Chapter 16

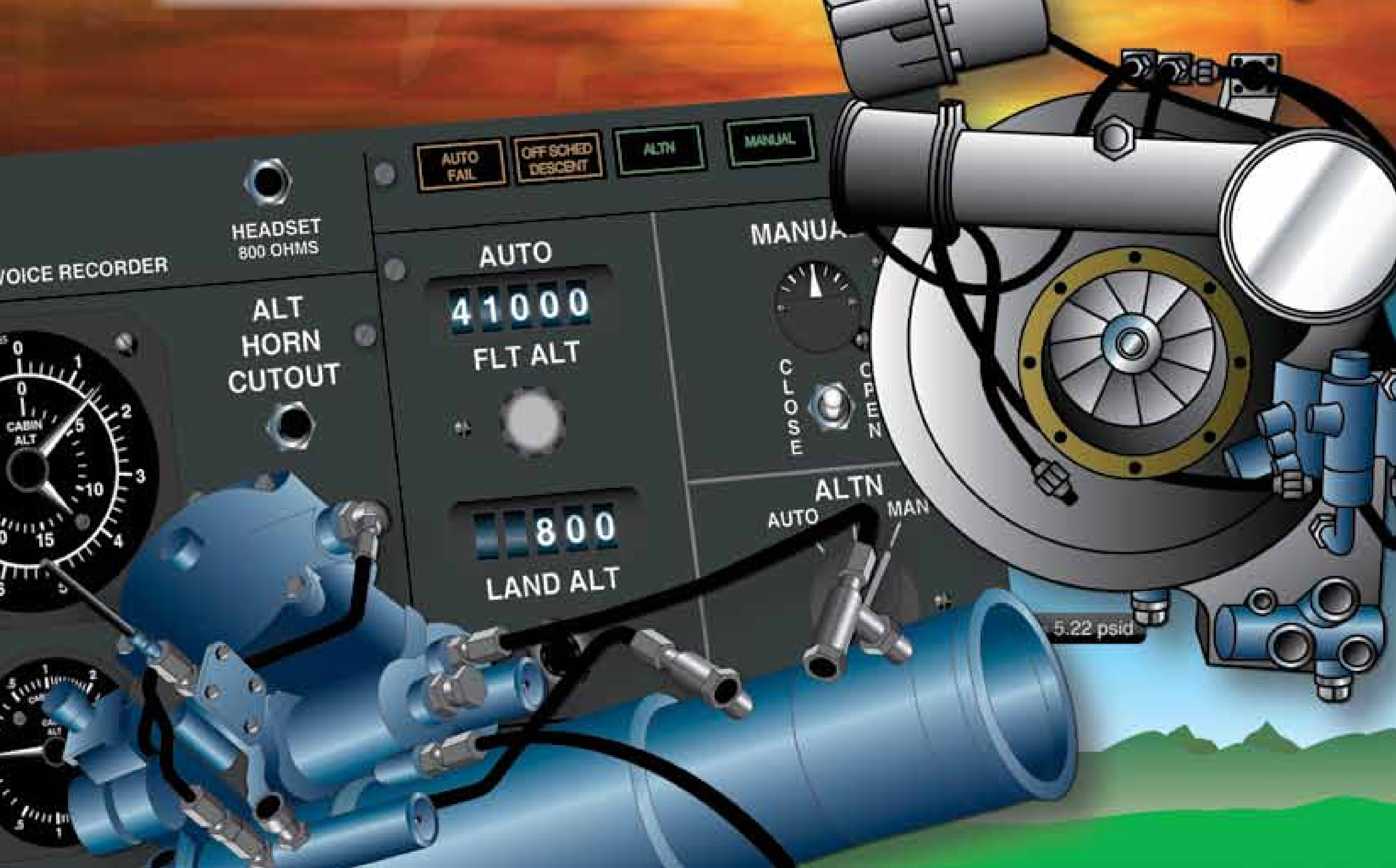
Cabin Environmental Control Systems

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.



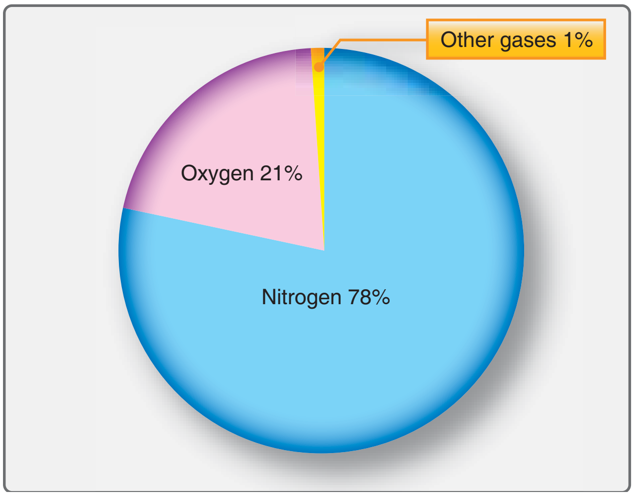


Figure 16-1. *The percentage of the various gases that comprise the atmosphere.*

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]*

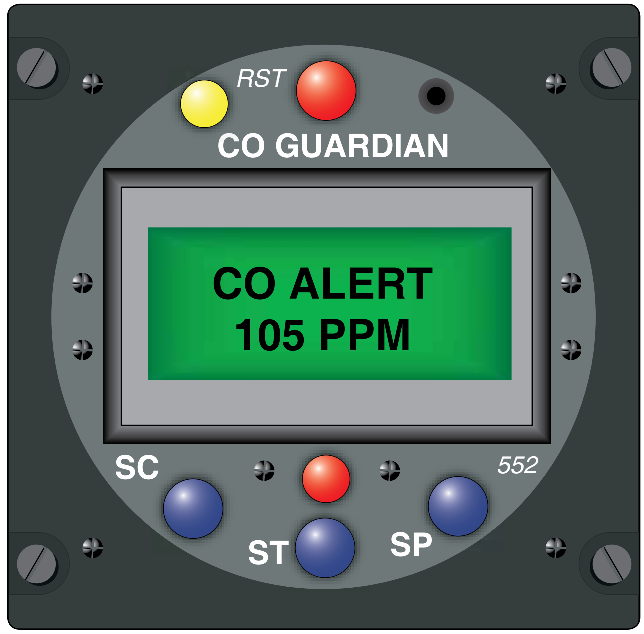


Figure 16-3. *An example of a carbon monoxide detector sold in the aviation market.*

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.

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]*

Figure 16-4. *"Aviator's breathing oxygen" is marked on all oxygen cylinders designed for this purpose.*

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 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

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.*

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 nearly exclusively in military aviation.

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 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]*

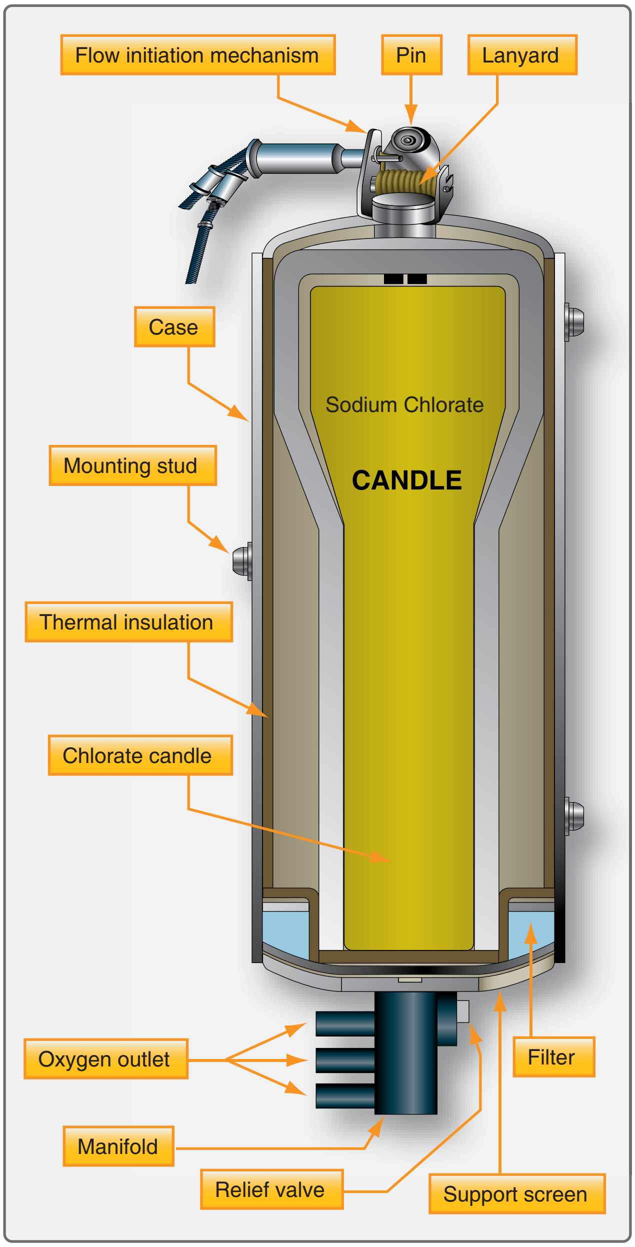


Figure 16-7. *A sodium chlorate solid oxygen candle is at the core of a chemical oxygen generator.*

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.

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.

Figure 16-8. *This onboard oxygen generating system uses molecular sieve technology.*

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.

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.*

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.

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 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

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.*

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]*

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.*

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 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

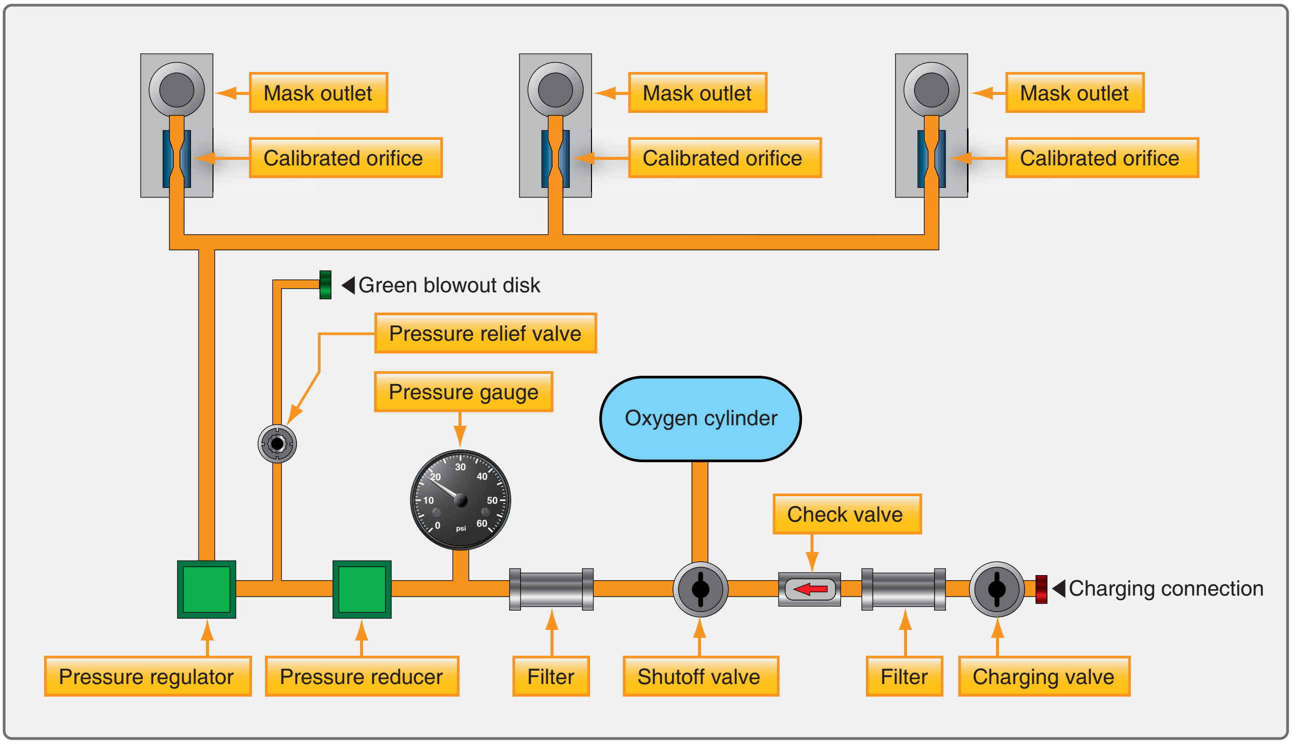


Figure 16-13. *Continuous flow oxygen system found on small to medium size aircraft.*

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 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

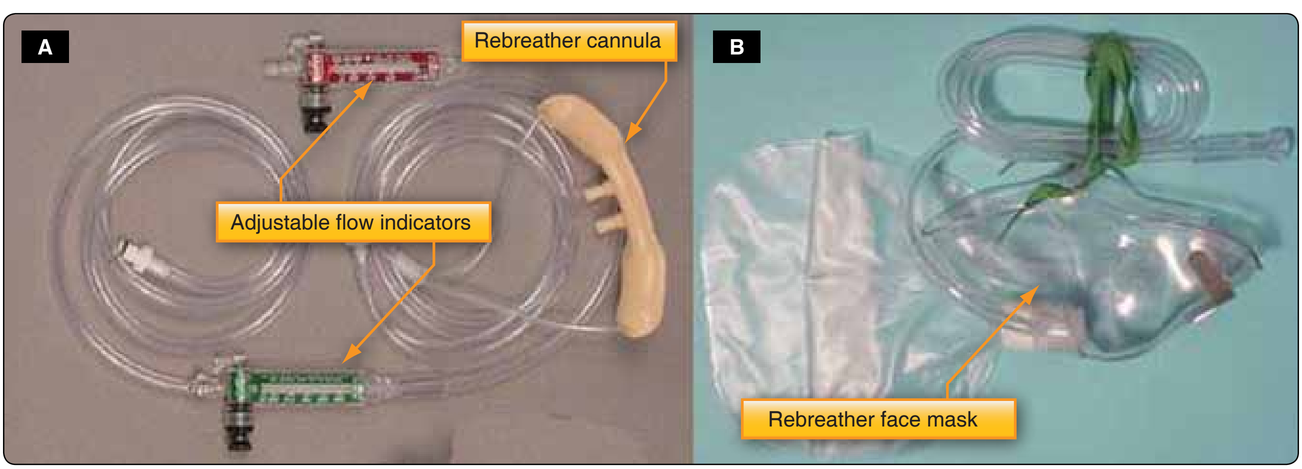


Figure 16-14. *A rebreather cannula (A) and rebreather bag (B) capture exhaled oxygen to be inhaled on the next breath. This conserves oxygen by permitting lower flow rates in continuous flow systems. The red and green devices are optional flow indicators that allow the user to monitor oxygen flow rate. The type shown also contains needle valves for final regulation of the flow rate to each user.*

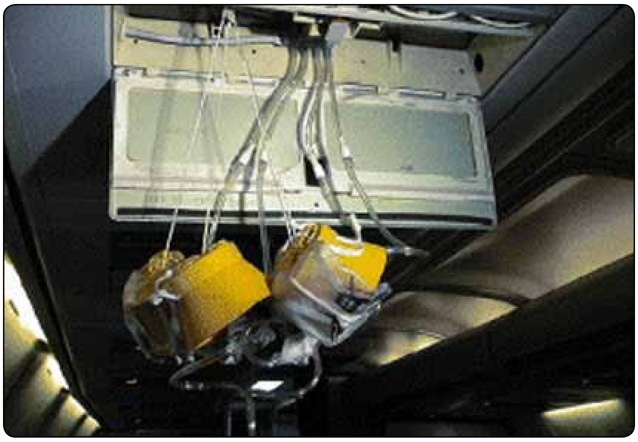


Figure 16-15. *A passenger service unit (psu) is hinged over each row of seats in an airliner. Four yellow continuous flow oxygen masks are shown deployed. They are normally stored behind a separate hinged panel that opens to allow the masks to fall from the PSU for use.*

Figure 16-16. *The crew can deploy passenger emergency continuous-flow oxygen masks and supply with a switch in the cockpit.*

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]*

Figure 16-17. *Examples of different continuous-flow oxygen masks.*

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]*

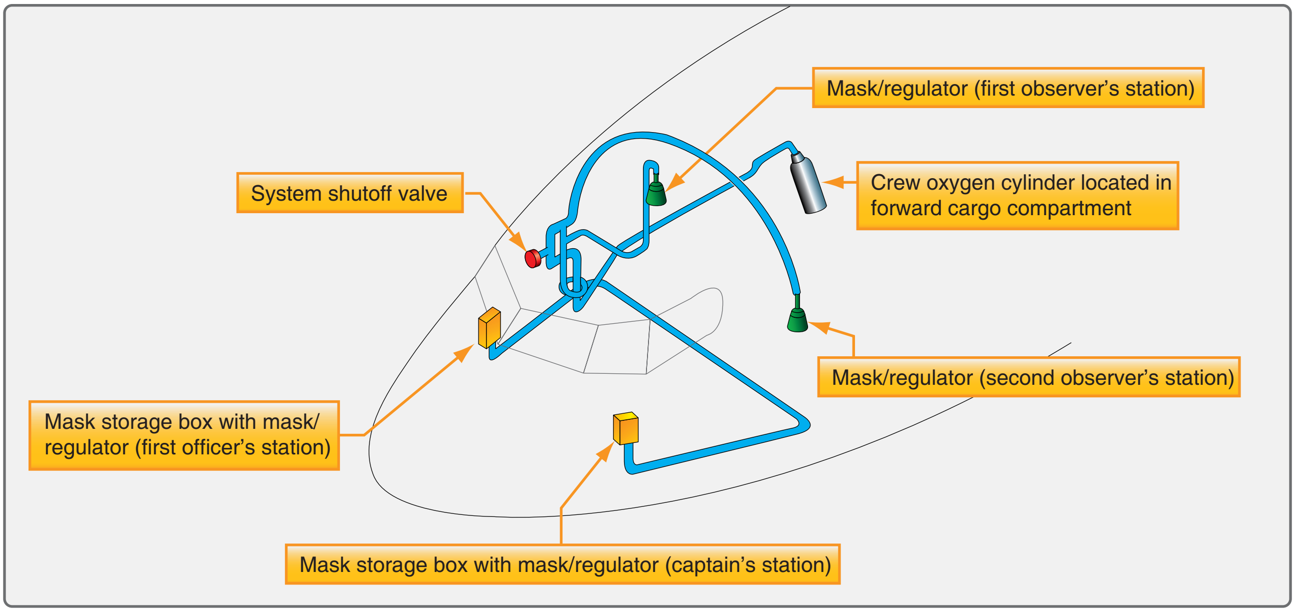


Figure 16-18. *Location of demand-flow oxygen components on a transport category aircraft.*

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]*

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 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

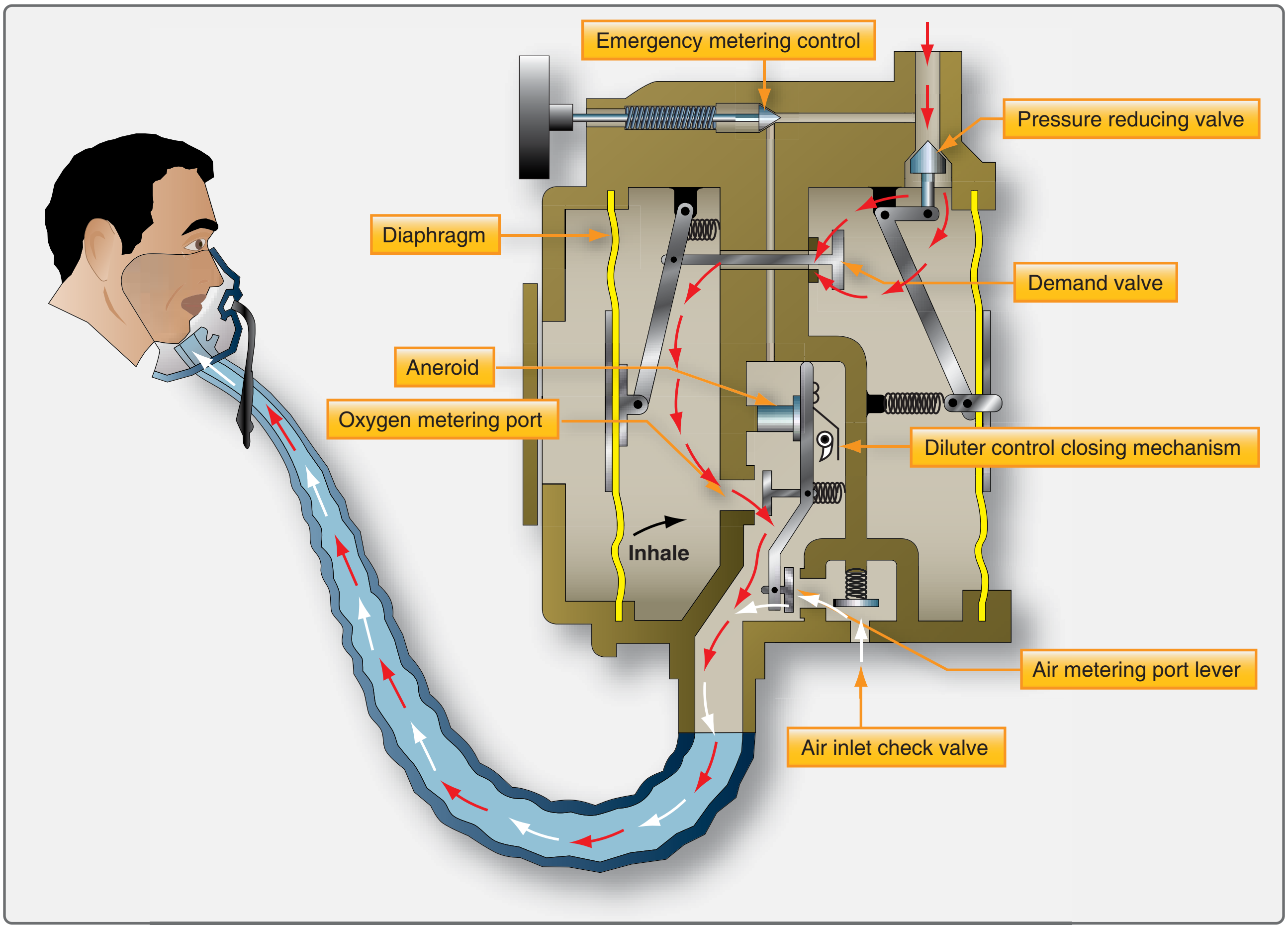


Figure 16-19. *A demand regulator and demand-type mask work together to control flow and conserve oxygen. Demand-flow masks are close fitting so that when the user inhales, low pressure is created in the regulator, which allows oxygen to flow. Exhaled air escapes through ports in the mask, and the regulator ceases the flow of oxygen until the next inhalation.*

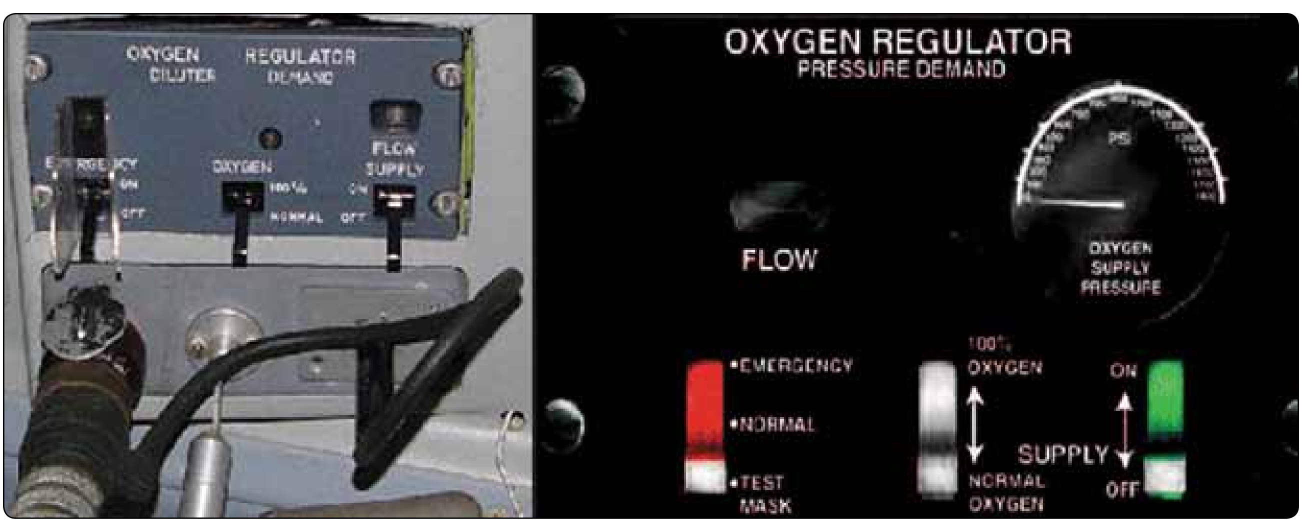


Figure 16-20. *The two basic types of regulators used in demand flow oxygen systems. The panel below the diluter demand regulator on the left is available for mask hose plug in (left), lanyard mask hanger (center), and microphone plug in (right). Most high performance demand type masks have a microphone built-in.*

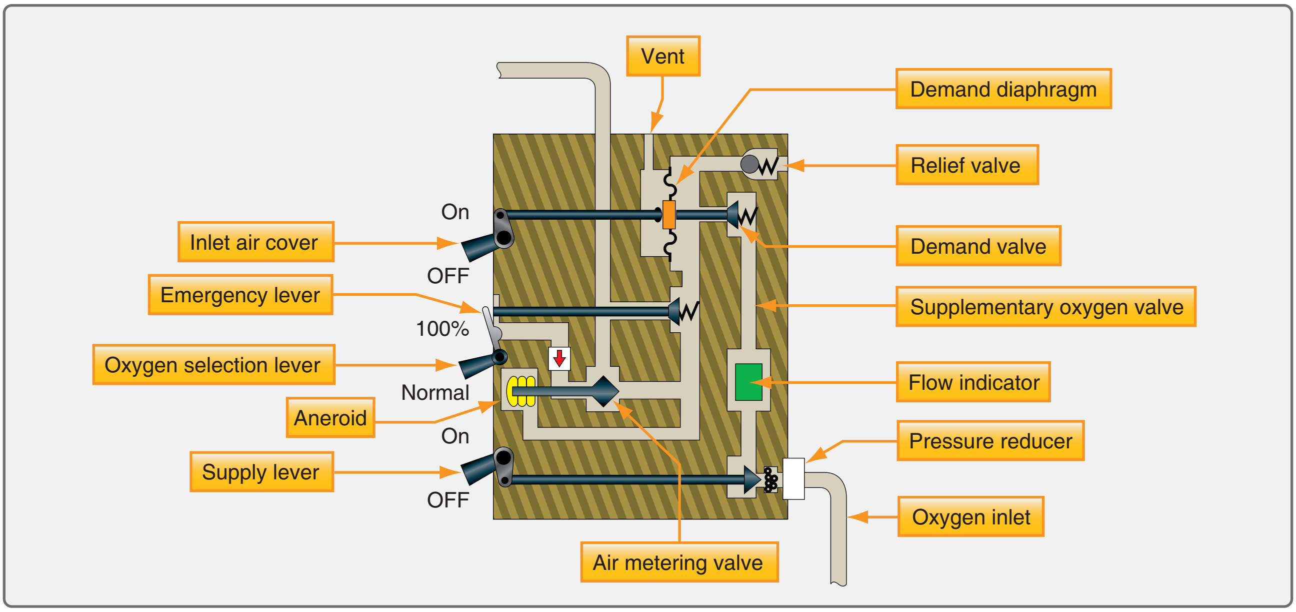


Figure 16-21. *A diluter-demand regulator operates when low pressure caused by inhalation moves the demand diaphragm. A demand valve connected to the diaphragm opens, letting oxygen flow through the metering valve. The metering valve adjusts the mixture of cabin air and pure oxygen via a connecting link 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.*

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

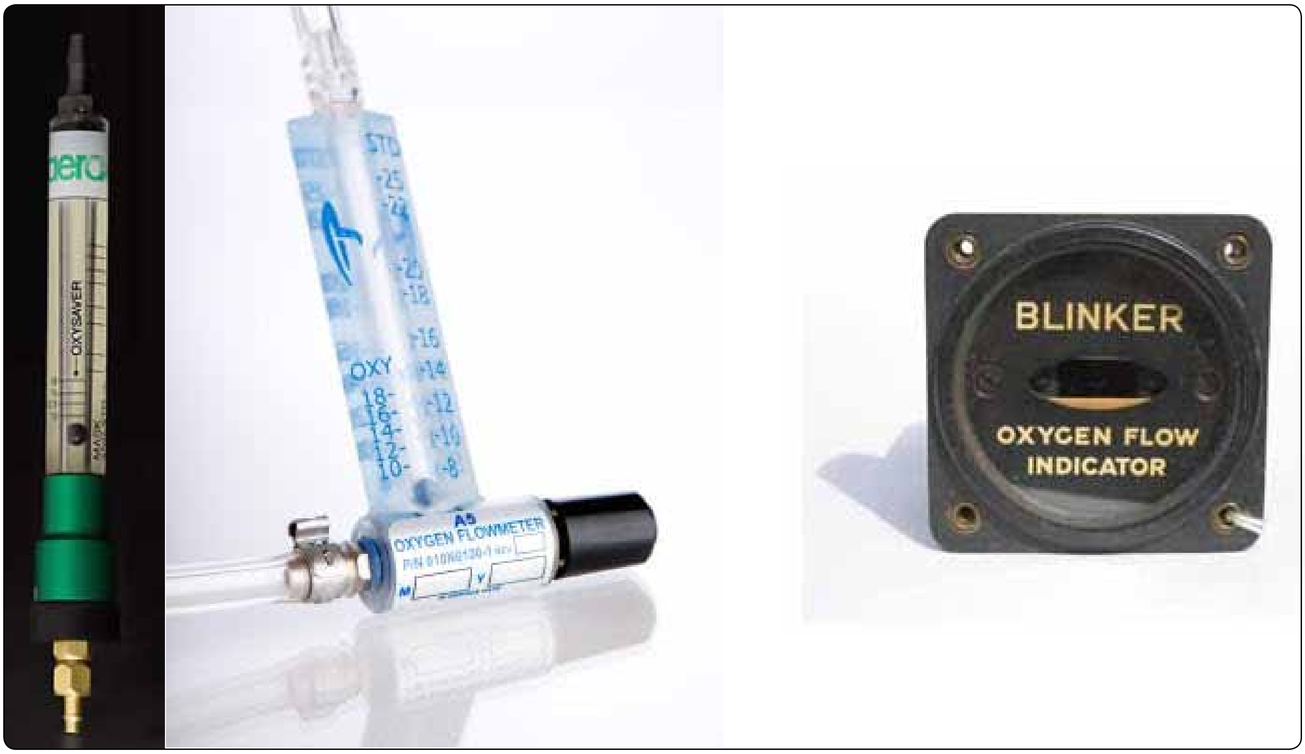


Figure 16-23. *Different flow indicators are used to provide verification that the oxygen system is functioning: continuous-flow, in-line (left); continuous-flow, in-line with valve adjuster (center); and old style demand flow (right).*

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]*

Figure 16-24. *A portable two-person electronic pulse-demand (EPD) oxygen regulating unit.*

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 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]*

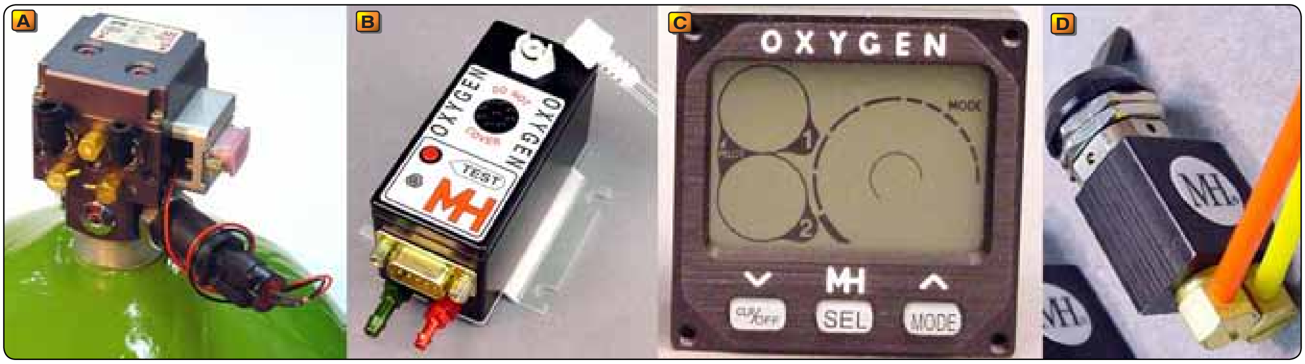


Figure 16-25. *The key components of a built-in electronic pulse demand oxygen metering system: (A) electronic regulator, (B) oxygen station distributer unit, (C) command/display unit, (D) emergency bypass switch.*

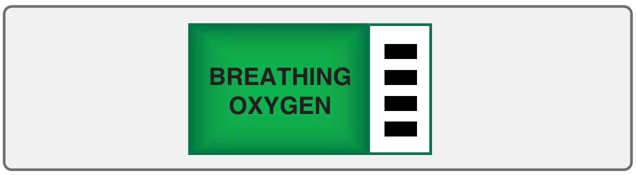


Figure 16-26. *Color-coded tape used to identify oxygen tubing.*

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.

To combat this issue, all oxygen shutoff valves are slow, opening valves designed to decrease velocity. *[Figure 16-27]*

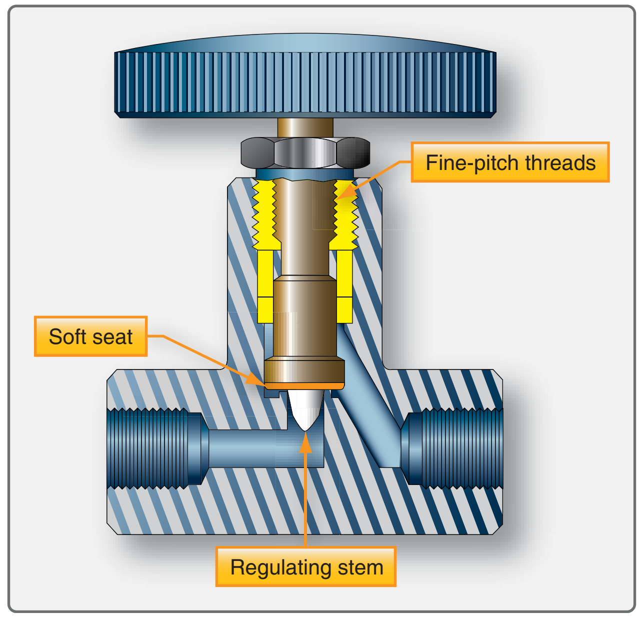


Figure 16-27. *This high-pressure oxygen system shutoff valve has fine-pitch threads and a regulating stem to slow the flow of oxygen through the valve. A soft valve seat is also included to assure the valve closes completely.*

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]*

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

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 16-29. *An oxygen generator mounted in place in an overhead passenger service unit of an air transport category aircraft.*

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.

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 light weight 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 emergency 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 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.

Figure 16-31. *Typical oxygen servicing cart used to fill an aircraft system.*

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. Others 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]*

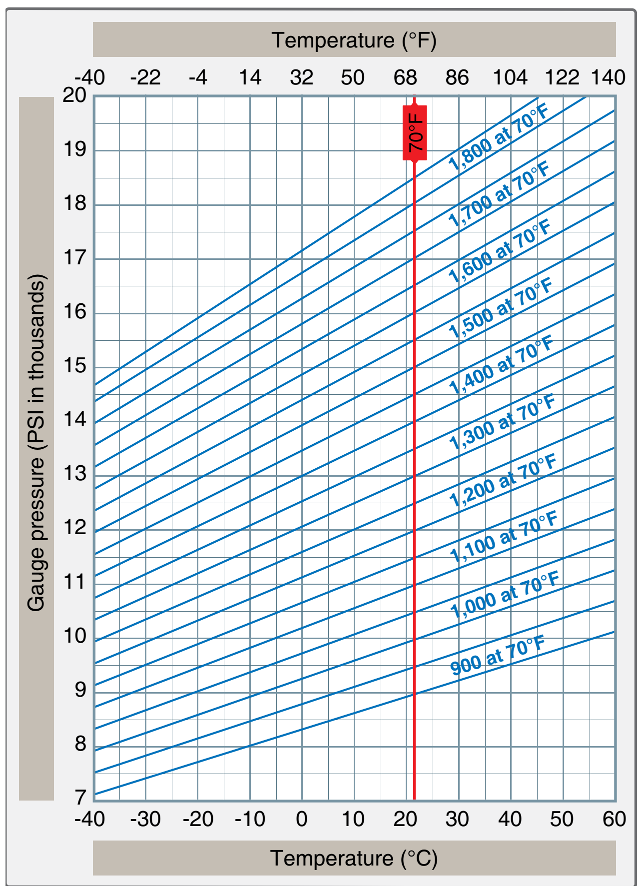


Figure 16-32. *A temperature-compensating pressure refill chart is used by the technician to ensure proper oxygen cylinder pressure in the aircraft system.*

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.

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.

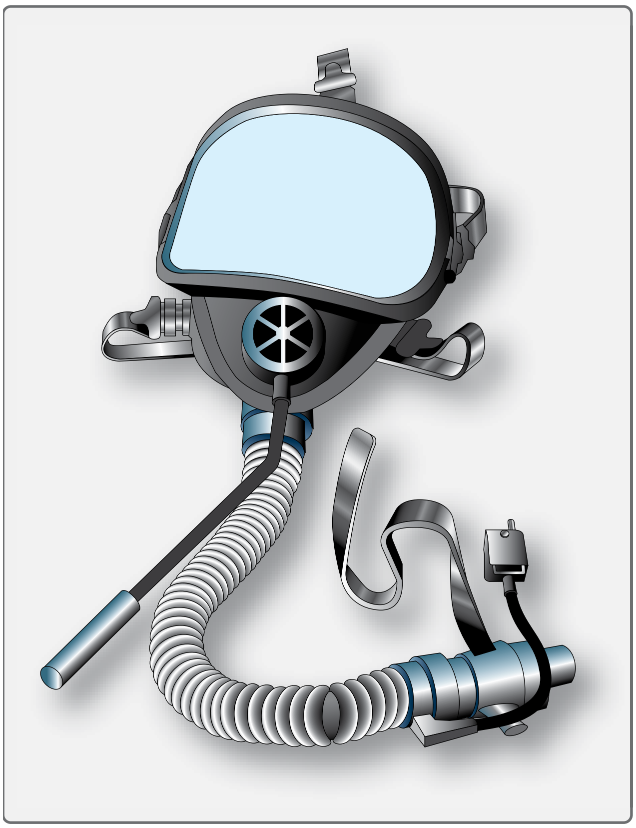


Figure 16-33. *Smoke masks cover the eyes as well as the nose and mouth of the user.*

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 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 hanger 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]*

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.

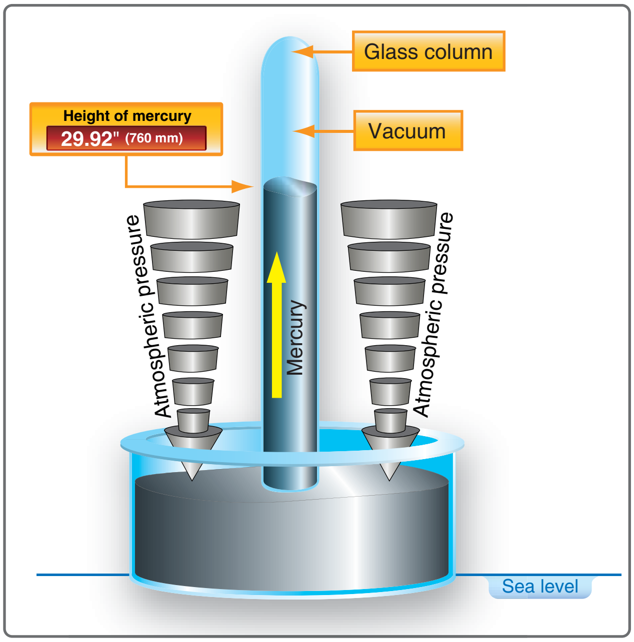


Figure 16-35. *The weight of the atmosphere pushes down on the mercury in the reservoir of a barometer, which causes mercury to rise in the column. At sea level, mercury is forced up into the column approximately 29.92 inches. Therefore, it is said that barometric pressure is 29.92 inches of mercury at sea level.*

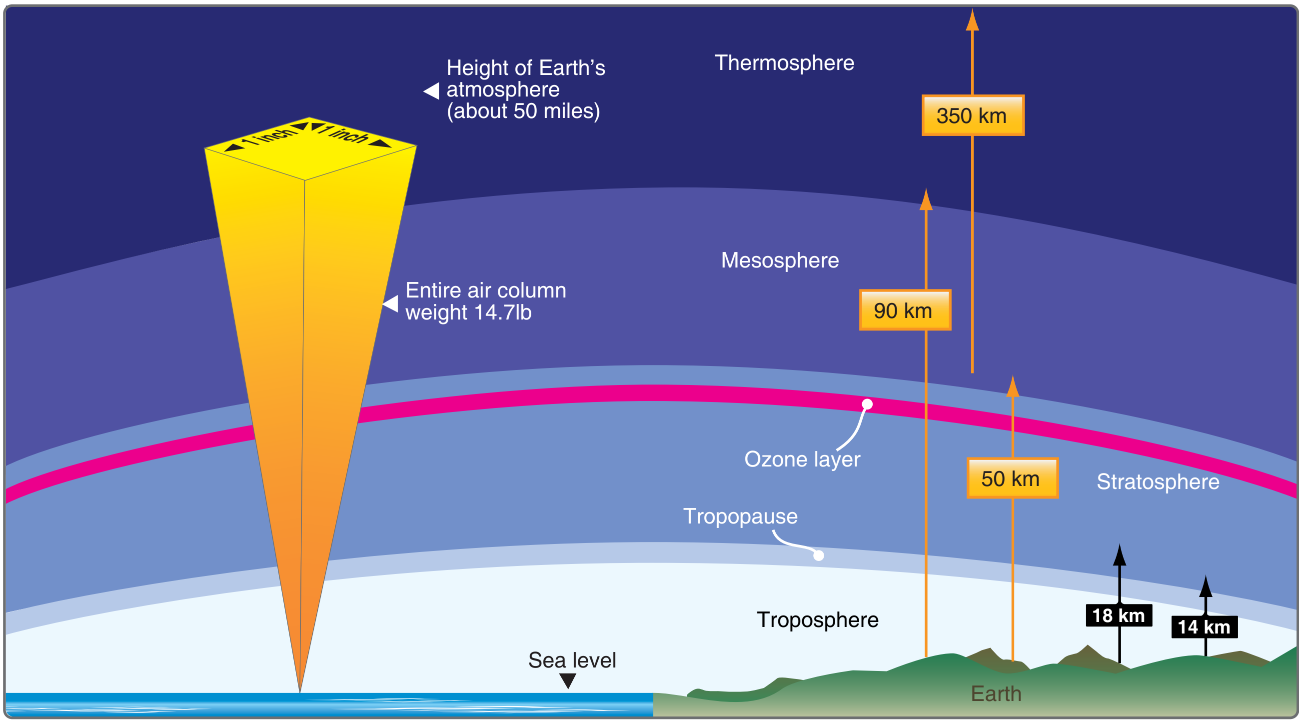


Figure 16-34. *The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.*

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 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 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.

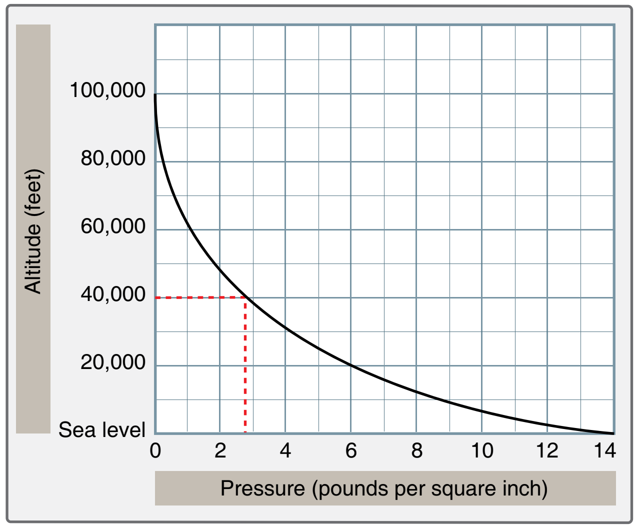


Figure 16-37. *Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40,000 feet, as the dotted lines show, the pressure is only 2.72 psi.*

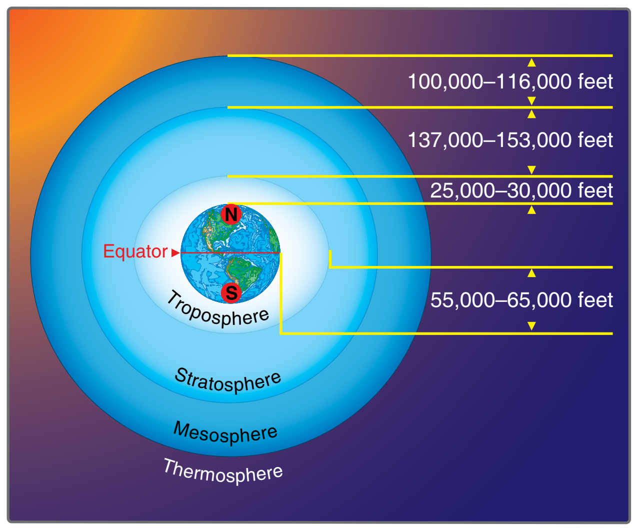


Figure 16-38. *The troposphere extends higher above the earth's surface at the equator than it does at the poles.*

Figure 16-39 diagrams the temperature variations in different layers of the atmosphere.

Atmospheric Pressure

Standard atmospheric pressure at sea level is also known as 1 atmosphere, or 1 atm. The following measurements of standard atmospheric pressure are all equal to each other.

1 atm (atmosphere) = 14.7 psi (prounds per square inch) = 29.92 in Hg (inches of mercury) = 1013.2 hPa (hectopascals or newtons per square meter = 1013.2 mb (millibars) = 760 mm Hg (millimeters of mercury)

Figure 16-36. *Various equivalent representations of atmospheric pressure at sea level.*

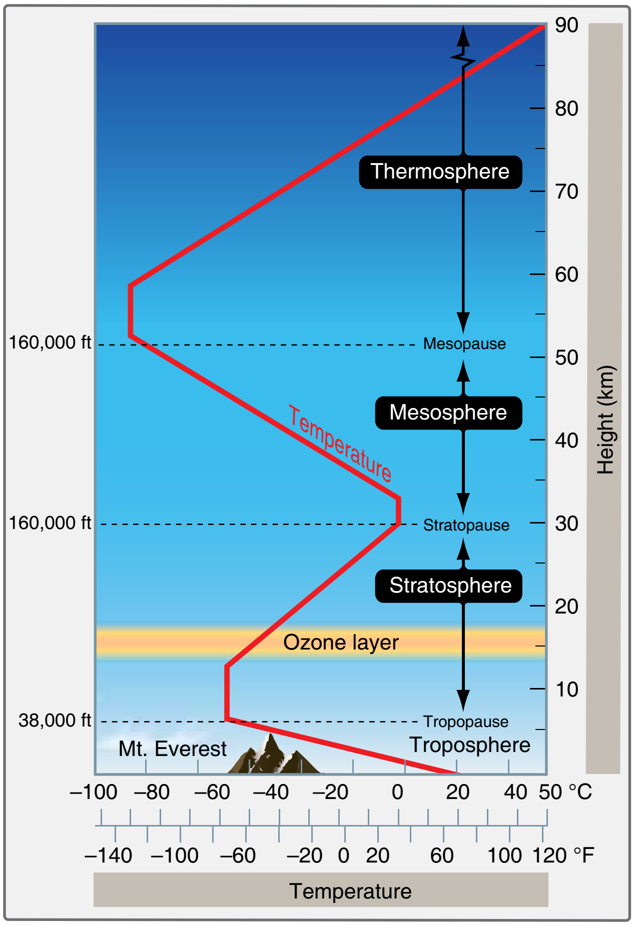


Figure 16-39. *The atmospheric layers with temperature changes depicted by the red line.*

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.*

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.

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. 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.

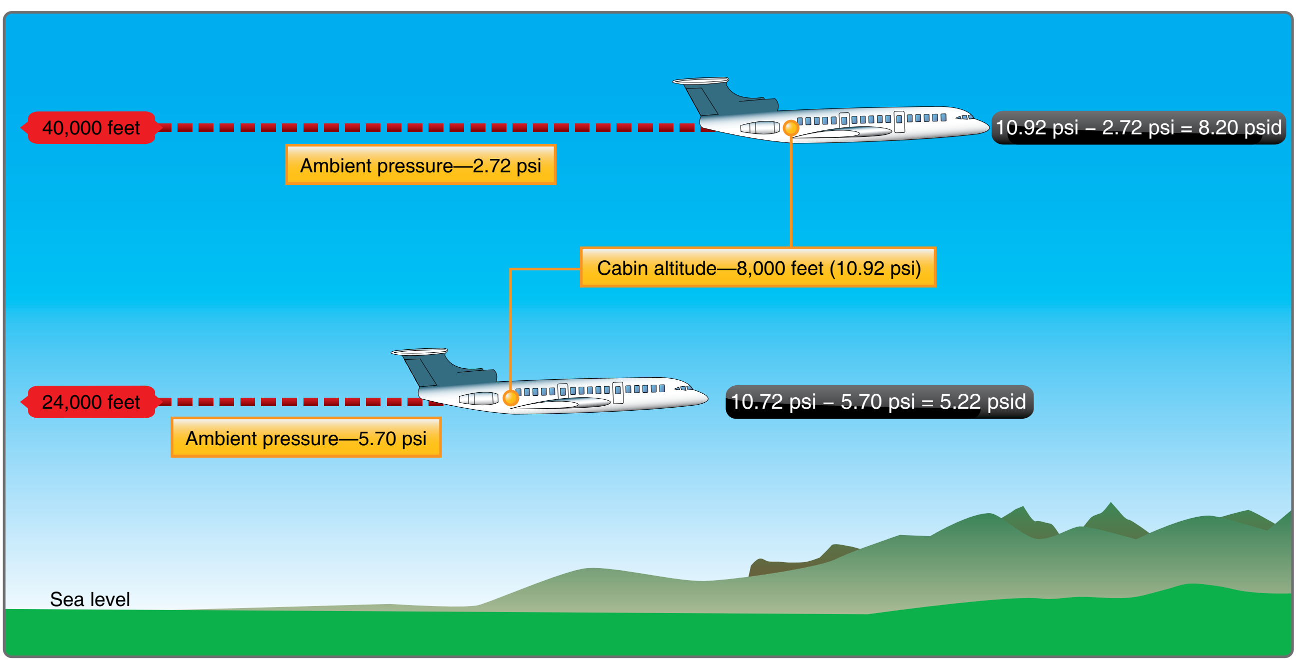


Figure 16-41. *Differential pressure (psid) is calculated by subtracting the ambient air pressure from the cabin air pressure.*

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.

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]*

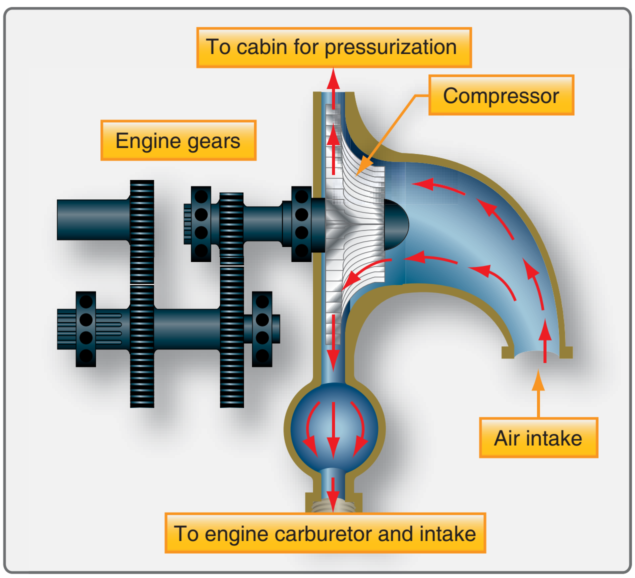


Figure 16-42. *A reciprocating engine supercharger can be used as a source of pressurization if it is upstream of carburetion.*

Figure 16-43. *The radial engine supercharger cannot be used since fuel is introduced before the supercharger impeller compresses the air.*

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.

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.

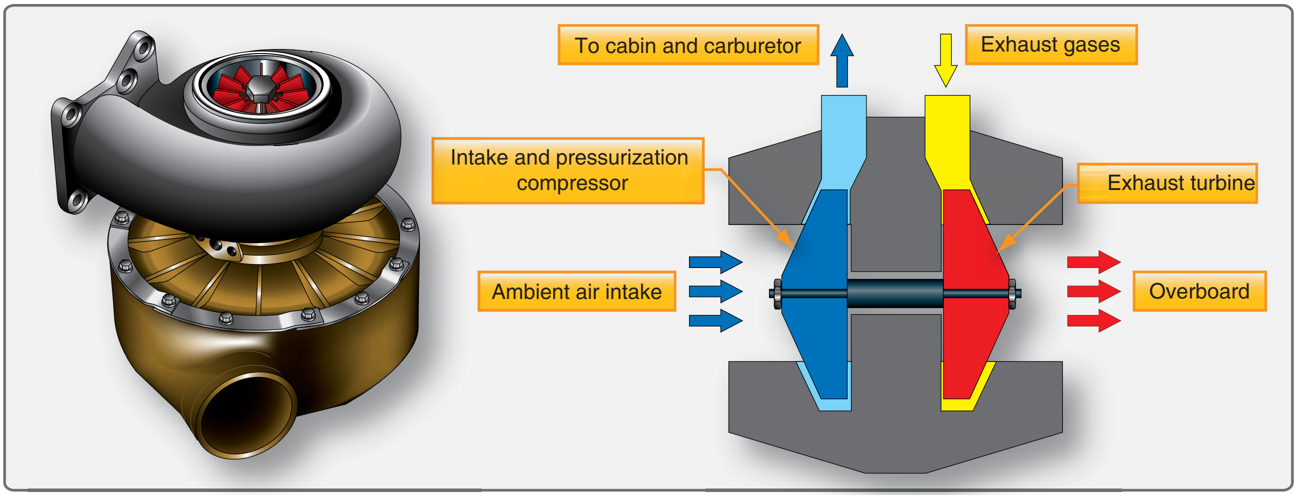


Figure 16-44. *A turbocharger used for pressurizing cabin air and engine intake air on a reciprocating engine aircraft.*

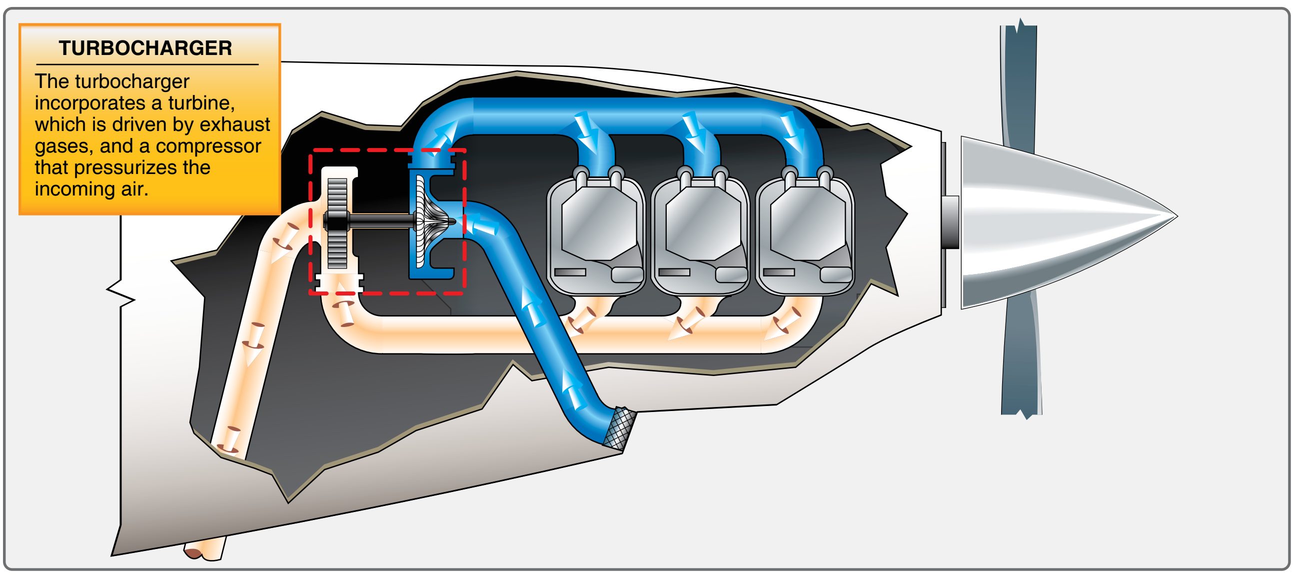


Figure 16-45. *A turbocharger installation on a reciprocating aircraft engine (top left side).*

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 pressurized. Due to the low pressure established in the

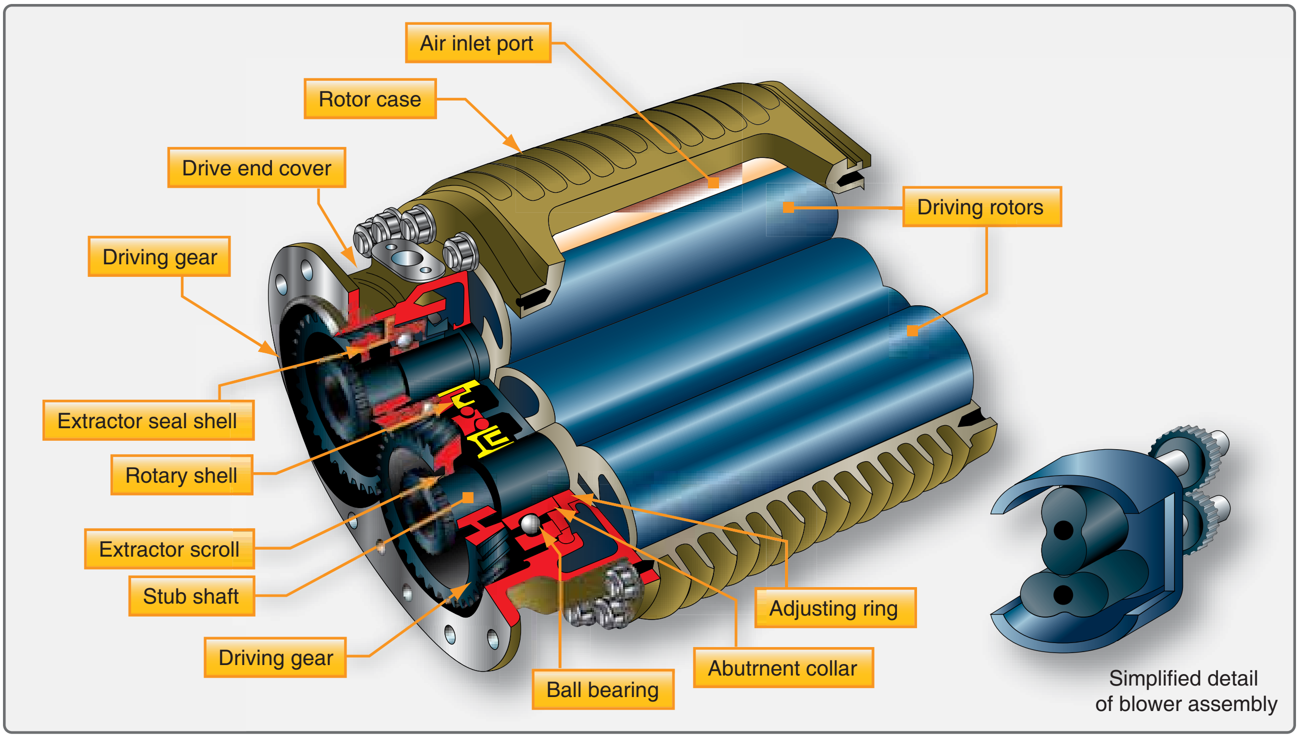


Figure 16-46. *A roots blower found on older pressurized aircraft is gear driven by the engine. It pressurizes air as the rotors rotate very close to each other without touching.*

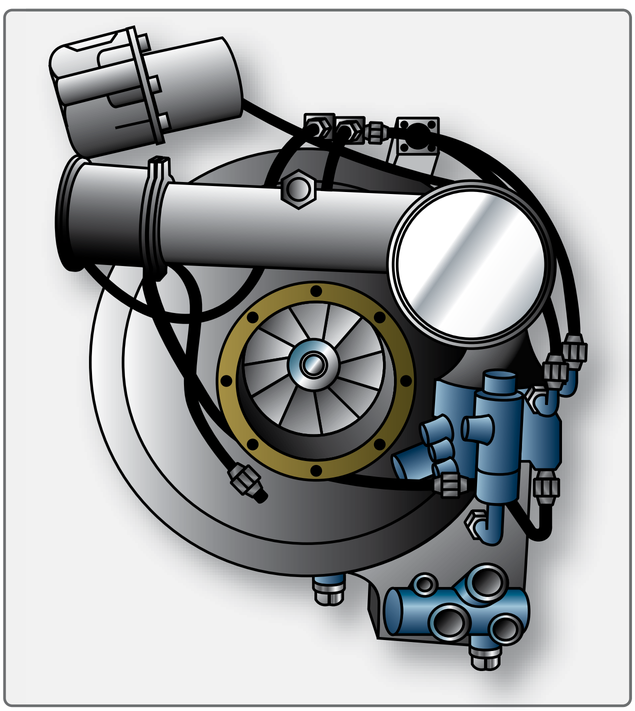


Figure 16-47. *A centrifugal cabin supercharger.*

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]*

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,

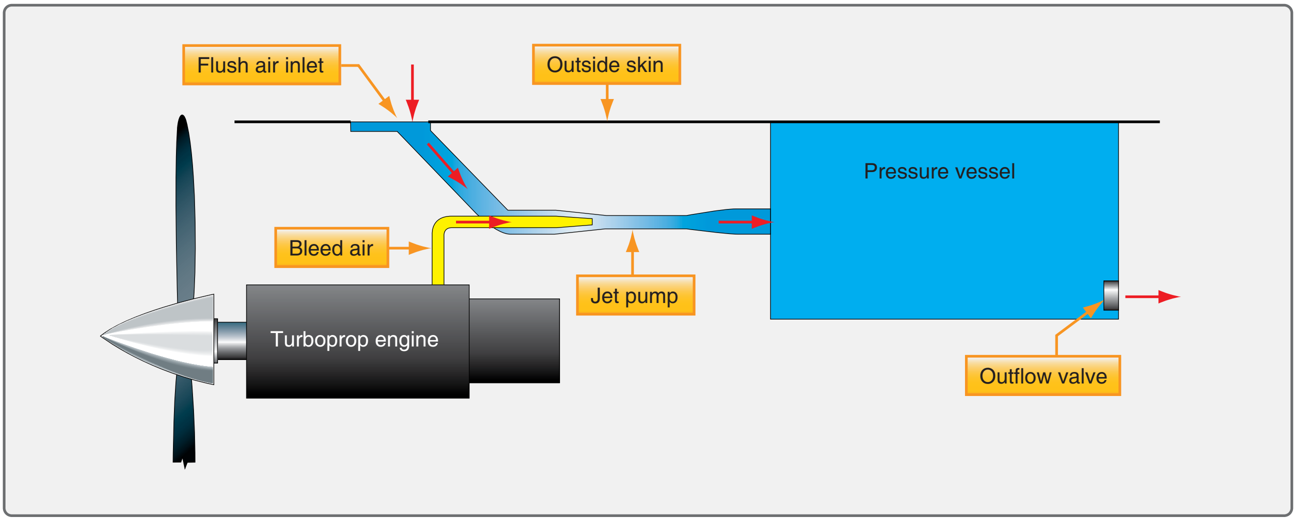


Figure 16-48. *A jet pump flow multiplier ejects bleed air into a venturi which draws air for pressurization from outside the aircraft.*

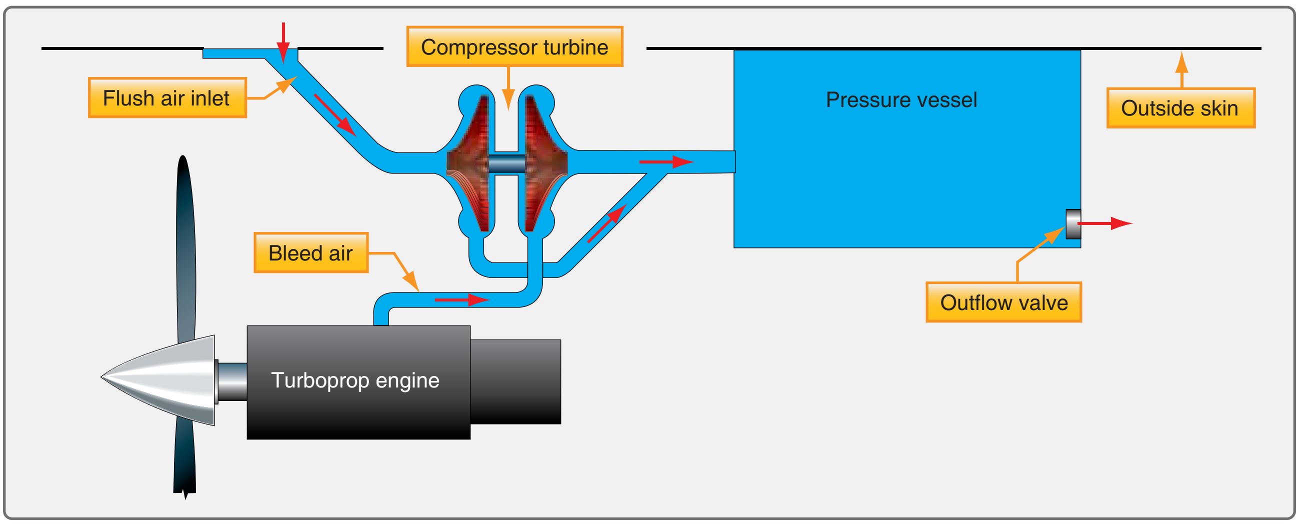


Figure 16-49. *A turbo compressor used to pressurize cabins mostly in turboprop aircraft.*

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 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]*

Figure 16-50. *An air cycle air conditioning system used to pressurize the cabin of a business jet.*

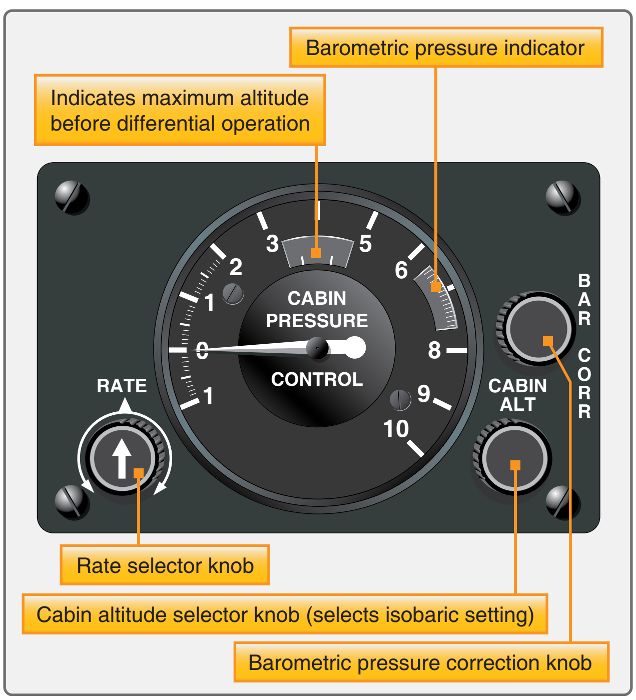


Figure 16-51. *A pressure controller for an all pneumatic cabin pressure control system.*

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.

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

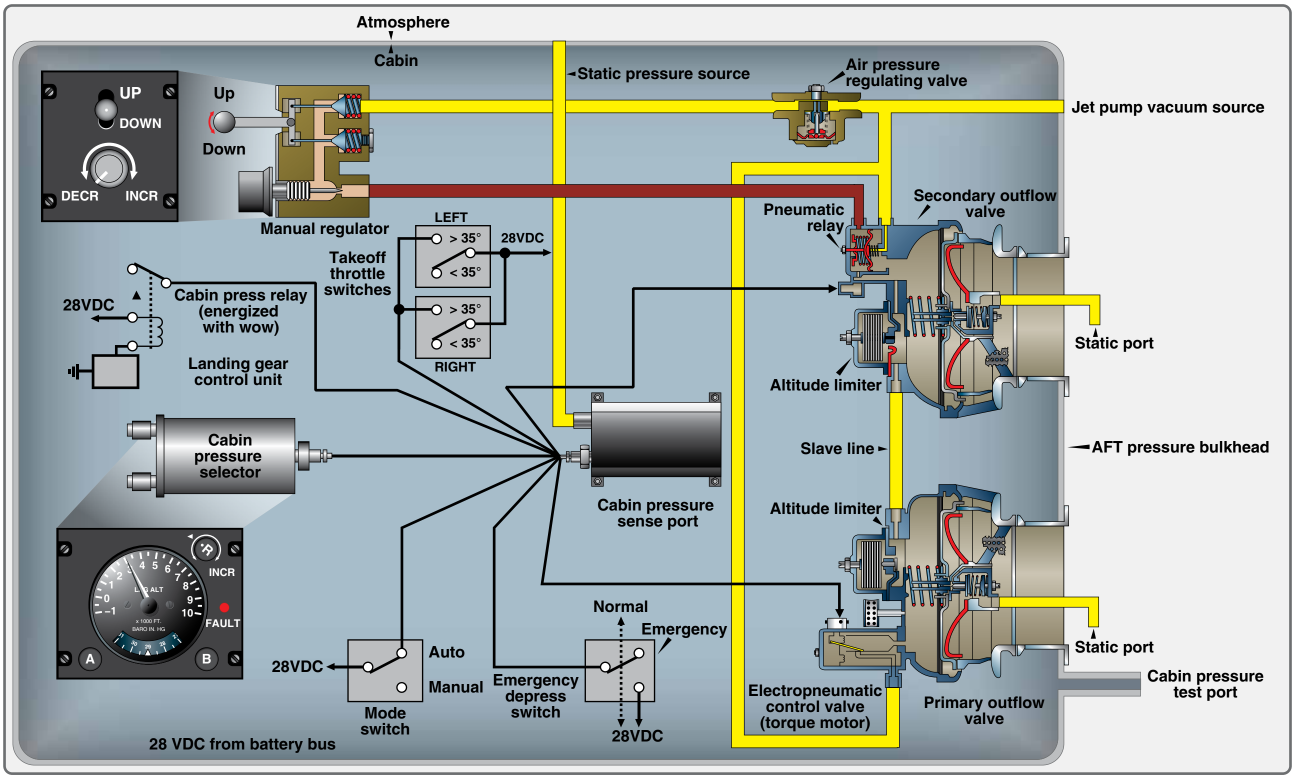


Figure 16-52. *The pressurization control system on many small transports and business jets utilizes a combination of electronic, electric, and pneumatic control elements.*

and communication with the ADC and the flight management 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]*

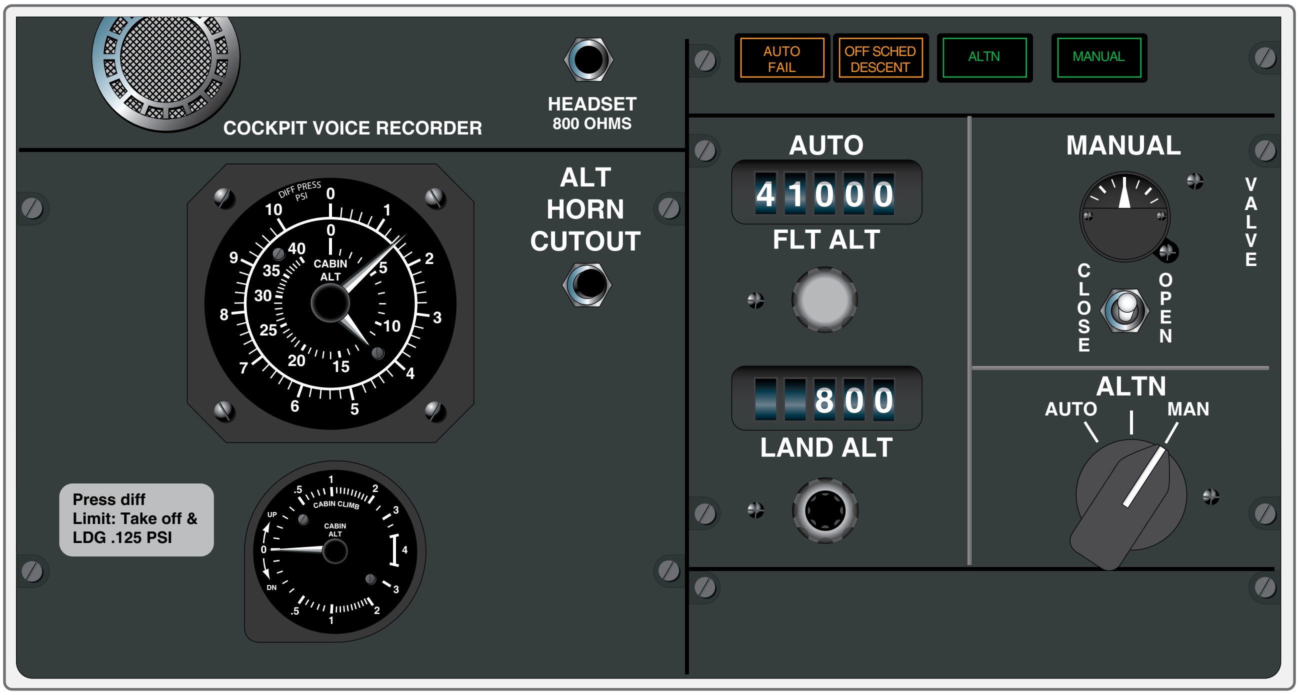


Figure 16-53. *This pressurization panel from an 800 series Boeing 737 has input selections of flight altitude and landing altitude.*

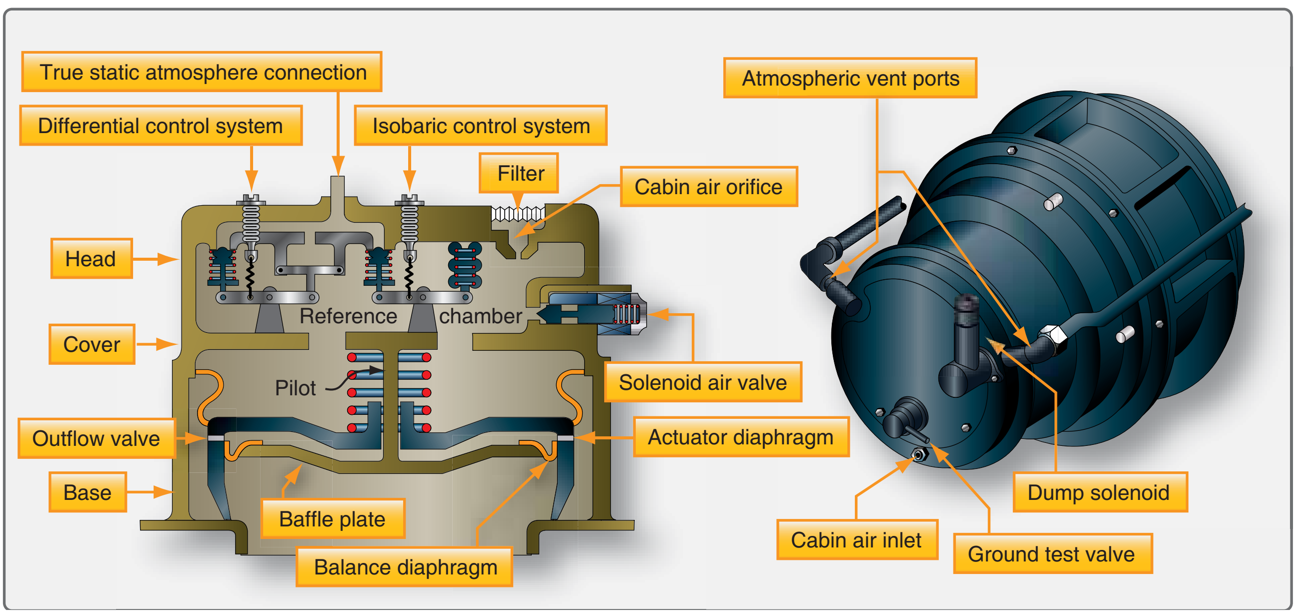


Figure 16-54. *An all-pneumatic cabin pressure regulator and outflow valve.*

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 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. Wide-body transport category aircraft cabins may have more than one cabin pressurization safety valve.

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.*

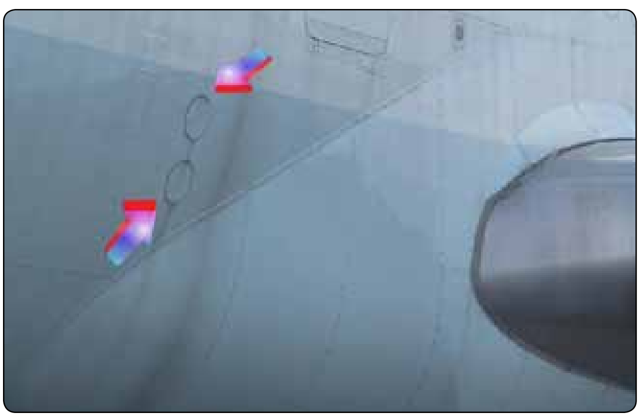


Figure 16-56. *Two pressurization safety valves are shown on a Boeing 747.*

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 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 selected. This also provides automatic control

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.*

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 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

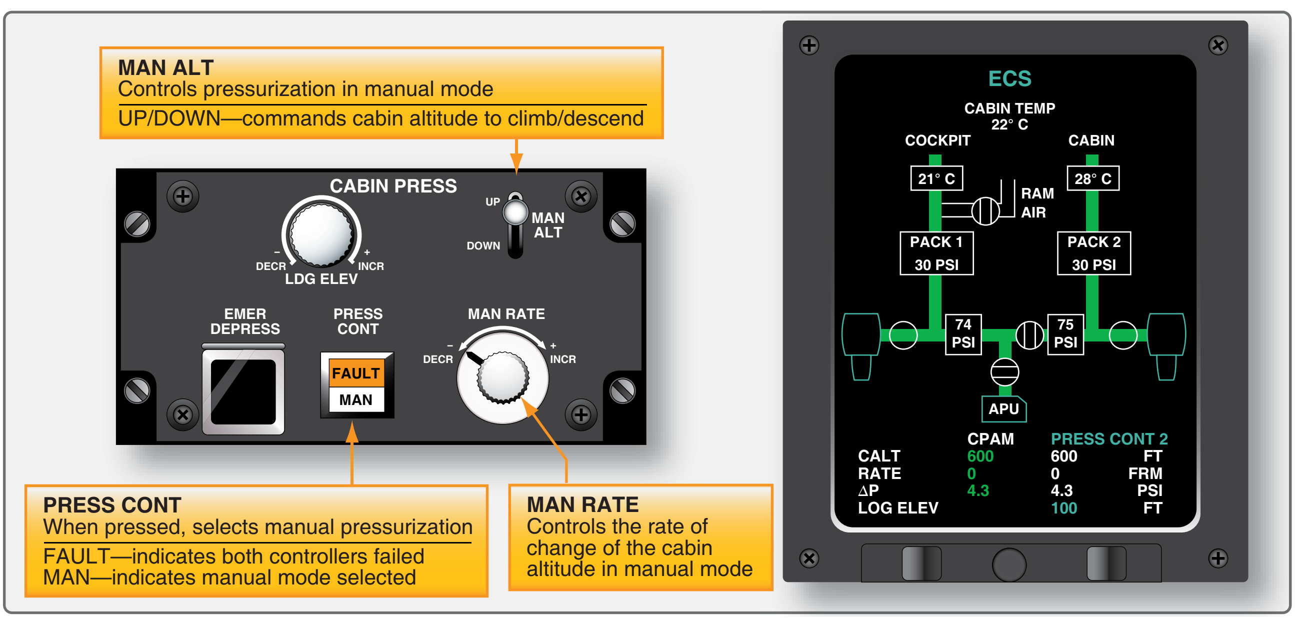


Figure 16-58. *The pressurization panel and environmental control system page on a Bombardier CRJ200 50 passenger jet have no gauges. Traditional pressurization data is presented in digital format at the bottom of the page.*

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]*

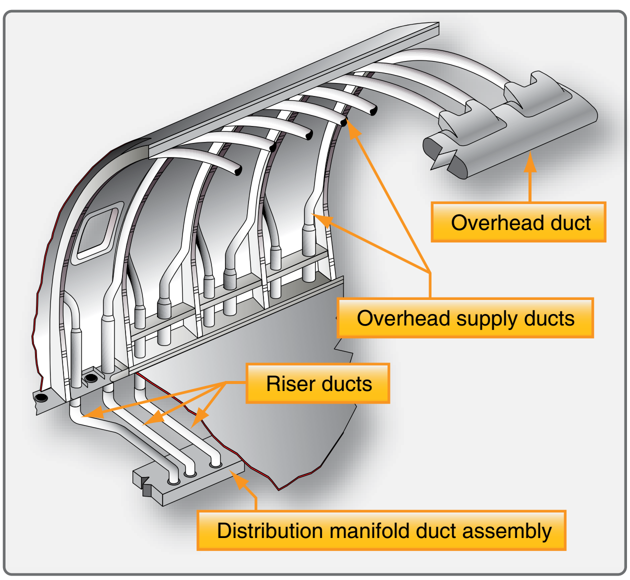


Figure 16-59. *Centralized manifolds from which air can be distributed are common.*

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 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

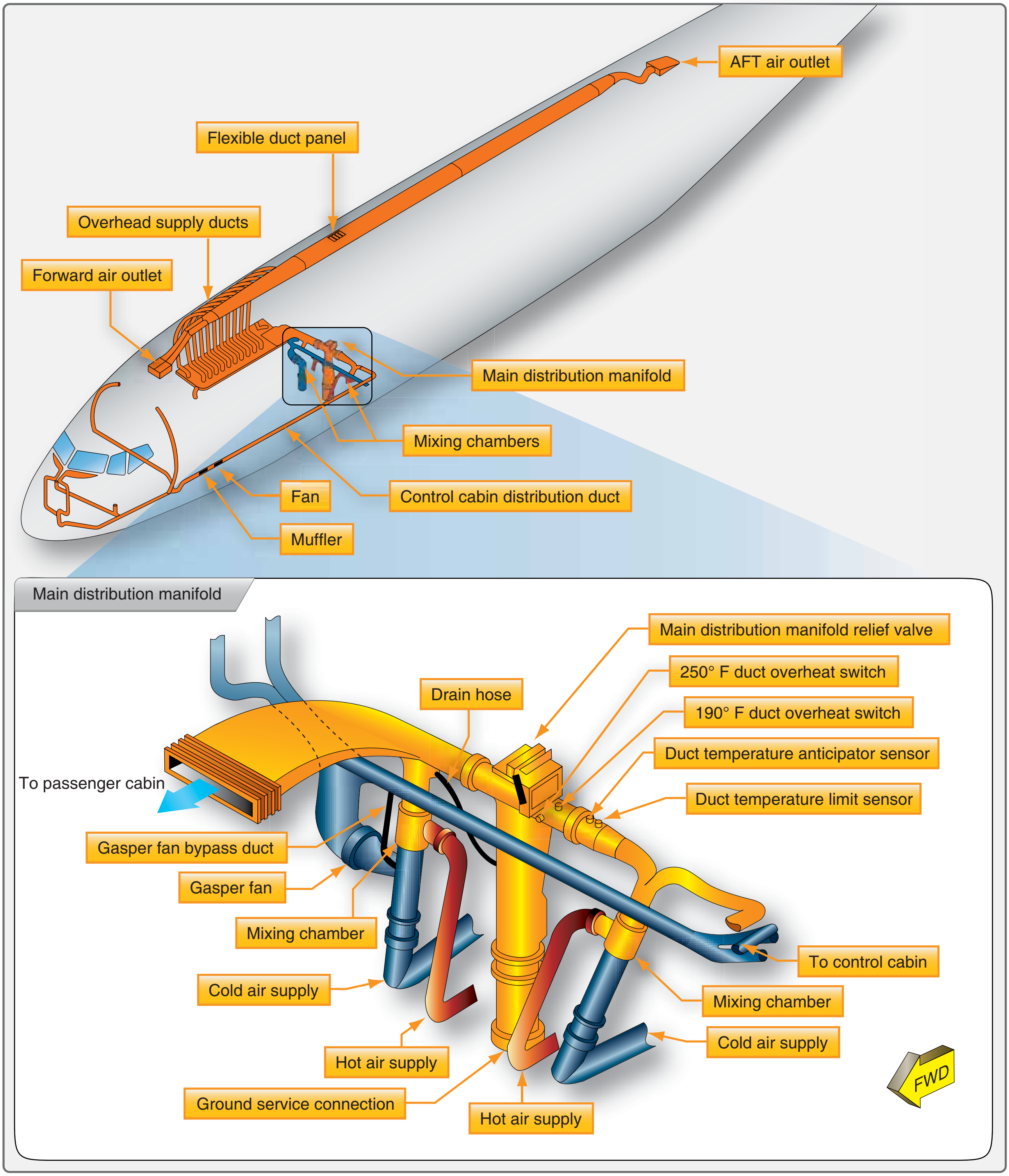


Figure 16-60. *The conditioned air distribution system on a Boeing 737. The main distribution manifold is located under the cabin floor. Riser ducts run horizontally then vertcally from the manifold to supply ducts, which follow the curvature of the fuselage carrying conditioned air to be released in the cabin.*

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

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.*

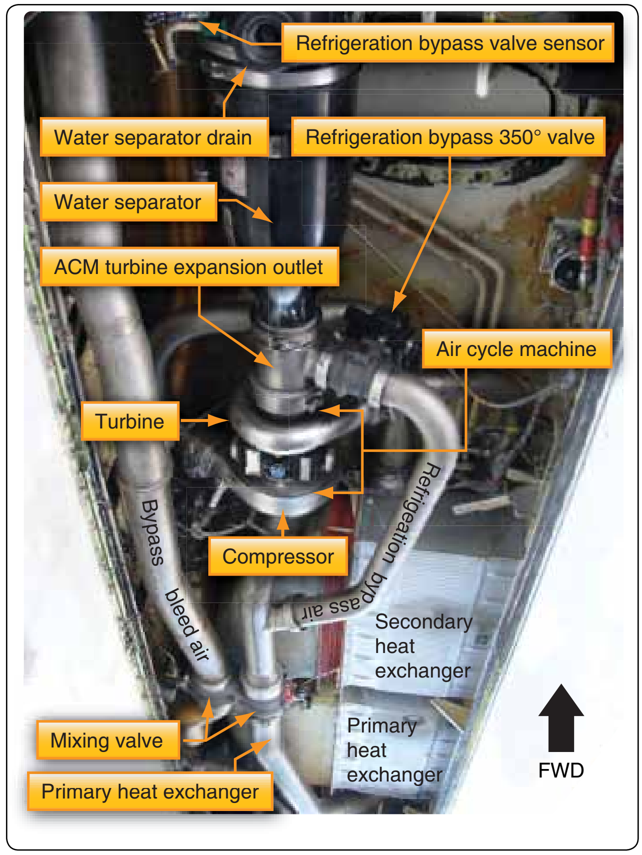


Figure 16-62. *Boeing 737 air cycle system. The photo is taken looking up into the air conditioning bay located in the lower fuselage on each side of the aircraft.*

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.

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

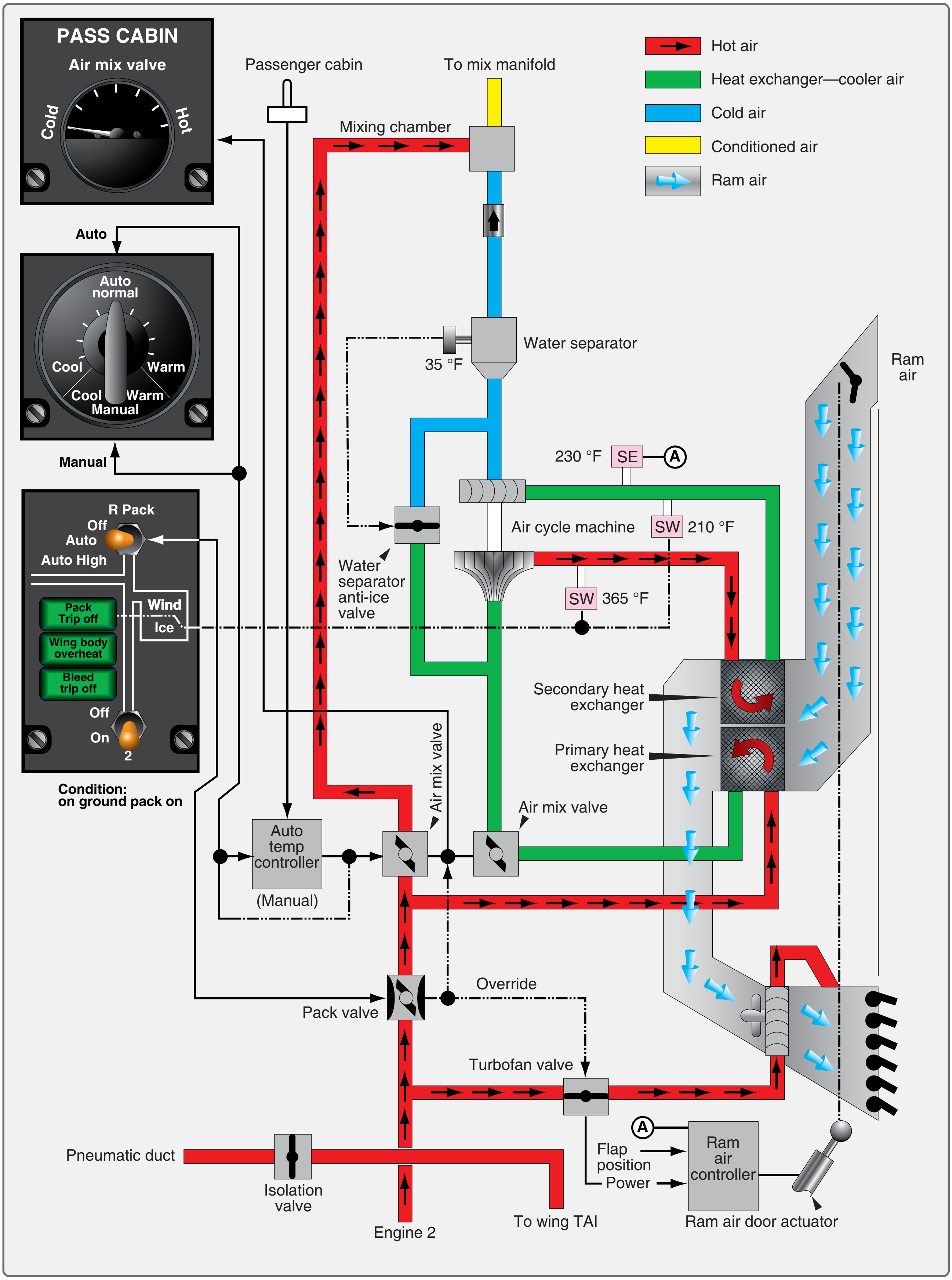


Figure 16-63. *The air cycle air conditioning system on a Boeing 737.*

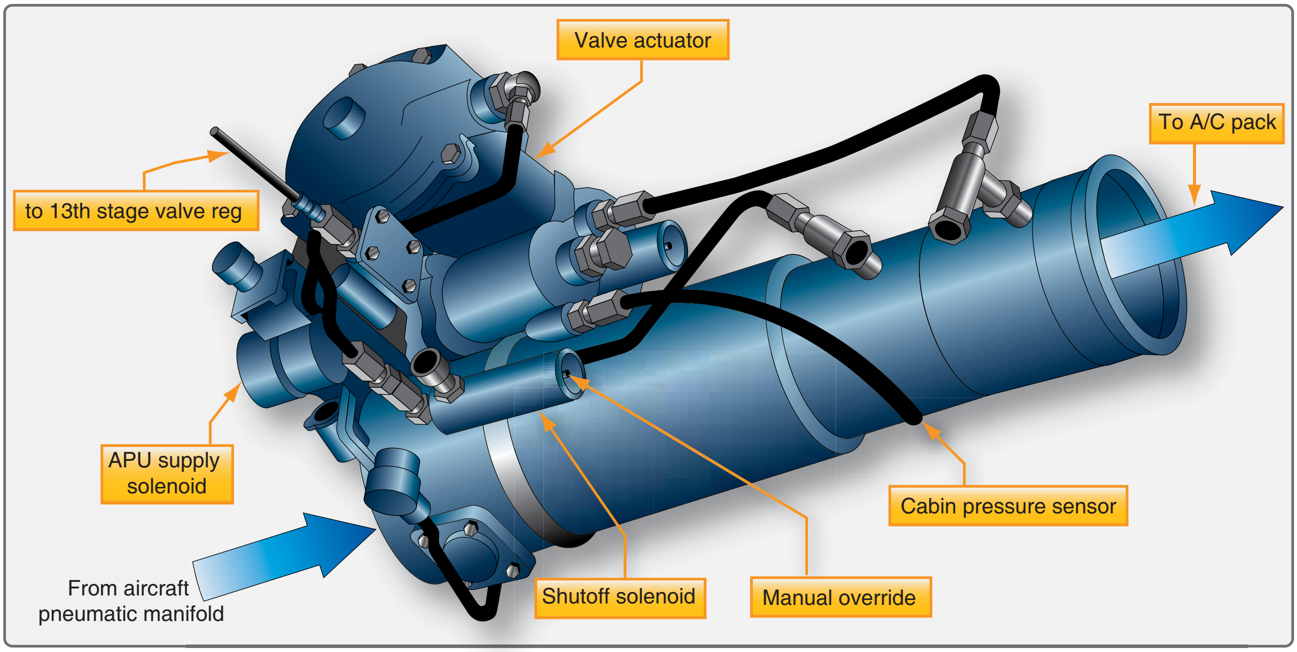


Figure 16-64. *This pack valve drawing illustrates the complexity of the valve, which opens, closes, and modulates. It is manually actuated from the cockpit and automatically responds to supply and air cycle system parameter inputs.*

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

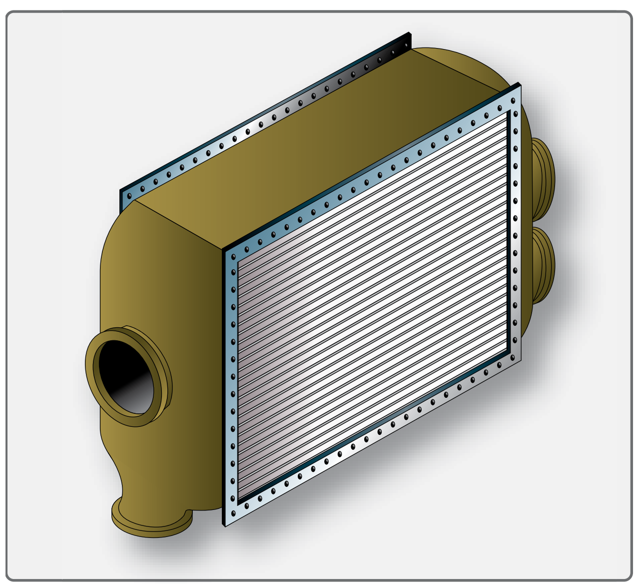


Figure 16-65. *The primary and secondary heat exchangers in an air cycle air conditioning system are of similar construction. They both cool bleed air when ram air passes over the exchanger coils and fins.*

air to the exchanger. Similar operation is accomplished with a valve on smaller aircraft. *[Figure 16-66]*

Figure 16-66. *A ram air door controls the flow of air through the primary and secondary heat exchangers.*

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, 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. 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]*

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

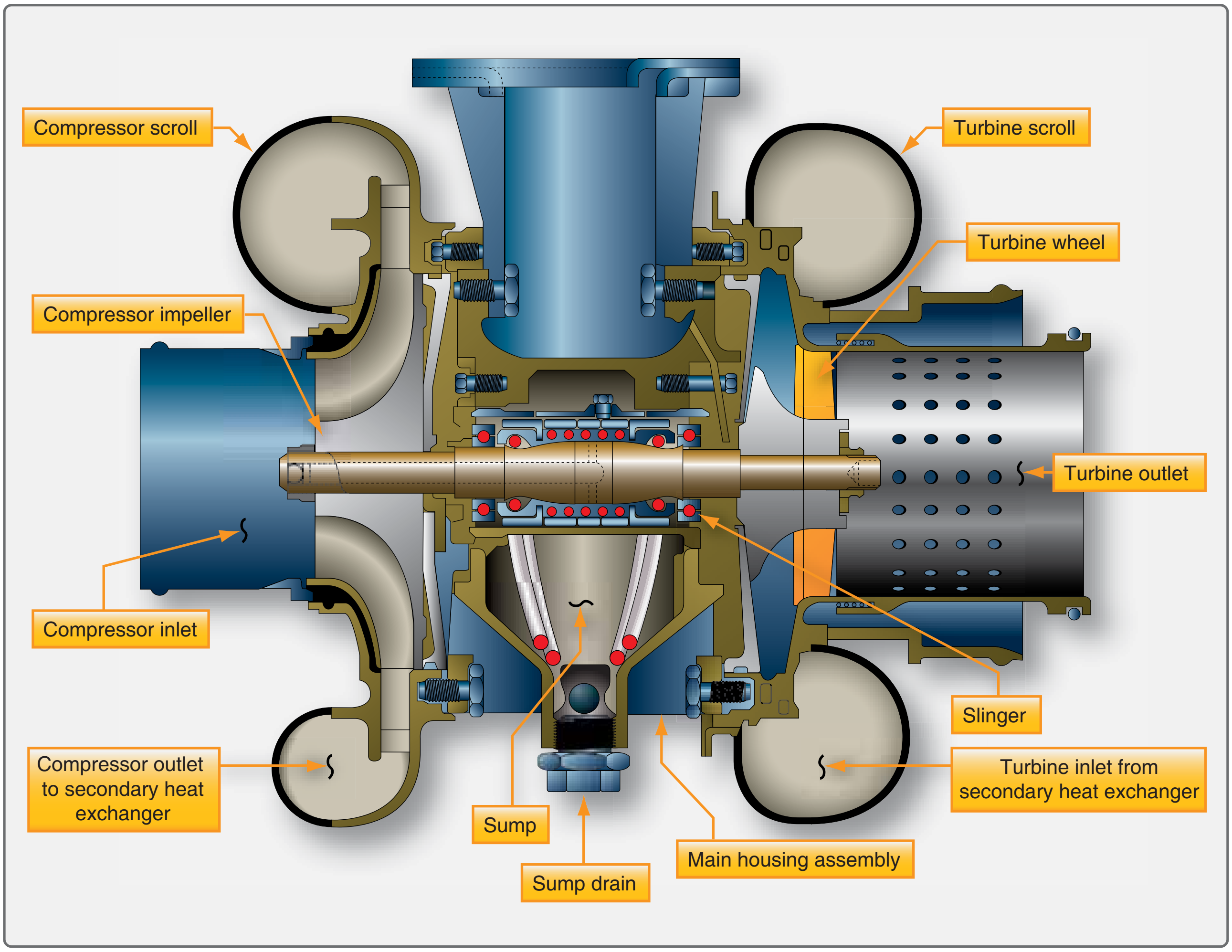


Figure 16-67. *A cutaway diagram of an air cycle machine. The main housing supports the single shaft to which the compressor and turbine are attached. Oil lubricates and cools the shaft bearings.*

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.

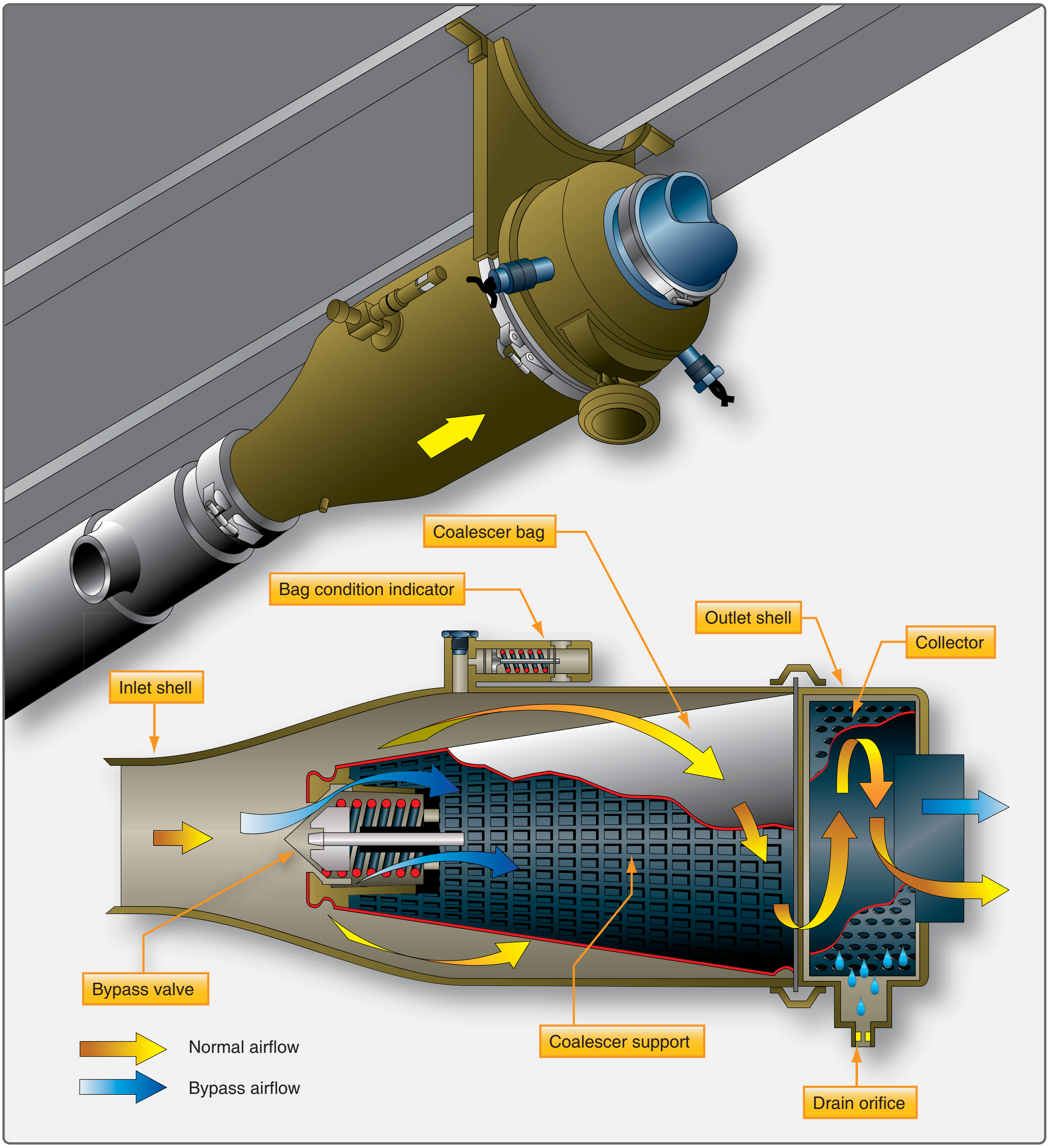


Figure 16-68. *A water separator coalesces and removes water by swirling the air/water mixture from ACM expansion turbine. Centrifugal force sends the water to the walls of the collector where it drains from the unit.*

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]*

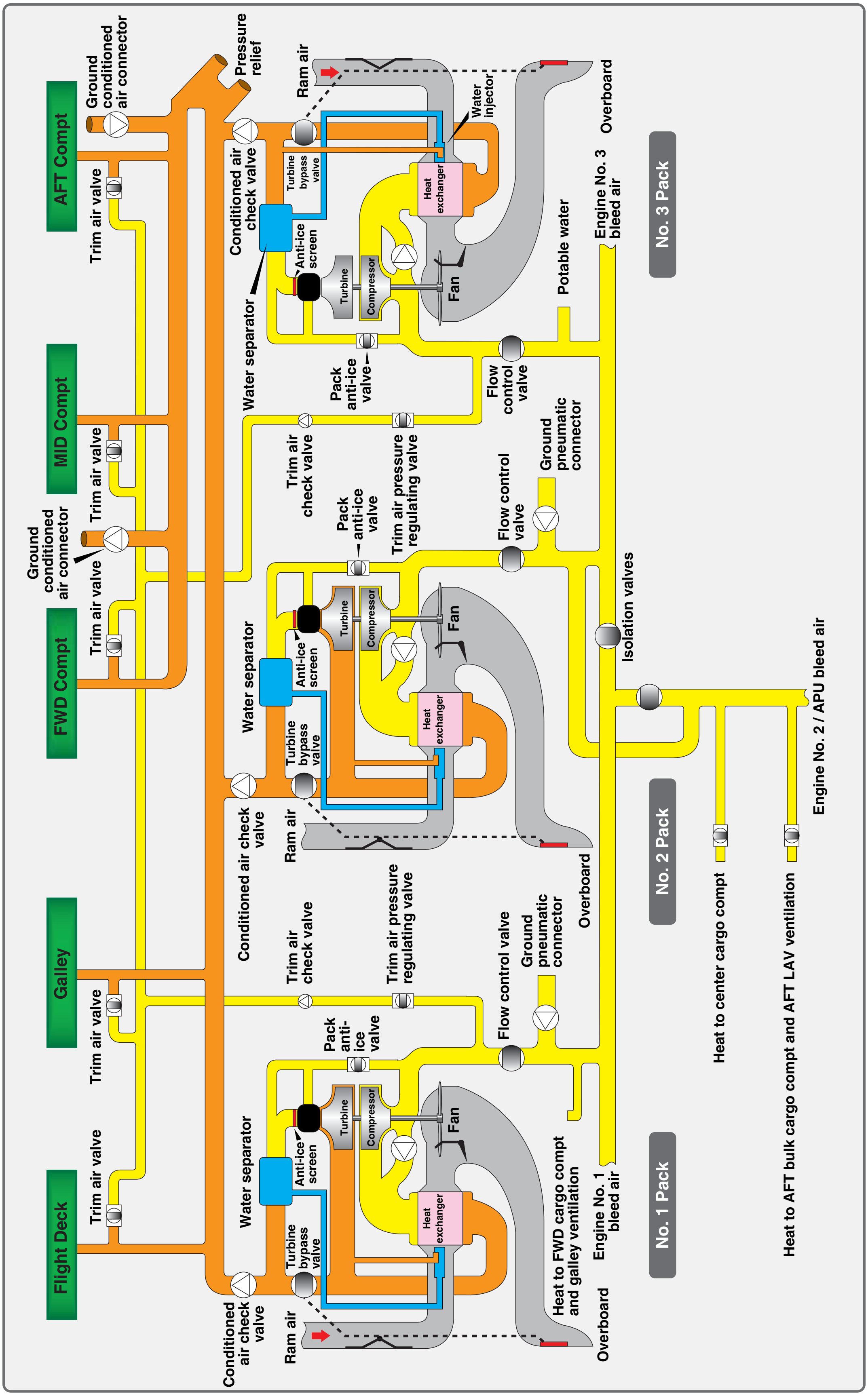


Figure 16-69. *The air cycle air conditioning system of a DC-10 transport category aircraft uses only one heat exchanger per ACM.*

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.*

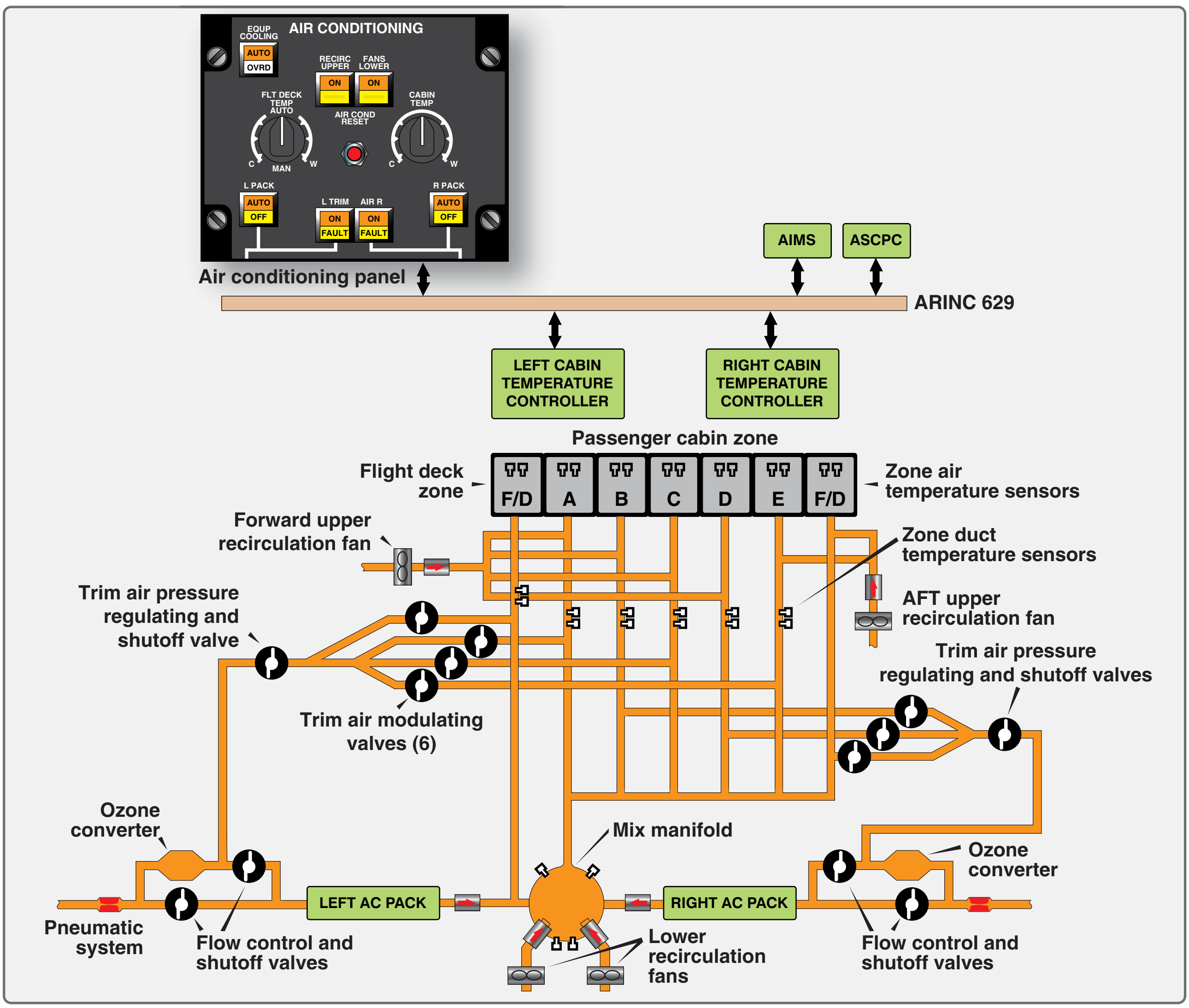


Figure 16-71. *The temperature control system of a Boeing 777 combines the use of zone and duct temperature sensors with trim air modulating valves for each zone. Redundant digital left and right cabin temperature controllers process temperature input signals from the sensors and temperature selectors on the cockpit panel and throughout the aircraft to modulate the valves.*

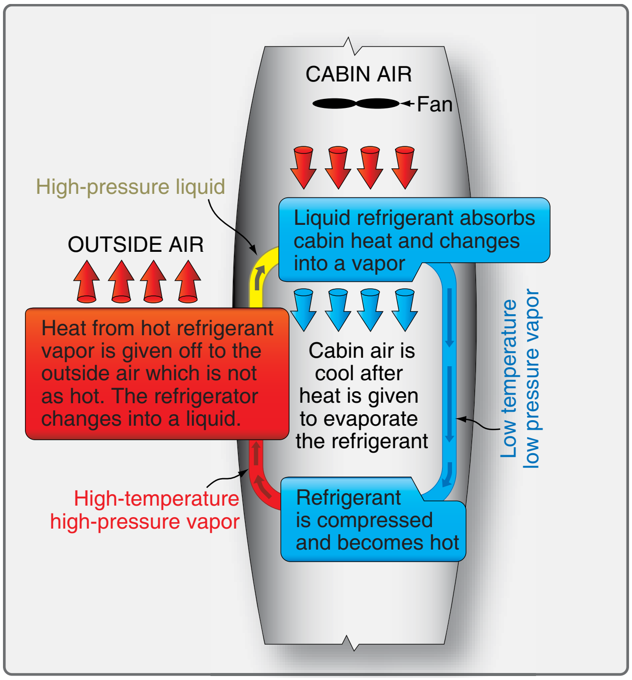


Figure 16-72. *In vapor cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapor and back again.*

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).

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]*

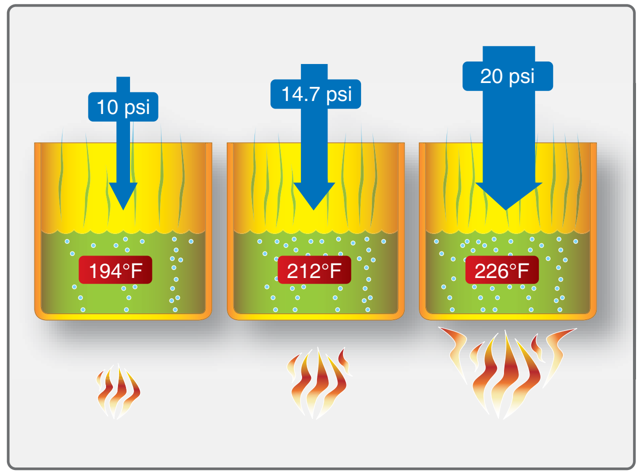


Figure 16-73. *Boiling point of water changes as pressure changes.*

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 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.

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.

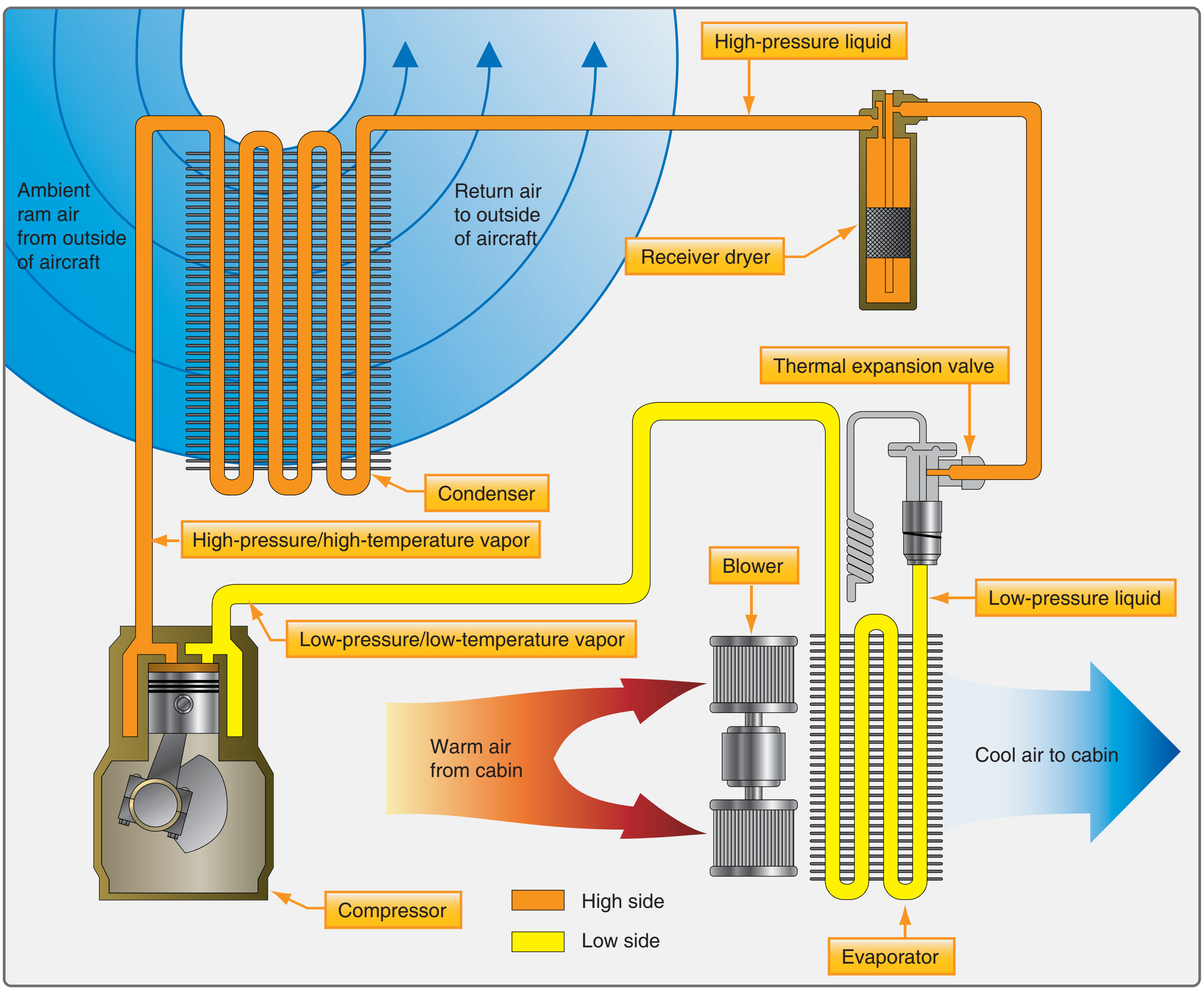


Figure 16-74. *A basic vapor cycle air conditioning system. The compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. This figure illustrates this division. Refrigerant on the low side is characterized as having low pressure and temperature. 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.

Figure 16-75. *A small can of R134a refrigerant used in vapor cycle air conditioning systems.*

R134a is a halogen compound (CF_3CFH_2). 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 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 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

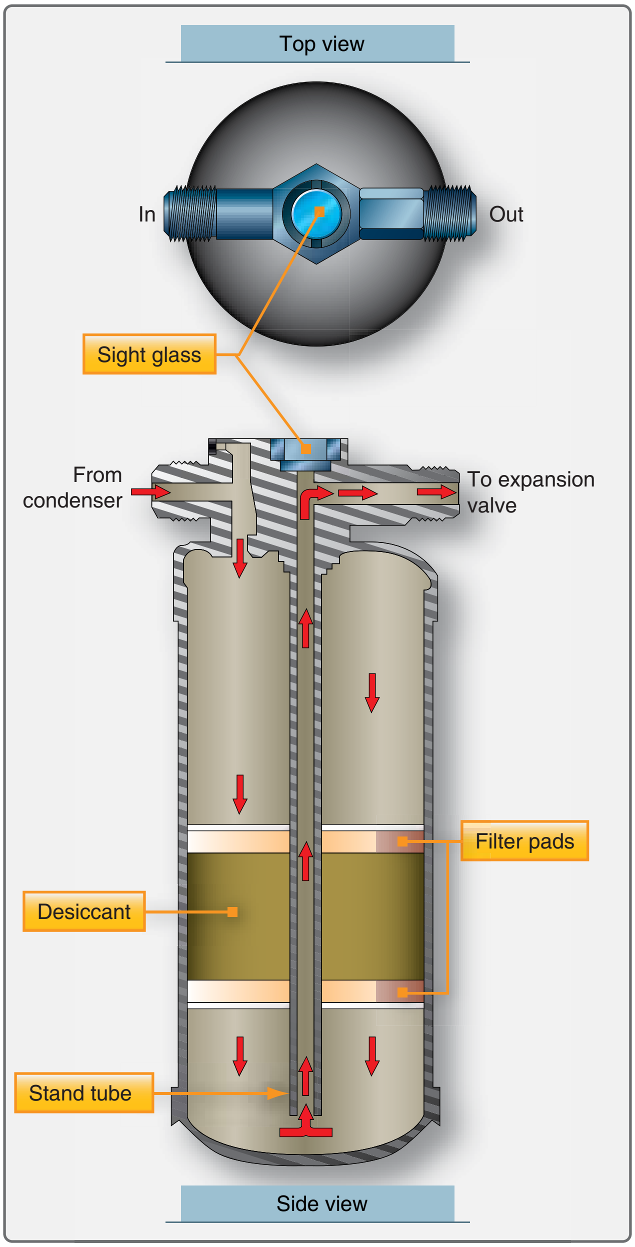


Figure 16-76. *A receiver dryer acts as reservoir and filter in a vapor cycle system. Bubbles viewed in the sight glass indicate the system is low on refrigerant and needs to be serviced.*

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]*

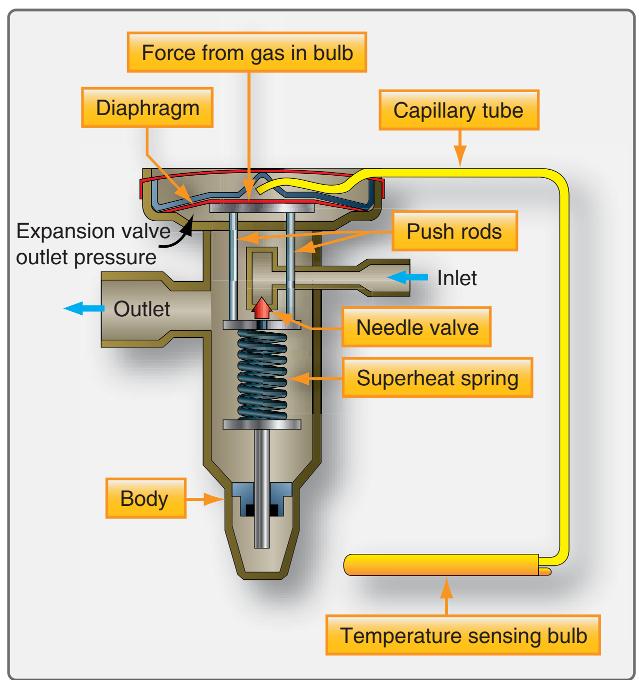


Figure 16-77. *An internally equalized expansion valve.*

Vapor cycle air conditioning systems that have large evaporators experience significant pressure drops while 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]*

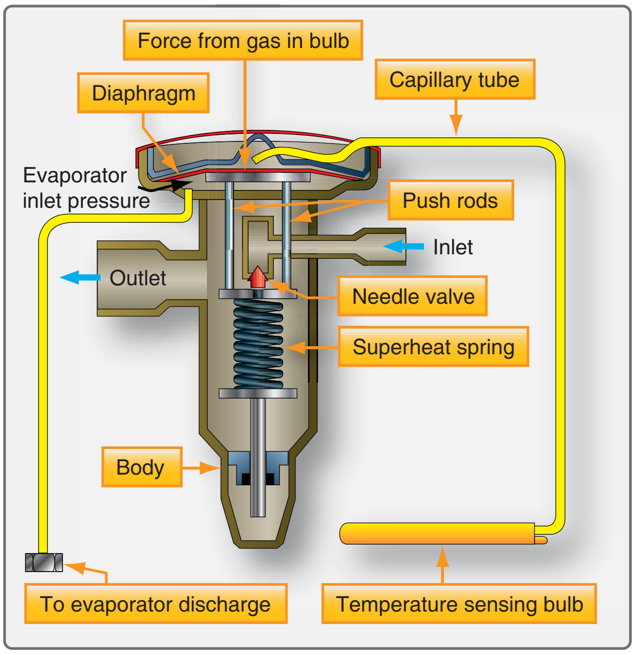


Figure 16-78. *An externally equalized expansion valve uses evaporator discharge temperature and pressure to regulate the amount of refrigerant passing through the valve and into the evaporator.*

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 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 system and cockpit mounted switches for the fans, as well as engaging and disengaging the system.

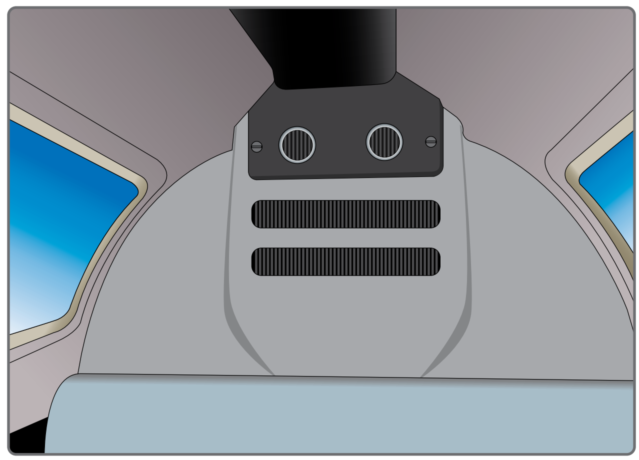


Figure 16-79. *The evaporator of this aircraft's vapor cycle air conditioning system is visible in the forward cabin sidewall behind the right rudder pedal.*

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

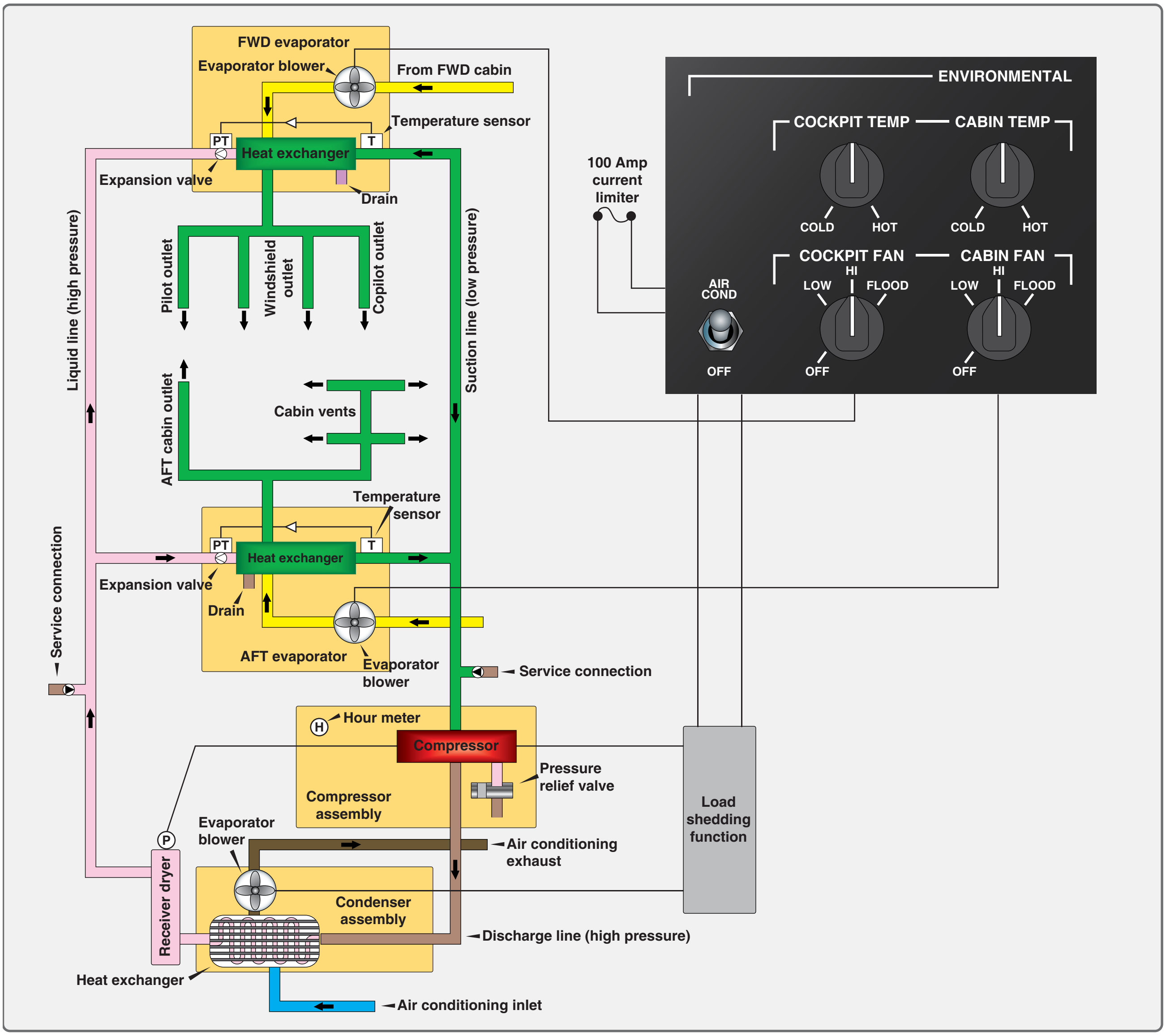


Figure 16-80. *The vapor cycle air conditioning system on a Cessna Mustang has two evaporators, one for the cockpit and one for the cabin. Each evaporator assembly contains the evaporator, a blower, a thermal expansion valve and the temperature feedback line from the outlet of the evaporator to the expansion valve.*

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 16-81. *A typical belt drive engine driven compressor. The electromagnetic clutch pulley assembly in the front starts and stops the compressor depending on cooling demand.*

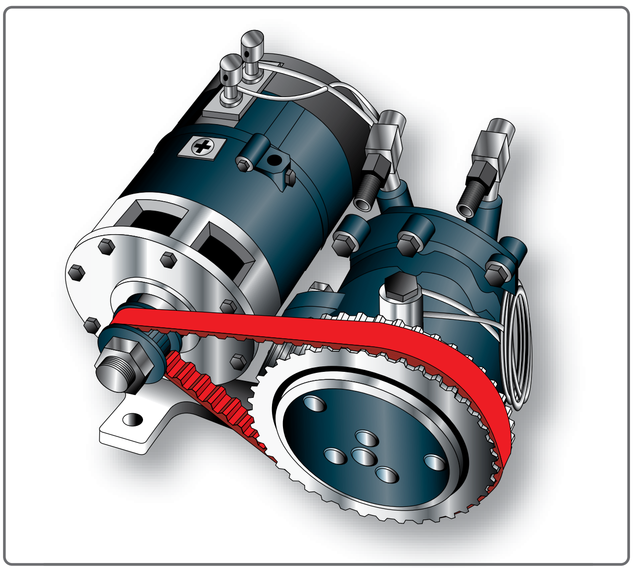


Figure 16-82. *Examples of electric motor driven vapor cycle air conditioning compressors.*

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]*

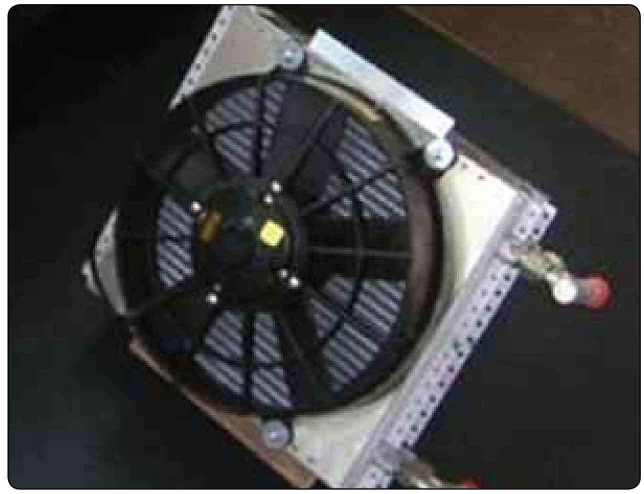


Figure 16-83. *A vapor cycle air conditioning condenser assembly with an integral fan used to pull outside air through the unit during ground operation.*

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 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.

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.

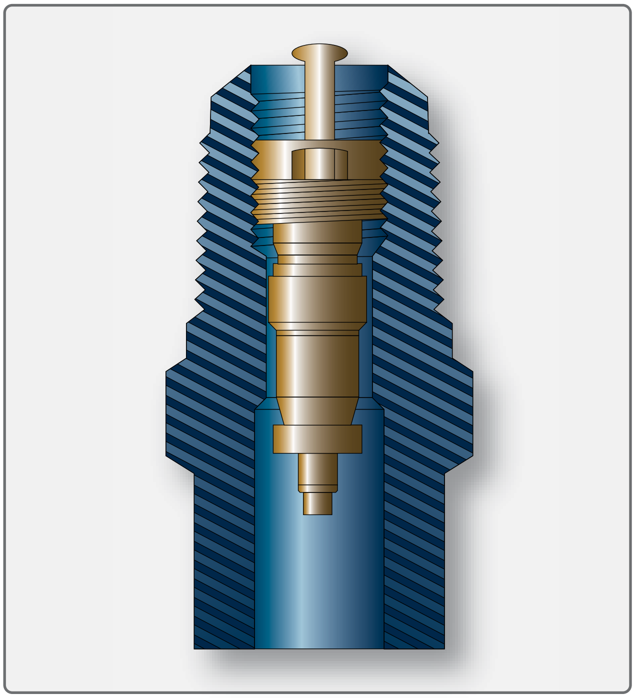


Figure 16-84. *Cross-section of an R12 refrigerant service valve.*

Another type of valve called a compressor isolation valve is used on some aircraft. It serves two purposes. Like 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]*

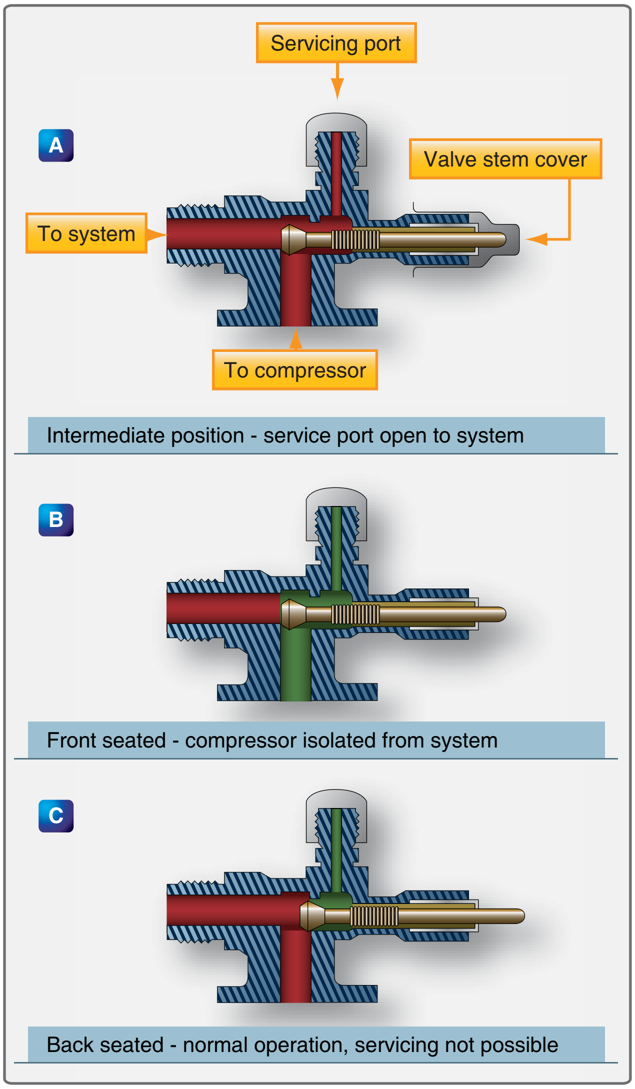


Figure 16-85. *Compressor isolation valves isolate the compressor for maintenance or replacement. They also allow normal operation and servicing of the vapor cycle air conditioning system with refrigerant.*

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]*

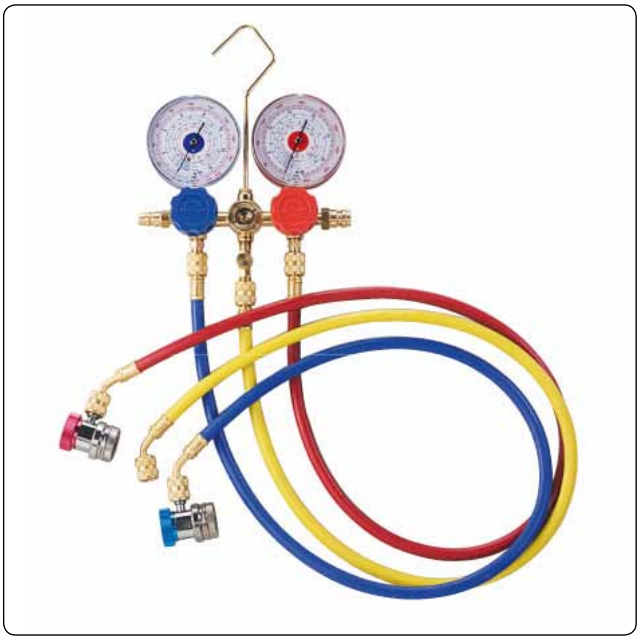


Figure 16-86. *A basic manifold set for servicing a vapor cycle air conditioning system.*

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*.

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]*

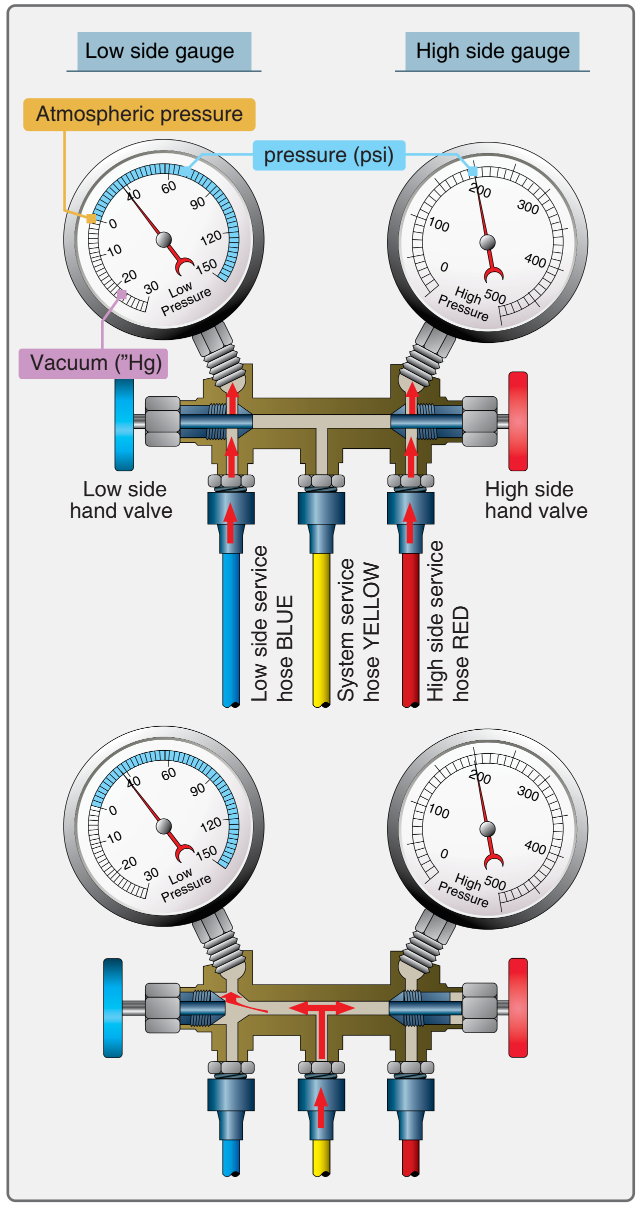


Figure 16-87. *The internal workings of a manifold set with the center fitting isolated (top). Opening a valve connects the center hose to that side of the system and the gauge (bottom).*

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 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

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.*

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 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]*

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.*

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.*

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.

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]*

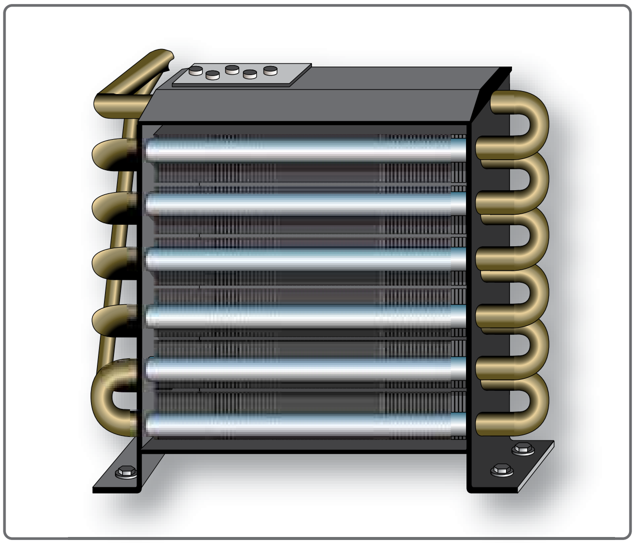


Figure 16-93. *Damaged fins on a condenser*

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, 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

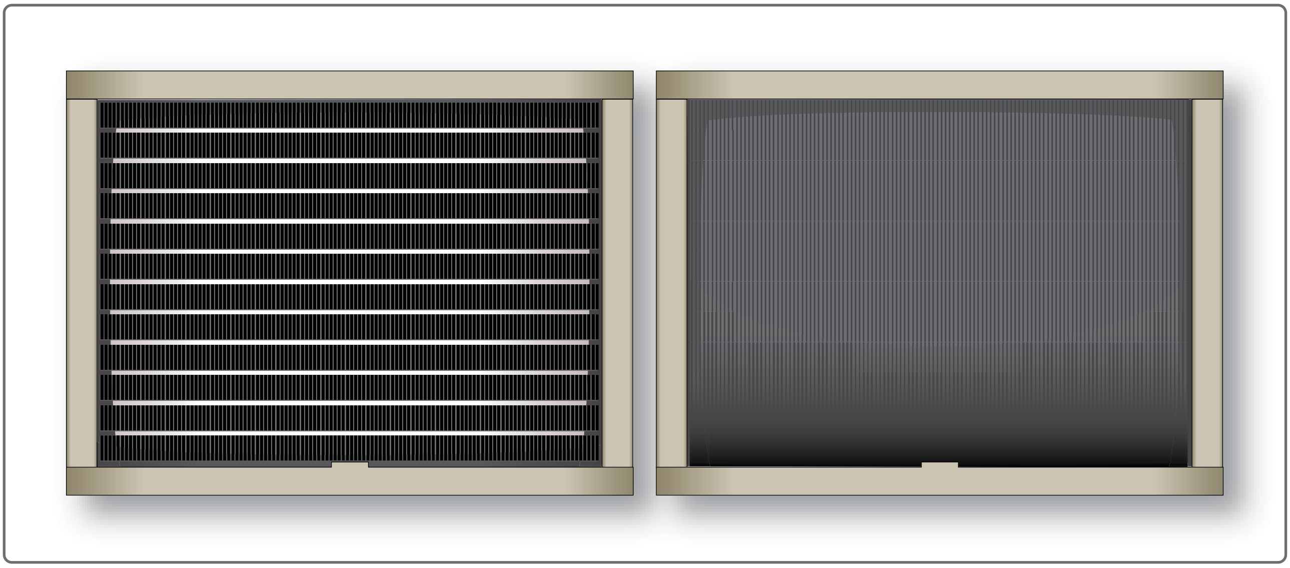


Figure 16-94. *Ice on the evaporator coils is cause for investigation. It prevents proper heat exchange to the refrigerant.*

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. 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]*

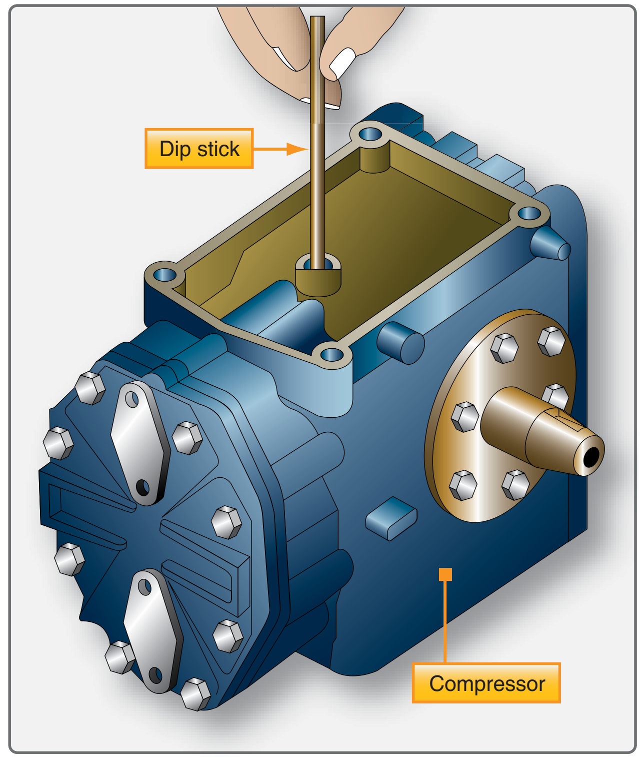


Figure 16-95. *Checking the compressor oil when the system is open.*

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 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]*

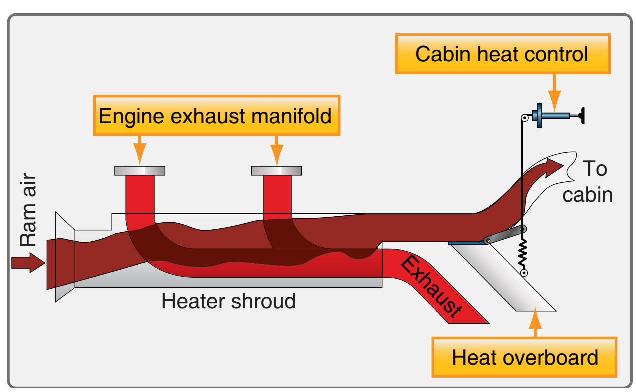


Figure 16-96. *The basic arrangement of an aircraft exhaust shroud heater.*

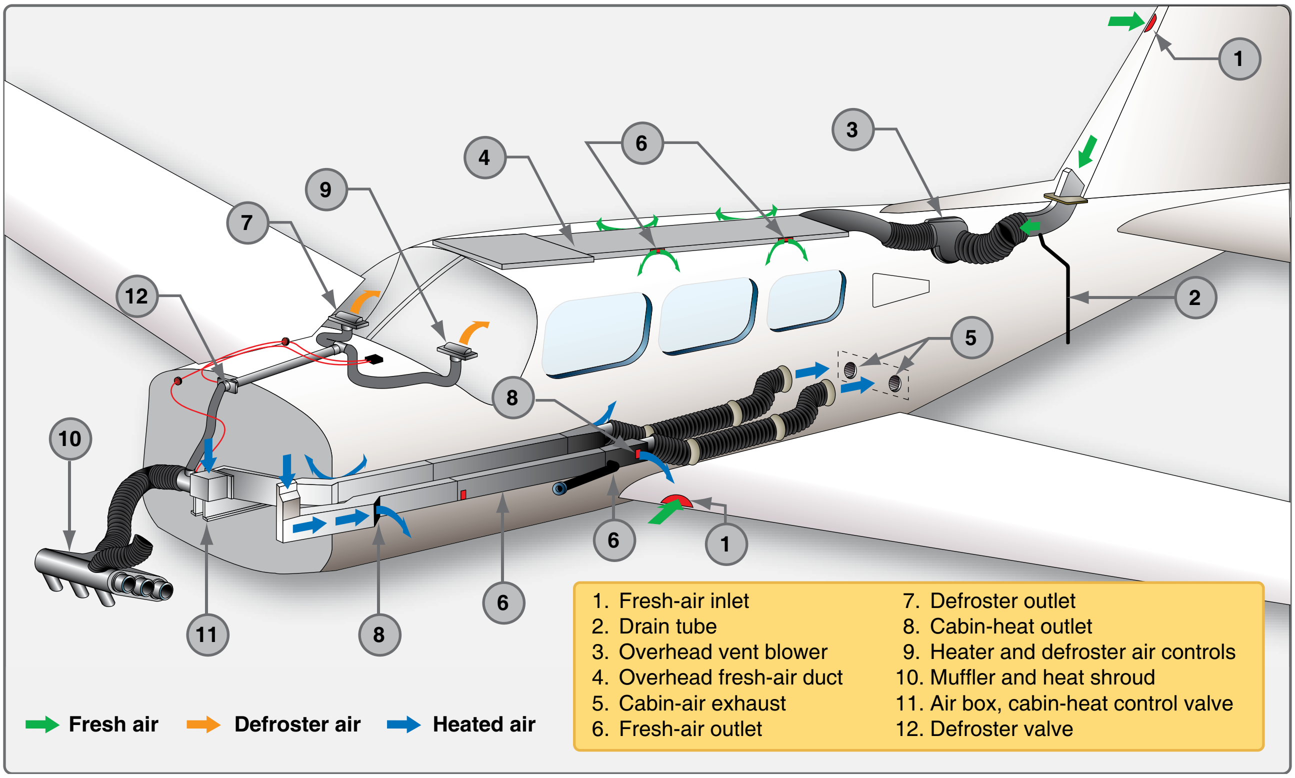


Figure 16-97. *The environmental system of a single-engine Piper aircraft with an exhaust shroud heating system.*

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]*

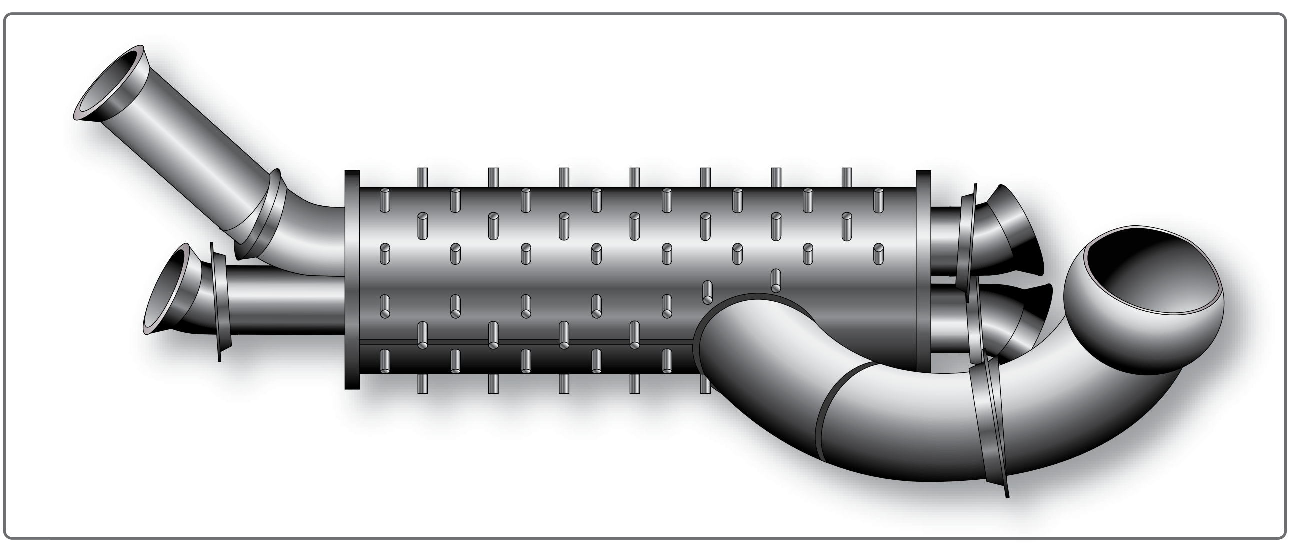


Figure 16-98. *An exhaust manifold with its shroud removed showing numerous welded studs used to increase heat transfer from the exhaust to the ambient air going to the cabin.*

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.

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.

Figure 16-99. *A modern combustion heater.*

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.

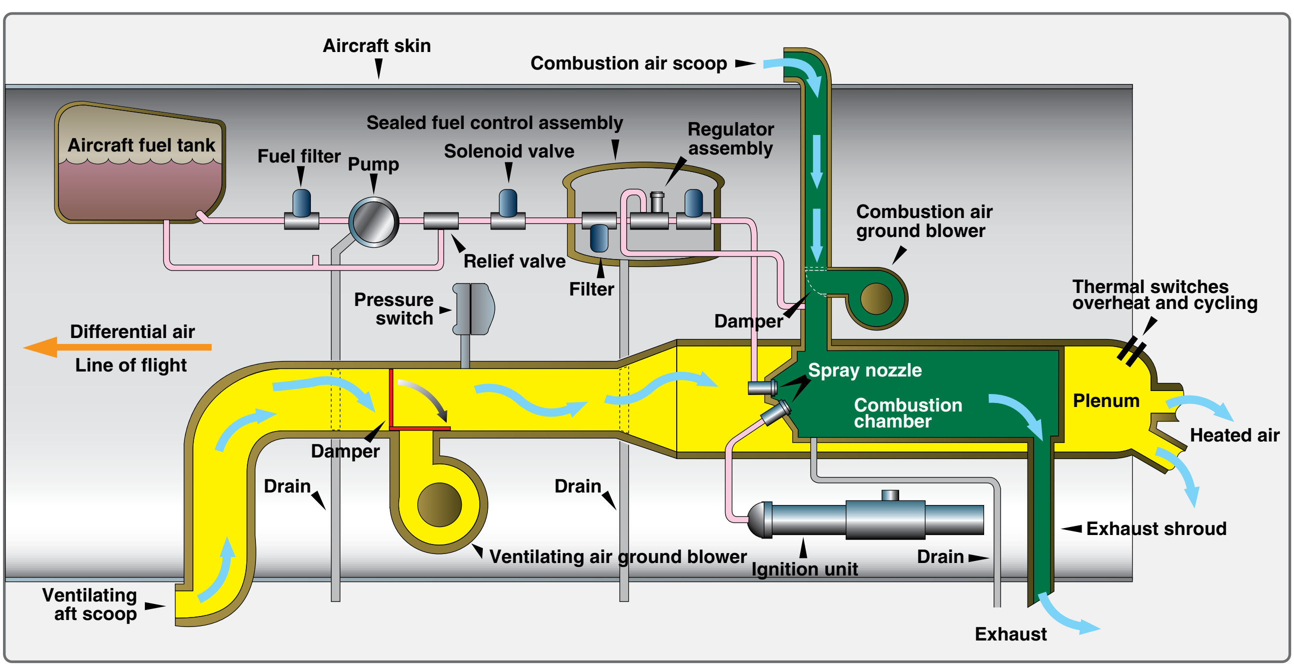


Figure 16-100. *A diagram of a typical combustion heater and its components.*

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 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]*

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.

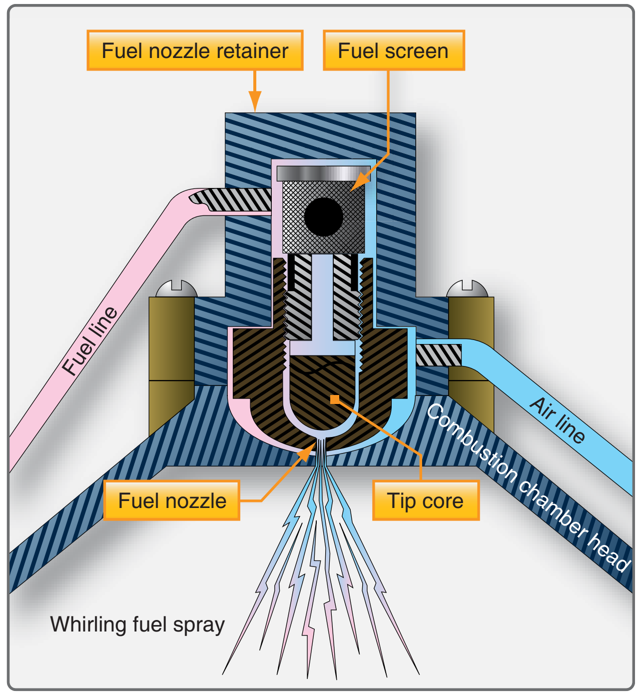


Figure 16-101. *The fuel nozzle located at the end of the combustion chamber sprays aircraft fuel, which is lit by a continuous sparking ignition system spark plug.*

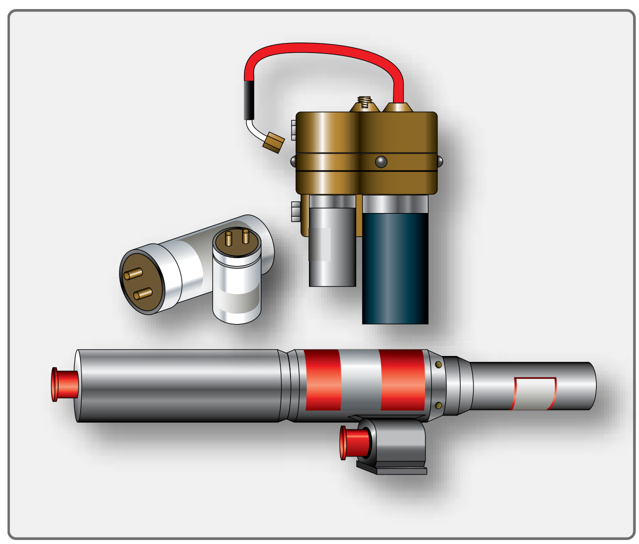


Figure 16-102. *Examples of ignition units used on combustion heaters.*

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.

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.