteration. An alteration not listed in the aircraft, aircraft engine, or propeller specifications. It is one that might appreciably affect weight, balance, structural strength performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness, or that cannot be made with elementary operations.

Major repair. A repair to an aircraft structure or component that if improperly made might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness, or that is not done according to accepted practices, or cannot be made with elementary operation.

Manifold cross-feed fuel system. A type of fuel system commonly used in large transport category aircraft. All fuel tanks feed into a common manifold, and the dump chutes and the single-point fueling valves are connected to the manifold. Fuel lines to each engine are taken from the manifold.

Manifold pressure. The absolute pressure of the air in the induction system of a reciprocating engine.

Manifold pressure gauge. A pressure gauge that measures the absolute pressure inside the induction system of a reciprocating engine. When the engine is not operating, this instrument shows the existing atmospheric pressure.

Master switch. A switch in an aircraft electrical system that can disconnect the battery from the bus and open the generator or alternator field circuit.

Matrix. The material used in composite construction to bond the fibers together and to transmit the forces into the fibers. Resins are the most widely used matrix materials.

Mean camber. A line that is drawn midway between the upper and lower camber of an airfoil section. The mean camber determines the aerodynamic characteristics of the airfoil.

MEK. Methyl-ethyl-ketone is an organic chemical solvent that is soluble in water and is used as a solvent for vinyl and nitrocellulose films. MEK is an efficient cleaner for preparing surfaces for priming or painting.

Mercerize. A treatment given to cotton thread to make it strong and lustrous. The thread is stretched while it is soaked in a solution of caustic soda.

MFD. Multi-function display.

MHz (megahertz). 1,000,000 cycles per second.

Microballoons. Tiny, hollow spheres of glass or phenolic material used to add body to a resin.

Microbial contaminants. The scum that forms inside the fuel tanks of turbine-engine-powered aircraft that is caused by micro-organisms. These micro-organisms live in water that condenses from fuel, and they feed on the fuel. The scum they form clogs fuel filters, lines, and fuel controls and holds water in contact with the aluminum alloy structure, causing corrosion.

Micro-Mesh. A patented graduated series of cloth-backed cushioned seats that contain abrasive crystals. Micro-Mesh is used for polishing and restoring transparency to acrylic plastic windows and windshields.

Micron ("micro meter"). A unit of linear measurement equal to one millionth of a meter, one thousandth of a millimeter, or 0.000039 inch. A micron is also called a micrometer.

Micronic filter. The registered trade name of a type of fluid filter whose filtering element is a specially treated cellulose paper formed into vertical convolutions, or wrinkles. Micronic filters prevent the passage of solids larger than about 10 microns, and are normally replaced with new filters rather than cleaned.

Micro-organism. An organism, normally bacteria or fungus, or microscopic size.

Microswitch. The registered trade name for a precision switch that uses a short throw of the control plunger to actuate the contacts. Microswitches are used primarily as limit switches to control electrical units automatically.

MIG welding. Metal inert gas welding is a form of electric arc welding in which the electrode is an expendable wire. MIG welding is now called GMA (gas metal arc) welding.

Mil. One thousandth of an inch (0.001 inch). Paint film thickness is usually measured in mils.

Mildew. A gray or white fungus growth that forms on organic materials. Mildew forms on cotton and linen aircraft fabric and destroys its strength.

Millivoltmeter. An electrical instrument that measures voltage in units of millivolts (thousandths of a volt).

Mist coat. A very light coat of zinc chromate primer. It is so thin that the metal is still visible, but the primer makes pencil marks easy to see.

Moisture separator. A component in a high-pressure pneumatic system that removes most of the water vapor from the compressed air. When the compressed air is used, its pressure drops, and this pressure drop causes a drop in temperature. If any moisture were allowed to remain in the air, it would freeze and block the system.

Mold line. A line used in the development of a flat pattern for a formed piece of sheet metal. The mold line is an extension of the flat side of a part beyond the radius. The mold line dimension of a part is the dimension made to the intersection of mold lines and is the dimension the part would have if its corners had no radius.

Mold point. The intersection of two mold lines of a part. Mold line dimensions are made between mold points.

Moment. A force that causes or tries to cause an object to rotate. The value of a moment is the product of the weight of an object (or the force), multiplied by the distance between the center of gravity of the object (or the point of application of the force) and the fulcrum about which the object rotates.

Monel. An alloy of nickel, copper, and aluminum or silicon.

Monocoque. A single-shell type of aircraft structure in which all of the flight loads are carried in the outside skin of the structure.

MSDS. Material Safety Data Sheets. MSDS are required by the Federal Government to be available in workplaces to inform workers of the dangers that may exist from contact with certain materials.

MSL. Mean sea level. When the letters MSL are used with an altitude, it means that the altitude is measured from mean, or average, sea level.

MTBF. Mean time between failures.

Multimeter. An electrical test instrument that consists of a single current-measuring meter and all of the needed components to allow the meter to be used to measure voltage, resistance, and current. Multimeters are available with either analog-or digital-type displays.

Multiple-disk brakes. Aircraft brakes in which one set of disks is keyed to the axle and remains stationary. Between each stationary disk there is a rotating disk that is keyed to the inside of the wheel. When the brakes are applied, the stationary disks are forced together, clamping the rotating disks between them. The friction between the disks slows the aircraft.

Nailing strip. A method of applying pressure to the glue in a scarf joint repair in a plywood skin. A strip of thin plywood is nailed over the glued scarf joint with the nails extending into a supporting structure beneath the skin. The strip is installed over vinyl sheeting to prevent it sticking to the skin. When the glue is thoroughly dry, the nailing strip is broken away and the nails removed.

Nap of the fabric. The ends of the fibers in a fabric. The first coat of dope on cotton or linen fabric raises the nap, and the fiber ends stick up. These ends must be carefully removed by sanding to get a smooth finish.

Naphtha. A volatile and flammable hydrocarbon liquid used chiefly as a solvent or as a cleaning fluid.

NDB. Non-directional beacons.

Negative pressure relief valve (pressurization component). A valve that opens anytime the outside air pressure is greater than the cabin pressure. It prevents the cabin altitude from ever becoming greater than the aircraft flight altitude.

Neutral axis (neutral plane). A line through a piece of material that is bent. The material in the outside of the bend is stretched and that on the inside of the bend is shrunk. The material along the neutral plane is neither shrunk nor stretched.

Neutral flame. An oxyacetylene flame produced when the ratio of oxygen and acetylene is chemically correct and there is no excess of oxygen or carbon. A neutral flame has a rounded inner cone and no feather around it.

Noise (electrical). An unwanted electrical signal within a piece of electronic equipment.

Nomex. A patented nylon material used to make the honeycomb core for certain types of sandwich materials.

Nonenergizing brake. A brake that does not use the momentum of the aircraft to increase the friction.

Nonvolatile memory. Memory in a computer that is not lost when power to the computer is lost.

Normal heptane. A hydrocarbon, C_7H_{16}, with a very low critical pressure and temperature. Normal heptane is used as the low reference in measuring the anti-detonation characteristics of a fuel.

Normal shock wave. A shock wave that forms ahead of a blunt object moving through the air at the speed of sound. The shock wave is normal (perpendicular) to the air approaching the object. Air passing through a normal shock wave is slowed to a subsonic speed and its static pressure is increased.

Normalizing. A process of strain-relieving steel that has been welded and left in a strained condition. The steel is heated to a specified temperature, usually red hot, and allowed to cool in still air to room temperature.

Nose-gear centering cam. A cam in the nose-gear shock strut that causes the piston to center when the strut fully extends. When the aircraft takes off and the strut extends, the wheel is straightened in its fore-and-aft position so it can be retracted into the wheel well.

NPN transistor. A bipolar transistor made of a thin base of P-type silicon or geranium sandwiched between a collector and an emitter, both of which are made of N-type material.

Null position. The position of an ADF loop antenna when the signal being received is canceled in the two sides of the loop and the signal strength is the weakest.

Oblique shock wave. A shock wave that forms on a sharp-pointed object moving through air at a speed greater than the speed of sound. Air passing through an oblique shock wave is slowed down, but not to a subsonic speed, and its static pressure is increased.

Oleo shock absorber. A shock absorber used on aircraft landing gear. The initial landing impact is absorbed by oil transferring from one compartment in the shock strut into another compartment through a metering orifice. The shocks of taxiing are taken up by a cushion of compressed air.

Octane rating. A rating of the anti-detonation characteristics of a reciprocating engine fuel. It is based on the performance of the fuel in a special test engine. When a fuel is given a dual rating such as 80/87, the first number is its anti-detonating rating with a lean fuel-air mixture, and the higher number is its rating with a rich mixture.

Open angle. An angle in which sheet metal is bent less than 90°.

Open assembly time. The period of time between the application of the glue and the assembly of the joint components.

Open-hydraulic system. A fluid power system in which the selector valves are arranged in series with each other. Fluid flows from the pump through the center of the selector valves, back into the reservoir when no unit is being actuated.

Open-center selector valve. A type of selector valve that functions as an unloading valve as well as a selector valve. Open-center selector valves are installed in series, and when no unit is actuated, fluid from the pump flows through the centers of all the valves and returns to the reservoir. When a unit is selected for actuation, the center of the selector valve is shut off and the fluid from the pump goes through the selector valve into one side of the actuator. Fluid from the other side of the actuator returns to the valve and goes back to the reservoir through the other selector valves. When the actuation is completed, the selector valve is placed in its neutral position. Its center opens, and fluid from the pump flows straight through the valve.

Open wiring. An electrical wiring installation in which the wires are tied together in bundles and clamped to the aircraft structure rather than being enclosed in conduit.

Orifice check valve. A component in a hydraulic or pneumatic system that allows unrestricted flow in one direction, and restricted flow in the opposite direction.

O-ring. A widely used type of seal made in the form of a rubber ring with a round cross section. An O-ring seals in both directions, and it can be used as a packing or a gasket.

Ornithopter. A heavier-than-air flying machine that produces lift by flapping its wings. No practical ornithopter has been built.

Oscilloscope. An electrical instrument that displays on the face of a cathode-ray tube the waveform of the electrical signal it is measuring.

Outflow valve (pressurization component). A valve in the cabin of a pressurized aircraft that controls the cabin pressure by opening to relieve all pressure above that for which the cabin pressure control is set.

Overvoltage protector. A component in an aircraft electrical system that opens the alternator field circuit any time the alternator output voltage is too high.

Oxidizing flame. An oxyacetylene flame in which there is an excess of oxygen. The inner cone is pointed and often a hissing sound is heard.

Ozone. An unstable form of oxygen produced when an electric spark passes through the air. Ozone is harmful to rubber products.

Packing. A seal between two parts where there is relative motion.

Paint. A covering applied to an object or structure to protect it and improve its appearance. Paint consists of a pigment suspended in a vehicle such as oil or water. When the vehicle dries by evaporation or curing, the pigment is left as a film on the surface.

Parabolic reflector. A reflector whose surface is made in the form of a parabola.

Parallel circuit. A method of connecting electrical components so that each component is in a path between the terminals of the source of electrical energy.

Paralleling circuit. A circuit in a multi-engine aircraft electrical system that controls a flow of control current which is used to keep the generators or alternators sharing the electrical load equally. The relay opens automatically to shut off the flow of paralleling current any time the output of either alternator or generator drops to zero.

Paralleling relay. A relay in multi-engine aircraft electrical system that controls a flow of control current which is used to keep the generators or alternators sharing the electrical load equally. The relay opens automatically to shut off the flow of paralleling current any time the output of either alternator or generator drops to zero.

Parasite drag. A form of aerodynamic drag caused by friction between the air and the surface over which it is flowing.

Parent metal. The metal being welded. This term is used to distinguish between the metal being welded and the welding rod.

Partial pressure. The percentage of the total pressure of a mixture of gases produced by each of the individual gases in the mixture.

Parting film. A layer of thin plastic material placed between a composite lay-up and the heating blanket. It prevents the blanket from sticking to the fabric.

Pascal's Law. A basic law of fluid power which states that the pressure in an enclosed container is transmitted equally and undiminished to all points of the container, and the force acts at right angles to the enclosing walls.

Performance number. The anti-detonation rating of a fuel that has a higher critical pressure and temperature than iso-octane (a rating of 100). Iso-octane that has been treated with varying amounts of tetraethyl lead is used as the reference fuel.

Petrolatum-zinc dust compound. A special abrasive compound used inside an aluminum wire terminal being swaged onto a piece of aluminum electrical wire. When the terminal is compressed, the zinc dust abrades the oxides from the wire, and the petrolatum prevents oxygen reaching the wire so no more oxides can form.

Petroleum fractions. The various components of a hydrocarbon fuel that are separated by boiling them off at different temperatures in the process of fractional distillation.

Phased array antenna. A complex antenna which consists of a number of elements. A beam of energy is formed by the superimposition of the signals radiating from the elements. The direction of the beam can be changed by varying the relative phase of the signals applied to each of the elements.

Phenolic plastic. A plastic material made of a thermosetting phenol-formaldehyde resin, reinforced with cloth or paper. Phenolic plastic materials are used for electrical insulators and for chemical-resistant table tops.

Pilot hole. A small hole punched or drilled in a piece of sheet metal to locate a rivet hole.

Pin knot cluster. A group of knots, all having a diameter of less than approximately 1⁄16 inch.

Pinked-edge tape. Cloth tape whose edges have small V-shaped notches cut along their length. The pinked edges prevent the tape from raveling.

Pinking shears. Shears used to cut aircraft fabric with a series of small notches along the cut edge.

Pinion. A small gear that meshes with a larger gear, a sector of a gear, or a toothed rack.

Piston. A sliding plug in an actuating cylinder used to convert pressure into force and then into work.

Pitch (aircraft maneuver). Rotation of an aircraft about its lateral axis.

Pitch (rivet). The distance between the centers of adjacent rivets installed in the small row.

Pitch pocket (wood defect). Pockets of pitch that appear in the growth rings of a piece of wood.

Pitot pressure. Ram air pressure used to measure airspeed. The pitot tube faces directly into the air flowing around the aircraft. It stops the air and measures its pressure.

Plain-weave fabric. Fabric in which each warp thread passes over one fill thread and under the next. Plain-weave fabric typically has the same strength in both warp and fill directions.

Plan position indicator (PPI). A type of radar scope that shows both the direction and distance of the target from the radar antenna. Some radar antenna rotate and their PPI scopes are circular. Other antenna oscillate and their PPI scopes are fan shaped.

Planer. A woodworking power tool used to smooth the surfaces of a piece of wood.

Plasticizer. A constituent in dope or lacquer that gives its film flexibility and resilience.

Plastic media blasting (PMB). A method of removing paint from an aircraft surface by dry-blasting it with tiny plastic beads.

Plastics. The generic name for any of the organic materials produced by polymerization. Plastics can be shaped by molding or drawing.

Plenum. An enclosed chamber in which air can be held at a pressure higher than that of the surrounding air.

Ply rating. The rating of an aircraft tire that indicates its relative strength. The ply rating does not indicate the actual number of plies of fabric in the tire; it indicates the number of piles of cotton fabric needed to produce the same strength as the actual piles.

Plywood. A wood product made by gluing several pieces of thin wood veneer together. The grain of the wood in each layer runs at 90° or 45° to the grain of the layer next to it.

Pneumatics. The system of fluid power which transmits force by the use of a compressible fluid.

PNP transistor. A bipolar transistor made of a thin base of N-type silicon or germanium sandwiched between a collector and an emitter, both of which are made of P-type material.

Polyester fibers. A synthetic fiber made by the polymerization process in which tiny molecules are united to form a long chain of molecules. Polyester fibers are woven into fabrics that are known by their trade names of Dacron, Fortrel, and Kodel. Polyester film and sheet are known as Mylar and Celenar.

Polyester resin. A thermosetting resin used as a matrix for much of the fiberglass used in composite construction.

Polyurethane enamel. A hard, chemically resistant finish used on aircraft. Polyurethane enamel is resistant to damage from all types of hydraulic fluid.

Polyvinyl chloride. A thermoplastic resin used in the manufacture of transparent tubing for electrical insulation and fluid lines which are subject to low pressures.

Position error. The error in pitot-static instruments caused by the static ports not sensing true static air pressure. Position error changes with airspeed and is usually greatest at low airspeeds.

Potential energy. Energy possessed in an object because of its position, chemical composition, shape, or configuration.

Potentiometer. A variable resistor having connections to both ends of the resistance element and to the wiper that moves across the resistance.

Pot life. The length of time a resin will remain workable after the catalyst has been added. If a catalyzed material is not used within its usable pot life, it must be discarded and a new batch mixed up.

Power. The time rate of doing work. Power is force multiplied by distance (work), divided by time.

Power brakes. Aircraft brakes that use the main hydraulic system to supply fluid for the brake actuation. Aircraft that require a large amount of fluid for their brake actuation normally use power brakes, and the volume of fluid sent to the brakes is increased by the use of deboosters.

Power control valve. A hand-operated hydraulic pump unloading valve. When the valve is open, fluid flows from the pump to the reservoir with little opposition. To actuate a unit, turn the selector valve, and manually close the power control valve. Pressurized fluid flows to the unit, and when it is completely actuated, the power control valve automatically opens.

Precession. The characteristic of a gyroscope that causes a force to be felt, not at the point of application, but at a point 90° in the direction of rotation from that point.

Preflight inspection. A required inspection to determine the condition of the aircraft for the flight to be conducted. It is conducted by the pilot-in-command.

Precipitation heat treatment. A method of increasing the strength of heat-treated aluminum alloy. After the aluminum alloy has been solution-heat-treated by heating and quenching, it is returned to the oven and heated to a temperature lower than that used for the initial heat treatment. It is held at this temperature for a specified period of time, and then removed from the oven and allowed to cool slowly.

Prepreg (preimpregnated fabric). A type of composite material in which the reinforcing fibers are encapsulated in an uncured resin. Prepreg materials must be kept refrigerated to prevent them from curing before they are used.

Press-to-test light fixture. An indicator light fixture whose lens can be pressed in to complete a circuit that tests the filament of the light bulb.

Pressure. Force per unit area. Hydraulic and pneumatic pressure are normally given in units of pounds per square inch (psi).

Pressure altitude. The altitude in standard air at which the pressure is the same as that of the existing air. Pressure altitude is read on an altimeter when the barometric scale is set to the standard sea level pressure of 29.92 inches of mercury.

Pressure-demand oxygen system. A type of oxygen system used by aircraft that fly at very high altitude. This system functions as a diluter-demand system until, at about 40,000 feet, the output to the mask is pressurized enough to force the needed oxygen into the lungs, rather than depending on the low pressure produced when the wearer of the mask inhales to pull in the oxygen. (See diluter-demand oxygen system.)

Pressure fueling. The method of fueling used by almost all transport aircraft. The fuel is put into the aircraft through a single underwing fueling port. The fuel tanks are filled to the desired quantity and in the sequence selected by the person conducting the fueling operation. Pressure fueling saves servicing time by using a single point to fuel the entire aircraft, and it reduces the chances for fuel contamination.

Pressure manifold (hydraulic system component). The portion of a fluid power system from which the selector valves receive their pressurized fluid.

Pressure plate (brake component). A strong, heavy plate used in a multiple-disk brake. The pressure plate receives the force from the brake cylinders and transmits this force to the disks.

Pressure reducing valve (oxygen system component). A valve used in an oxygen system to change high cylinder pressure to low system pressure.

Pressure relief valve (oxygen system component). A valve in an oxygen system that relieves the pressure if the pressure reducing valve should fail.

Pressure vessel. The strengthened portion of an aircraft structure that is sealed and pressurized in flight.

Primer (finishing system component). A component in a finishing system that provides a good bond between the surface and the material used for the topcoats.

Profile drag. Aerodynamic drag produced by skin friction. Profile drag is a form of parasite drag.

Progressive inspection. An inspection that may be used in place of an annual or 100-hour inspection. It has the same scope as an annual inspection, but it may be performed in increments so the aircraft will not have to be out of service for a lengthy period of time.

Pump control valve. A control valve in a hydraulic system that allows the pilot to manually direct the output of the hydraulic pump back to the reservoir when no unit is being actuated.

Pureclad. A registered trade name for clad aluminum alloy.

Purge (air conditioning system operation). To remove all of the moisture and air from a cooling system by flushing the system with a dry gaseous refrigerant.

Pusher powerplant. A powerplant whose propeller is mounted at the rear of the airplane and pushes, rather than pulls, the airplane through the air.

PVC (Polyvinylchloride). A thermoplastic resin used to make transparent tubing for insulating electrical wires.

Quartersawed wood. Wood sawed from a tree in such a way that the annual rings cross the plank at an angle greater than 45°.

Quick-disconnect fitting. A hydraulic line fitting that seals the line when the fitting is disconnected. Quick-disconnect fittings are used on the lines connected to the engine-driven hydraulic pump. They allow the pump to be disconnected and an auxiliary hydraulic power system connected to perform checks requiring hydraulic power while the aircraft is in the hangar.

Rack-and-pinion actuator. A form of rotary actuator where the fluid acts on a piston on which a rack of gear teeth is cut. As the piston moves, it rotates a pinion gear which is mated with the teeth cut in the rack.

Radial. A directional line radiating outward from a radio facility, usually a VOR. When an aircraft is flying outbound on the 330º from the station.

Radius dimpling. A process of preparing a hole in sheet metal for flush riveting. A cone-shaped male die forces the edges of the rivet hole into the depression in a female die. Radius dimpling forms a round-edged depression into which the rivet head fits.

Range markings. Colored marks on an instrument dial that identify certain ranges of operation as specified in the aircraft maintenance or flight manual and listed in the appropriate aircraft Type Certificate Data Sheets or Aircraft Specifications. Color coding directs attention to approaching operating difficulties. Airspeed indicators and most pressure and temperature indicators are marked to show the various ranges of operation. These ranges and colors are the most generally used: Red radial line, do not exceed. Green arc, normal operating range. Yellow arc, caution range. Blue radial line, used on airspeed indicators to show best single-engine rate of climb speed. White arc, used on airspeed indicators to show flap operating range.

RDF. Radio direction finding.

Rebreather oxygen mask. A type of oxygen mask used with a continuous flow oxygen system. Oxygen continuously flows into the bottom of the loose-fitting rebreather bag on the mask. The wearer of the mask exhales into the top of the bag. The first air exhaled contains some oxygen, and this air goes into the bag first. The last air to leave the lungs contains little oxygen, and it is forced out of the bag as the bag is filled with fresh oxygen. Each time the wearer of the mask inhales, the air first exhaled, along with fresh oxygen, is taken into the lungs.

Receiver-dryer. The component in a vapor-cycle cooling system that serves as a reservoir for the liquid refrigerant. The receiver-dryer contains a desiccant that absorbs any moisture that may be in the system.

Rectangle. A plane surface with four sides whose opposite sides are parallel and whose angles are all right angles.

Rectification (arc welding condition). A condition in AC-electric arc welding in which oxides on the surface of the metal act as a rectifier and prevent electrons flowing from the metal to the electrode during the half cycle when the electrode is positive.

Reducing flame. See carburizing flame.

Reed valve. A thin, leaf-type valve mounted in the valve plate of an air conditioning compressor to control the flow of refrigerant gases into and out of the compressor cylinders.

Reinforcing tape. A narrow strip of woven fabric material placed over the fabric as it is being attached to the aircraft structure with rib lacing cord. This tape carries a large amount of the load and prevents the fabric tearing at the stitches.

Rejuvenator. A finishing material used to restore resilience to an old dope film. Rejuvenator contains strong solvents to open the dried-out film and plasticizers to restore resilience to the old dope.

Relative wind. The direction the wind strikes an airfoil.

Relay. An electrical component which uses a small amount of current flowing through a coil to produce a magnetic pull to close a set of contacts through which a large amount of current can flow. The core in a relay coil is fixed.

Relief hole. A hole drilled at the point at which two bend lines meet in a piece of sheet metal. This hole spreads the stresses caused by the bends and prevents the metal cracking.

Relief valve. A pressure-control valve that relieves any pressure over the amount for which it is set. They are damage-preventing units used in both hydraulic and pneumatic systems. In an aircraft hydraulic system, pressure relief valves prevent damaging high pressures that could be caused by a malfunctioning pressure regulator, or by thermal expansion of fluid trapped in portions of the system.

Repair. A maintenance procedure in which a damaged component is restored to its original condition, or at least to a condition that allows it to fulfill its design function.

Restrictor. A fluid power system component that controls the rate of actuator movement by restricting the flow of fluid into or out of the actuator.

Retard breaker points. A set of breaker points in certain aircraft magnetos that are used to provide a late (retarded) spark for starting the engine.

Retarder (finishing system component). Dope thinner that contains certain additives that slow its rate of evaporation enough to prevent dope blushing.

Retread. The replacement of the tread rubber on an aircraft tire.

Retreating blade. The blade on a helicopter rotor whose tip is moving in the direction opposite to that in which the helicopter is moving.

Retreating blade stall. The stall of a helicopter rotor disc that occurs near the tip of the retreating blade. A retreating blade stall occurs when the flight airspeed is high and the retreating blade airspeed is low. This results in a high angle of attack, causing the stall.

Return manifold. The portion of a fluid power system through which the fluid is returned to the reservoir.

Reverse polarity welding. DC-electric arc welding in which the electrode is positive with respect to the work.

Rib thread. A series of circumferential grooves cut into the tread of a tire. This tread pattern provides superior traction and directional stability on hard-surfaced runways.

Ribbon direction. The direction in a piece of honeycomb material that is parallel to the length of the strips of material that make up the core.

Rigid conduit. Aluminum alloy tubing used to house electrical wires in areas where they are subject to mechanical damage.

Rigidity in space. The characteristic of a gyroscope that prevents its axis of rotation tilting as the earth rotates. This characteristic is used for attitude gyro instruments.

Rime ice. A rough ice that forms on aircraft flying through visible moisture, such as a cloud, when the temperature is below freezing. Rime ice disturbs the smooth airflow as well as adding weight.

Rivet cutters. Special cutting pliers that resemble diagonal cutters except that the jaws are ground in such a way that they cut the rivet shank, or stem, off square.

Rivet set. A tool used to drive aircraft solid rivets. It is a piece of hardened steel with a recess the shape of the rivet head in one end. The other end fits into the rivet gun.

RMI. Radio magnetic indicator.

Rocking shaft. A shaft used in the mechanism of a pressure measuring instrument to change the direction of movement by 90º and to amplify the amount of movement.

Roll (aircraft maneuver). Rotation of an aircraft about its longitudinal axis.

Roots-type air compressor. A positive-displacement air pump that uses two intermeshing figure-8-shaped rotors to move the air.

Rosette weld. A method of securing one metal tube inside another by welding. Small holes are drilled in the outer tube and the inner tube is welded to it around the circumference of the holes.

Rotary actuator. A fluid power actuator whose output is rotational. A hydraulic motor is a rotary actuator.

Roving. A lightly twisted roll or strand of fibers.

RPM. Revolutions per minute.

Ruddervators. The two movable surfaces on a V-tail empennage. When these two surfaces are moved together with the in-and-out movement of the control yoke, they act as elevators, and when they are moved differentially with the rudder pedals, they act as the rudder.

Saddle gusset. A piece of plywood glued to an aircraft structural member. The saddle gusset has a cutout to hold a backing block or strip tightly against the skin to allow a nailing strip to be used to apply pressure to a glued joint in the skin.

Sailplane. A high-performance glider.

Sandwich material. A type of composite structural material in which a core material is bonded between face sheets of metal or resin-impregnated fabric.

Satin-weave fabric. Fabric in which the warp threads pass under one fill thread and over several others. Satin-weave fabrics are used when the lay-up must be made over complex shapes.

Scarf joint. A joint in a wood structure in which the ends to be joined are cut in a long taper, normally about 12:1, and fastened together by gluing. A glued scarf joint makes a strong splice because the joint is made along the side of the wood fibers rather than along their ends.

Schematic diagram. A diagram of an electrical system in which the system components are represented by symbols rather than drawings or pictures of the actual devices.

Schrader valve. A type of service valve used in an air conditioning system. This is a spring-loaded valve much like the valve used to put air into a tire.

Scissors. A name commonly used for torque links. See torque links.

Scrim cloth. Scrim cloth can be used in repair applications or for reinforcement of other types of materials including fiberglass, concrete and some plastics. When fully cured, the scrim cloth will add reinforcement and mimic the expansion and contraction of the surrounding substrate.

Scupper. A recess around the filler neck of an aircraft fuel tank. Any fuel spilled when the tank is being serviced collects in the scupper and drains to the ground through a drain line rather than flowing into the aircraft structure.

Sea level engine. A reciprocating engine whose rated takeoff power can be produced only at sea level.

Sector gear. A part of a gear wheel containing the hub and a portion of the rim with teeth.

Series circuit. A method of connecting electrical components in such a way that all the current flows through each of the components. There is only one path for current to flow.

Series-parallel circuit. An electrical circuit in which some of the components are connected in parallel and others are connected in series.

Selcal system. Selective calling system. Each aircraft operated by an airline is assigned a particular four-tone audio combination for identification purposes. A ground station keys the signal whenever contact with that particular aircraft is desired. The signal is decoded by the airborne selcal decoder and the crew alerted by the selcal warning system.

Selsyn system. A DC synchro system used in remote indicating instruments. The rotor in the indicator is a permanent magnet and the stator is a tapped toroidal coil. The transmitter is a circular potentiometer with DC power fed into its wiper which is moved by the object being monitored. The transmitter is connected to the indicator in such a way that rotation of the transmitter shaft varies the current in the sections of the indicator toroidal coil. The magnet in the indicator on which the pointer is mounted locks with the magnetic field produced by the coils and follows the rotation of the transmitter shaft.

Segmented-rotor brake. A heavy-duty, multiple-disk brake used on large, high-speed aircraft. Stators that are surfaced with a material that retains its friction characteristics at high temperatures are keyed to the axle. Rotors which are keyed into the wheels mesh with the stators. The rotors are made in segments to allow for cooling and for their large amounts of expansion.

Selector valve. A flow control valve used in hydraulic systems that directs pressurized fluid into one side of an actuator, and at the same time directs return fluid from the other side of the actuator back to the reservoir. There are two basic types of selector valves: open-center valves and closed-center valves. The four-port closed-center valve is the most frequently used type. See closed-center selector valve and open-center selector valve.

Selvage edge. The woven edge of fabric used to prevent the material unraveling during normal handling. The selvage edge, which runs the length of the fabric parallel to the warp threads, is usually removed from materials used in composite construction.

Semiconductor diode. A two-element electrical component that allows current to pass through it in one direction, but blocks its passage in the opposite direction. A diode acts in an electrical system in the same way a check valve acts in a hydraulic system.

Semimonocoque structure. A form of aircraft stressed skin structure. Most of the strength of a semimonocoque structure is in the skin, but the skin is supported on a substructure of formers and stringers that give the skin its shape and increase its rigidity.

Sensible heat. Heat that is added to a liquid causing a change in its temperature but not its physical state.

Sensitivity. A measure of the signal strength needed to produce a distortion-free output in a radio receiver.

Sequence valve. A valve in a hydraulic system that requires a certain action to be completed before another action can begin. Sequence valves are used to assure that the hydraulically actuated wheel-well doors are completely open before pressure is directed to the landing gear to lower it.

Servo. An electrical or hydraulic actuator connected into a flight control system. A small force on the flight deck control is amplified by the servo and provides a large force to move the control surface.

Servo amplifier. An electronic amplifier in an autopilot system that increases the signal from the autopilot enough that it can operate the servos that move the control surfaces.

Servo tab. A small movable tab built into the trailing edge of a primary control surface of an airplane. The flight deck controls move the tab in such a direction that it produces an aerodynamic force moving the surface on which it is mounted.

Setback. The distance the jaws of a brake must be set back from the mold line to form a bend. Setback for a 90° bend is equal to the inside radius of the bend plus the thickness of the metal being bent. For a bend other than 90°, a K-factor must be used. See also K-factor.

Shake (wood defect). Longitudinal cracks in a piece of wood, usually between two annual rings.

SHF. Super-high frequency.

Shear section. A necked-down section of the drive shaft of a constant-displacement engine-driven fluid pump. If the pump should seize, the shear section will break and prevent the pump from being destroyed or the engine from being damaged. Some pumps use a shear pin rather than a shear section.

Shear strength. The strength of a riveted joint in a sheet metal structure in which the rivets shear before the metal tears at the rivet holes.

Shelf life. The length of time a product is good when it remains in its original unopened container.

Shielded wire. Electrical wire enclosed in a braided metal jacket. Electromagnetic energy radiated from the wire is trapped by the braid and is carried to ground.

Shimmy. Abnormal, and often violent, vibration of the nose wheel of an airplane. Shimmying is usually caused by looseness of the nose wheel support mechanism or an unbalanced wheel.

Shimmy damper. A small hydraulic shock absorber installed between the nose wheel fork and the nose wheel cylinder attached to the aircraft structure.

Shock mounts. Resilient mounting pads used to protect electronic equipment by absorbing low-frequency, high amplitude vibrations.

Shock wave. A pressure wave formed in the air by a flight vehicle moving at a speed greater than the speed of sound. As the vehicle passes through the air, it produces sound waves that spread out in all directions. But since the vehicle is flying faster than these waves are moving, they build up and form a pressure wave at the front and rear of the vehicle. As the air passes through a shock wave it slows down, its static pressure increases, and its total energy decreases.

Shop head. The head of a rivet which is formed when the shank is upset.

Show-type finish. The type of finish put on fabric-covered aircraft intended for show. This finish is usually made up of many coats of dope, with much sanding and rubbing of the surface between coats.

Shunt winding. Field coils in an electric motor or generator that are connected in parallel with the armature.

Shuttle valve. An automatic selector valve mounted on critical components such as landing gear actuation cylinders and brake cylinders. For normal operation, system fluid flows into the actuator through the shuttle valve, but if normal system pressure is lost, emergency system pressure forces the shuttle over and emergency fluid flows into the actuator.

Sidestick controller. A flight deck flight control used on some of the fly-by-wire equipped airplanes. The stick is mounted rigidly on the side console of the flight deck, and pressures exerted on the stick by the pilot produce electrical signals that are sent to the computer that flies the airplane.

Sight glass (air conditioning system component). A small window in the high side of a vapor-cycle cooling system. Liquid refrigerant flows past the sight glass, and if the charge of refrigerant is low, bubbles will be seen. A fully charged system has no bubbles in the refrigerant.

Sight line. A line drawn on a sheet metal layout that is one bend radius from the bend-tangent line. The sight line is lined up directly below the nose of the radius bar in a cornice brake. When the metal is clamped in this position, the bend tangent line is in the correct position for the start of the bend.

Silicon controlled rectifier (SCR). A semiconductor electron control device. An SCR blocks current flow in both directions until a pulse of positive voltage is applied to its gate. It then conducts in its forward direction, while continuing to block current in its reverse direction.

Silicone rubber. An elastomeric material made from silicone elastomers. Silicone rubber is compatible with fluids that attack other natural or synthetic rubbers.

Single-acting actuator. A linear hydraulic or pneumatic actuator that uses fluid power for movement in one direction and a spring force for its return.

Single-action hand pump. A hand-operated fluid pump that moves fluid only during one stroke of the pump handle. One stroke pulls the fluid into the pump and the other forces the fluid out.

Single-disk brakes. Aircraft brakes in which a single steel disk rotates with the wheel between two brake-lining blocks. When the brake is applied, the disk is clamped tightly between the lining blocks, and the friction slows the aircraft.

Single-servo brakes. Brakes that uses the momentum of the aircraft rolling forward to help apply the brakes by wedging the brake shoe against the brake drum.

Sintered metal. A porous material made by fusing powdered metal under heat and pressure.

Skydrol hydraulic fluid. The registered trade name for a synthetic, nonflammable, phosphate ester-base hydraulic fluid used in modern high-temperature hydraulic systems.

Slat. A secondary control on an aircraft that allows it to fly at a high angle of attack without stalling. A slat is a section of leading edge of wing mounted on curved tracks that move into and out of the wing on rollers.

Slip roll former. A shop tool used to form large radius curves on sheet metal.

Slippage mark. A paint mark extending across the edge of an aircraft wheel onto a tube-type tire. When this mark is broken, it indicates the tire has slipped on the wheel, and there is a good reason to believe the tube has been damaged.

Slipstream area. For the purpose of rib stitch spacing, the slipstream area is considered to be the diameter of the propeller plus one wing rib on each side.

Slot (aerodynamic device). A fixed, nozzle-like opening near the leading edge of an airplane wing ahead of the aileron. A slot acts as a duct to force high-energy air down on the upper surface of the wing when the airplane is flying at a high angle of attack. The slot, which is located ahead of the aileron, causes the inboard portion of the wing to stall first, allowing the aileron to remain effective throughout the stall.

Slow-blow fuse. An electrical fuse that allows a large amount of current to flow for a short length of time but melts to open the circuit if more than its rated current flows for a longer period.

Smoke detector. A device that warns the flight crew of the presence of smoke in cargo and/or baggage compartments. Some smoke detectors are of the visual type, others are photoelectric or ionization devices.

Snubber. A device in a hydraulic or pneumatic component that absorbs shock and/or vibration. A snubber is installed in the line to a hydraulic pressure gauge to prevent the pointer fluctuating.

Softwood. Wood from a tree that bears cones and has needles rather than leaves.

Soldering. A method of thermally joining metal parts with a molten nonferrous alloy that melts at a temperature below 800 °F. The molten alloy is pulled up between close-fitting parts by capillary action. When the alloy cools and hardens, it forms a strong, leak-proof connection.

Solenoid. An electrical component using a small amount of current flowing through a coil to produce a magnetic force that pulls an iron core into the center of the coil. The core may be attached to a set of heavy-duty electrical contacts, or it may be used to move a valve or other mechanical device.

Solidity (helicopter rotor characteristic). The solidity of a helicopter rotor system is the ratio of the total blade area to the disc area.

Solution heat treatment. A type of heat treatment in which the metal is heated in a furnace until it has a uniform temperature throughout. It is then removed and quenched in cold water. When the metal is hot, the alloying elements enter into a solid solution with the base metal to become part of its basic structure. When the metal is quenched, these elements are locked into place.

Sonic venturi. A sonic venturi in a line between a turbine engine or turbocharger and a pressurization system. When the air flowing through the sonic venturi reaches the speed of sound, a shock wave forms across the throat of the sonic venturi and limits the flow. A sonic venturi is also called a flow limiter.

Specific heat. The number of BTUs of heat energy needed to change the temperature of one pound of a substance 1 °F.

Speed brakes. A secondary control of an airplane that produces drag without causing a change in the pitch attitude of the airplane. Speed brakes allow an airplane to make a steep descent without building up excessive forward airspeed.

Spike knot. A knot that runs through the depth of a beam perpendicular to the annual rings. Spike knots appear most frequently in quartersawed wood.

Spin. A flight maneuver in which an airplane descends in a corkscrew fashion. One wing is stalled and the other is producing lift.

Spirit level. A curved glass tube partially filled with a liquid, but with a bubble in it. When the device in which the tube is mounted is level, the bubble will be in the center of the tube.

Splayed patch (wood structure repair). A type of patch made in an aircraft plywood structure in which the edges of the patch are tapered for approximately five times the thickness of the plywood. A splayed patch is not recommended for use on plywood less than $\frac{1}{10}$ inch thick.

Split bus. A type of electrical bus that allows all of the voltage-sensitive avionic equipment to be isolated from the rest of the aircraft electrical system when the engine is being started or when the ground-power unit is connected.

Split-rocker switch. An electrical switch whose operating rocker is split so one half of the switch can be opened without affecting the other half. Split-rocker switches are used as aircraft master switches. The battery can be turned on without turning on the alternator, but the alternator cannot be turned on without also turning on the battery. The alternator can be turned off without turning off the battery, but the battery cannot be turned off without also turning off the alternator.

Split (wood defect). A longitudinal crack in a piece of wood caused by externally induced stress.

Spoilers. Flight controls that are raised up from the upper surface of a wing to destroy, or spoil, lift. Flight spoilers are used in conjunction with the ailerons to decrease lift and increase drag on the descending wing. Ground spoilers are used to produce a great amount of drag to slow the airplane on its landing roll.

Spongy brakes. Hydraulic brakes whose pedal has a spongy feel because of air trapped in the fluid.

Spontaneous combustion. Self-ignition of a material caused by heat produced in the material as it combines with oxygen from the air.

Springwood. The portion of an annual ring in a piece of wood formed principally during the first part of the growing season, the spring of the year. Springwood is softer, more porous, and lighter than the summerwood.

Square. A four-sided plane figure whose sides are all the same length, whose opposite sides are parallel, and whose angles are all right angles.

Squat switch. An electrical switch actuated by the landing gear scissors on the oleo strut. When no weight is on the landing gear, the oleo piston is extended and the switch is in one position, but when weight is on the gear, the oleo strut compresses and the switch changes its position. Squat switches are used in antiskid brake systems, landing gear safety circuits, and cabin pressurization systems.

Squib. An explosive device in the discharge valve of a high-rate-discharge container of fire-extinguishing agent. The squib drives a cutter into the seal in the container to discharge the agent.

SRM. Structural Repair Manual.

Stabilator. A flight control on the empennage of an airplane that acts as both a stabilizer and an elevator. The entire horizontal tail surface pivots and is moved as a unit.

Stability. The characteristic of an aircraft that causes it to return to its original flight condition after it has been disturbed.

Stabilons. Small wing-like horizontal surfaces mounted on the aft fuselage to improve longitudinal stability of airplanes that have an exceptionally wide center of gravity range.

Stagnation point. The point on the leading edge of a wing at which the airflow separates, with some flowing over the top of the wing and the rest below the wing.

Stall. A flight condition in which an angle of attack is reached at which the air ceases to flow smoothly over the upper surface of an airfoil. The air becomes turbulent and lift is lost.

Stall strip. A fixed device employed on the leading edge of fixed-wing aircraft to initiate flow separation at chosen locations on the wing during high-angle of attack flight, so as to improve the controllability of the aircraft when it enters stall.

Standpipe. A pipe sticking up in a tank or reservoir that allows part of the tank to be used as a reserve, or standby, source of fluid.

Starter-generator. A single-component starter and generator used on many of the smaller gas-turbine engines. It is used as a starter, and when the engine is running, its circuitry is shifted so that it acts as a generator.

Static. Still, not moving.

Static air pressure. Pressure of the ambient air surrounding the aircraft. Static pressure does not take into consideration any air movement.

Static dischargers. Devices connected to the trailing edges of control surfaces to discharge static electricity harmlessly into the air. They discharge the static charges before they can build up high enough to cause radio receiver interference.

Static stability. The characteristic of an aircraft that causes it to return to straight and level flight after it has been disturbed from that condition.

Stoddard solvent. A petroleum product, similar to naphtha, used as a solvent and a cleaning fluid.

STOL. Short takeoff and landing.

Stop drilling. A method of stopping the growth of a crack in a piece of metal or transparent plastic by drilling a small hole at the end of the crack. The stresses are spread out all around the circumference of the hole rather than concentrated at the end of the crack.

Straight polarity welding. DC-electric arc welding in which the electrode is negative with respect to the work.

Strain. A deformation or physical change in a material caused by a stress.

Stress. A force set up within an object that tries to prevent an outside force from changing its shape.

Stressed skin structure. A type of aircraft structure in which all or most of the stresses are carried in the outside skin. A stressed skin structure has a minimum of internal structure.

Stress riser. A location where the cross-sectional area of the part changes abruptly. Stresses concentrate at such a location and failure is likely. A scratch, gouge, or tool mark in the surface of a highly stressed part can change the area enough to concentrate the stresses and become a stress riser.

Stringer. A part of an aircraft structure used to give the fuselage its shape and, in some types of structure, to provide a small part of fuselage strength. Formers give the fuselage its cross-sectional shape and stringers fill in the shape between the formers.

Stroboscopic tachometer. A tachometer used to measure the speed of any rotating device without physical contact. A highly accurate variable-frequency oscillator triggers a high-intensity strobe light.

Sublimation. A process in which a solid material changes directly into a vapor without passing through the liquid stage.

Subsonic flight. Flight at an airspeed in which all air flowing over the aircraft is moving at a speed below the speed of sound.

Summerwood. The less porous, usually harder portion of an annual ring that forms in the latter part of the growing season, the summer of the year.

Sump. A low point in an aircraft fuel tank in which water and other contaminants can collect and be held until they can be drained out.

Supercooled water. Water in its liquid form at a temperature well below its natural freezing temperature. When supercooled water is disturbed, it immediately freezes.

Superheat. Heat energy that is added to a refrigerant after it changes from a liquid to a vapor.

Super heterodyne circuit. A sensitive radio receiver circuit in which a local oscillator produces a frequency that is a specific difference from the received signal frequency. The desired signal and the output from the oscillator are mixed, and they produce a single, constant intermediate frequency. This IF is amplified, demodulated, and detected to produce the audio frequency that is used to drive the speaker.

Supersonic flight. Flight at an airspeed in which all air flowing over the aircraft is moving at a speed greater than the speed of sound.

Supplemental Type Certificate (STC). An approval issued by the FAA for a modification to a type certificated airframe, engine, or component. More than one STC can be issued for the same basic alteration, but each holder must prove to the FAA that the alteration meets all the requirements of the original type certificate.

Surface tape. Strips of aircraft fabric that are doped over all seams and places where the fabric is stitched to the aircraft structure. Surface tape is also doped over the wing leading edges where abrasive wear occurs. The edges of surface tape are pink, or notched, to keep them from raveling before the dope is applied.

Surfactant. A surface active agent, or partially soluble contaminant, which is a by-product of fuel processing or of fuel additives. Surfactants adhere to other contaminants and cause them to drop out of the fuel and settle to the bottom of the fuel tank as sludge.

Surveyor's transit. An instrument consisting of a telescope mounted on a flat, graduated, circular plate on a tripod. The plate can be adjusted so it is level, and its graduations oriented to magnetic north. When an object is viewed through the telescope, its azimuth and elevation may be determined.

Swashplate. The component in a helicopter control system that consists basically of two bearing races with ball bearings between them. The lower, or nonrotating, race is tilted by the cyclic control, and the upper, or rotating, race has arms which connect to the control horns on the rotor blades. Movement of the cyclic pitch control is transmitted to the rotor blades through the swashplate. Movement of the collective pitch control raises or lowers the entire swashplate assembly to change the pitch of all the blades at the same time.

Synchro system. A remote instrument indicating system. A synchro transmitter is actuated by the device whose movement is to be measured, and it is connected electrically with wires to a synchro indicator whose pointer follows the movement of the shaft of the transmitter.

Symmetrical airfoil. An airfoil that has the same shape on both sides of its chord line, or center line.

Symmetry check. A check of an airframe to determine that the wings and tail are symmetrical about the longitudinal axis.

System-pressure regulator (hydraulic system component). A type of hydraulic system-pressure control valve. When the system pressure is low, as it is when some unit is actuated, the output of the constant-delivery pump is directed into the system. When the actuation is completed and the pressure builds up to a specified kick-out pressure, the pressure regulator shifts. A check valve seals the system off and the pressure is maintained by the accumulator. The pump is unloaded and its output is directed back into the reservoir with very little opposition. The pump output pressure drops, but the volume of flow remains the same. When the system pressure drops to the specified kick-in pressure, the regulator again shifts and directs fluid into the system. Spool-type and balanced-pressure-type system pressure regulators are completely automatic in their operation and require no attention on the part of the flight crew.

TACAN (Tactical Air Navigation). A radio navigation facility used by military aircraft for both direction and distance information. Civilian aircraft receive distance information from a TACAN on their DME.

Tack coat. A coat of finishing material sprayed on the surface and allowed to dry until the solvents evaporate. As soon as the solvents evaporate, a wet full-bodied coat of material is sprayed over it.

Tack rag. A clean, lintless rag, slightly damp with thinner. A tack rag is used to wipe a surface to prepare it to receive a coat of finishing material.

Tack weld. A method of holding parts together before they are permanently welded. The parts are assembled, and small spots of weld are placed at strategic locations to hold them in position.

Tacky. Slightly sticky to the touch.

Tailets. Small vertical surfaces mounted underside of the horizontal stabilizer of some airplanes to increase the directional stability.

Takeoff warning system. An aural warning system that provides audio warning signals when the thrust levers are advanced for takeoff if the stabilizer, flaps, or speed brakes are in an unsafe condition for takeoff.

Tang. A tapered shank sticking out from the blade of a knife or a file. The handle of a knife or file is mounted on the tang.

TCAS. Traffic Alert Collision Avoidance System.

Teflon. The registered trade name for a fluorocarbon resin used to make hydraulic and pneumatic seals, hoses, and backup rings.

Tempered glass. Glass that has been heat-treated to increase its strength. Tempered glass is used in bird-proof, heated windshields for high-speed aircraft.

Terminal strips. A group of threaded studs mounted in a strip of insulating plastic. Electrical wires with crimped-on terminals are placed over the studs and secured with nuts.

Terminal VOR. A low-powered VOR that is normally located on an airport.

Tetraethyl lead (TEL). A heavy, oily, poisonous liquid, $Pb(C_2H_5)^4$, that is mixed into aviation gasoline to increase its critical pressure and temperature.

Therapeutic mask adapter. A calibrated orifice in the mask adapter for a continuous-flow oxygen system that increases the flow of oxygen to a mask being used by a passenger who is known to have a heart or respiratory problem.

Thermal dimpling. See hot dimpling.

Thermal relief valve. A relief valve in a hydraulic system that relieves pressure that builds up in an isolated part of the system because of heat. Thermal relief valves are set at a higher pressure than the system pressure relief valve.

Thermistor. A special form of electrical resistor whose resistance varies with its temperature.

Thermistor material. A material with a negative temperature coefficient that causes its resistance to decrease as its temperature increases.

Thermocouple. A loop consisting of two kinds of wire, joined at the hot, or measuring, junction and at the cold junction in the instrument. The voltage difference between the two junctions is proportional to the temperature difference between the junctions. In order for the current to be meaningful, the resistance of the thermocouple is critical, and the leads are designed for a specific installation. Their length should not be altered. Thermocouples used to measure cylinder head temperature are usually made of iron and constantan, and thermocouples that measure exhaust gas temperature for turbine engines are made of chromel and alumel.

Thermocouple fire-detection system. A fire-detection system that works on the principle of the rate-of-temperature rise. Thermocouples are installed around the area to be protected, and one thermocouple is surrounded by thermal insulation that prevents its temperature changing rapidly. In the event of a fire, the temperature of all the thermocouples except the protected one will rise immediately and a fire warning will be initiated. In the case of a general overheat condition, the temperature of all the thermocouples will rise uniformly and there will be no fire warning.

Thermoplastic resin. A type of plastic material that becomes soft when heated and hardens when cooled.

Thermosetting resin. A type of plastic material that, when once hardened by heat, cannot be softened by being heated again.

Thermostatic expansion valve (TEV). The component in a vapor-cycle cooling system that meters the refrigerant into the evaporator. The amount of refrigerant metered by the TEV is determined by the temperature and pressure of the refrigerant as it leaves the evaporator coils. The TEV changes the refrigerant from a high-pressure liquid into a low-pressure liquid.

Thixotropic agents. Materials, such as microballoons, added to a resin to give it body and increase its workability.

TIG welding. Tungsten inert welding is a form of electric arc welding in which the electrode is a nonconsumable tungsten wire. TIG welding is now called GTA (gas tungsten arc) welding.

Toe-in. A condition of landing gear alignment in which the front of the tires are closer together than the rear. When the aircraft rolls forward, the wheels try to move closer together.

Toe-out. A condition of landing gear alignment in which the front of the tires are further apart than the rear. When the aircraft rolls forward, the wheels try to move farther apart.

Torque. A force that produces or tries to produce rotation.

Torque links. The hinged link between the piston and cylinder of an oleo-type landing gear shock absorber. The torque links allow the piston to move freely in and out of the landing gear cylinder, but prevent it rotating. The torque links can be adjusted to achieve and maintain the correct wheel alignment. Torque links are also called scissors and nutcrackers.

Torque tube. A tube in an aircraft control system that transmits a torsional force from the operating control to the control surface.

Torsion rod. A device in a spring tab to which the control horn is attached. For normal operation, the torsion rod acts as a fixed attachment point, but when the control surface loads are high, the torsion rod twists and allows the control horn to deflect the spring tab.

Total air pressure. The pressure a column of moving air will have if it is stopped.

TMC. Thrust management computer.

Toroidal coil. An electrical coil wound around a ring-shaped core of highly permeable material.

Total air temperature. The temperature a column of moving air will have if it is stopped.

TR unit. A transformer-rectifier unit. A TR unit reduces the voltage of AC and changes it into DC.

Tractor powerplant. An airplane powerplant in which the propeller is mounted in the front, and its thrust pulls the airplane rather than pushes it.

Trammel (verb). To square up the Pratt truss used in an airplane wing. Trammel points are set on the trammel bar so they measure the distance between the center of the front spar, at the inboard compression strut, and at the center of the rear spar at the next compression strut outboard. The drag and antidrug wires are adjusted until the distance between the center of the rear spar at the inboard compression strut and the center of the front spar at the next outboard compression strut is exactly the same as that between the first points measured.

Trammel bar. A wood or metal bar on which trammel points are mounted to compare distances.

Trammel points. A set of sharp-pointed pins that protrude from the sides of a trammel bar.

Transducer. A device that changes energy from one form to another. Commonly used transducers change mechanical movement or pressures into electrical signals.

Transformer rectifier. A component in a large aircraft electrical system used to reduce the AC voltage and change it into DC for charging the battery and for operating DC equipment in the aircraft.

Translational lift. The additional lift produced by a helicopter rotor as the helicopter changes from hovering to forward flight.

Transonic flight. Flight at an airspeed in which some air flowing over the aircraft is moving at a speed below the speed of sound, and other air is moving at a speed greater than the speed of sound.

Transverse pitch. See gauge.

Triangle. A three-sided, closed plane figure. The sum of the three angles in a triangle is always equal to 180°.

Tricresyl phosphate (TCP). A chemical compound, $(CH_3C_6H_4O)^3PO$, used in aviation gasoline to assist in scavenging the lead deposits left from the tetraethyl lead.

Trim tab. A small control tab mounted on the trailing edge of a movable control surface. The tab may be adjusted to provide an aerodynamic force to hold the surface on which it is mounted deflected in order to trim the airplane for hands-off flight at a specified airspeed.

Trimmed flight. A flight condition in which the aerodynamic forces acting on the control surfaces are balanced and the aircraft is able to fly straight and level with no control input.

Trip-free circuit breaker. A circuit breaker that opens a circuit any time an excessive amount of current flows, regardless of the position of the circuit breaker's operating handle.

Troubleshooting. A procedure used in aircraft maintenance in which the operation of a malfunctioning system is analyzed to find the reason for the malfunction and to find a method for returning the system to its condition of normal operation.

True airspeed (TAS). Airspeed shown on the airspeed indicator (indicated airspeed) corrected for position error and nonstandard air temperature and pressure.

Trunnion. Projections from the cylinder of a retractable landing gear strut about which the strut pivots retract.

Truss-type structure. A type of structure made up of longitudinal beams and cross braces. Compression loads between the main beams are carried by rigid cross braces. Tension loads are carried by stays, or wires, that go from one main beam to the other and cross between the cross braces.

Turbine. A rotary device actuated by impulse or reaction of a fluid flowing through vanes or blades that are arranges around a central shaft.

Turn and slip indicator. A rate gyroscopic flight instrument that gives the pilot an indication of the rate of rotation of the aircraft about its vertical axis. A ball in a curved glass tube shows the pilot the relationship between the centrifugal force and the force of gravity. This indicates whether or not the angle of bank is proper for the rate of turn. The turn and slip indicator shows the trim condition of the aircraft and serves as an emergency source of bank information in case the attitude gyro fails. Turn and slip indicators were formerly called needle and ball and turn and bank indicators.

Turnbuckle. A component in an aircraft control system used to adjust cable tension. A turnbuckle consists of a brass tubular barrel with right-hand threads in one end and left-hand in the other end. Control cable terminals screw into the two ends of the barrel, and turning the barrel pulls the terminals together, shortening the cable.

Twist drill. A metal cutting tool turned in a drill press or handheld drill motor. A twist drill has a straight shank and spiraled flutes. The cutting edge is ground on the end of the spiraled flutes.

Twist rope. A stripe of paint on flexible hose that runs the length of the hose. If this stripe spirals around the hose after it is installed, it indicates the hose was twisted when it was installed. Twist stripes are also called lay lines.

Two-terminal spot-type fire detection system. A fire detection system that uses individual thermoswitches installed around the inside of the area to be protected. These thermoswitches are wired in parallel between two separate circuits. A short or an open circuit can exist in either circuit without causing a fire warning.

Type Certificate Data Sheets (TCDS). The official specifications of an aircraft, engine, or propeller issued by the Federal Aviation Administration. The TCDS lists pertinent specifications for the device, and it is the responsibility of the mechanic and/or inspector to ensure, on each inspection, that the device meets these specifications.

UHF. Ultrahigh frequency.

Ultimate tensile strength. The tensile strength required to cause a material to break or to continue to deform under a decreasing load.

Ultraviolet-blocking dope. Dope that contains aluminum powder or some other pigment that blocks the passage of ultraviolet rays of the sun. The coat of dope protects the organic fabrics and clear dope from deterioration by these rays.

Undamped oscillation. Oscillation that continues with an unchanging amplitude once it has started.

Underslung rotor. A helicopter rotor whose center of gravity is below the point at which it is attached to the mast.

Unidirectional fabric. Fabric in which all the threads run in the same direction. These threads are often bound with a few fibers run at right angles, just enough to hold the yarns together and prevent their bunching.

Unloading valve. This is another name for system pressure regulator. See system pressure regulator.

Utility finish. The finish of an aircraft that gives the necessary tautness and fill to the fabric and the necessary protection to the metal, but does not have the glossy appearance of a show-type finish.

Vapor lock. A condition in which vapors form in the fuel lines and block the flow of fuel to the carburetor.

Vapor pressure. The pressure of the vapor above a liquid needed to prevent the liquid evaporating. Vapor pressure is always specified at a specific temperature.

Variable displacement pump. A fluid pump whose output is controlled by the demands of the system. These pumps normally have a built-in system pressure regulator. When the demands of the system are low, the pump moves very little fluid, but when the demands are high, the pump moves a lot of fluid. Most variable displacement pumps used in aircraft hydraulic systems are piston-type pumps.

Varnish (aircraft finishing material). A material used to produce an attractive and protective coating on wood or metal. Varnish is made of a resin dissolved in a solvent and thinned until it has the proper viscosity to spray or brush. The varnish is spread evenly over the surface to be coated, and when the solvents evaporate, a tough film is left.

Varsol. A petroleum product similar to naphtha used as a solvent and cleaning fluid.

Veneer. Thin sheets of wood "peeled" from a log. A wide-blade knife held against the surface of the log peels away the veneer as the log is rotated in the cutter. Veneer is used for making plywood. Several sheets of veneer are glued together, with the grain of each sheet placed at 45° or 90° to the grain of the sheets next to it.

Vertical axis. An imaginary line, passing vertically through the center of gravity of an airplane.

Vertical fin. The fixed vertical surface in the empennage of an airplane. The vertical fin acts as a weathervane to give the airplane directional stability.

VFR. Visual flight rules.

VHF. Very high frequency.

Vibrator-type voltage regulator. A type of voltage regulator used with a generator or alternator that intermittently places a resistance in the field circuit to control the voltage. A set of vibrating contacts puts the resistor in the circuit and takes it out several times a second.

Viscosity. The resistance of a fluid to flow. Viscosity refers to the "stiffness" of the fluid, or its internal friction.

Viscosity cup. A specially shaped cup with an accurately sized hole in its bottom. The cup is submerged in the liquid to completely fill it. It is then lifted from the liquid and the time in seconds is measured from the beginning of the flow through the hole until the first break in this flow. The viscosity of the liquid relates to this time.

Vixen file. A metal-cutting hand file that has curved teeth across its faces. Vixen files are used to remove large amounts of soft metal.

V_{NE}. Never-exceed speed. The maximum speed the aircraft is allowed to attain in any conditions of flight.

Volatile liquid. A liquid that easily changes into a vapor.

Voltmeter multiplier. A precision resistor in series with a voltmeter mechanism used to extend the range of the basic meter or to allow a single meter to measure several ranges of voltage.

VOR. Very high frequency Omni Range navigation.

VORTAC. An electronic navigation system that contains both a VOR and a TACAN facility.

Vortex (plural vortices). A whirling motion in a fluid.

Vortex generator. Small, low-aspect-ratio airfoils installed in pairs on the upper surface of a wing, on both sides of the vertical fin just ahead of the rudder, and on the underside of the vertical stabilizers of some airplanes. Their function is to pull high-energy air down to the surface to energize the boundary layer and prevent airflow separation until the surface reaches a higher angle of attack.

Warp clock. An alignment indicator included in a structural repair manual to show the orientation of the piles of a composite material. The ply direction is shown in relation to a reference direction.

Warp threads. Threads that run the length of the roll of fabric, parallel to the selvage edge. Warp threads are often stronger than fill threads.

Warp tracers. Threads of a different color from the warp threads that are woven into a material to identify the direction of the warp threads.

Wash in. A twist in an airplane wing that increases its angle of incidence near the tip.

Wash out. A twist in an airplane wing that decreases its angle of incidence near the tip.

Watt. The basic unit of electrical power. One watt is equal to $1/746$ horsepower.

Way point. A phantom location created in certain electronic navigation systems by measuring direction and distance from a VORTAC station or by latitude and longitude coordinates from Loran or GPS.

Web of a spar. The part of a spar between the caps.

Weft threads. See fill threads.

Wet-type vacuum pump. An engine-driven air pump that uses steel vanes. These pumps are lubricated by engine oil drawn in through holes in the pump base. The oil passes through the pump and is exhausted with the air. Wet-type pumps must have oil separators in their discharge line to trap the oil and return it to the engine crankcase.

Wing fences. Vertical vanes that extend chordwise across the upper surface of an airplane wing to prevent spanwise airflow.

Wing heavy. An out-of-trim flight condition in which an airplane flies hands off, with one wing low.

Wire bundle. A compact group of electrical wires held together with special wrapping devices or with waxed string. These bundles are secured to the aircraft structure with special clamps.

Woof threads. See fill threads.

Work. The product of force times distance.

Yaw. Rotation of an aircraft about its vertical axis.

Yaw damper. An automatic flight control system that counteracts the rolling and yawing produced by Dutch roll. See Dutch roll. A yaw damper senses yaw with a rate gyro and moves the rudder an amount proportional to the rate of yaw, but in the opposite direction.

Yield strength. The amount of stress needed to permanently deform a material.

Zener diode. A special type of solid-state diode designed to have a specific breakdown voltage and to operate with current flowing through it in its reverse direction.

Zeppelin. The name of large, rigid, lighter-than-air ships built by the Zeppelin Company in Germany prior to and during World War I.

Zero-center ammeter. An ammeter in a light aircraft electrical system located between the battery and the main bus. This ammeter shows the current flowing into or out of the battery.

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