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

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.

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

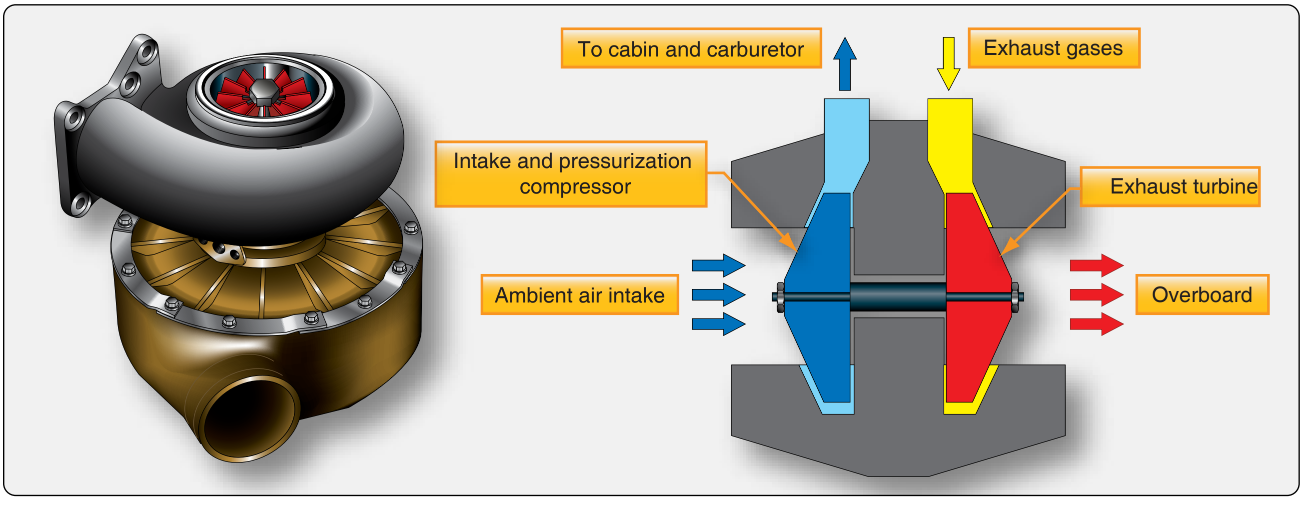

Figure 16-44. *A turbocharger used for pressurizing cabin air and engine intake air on a reciprocating engine aircraft.*

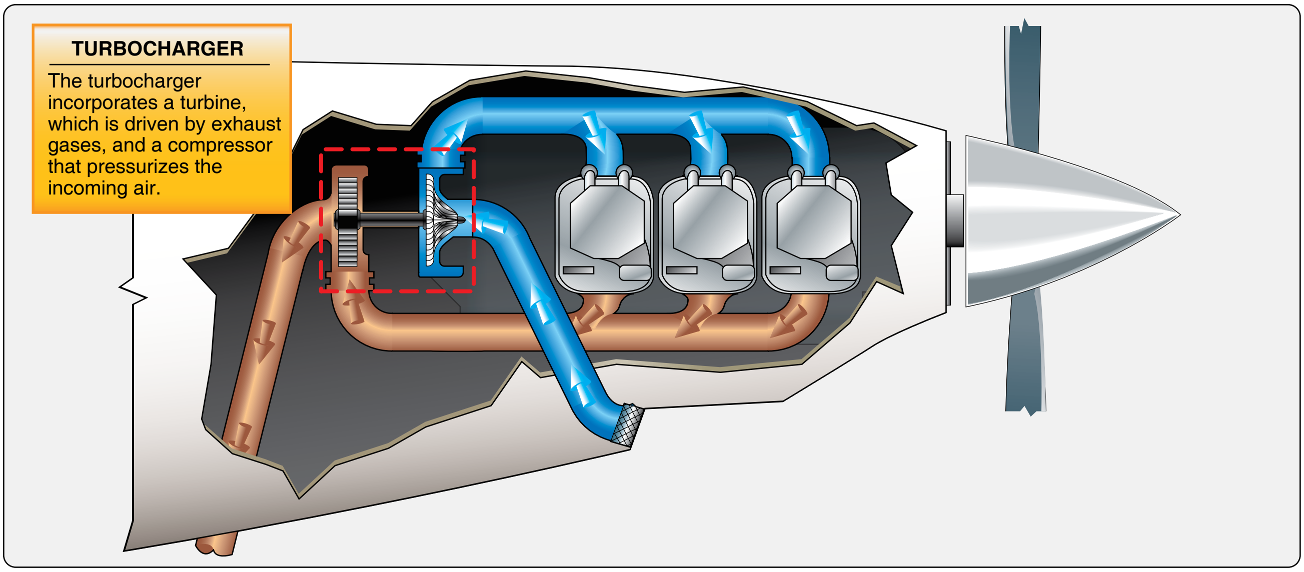

Figure 16-45. *A turbocharger installation on a reciprocating aircraft engine (top left side).*

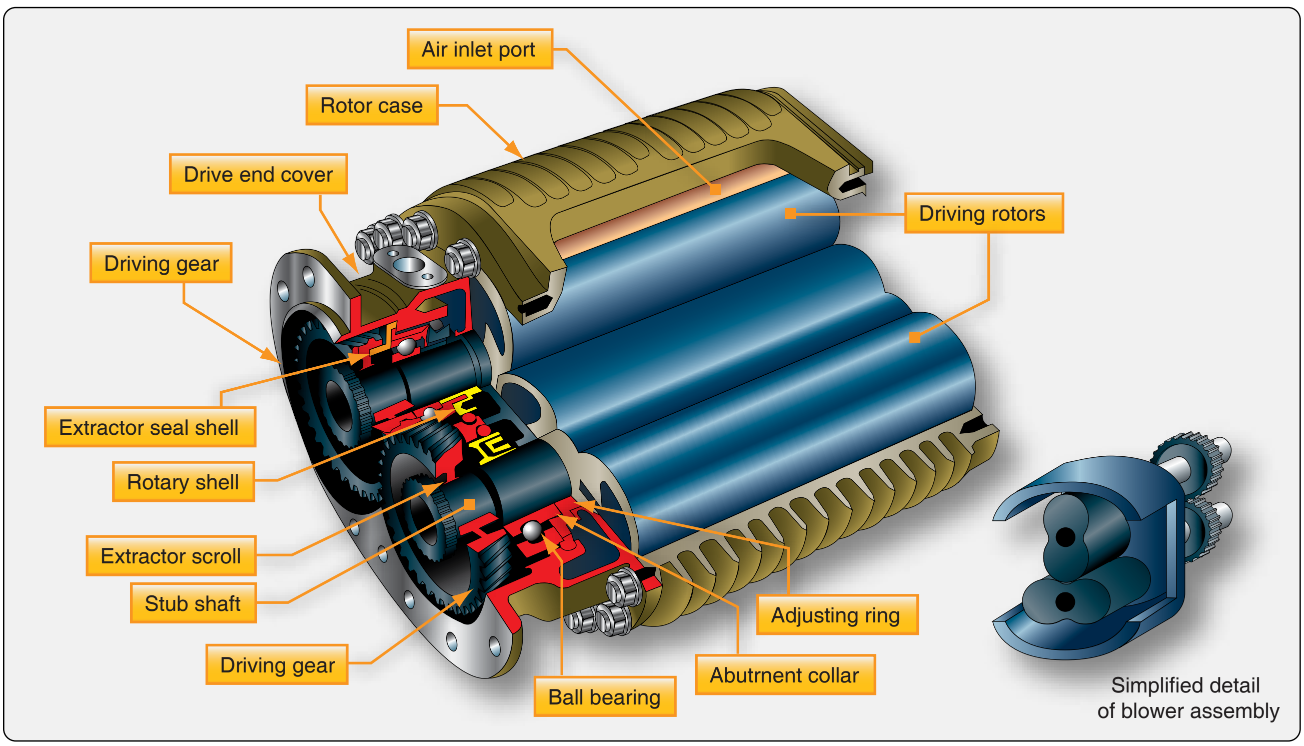

Figure 16-46. *A roots blower found on older pressurized aircraft is gear driven by the engine. It pressurizes air as the rotors rotate very close to each other without touching.*

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 venturi by the bleed air flow, air is drawn in from outside

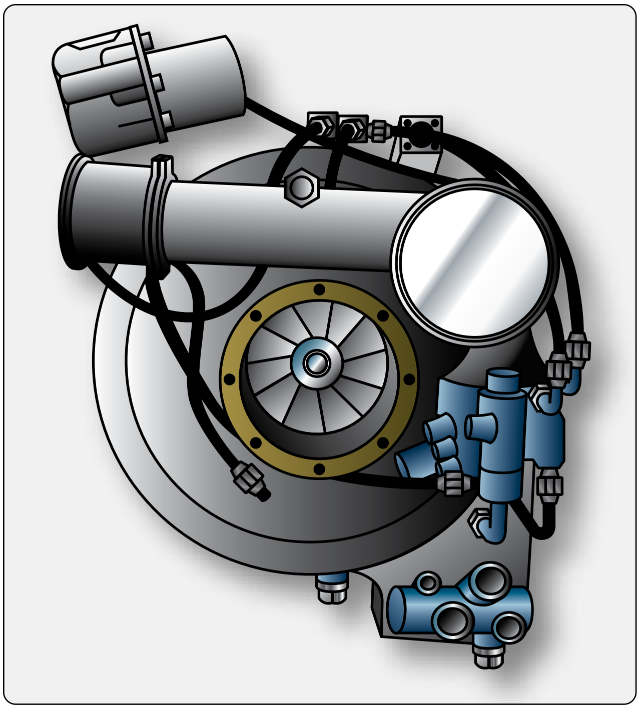

Figure 16-47. *A centrifugal cabin supercharger.*

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, 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

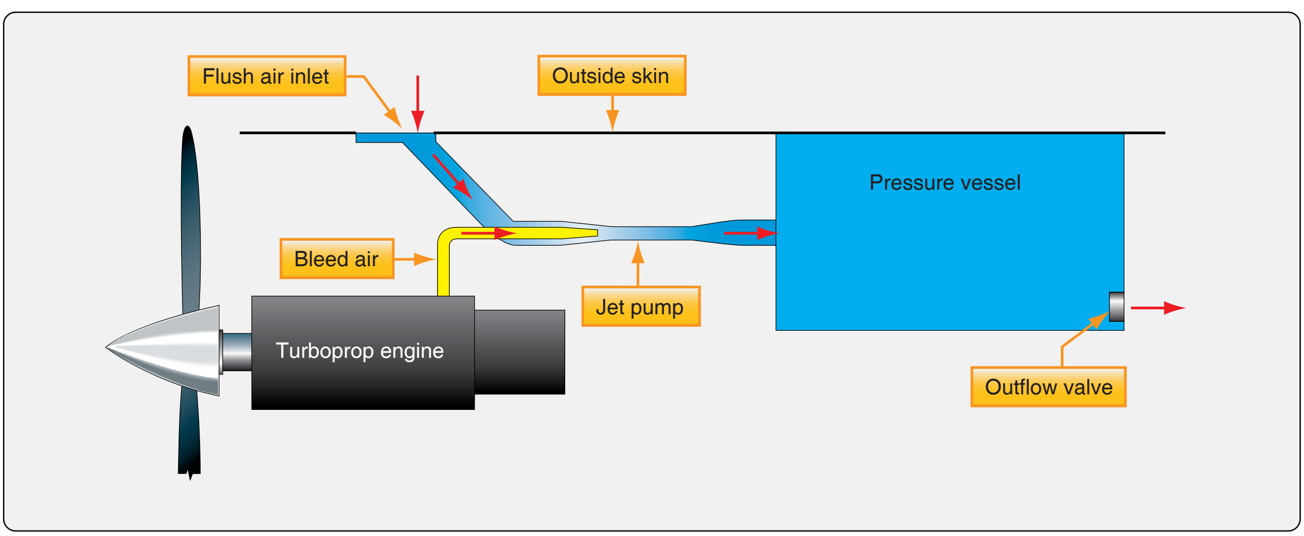

Figure 16-48. *A jet pump flow multiplier ejects bleed air into a venturi which draws air for pressurization from outside the aircraft.*

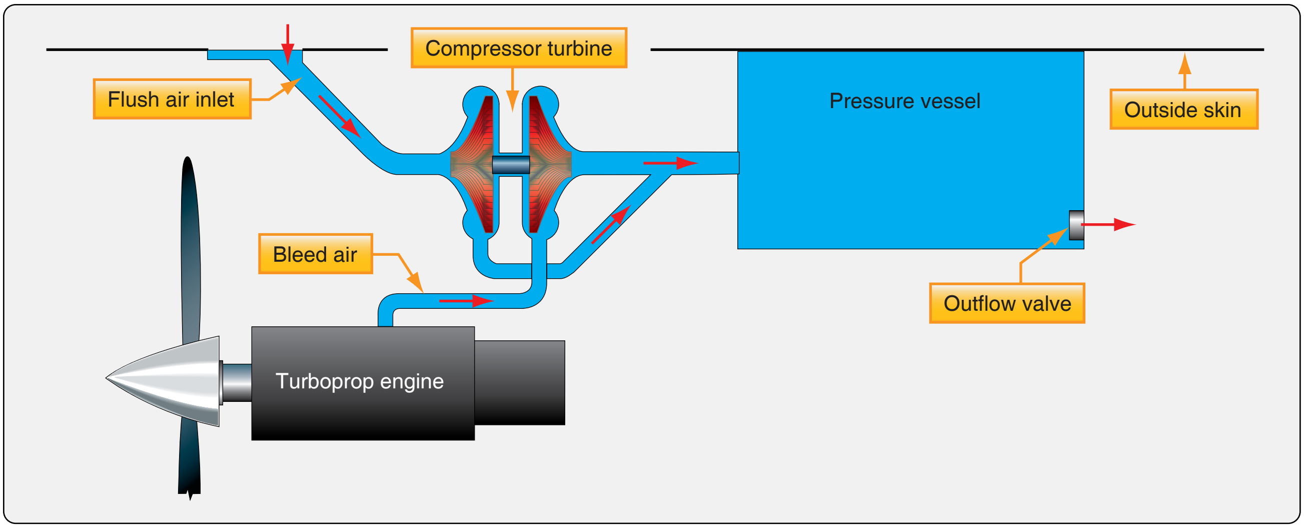

Figure 16-49. *A turbo compressor used to pressurize cabins mostly in turboprop aircraft.*

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

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.

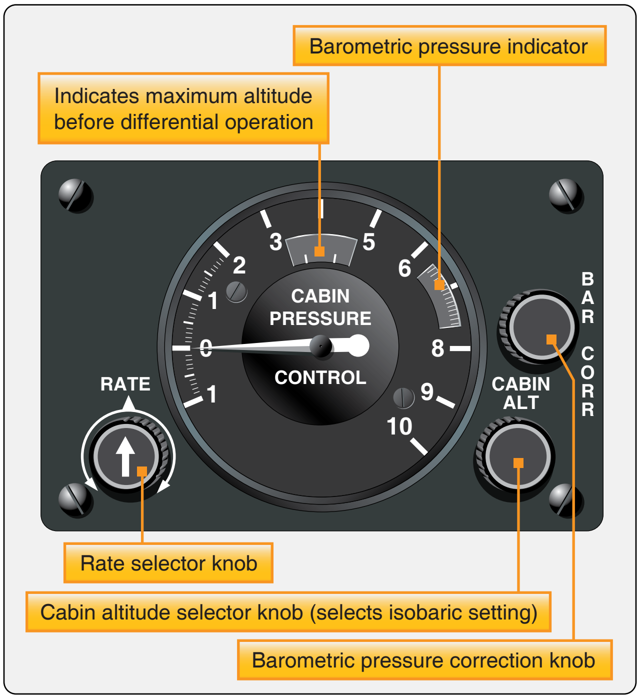

Figure 16-51. *A pressure controller for an all pneumatic cabin pressure control system.*

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 flight deck. *[Figure 16-51]*

Adjustments and settings on the pressure controller are the control input parameters for the cabin pressure regulator. The regulator controls the position of the outflow valve(s) normally located at the rear of the aircraft pressure vessel. Valve position determines the pressure level in the cabin.

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 flight deck. 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 flight deck 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

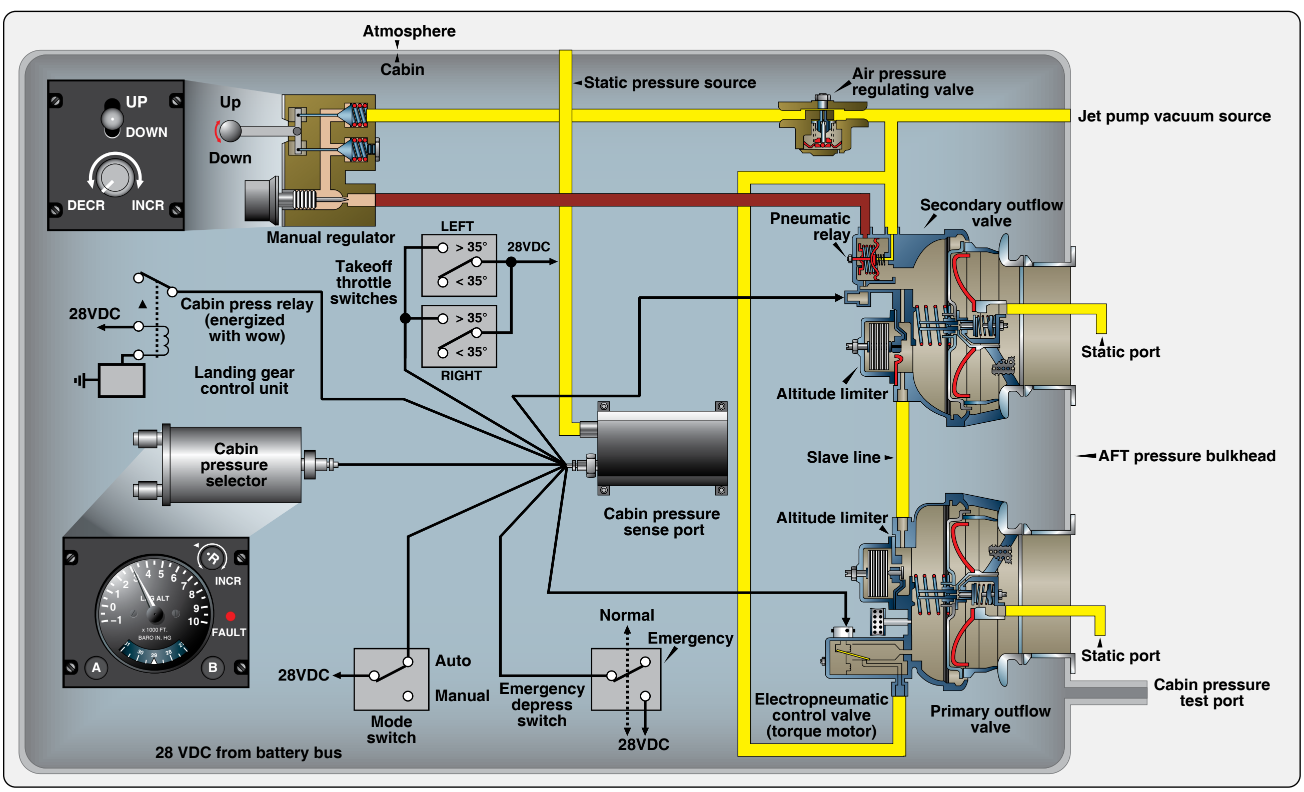

Figure 16-52. *The pressurization control system on many small transports and business jets utilizes a combination of electronic, electric, and pneumatic control elements.*

a computer, supplies pressurization logic for various stages of a flight. On many small transport and business jets, the controller's electric output signal drives a torque motor in the primary outflow valve. This modulates pneumatic airflow through the valve, which positions the valve to maintain the pressurization schedule.

On many transport category aircraft, two cabin pressure controllers, or a single controller with redundant circuitry, are used. Located in the electronics equipment bay, they receive electric input from the panel selector, as well as ambient and cabin pressure input. Flight altitude and landing field altitude information are often the crew selection choices on the pressurization control panel. Cabin altitude, rate of climb, and barometric setting are automatic through built-in logic and communication with the ADC and the flight management 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 & 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 flight deck 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

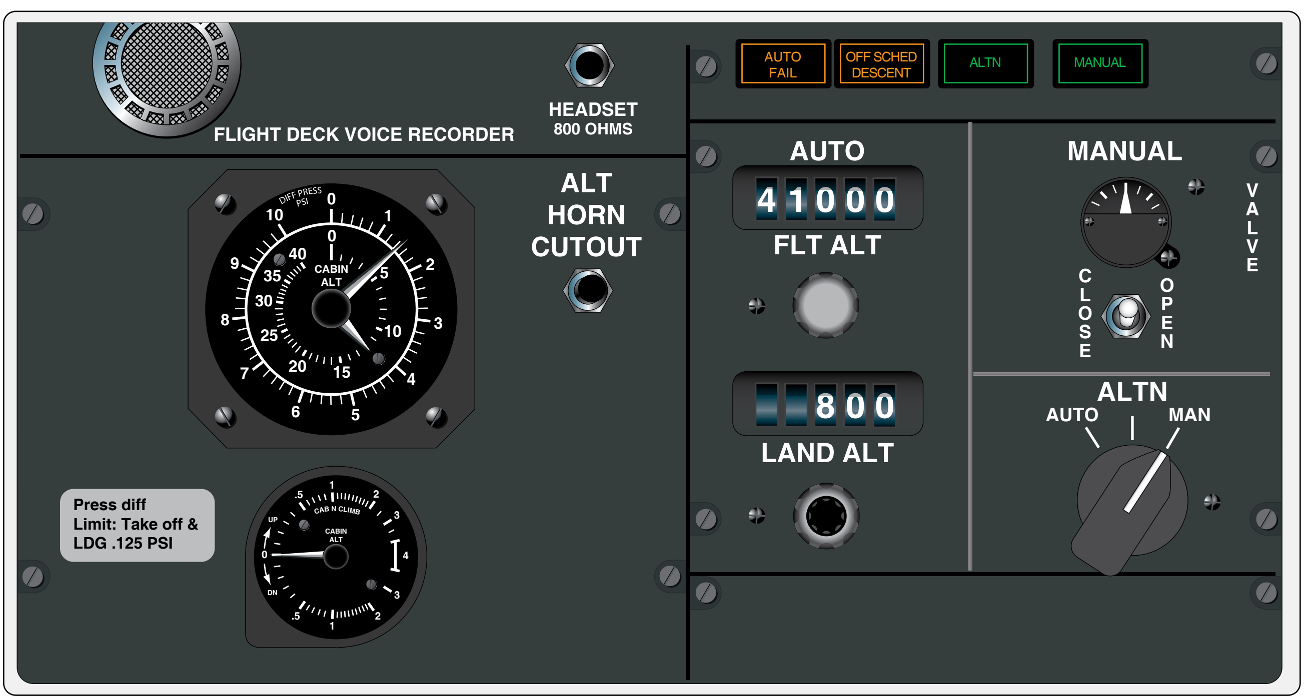

Figure 16-53. *This pressurization panel from an 800 series Boeing 737 has input selections of flight altitude and landing altitude.*

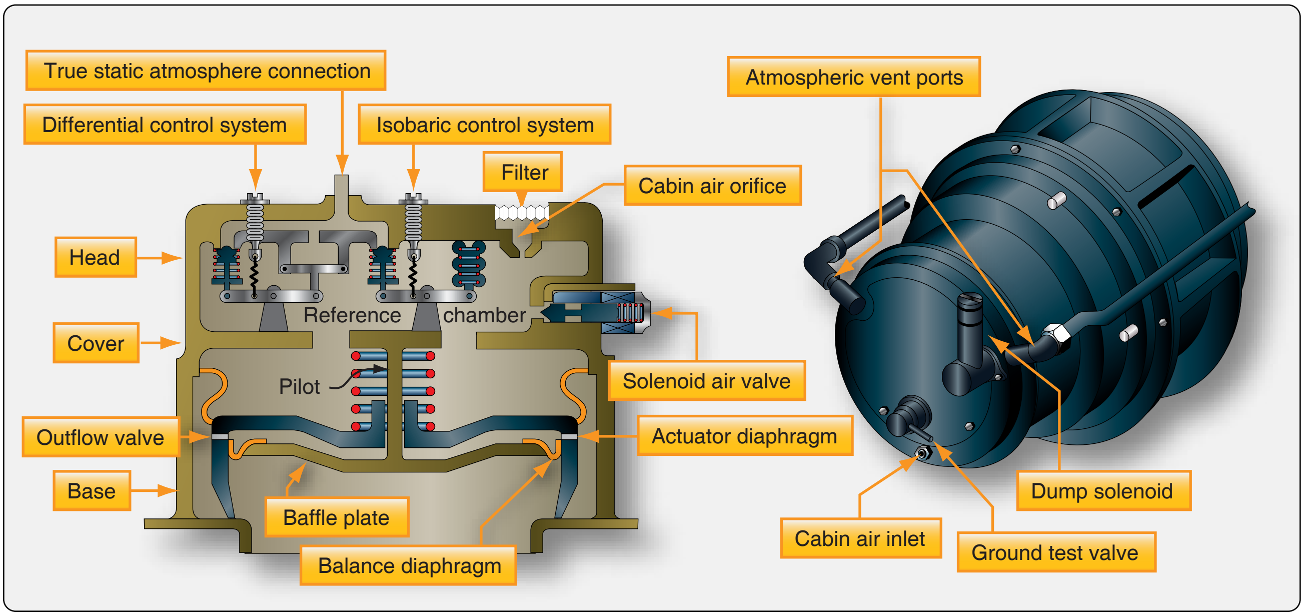

Figure 16-54. *An all-pneumatic cabin pressure regulator and outflow valve.*

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 flight deck pressurization panel selectors according to predetermined pressurization schedules. Signals are sent to electric motors to move the valve as needed. On transports, often AC motors are used with a redundant DC motor for standby or manual operations. *[Figure 16-55]*

Cabin Air Pressure Safety Valve Operation

Aircraft pressurization systems incorporate various features to limit human and structural damage should the system malfunction or become inoperative. A means for preventing overpressurization is incorporated to ensure the structural integrity of the aircraft if control of the pressurization system is lost. A cabin air safety valve is a pressure relief valve set to open at a predetermined pressure differential. It allows air to 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.

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 16-55. *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 used when in standby mode. A DC motor also on the valve is used for manual operation.*

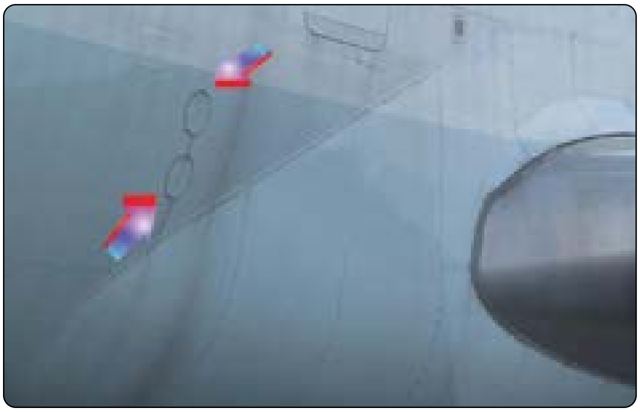

Figure 16-56. *Two pressurization safety valves are shown on a Boeing 747.*

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 flight deck. 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 flight deck. 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 flight deck 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 flight deck 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 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. Another name for the WOW switch is "squat" switch. During ground operations and prior to

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.*

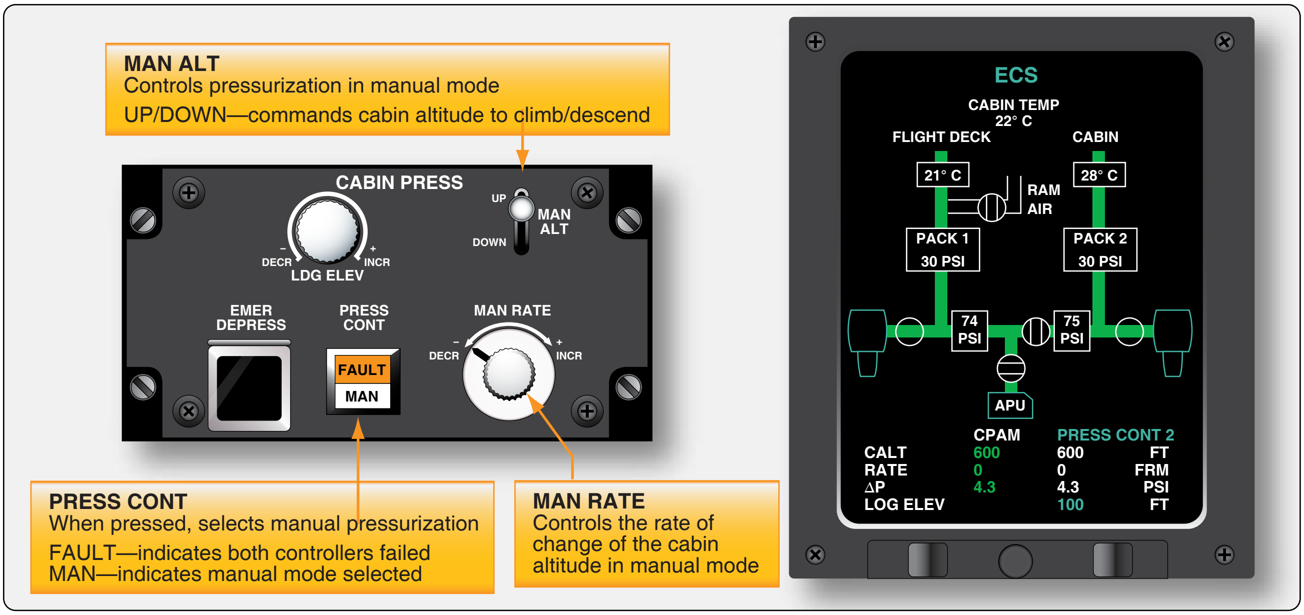

Figure 16-58. *The pressurization panel and environmental control system page on a Bombardier CRJ200 50 passenger jet have no gauges. Traditional pressurization data is presented in digital format at the bottom of the page.*

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 mode. This allows the technician to control the position of all valves from the flight deck 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 flight deck or cabin by a temperature selector. Centralized manifolds from which air can be distributed are common. *[Figure 16-59]*

Large aircraft may be divided into zones for air distribution. Each zone has its own temperature selector and associated valve to mix conditioned and bleed air so that each zone can be maintain at a temperature independent of the others.

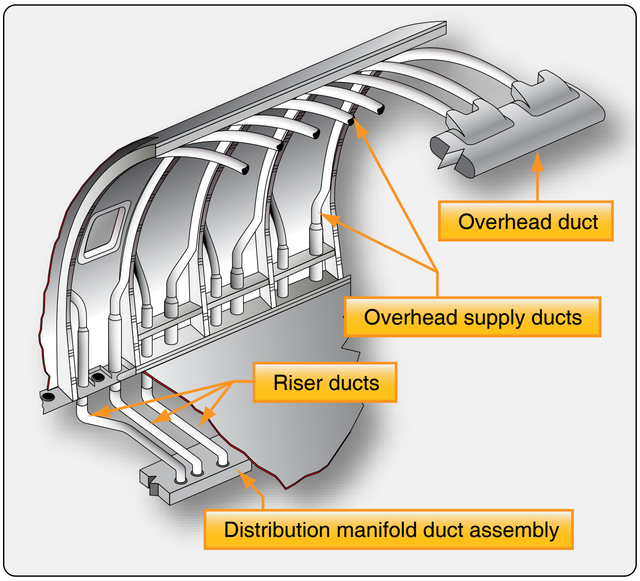

Figure 16-59. *Centralized manifolds from which air can be distributed are common.*

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 flight deck 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 cycle air conditioning systems are often used on reciprocating aircraft. This type system is similar to that found in homes and automobiles. Note that some turbine-powered aircraft also use vapor cycle air conditioning.

Air Cycle Air Conditioning

Air cycle air conditioning prepares engine bleed air to pressurize the aircraft cabin. The temperature and quantity of the air must be controlled to maintain a comfortable cabin environment at all altitudes and on the ground. The air cycle system is often called the air conditioning package or pack. It is usually located in the lower half of the fuselage or in the tail section of turbine-powered aircraft. *[Figure 16-62]*

System Operation

Even with the frigid temperatures experienced at high altitudes, bleed air is too hot to be used in the cabin without being cooled. It is let into the air cycle system and routed through a heat exchanger where ram air cools the bleed air. This cooled bleed air is directed into an air cycle machine. There, it is compressed before flowing through a secondary heat exchange that cools the air again with ram air. The bleed air then flows back into the air cycle machine where it drives an expansion turbine and cools even further. Water is then removed, and the air is mixed with bypassed bleed air for final temperature adjustment. It is sent to the cabin through the air distribution system. By examining the operation of each component in the air cycle process, a better understanding can be developed of how bleed air is conditioned for cabin use. Refer to *Figure 16-63,* which diagrams the air cycle air conditioning system of the Boeing 737.

Pneumatic System Supply

The air cycle air conditioning system is supplied with air by the aircraft pneumatic system. In turn, the pneumatic system is supplied by bleed air tap-offs on each engine compressor section or from the APU pneumatic supply. An external pneumatic air supply source may also be connected while

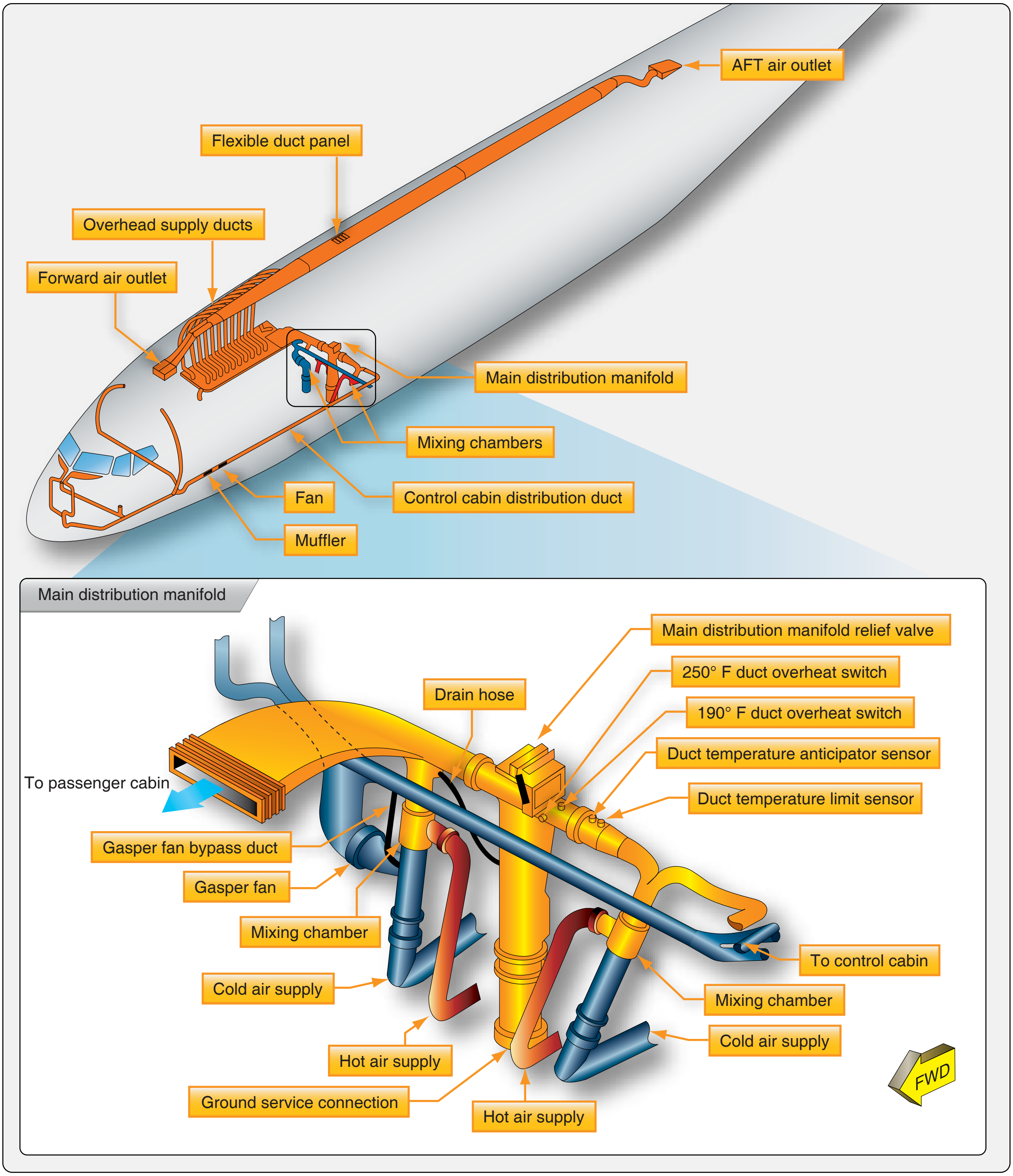

Figure 16-60. *The conditioned air distribution system on a Boeing 737. The main distribution manifold is located under the cabin floor. Riser ducts run horizontally then vertically from the manifold to supply ducts, which follow the curvature of the fuselage carrying conditioned air to be released in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

Figure 16-61. *A duct hose installed on this airliner distributes hot or cold air from a ground-based source throughout the cabin using the aircraft's own air distribution system ducting.*

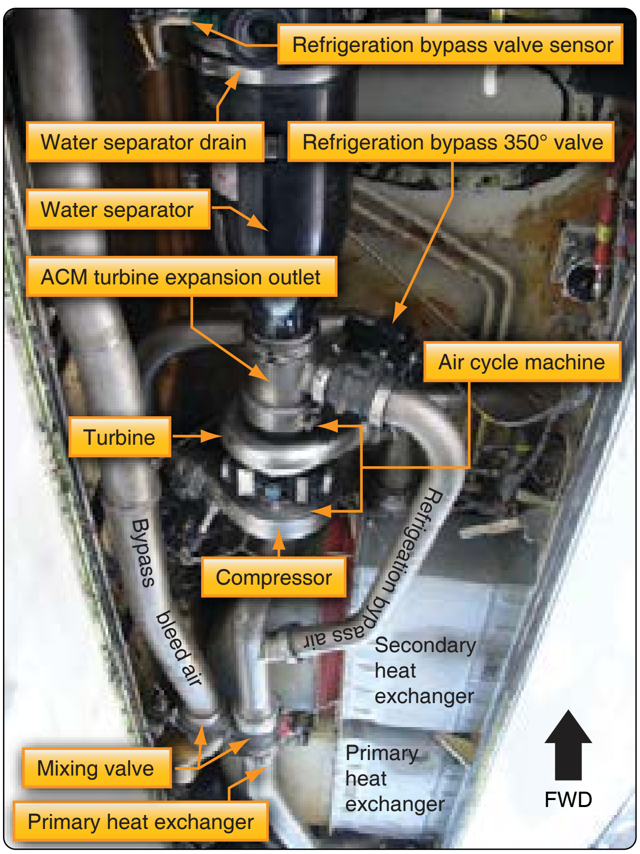

Figure 16-62. *Boeing 737 air cycle system. The photo is taken looking up into the air conditioning bay located in the lower fuselage on each side of the aircraft.*

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 flight deck. Many pack valves are electrically controlled and pneumatically operated. Also known as the supply shutoff valve, the pack valve opens, closes, and modulates to allow the air cycle air conditioning system to be supplied with a designed volume of hot, pressurized air. *[Figure 16-64]* When an overheat or other abnormal condition requires that the air conditioning package be shut down, a signal is sent to the pack valve to close.

Bleed Air Bypass

A means for bypassing some of the pneumatic air supplied to the air cycle air conditioning system around the system is present on all aircraft. This warm bypassed air must be mixed with the cold air produced by the air cycle system so the air delivered to the cabin is a comfortable temperature. In the system shown in *Figure 16-58,* this is accomplished by the mixing valve. It simultaneously controls the flow of bypassed air and air to be cooled to meet the requirements of the auto temperature controller. It can also be controlled manually with the cabin temperature selector in manual mode. Other air cycle systems may refer to the valve that controls the air bypassed around the air cycle cooling system as a temperature control valve, trim air pressure regulating valve, or something similar.

Primary Heat Exchanger

Generally, the warm air dedicated to pass through the air cycle system first passes through a primary heat exchanger. It acts similarly to the radiator in an automobile. A controlled flow of ram air is ducted over and through the exchanger, which reduces the temperature of the air inside the system. *[Figure 16-65]* A fan draws air through the ram air duct when the aircraft is on the ground so that the heat exchange is possible when the aircraft is stationary. In flight, ram air doors are modulated to increase or decrease ram air flow to the exchanger according to the position of the wing flaps. During slow flight, when the flaps are extended, the doors are open. At higher speeds, with the flaps retracted, the doors move toward the closed position reducing the amount of ram air to the exchanger. Similar operation is accomplished with a valve on smaller aircraft. *[Figure 16-66]*

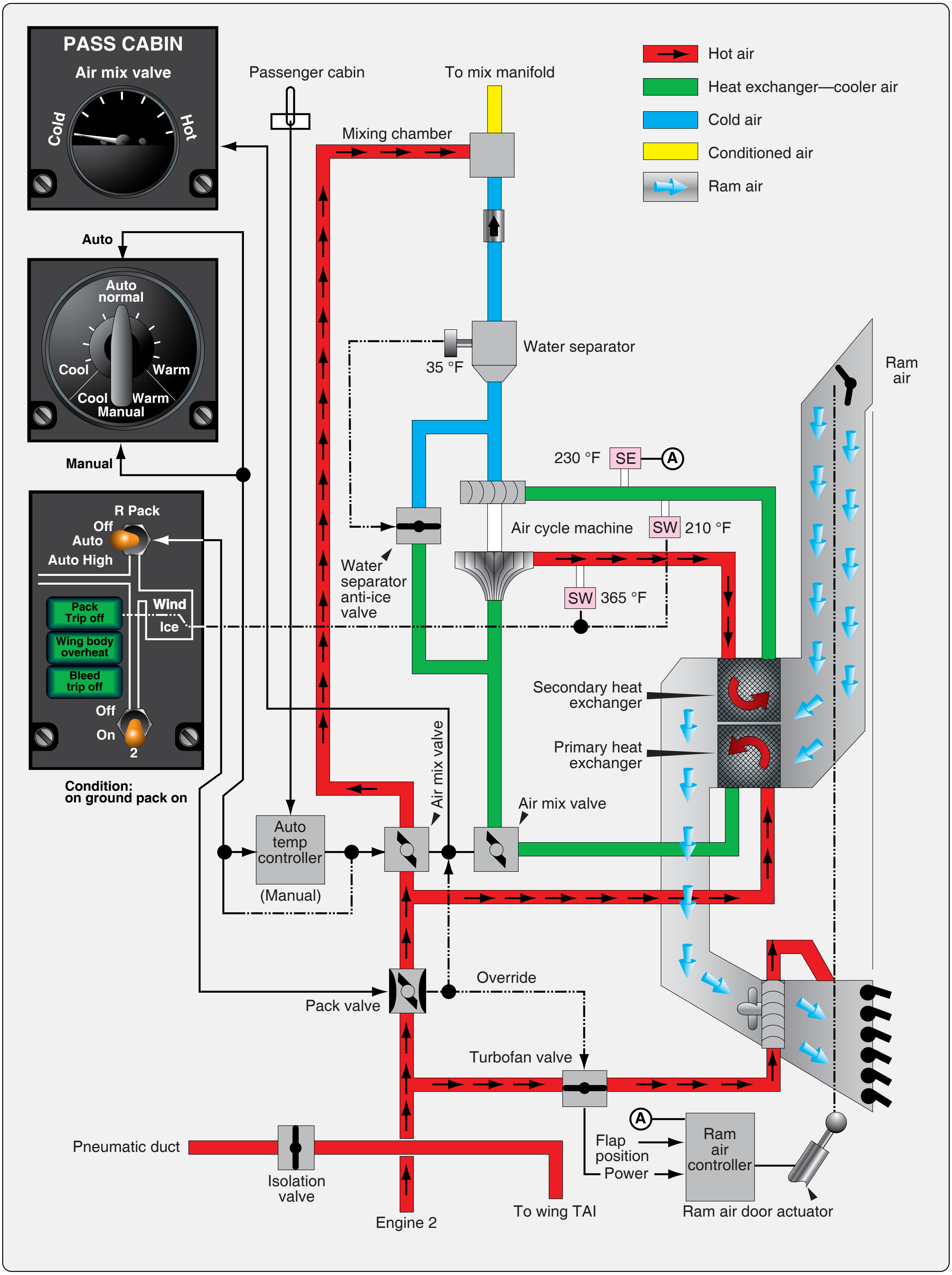

Figure 16-63. *The air cycle air conditioning system on a Boeing 737.*

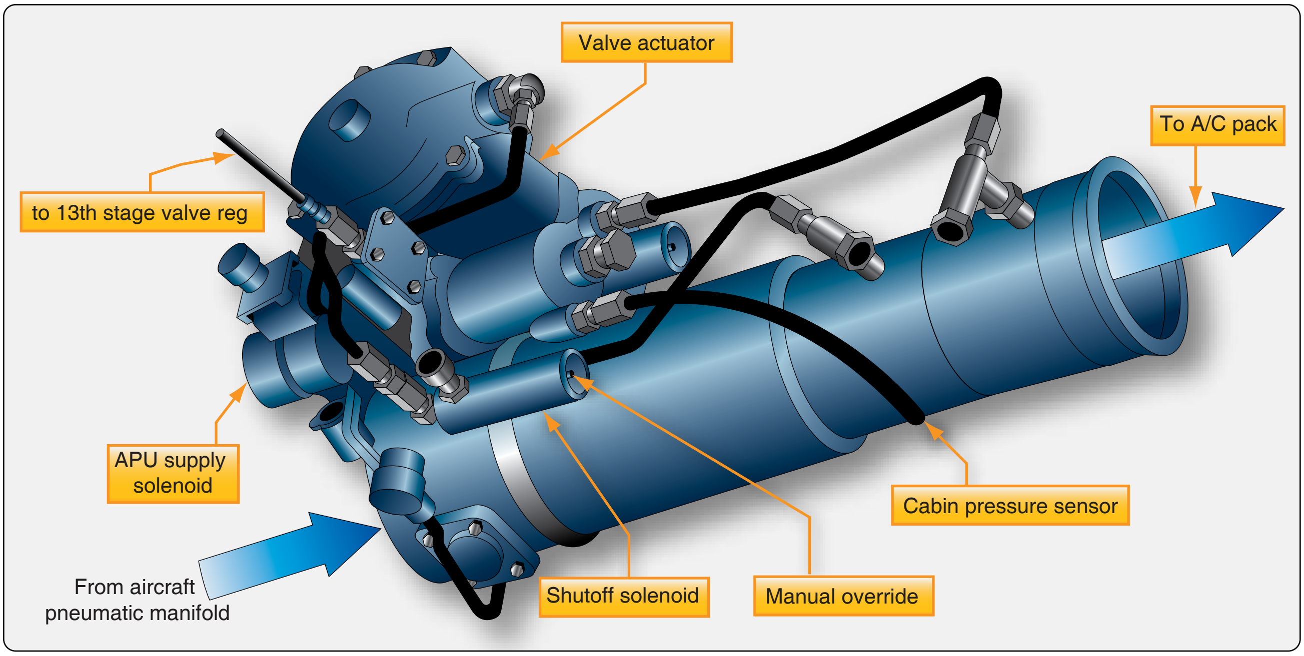

Figure 16-64. *This pack valve drawing illustrates the complexity of the valve, which opens, closes, and modulates. It is manually actuated from the flight deck and automatically responds to supply and air cycle system parameter inputs.*

Refrigeration Turbine Unit or Air Cycle Machine & 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

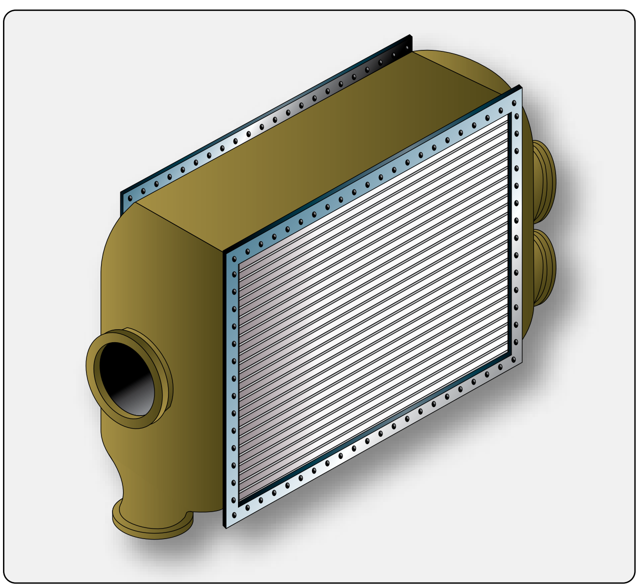

Figure 16-65. *The primary and secondary heat exchangers in an air cycle air conditioning system are of similar construction. They both cool bleed air when ram air passes over the exchanger coils and fins.*

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

the 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

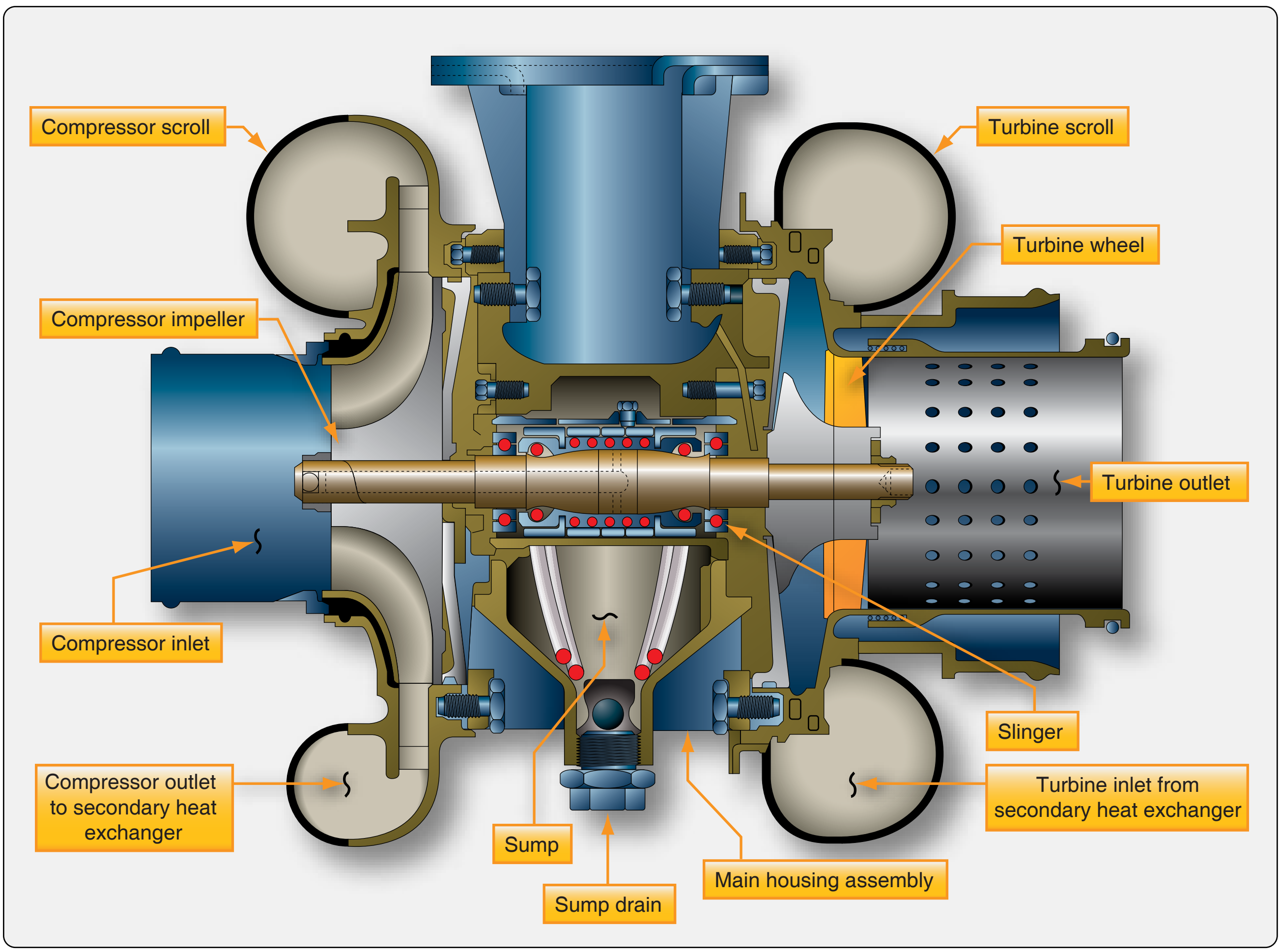

Figure 16-67. *A cutaway diagram of an air cycle machine. The main housing supports the single shaft to which the compressor and turbine are attached. Oil lubricates and cools the shaft bearings.*

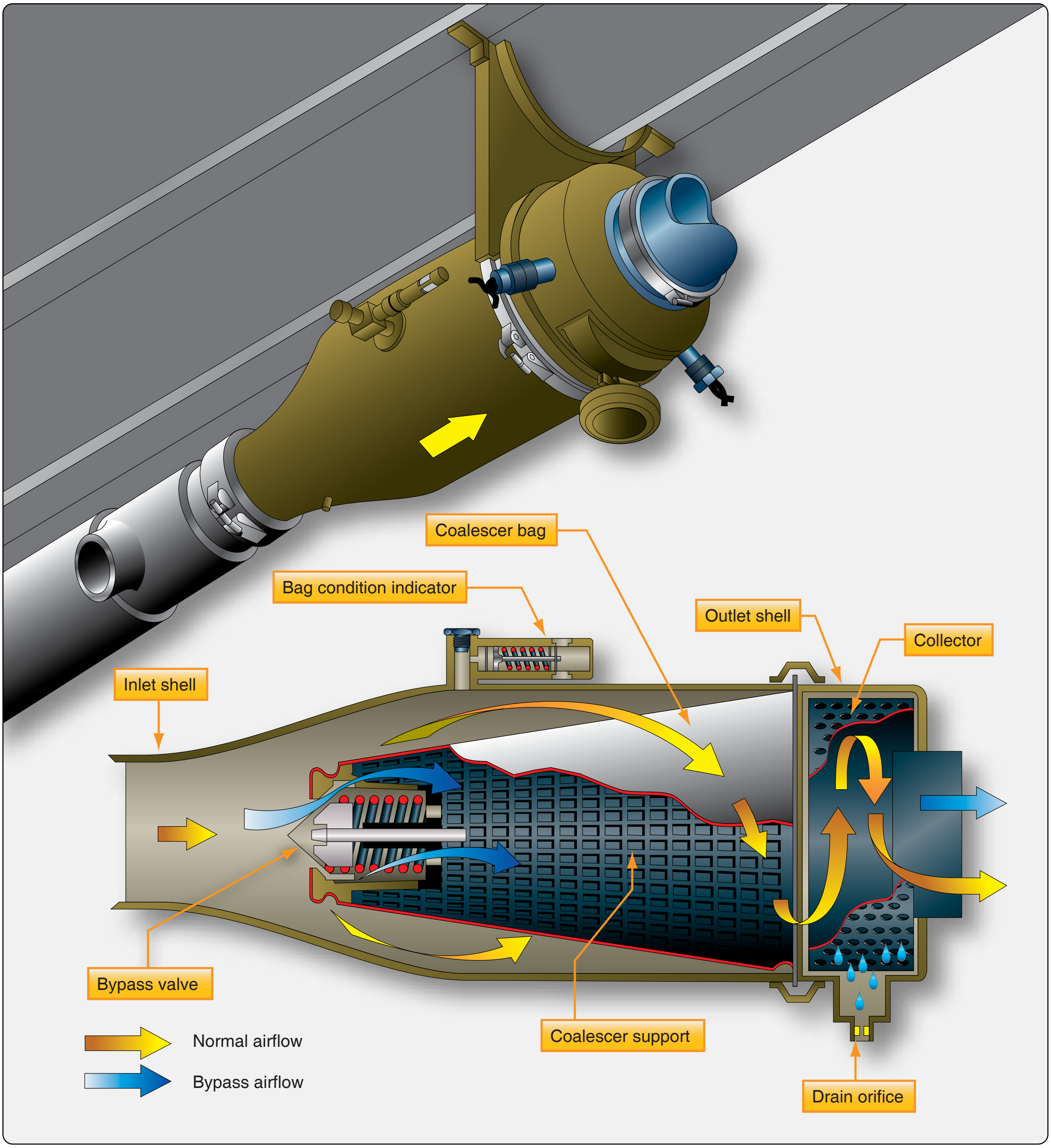

Figure 16-68. *A water separator coalesces and removes water by swirling the air/water mixture from ACM expansion turbine. Centrifugal force sends the water to the walls of the collector where it drains from the unit.*

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, flight deck, 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

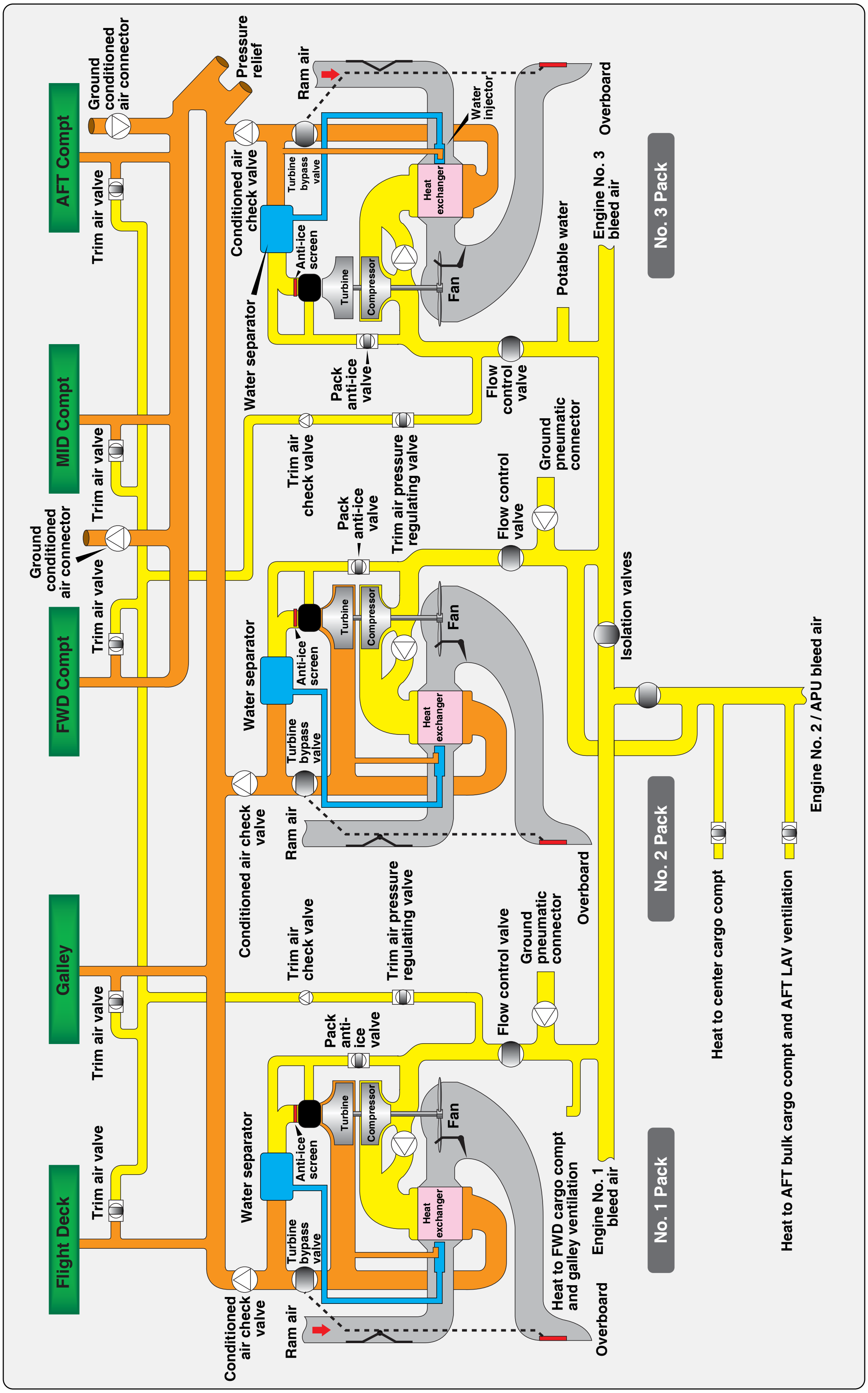

Figure 16-69. *The air cycle air conditioning system of a DC-10 transport category aircraft uses only one heat exchanger per ACM.*

temperature selector in the flight deck can be adjusted to input the desired temperature. *[Figure 16-70]* The temperature controller compares the actual temperature signals received from the various sensors with the desired temperature input. Circuit logic for the selected mode processes these input signals. An output signal is sent to a valve in the air cycle air conditioning system. This valve has different names depending on the aircraft manufacturer and design of the environmental control systems (i.e., mixing valve, temperature control valve, trim air valve). It mixes warm bleed air that bypassed the air cycle cooling process with the cold air produced by it. By modulating the valve in response to the signal from the temperature controller, air of the selected temperature is sent to the cabin through the air distribution system.

Cabin temperature pickup units and duct temperature sensors used in the temperature control system are thermistors. Their resistance changes as temperature changes. The temperature selector is a rheostat that varies its resistance as the knob is turned. In the temperature controller, resistances are compared in a bridge circuit. The bridge output feeds a temperature regulating function. An electric signal output is prepared and sent to the valve that mixes hot and cold air. On large aircraft with separate temperature zones, trim air modulating valves for each zone are used. The valves modulate to provide the correct mix required to match the selected temperature. Cabin, flight deck, and duct temperature sensors are strategically located to provide useful information to control cabin temperature. *[Figure 16-71]*

Vapor Cycle Air Conditioning

The absence of a bleed air source on reciprocating engine aircraft makes the use of an air cycle system impractical for conditioning cabin air. Vapor cycle air conditioning is used on most nonturbine aircraft that are equipped with air conditioning. However, it is not a source of pressurizing air as the air cycle system conditioned air is on turbine powered aircraft. The vapor cycle system only cools the cabin. If an aircraft equipped with a vapor cycle air conditioning system is pressurized, it uses one of the sources discussed in the pressurization section above. Vapor cycle air conditioning is a closed system used solely for the transfer of heat from inside the cabin to outside of the cabin. It can operate on the ground and in flight.

Theory of Refrigeration

Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapor cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapor. The vapor is compressed and becomes very hot. It is removed from the cabin where the very hot vapor refrigerant transfers its heat energy to the outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer. *[Figure 16-72]*

Heat is an expression of energy, typically measured by temperature. The higher the temperature of a substance, the more energy it contains. Heat always flows from hot to cold. These terms express the relative amount of energy present in two substances. They do not measure the absolute amount of heat present. Without a difference in energy levels, there is no transfer of energy (heat).

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

Figure 16-70. *Typical temperature selectors on a transport category aircraft temperature control panel in the flight deck (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.*

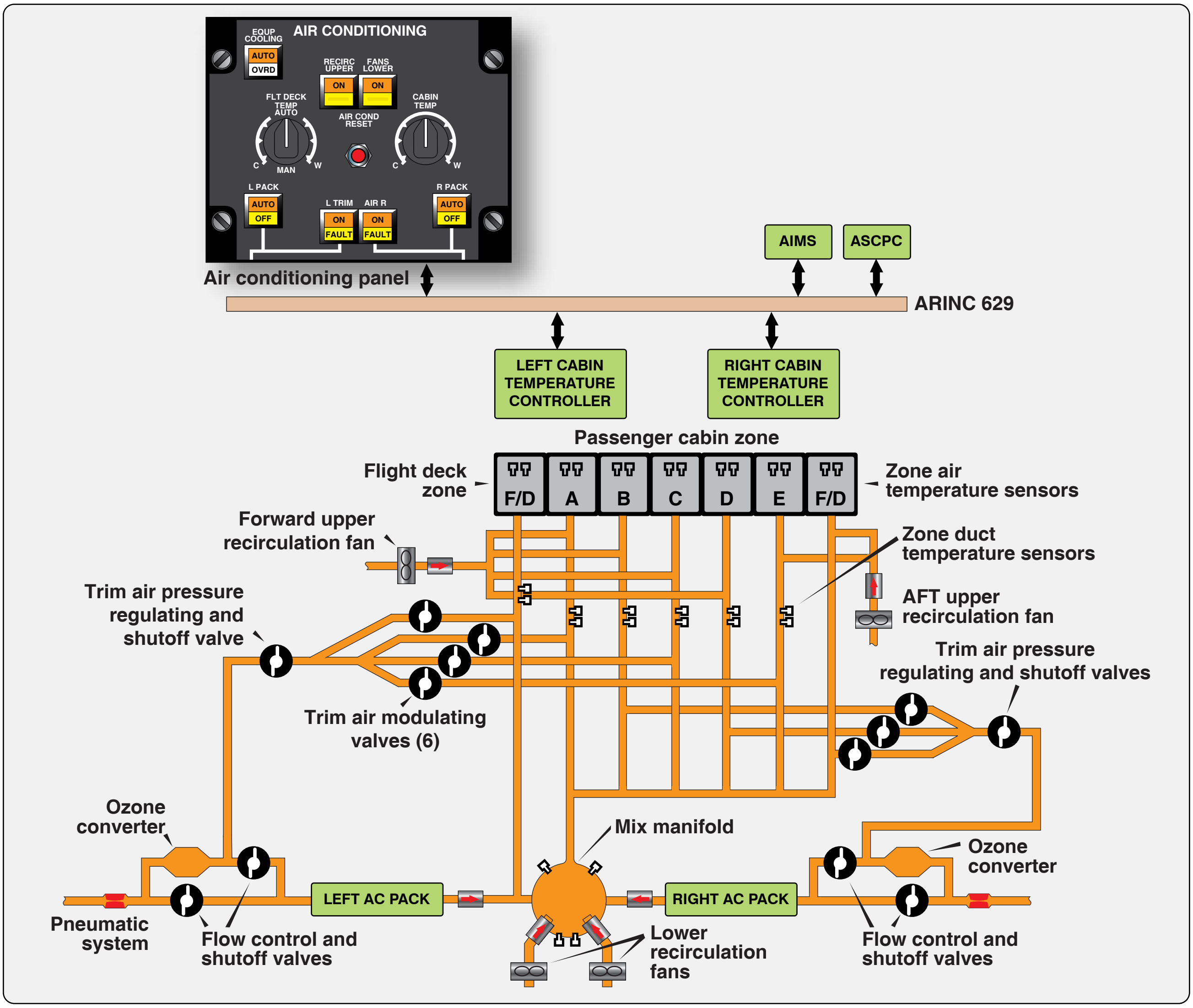

Figure 16-71. *The temperature control system of a Boeing 777 combines the use of zone and duct temperature sensors with trim air modulating valves for each zone. Redundant digital left and right cabin temperature controllers process temperature input signals from the sensors and temperature selectors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

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 pressure (14.7 psi). When pressure on liquid water is increased to 20 psi, it does not boil at 212 °F. More energy is required to overcome the increase in pressure. It boils at approximately 226.4 °F. The converse is also true. Water can also boil at a much lower temperature simply by reducing the pressure upon it. With only 10 psi of pressure upon liquid water, it boils at 194 °F. *[Figure 16-73]*

Vapor pressure is the pressure of the vapor that exists above a liquid that is in an enclosed container at any given temperature. The vapor pressure developed by various substances is unique to each substance. A substance that is said to be volatile, develops high vapor pressure at standard day temperature (59 °F). This is because the boiling point of the substance is much lower. The boiling point of tetrafluoroethane (R134a), the refrigerant used in most aircraft vapor cycle air conditioning systems, is approximately –15 °F. Its vapor pressure at 59 °F is about 71 psi. The vapor pressure of any substance varies directly with temperature.

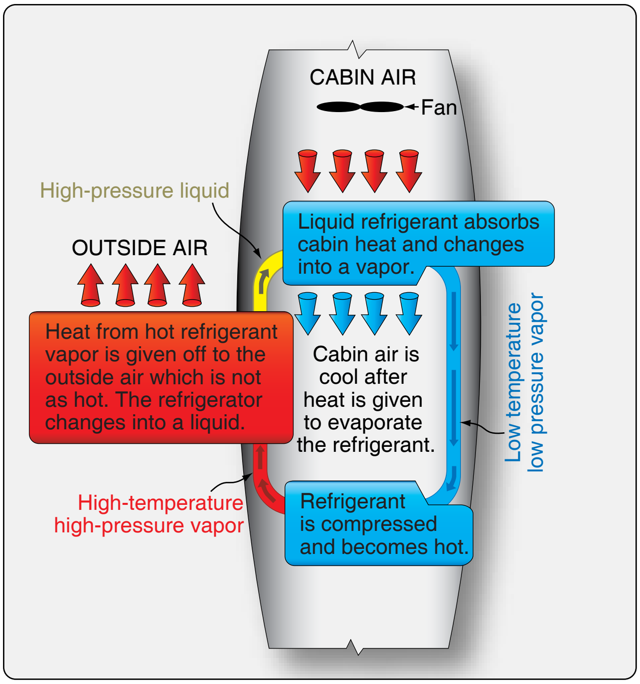

Figure 16-72. *In vapor cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapor and back again.*

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.

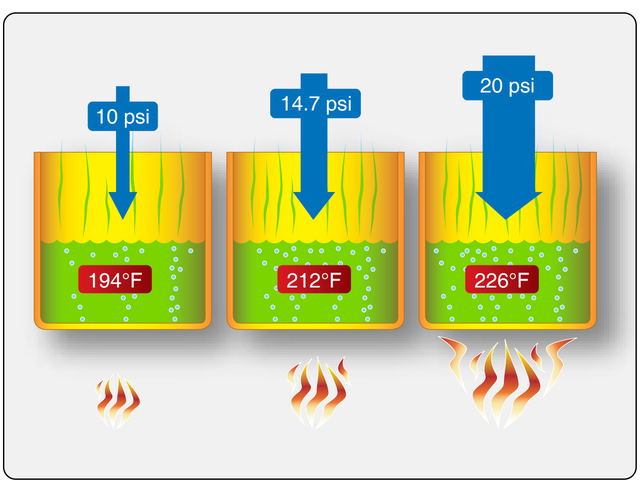

Figure 16-73. *Boiling point of water changes as pressure changes.*

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.

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.

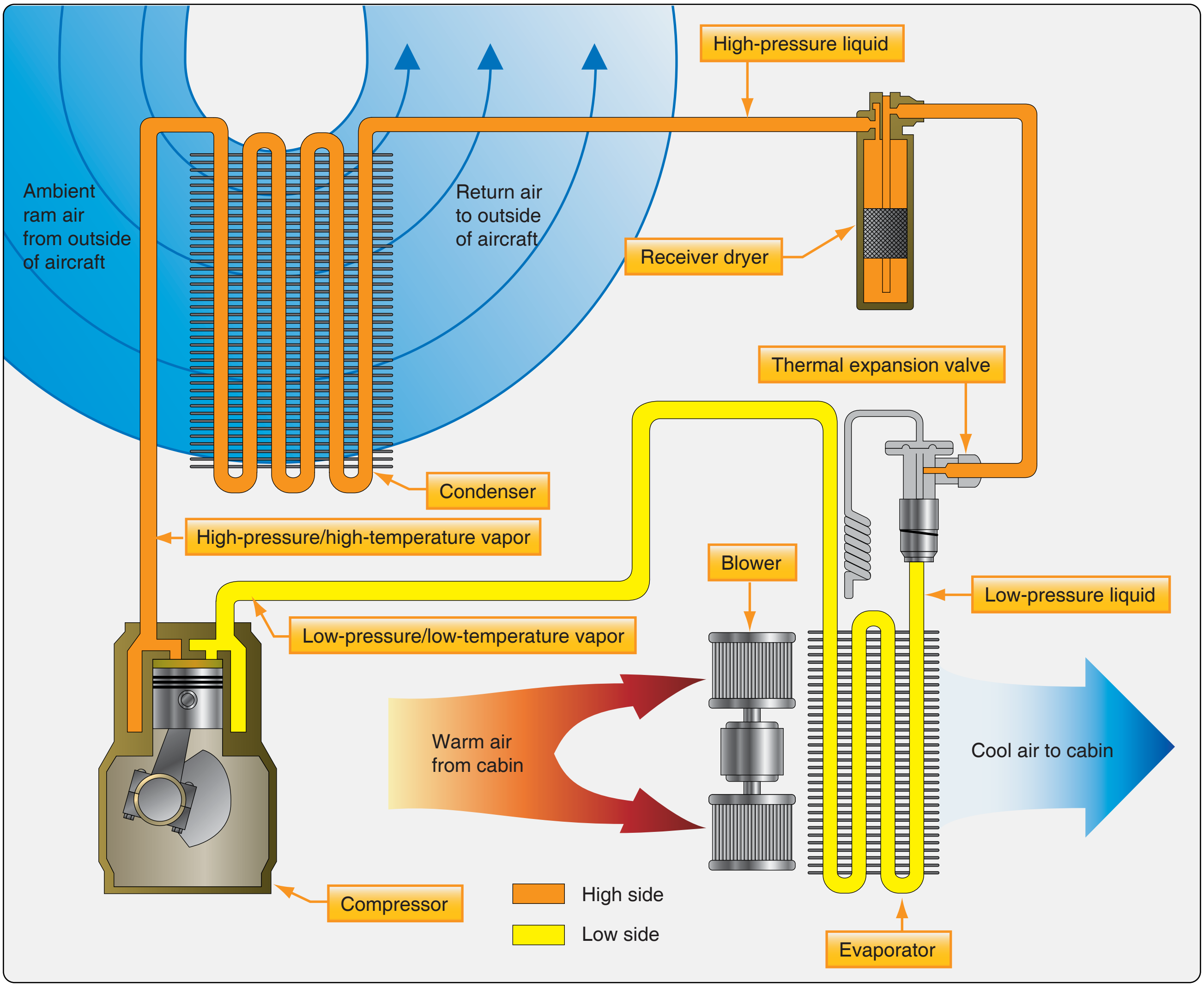

Figure 16-74. *A basic vapor cycle air conditioning system. The compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. This figure illustrates this division. Refrigerant on the low side is characterized as having low pressure and temperature.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

[Figure 16-75] R12 and R134a behave so similarly that the descriptions of the R134a vapor cycle air conditioning system and components in the following paragraphs also apply to an R12 system and its components.

R134a is a halogen compound (CF3CFH2). As mentioned, it has a boiling point of approximately –15 °F. It is not poisonous to inhale in small quantities, but it does displace oxygen. Suffocation is possible if breathed in mass quantity.

Regardless of manufacturer, refrigerants are sometimes called Freon®, which is a trade name owned by the Dupont Company. Caution should be used when handling any refrigerant. Because of the low boiling points, liquid 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

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

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 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.

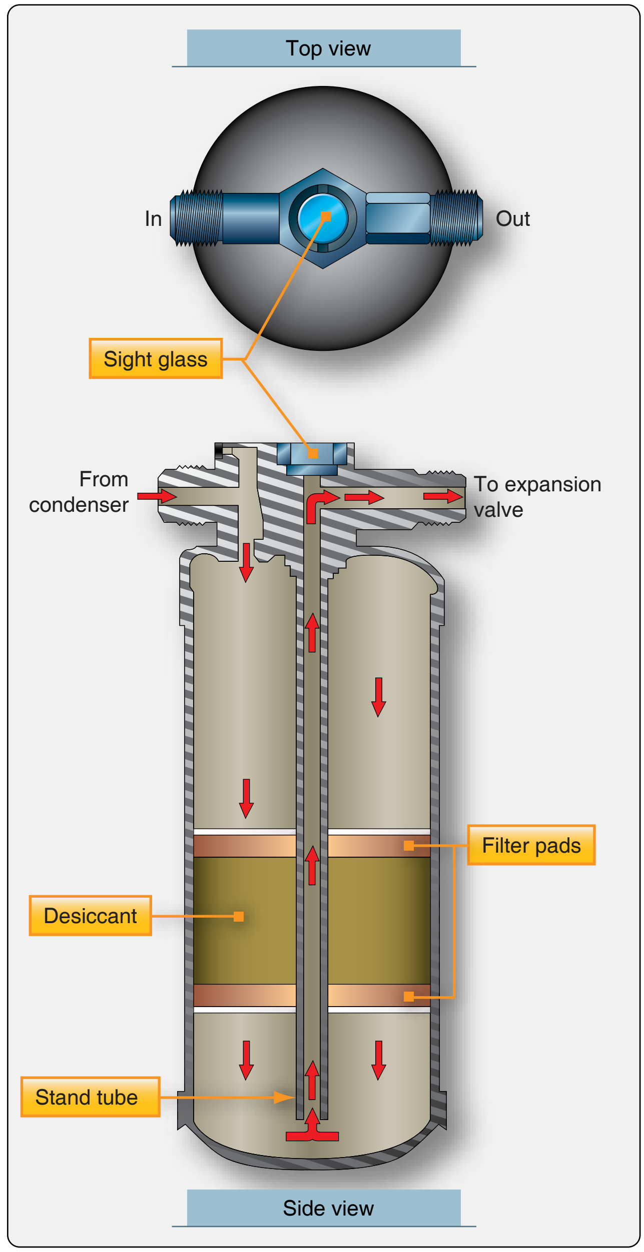

Figure 16-76. *A receiver dryer acts as reservoir and filter in a vapor cycle system. Bubbles viewed in the sight glass indicate the system is low on refrigerant and needs to be serviced.*

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 inlet of the evaporator. The result is low pressure inside the temperature bulb and above the expansion valve diaphragm. The superheat spring in the valve moves the needle valve toward the closed position, reducing the flow of refrigerant into the evaporator as the spring overcomes the lower pressure above the diaphragm. *[Figure 16-77]*

Vapor cycle air conditioning systems that have large evaporators experience significant pressure drops while refrigerant is flowing through them. Externally equalized expansion valves use a pressure tap from the outlet of the evaporator to help the superheat spring balance the diaphragm. This type of expansion valve is easily recognizable by the additional small-diameter line that comes from the evaporator into the valve (2 total). Better control of the proper amount of refrigerant allowed through the valve is attained by considering both the temperature and pressure of the evaporator refrigerant. *[Figure 16-78]*

Evaporator

Most evaporators are constructed of copper or aluminum tubing coiled into a compact unit. Fins are attached to increase surface area, facilitating rapid heat transfer between the cabin air blown over the outside of the evaporator with a fan and the refrigerant inside. The expansion valve, located at the evaporator inlet, changes the high pressure, high temperature refrigerant into low pressure, low temperature refrigerant which continues on 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.

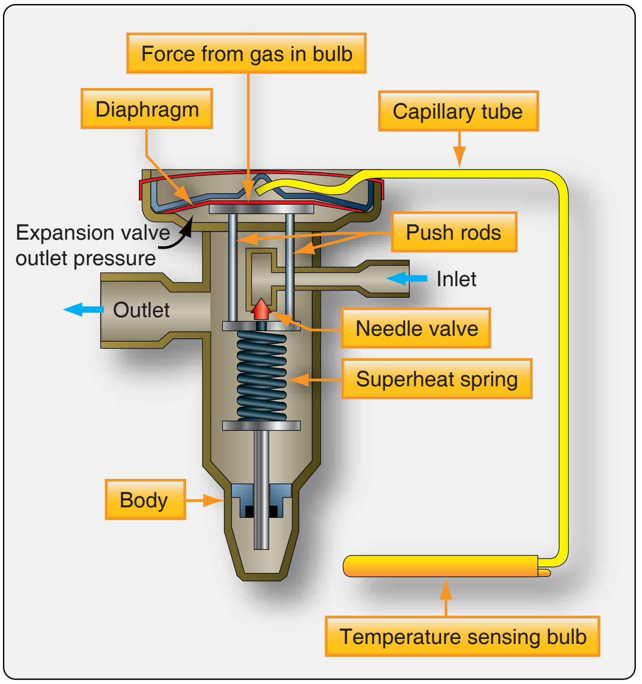

Figure 16-77. *An internally equalized expansion valve.*

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

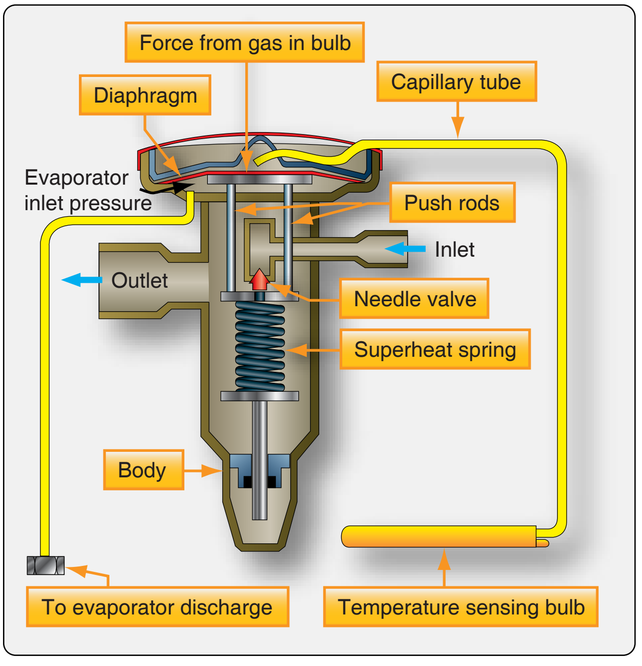

Figure 16-78. *An externally equalized expansion valve uses evaporator discharge temperature and pressure to regulate the amount of refrigerant passing through the valve and into the evaporator.*

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

When cabin air is cooled by flowing over the evaporator, it can no longer retain the water that it could at higher temperature. As a result, it condenses on the outside of the evaporator and needs to be collected and drained overboard. Pressurized aircraft may contain a valve in the evaporator drain line that opens only periodically to discharge the water, to maintain pressurization. Fins on the evaporator must be kept from being damaged, which could inhibit airflow. The continuous movement of warm cabin air around the fins keeps condensed water from freezing. Ice on the evaporator reduces the efficiency of the heat exchange to the refrigerant.

Compressor

The compressor is the heart of the vapor cycle air conditioning system. It circulates the refrigerant around the vapor cycle system. It receives low-pressure, low-temperature refrigerant vapor from the outlet of the evaporator and compresses it. As the pressure is increased, the temperature also increases. The refrigerant temperature is raised above that of the outside air temperature. The refrigerant then flows out of the compressor to the condenser where it gives off the heat to the outside air.

The compressor is the dividing point between the low side and the high side of the vapor cycle system. Often it is incorporated with fittings or has fittings in the connecting lines to it that are designed to service the system with refrigerant. Access to the low and high sides of the system are required for servicing, which can be accomplished with fitting upstream and downstream of the compressor.

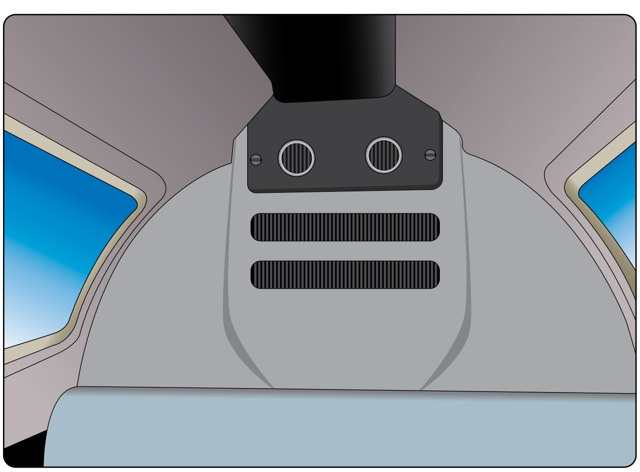

Figure 16-79. *The evaporator of this aircraft's vapor cycle air conditioning system is visible in the forward cabin sidewall behind the right rudder pedal.*

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.

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 condenser during ground operation. On some aircraft, outside air is ducted to the condenser. On others, the condenser is lowered into the airstream from the fuselage via a hinged panel. Often, the panel is controlled by a switch on the throttle levers. It is set to retract the compressor and streamline the fuselage when full power is required. *[Figure 16-83]*

The outside air absorbs heat from the refrigerant flowing through the condenser. The heat loss causes the refrigerant to change state back into a liquid. The high-pressure liquid refrigerant then leaves the condenser and flows to

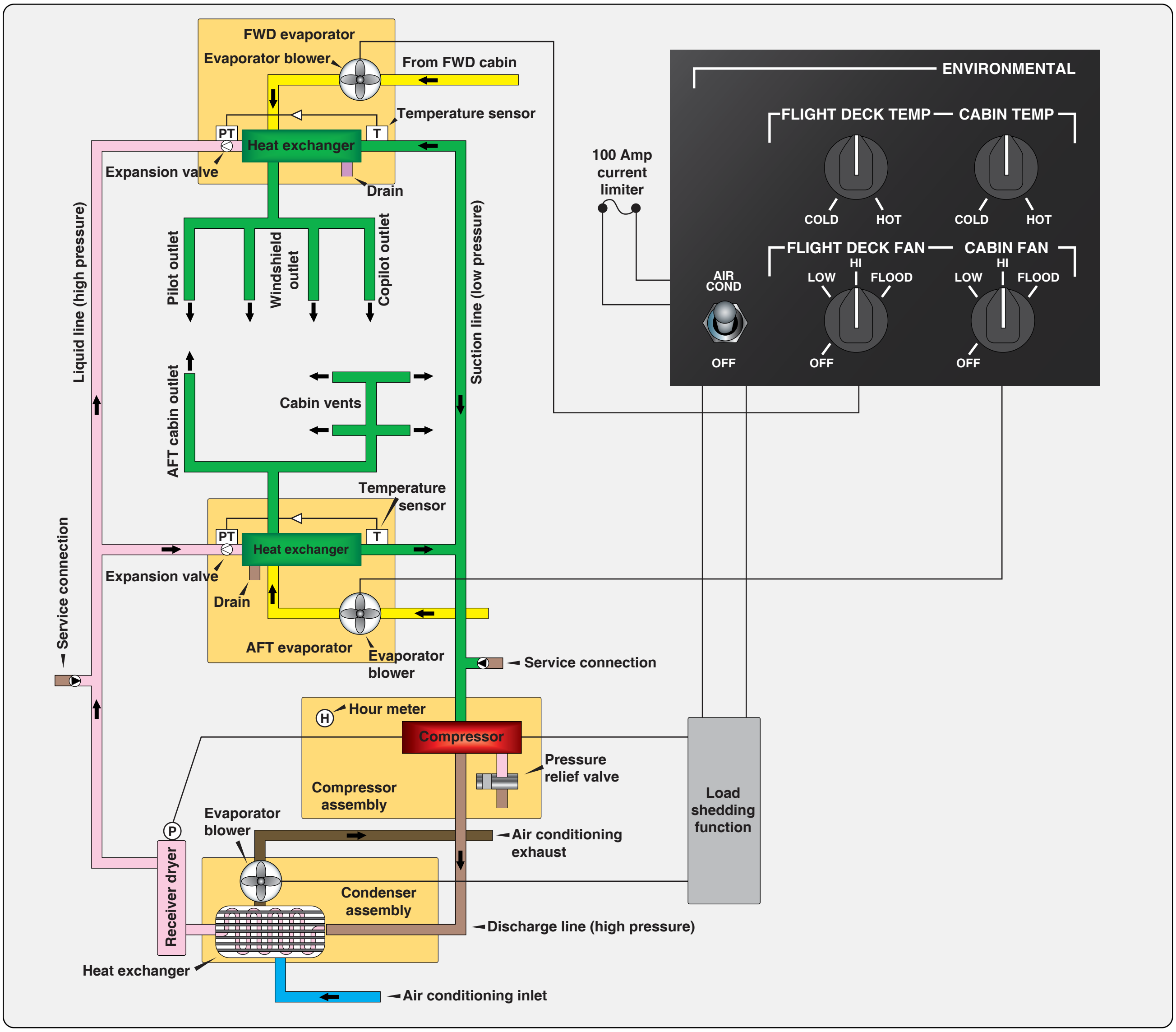

Figure 16-80. *The vapor cycle air conditioning system on a Cessna Mustang has two evaporators, one for the flight deck and one for the cabin. Each evaporator assembly contains the evaporator, a blower, a thermal expansion valve and the temperature feedback line from the outlet of the evaporator to the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

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.

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

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.*

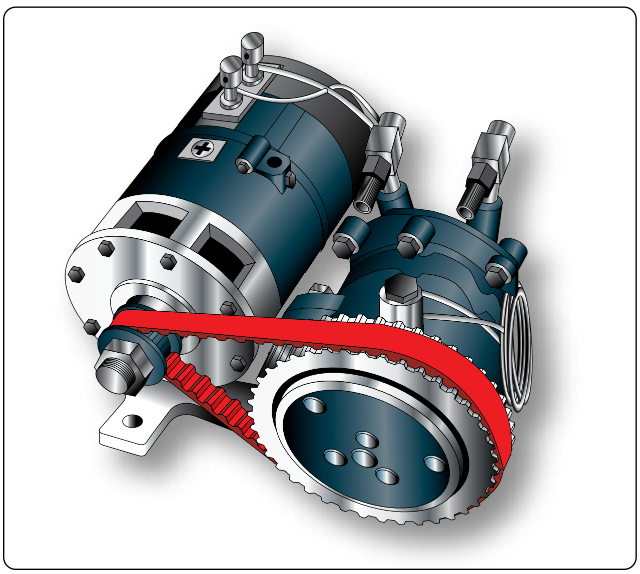

Figure 16-82. *Examples of electric motor-driven vapor cycle air conditioning compressors.*

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]*

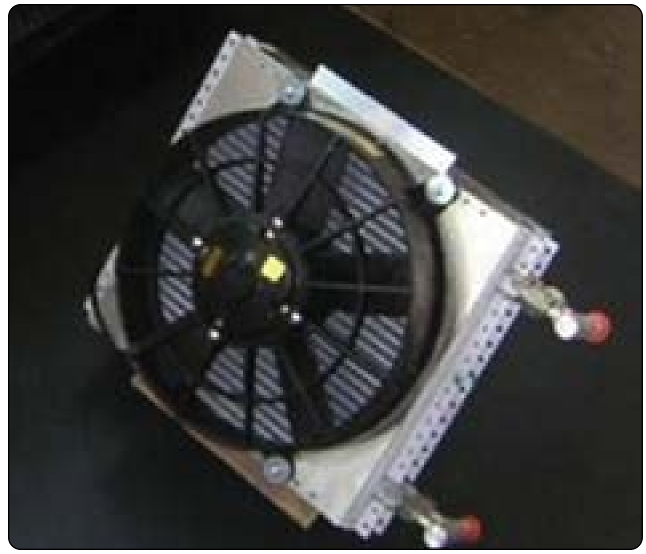

Figure 16-83. *A vapor cycle air conditioning condenser assembly with an integral fan used to pull outside air through the unit during ground operation.*

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

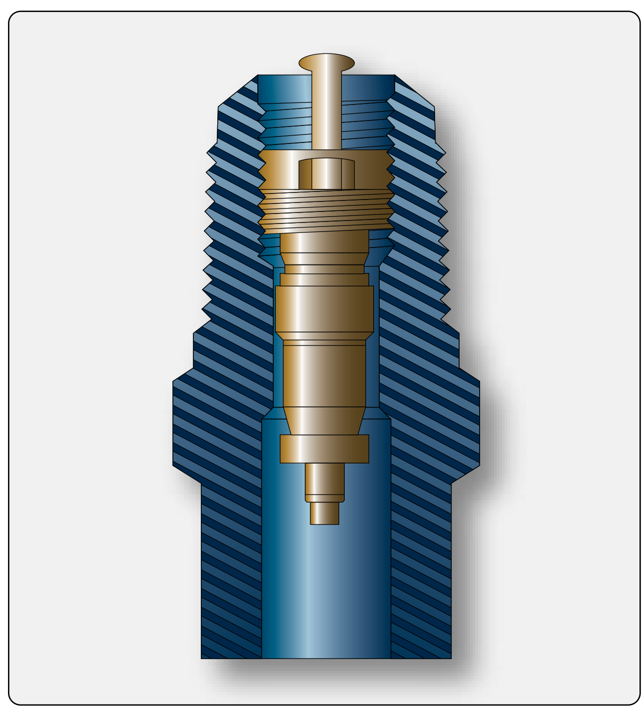

Figure 16-84. *Cross-section of an R12 refrigerant service valve.*

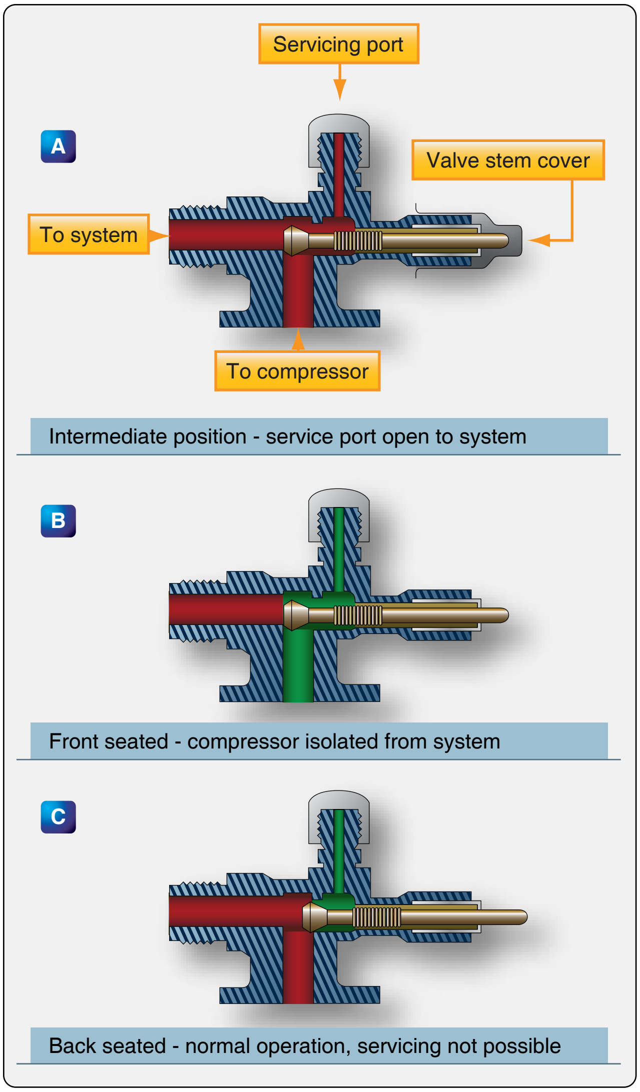

Figure 16-85. *Compressor isolation valves isolate the compressor for maintenance or replacement. They also allow normal operation and servicing of the vapor cycle air conditioning system with refrigerant.*

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, & Fittings

In the past, the main servicing device for vapor cycle air conditioning systems was the manifold set. It contains three hose fittings, two O-ring sealed valves, and two gauges. It is essentially a manifold into which the gauges, fittings, and valves are attached. The valves are positioned to connect or isolate the center hose with either fitting.

Hoses attach to the right and left manifold set fittings and the other ends of those hoses attach to the service valves in the vapor cycle system. The center fitting also has a hose attached to it. The other end of this hose connects to either a refrigerant supply or a vacuum pump, depending on the servicing function to be performed. All servicing operations are performed by manipulating the valves. *[Figure 16-86]*

The gauges on the manifold set are dedicated—one for the low side of the system and the other for the high side. The low-pressure gauge is a compound gauge that indicates pressures above or below atmospheric pressure (0-gauge pressure). Below atmospheric pressure, the gauge is scaled in inches of mercury down to 30 inches. This is to indicate a vacuum. 29.92 inches of mercury 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]*

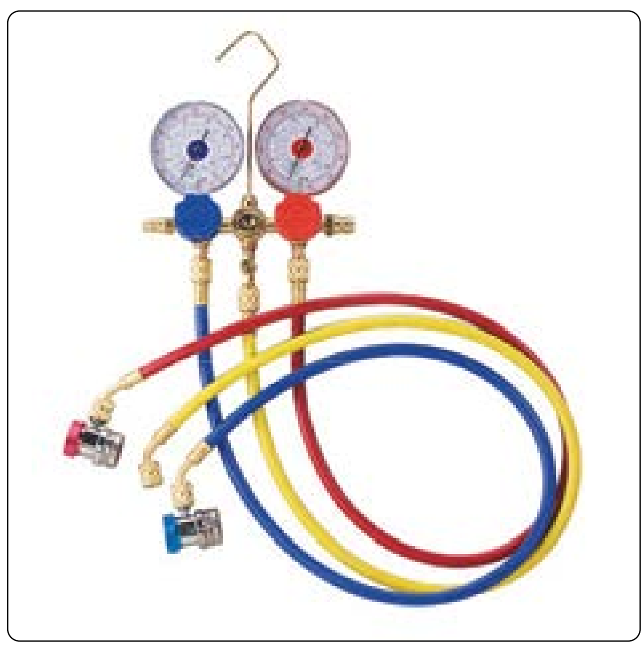

Figure 16-86. *A basic manifold set for servicing a vapor cycle air conditioning system.*

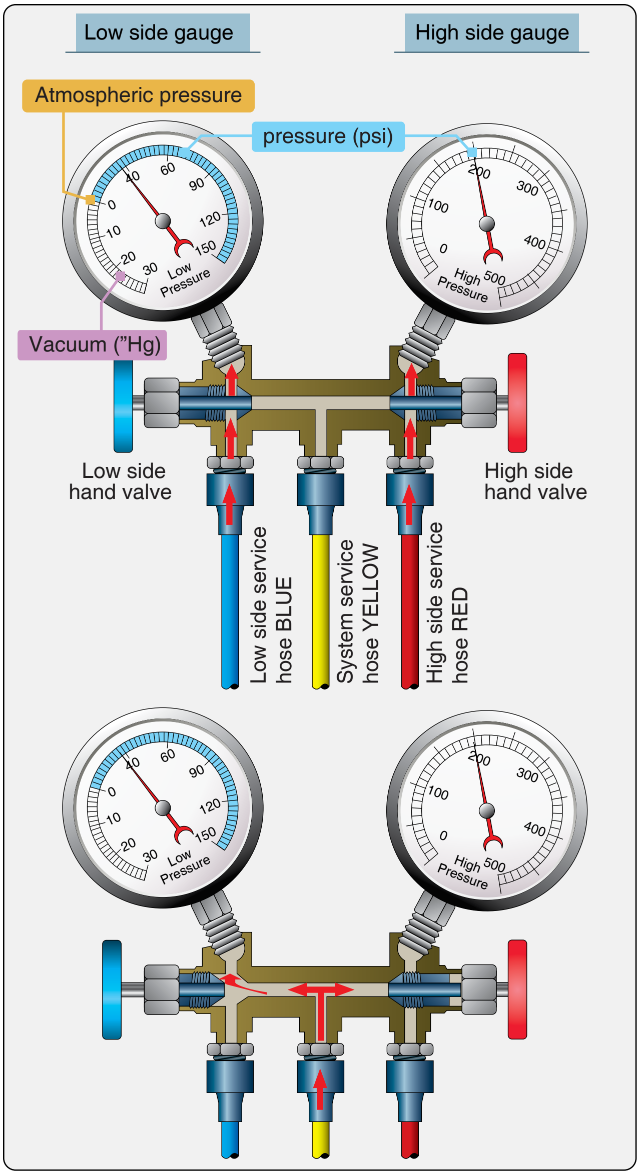

Figure 16-87. *The internal workings of a manifold set with the center fitting isolated (top). Opening a valve connects the center hose to that side of the system and the gauge (bottom).*

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, & 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

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.*

alarms signal the presence of refrigerant. A detector specified for the type of refrigerant in the system should be chosen. A good leak detector is sensitive enough to detect leaks that would result in less than ½ ounce of refrigerant to be lost per year. *[Figure 16-92]*

Other leak detection methods exist. A soapy solution can also be applied to fittings and inspected for the formation of bubbles indicating a leak. Special leak detection dyes compatible for use with refrigerant can be injected into the vapor cycle system and can be seen when they are forced out at a leak. Many of these are made to be visible under UV light. Occasionally, a leak can be detected upon close visual inspection. Oil in the system can be forced out of a leak, leaving a visible residue that is usually on the bottom side of a leaky fitting. Old hoses may become slightly porous and leak a significant amount of refrigerant over time. Because of the length and area through which the refrigerant is lost, this type of leak may be difficult to detect, even with leak detecting methods. Visibly deteriorated hoses should be replaced.

System Servicing

Vapor cycle air conditioning systems can give many hours of reliable, maintenance-free service. Periodic visual inspections, tests, and refrigerant level and oil level checks may be all that is required for some time. Follow the manufacturer's instructions for inspection criteria and intervals.

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

Figure 16-92. *This electronic infrared leak detector can detect leaks that would lose less than ¼ ounce of refrigerant per year.*

condenser at full power settings. Condensers may also have a fan to pull air over them during ground operation. It should be checked to ensure it functions correctly. *[Figure 16-93]* Be sure the capillary temperature feedback sensor to the expansion valve is securely attached to the evaporator outlet. Also, check the security of the pressure sensor and thermostat sensor if the system has them. The evaporator should not have ice on the outside. This prevents proper heat exchange to the refrigerant from the warm cabin air blown over the unit. The fan blower should be checked to ensure it rotates freely. Depending on the system, it should run whenever the cooling switch is selected and should change speeds as the selector is rotated to more or less cooling. Sometimes systems low on refrigerant can cause ice on the evaporator, 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]*

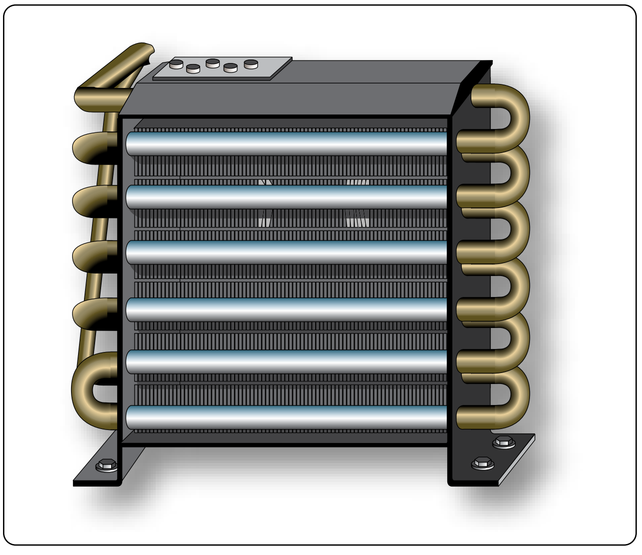

Figure 16-93. *Damaged fins on a condenser.*

Security and alignment of the compressor is critical and should be checked during inspection. Belt-driven compressors need to have proper belt tension to function properly. Check the manufacturer's data for information on how to determine the condition and tension of the belt, as well as how to make adjustments. Oil level should be sufficient. Typically, ¼ ounce of oil is added for each pound of refrigerant added to the system. When changing a component, additional oil may need to be added to replace that which is trapped in the replaced unit. Always use the oil specified in the manufacturer's maintenance manual.

Leak Test

As mentioned under the leak detector section above, leaks in a vapor cycle air conditioning system must be discovered and repaired. The most obvious sign of a possible leak is a low refrigerant level. Bubbles present in the sight glass of the receiver dryer while the system is operating indicate more refrigerant is needed. A system check for a leak may be in order. 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

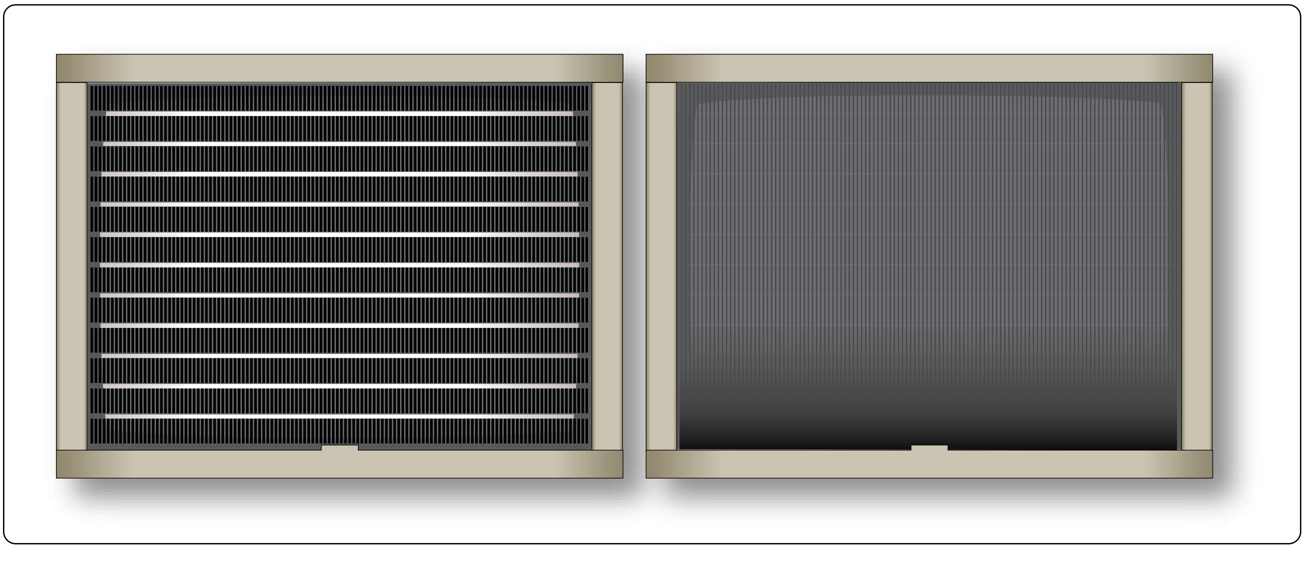

Figure 16-94. *Ice on the evaporator coils is cause for investigation. It prevents proper heat exchange to the refrigerant.*

verifies the orifice in the expansion valve is not clogged. When all refrigerant is lost due to a leak, the entire system should be checked. Each fitting and connection should be inspected visually and with a leak detector.

When a vapor cycle air conditioning system loses all of its refrigerant charge, air may enter the system. Water may also enter since it is in the air. This means that a full system evacuation must be performed after the leak is found and repaired. By establishing only a 50-psi charge in a depleted system, the leak(s) becomes detectable, but time and refrigerant are not wasted prior to evacuation. System evacuation is discussed below.

Performance Test

Verification of proper operation of a vapor cycle air conditioning system is often part of a performance test. This involves operating the system and checking parameters to ensure they are in the normal range. A key indication of performance is the temperature of the air that is cooled by the evaporator. This can be measured at the air outflow from the evaporator or at a nearby delivery duct outlet. An ordinary thermometer should read 40–50 °F, with the controls set to full cold after the system has been allowed to operate for a few minutes. Manufacturer's instructions include information on where to place the thermometer and the temperature range that indicates acceptable performance.

Pressures can also be observed to indicate system performance. Typically, low side pressure in a vapor cycle system operating normally is 10–50 psi, depending on ambient temperature. High side pressure is between 125 and 250 psi, again, depending on ambient temperature and the design of the system. All system performance tests are performed at a specified engine rpm (stable compressor speed) and involve a period of time to stabilize the operation of the vapor cycle. Consult the manufacturer's instructions for guidance.

Feel Test

A quick reference field test can be performed on a vapor cycle air conditioning system to gauge its health. In particular, components and lines in the high side (from the compressor to the expansion valve) should be warm or hot to the touch. The lines on both sides of the receiver dryer should be the same temperature. Low side lines and the evaporator should be cool. Ice should not be visible on the outside of the system. If any discrepancies exist, further investigation is needed. On hot, humid days, the cooling output of the vapor cycle system may be slightly compromised due to the volume of water condensing on the evaporator.

Purging the System

Purging the system means emptying it of its refrigerant charge. Since the refrigerant must be captured, a service cart with this capability should be used. By connecting the hoses to the high side and low side service valves and selecting recover, cart solenoid valves position so that a system purging compressor pumps the refrigerant out of the vapor cycle system and into a recovery tank.

Vapor cycle systems must be properly purged before opening for maintenance or component replacement. Once opened, precautions should be taken to prevent contaminants from entering the system. When suspicion exists that the system has been contaminated, such as when a component has catastrophically failed, it can be flushed clean. Special fluid flush formulated for vapor cycle air conditioning systems should be used. The receiver dryer is removed from the system for flushing and a new unit is installed, as it contains fresh filters. Follow the aircraft manufacturer's instructions.

Checking Compressor Oil

The compressor is a sealed unit in the vapor cycle system that is lubricated with oil. Any time the system is purged, it is an opportunity to check the oil quantity in the compressor crankcase. This is often done by removing a filler plug and using a dip stick. Oil quantity should be maintained within the proper range using oil recommended by the manufacturer. Be certain to replace the filler plug after checking or adding oil. *[Figure 16-95]*

Evacuating the System

Only a few drops of moisture can contaminate a vapor cycle air conditioning system. If this moisture freezes in the expansion valve, it could completely block the refrigerant flow. Water is removed from the system by evacuation. Anytime the system refrigerant charge falls below atmospheric pressure, the refrigerant is lost, or the system is opened, it must be evacuated before recharging.

Evacuating a vapor cycle air conditioning system is also known as pumping down the system. A vacuum pump is 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

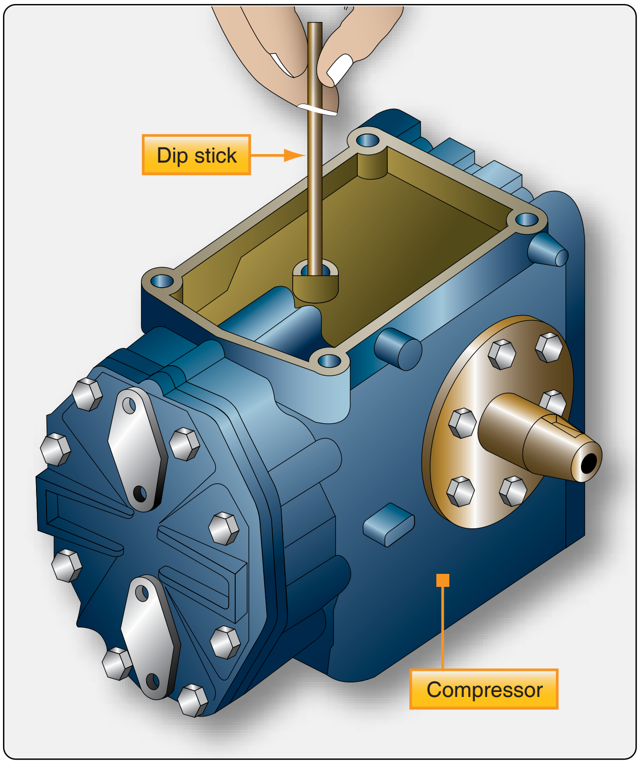

Figure 16-95. *Checking the compressor oil when the system is open.*

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 flight deck. 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 flight deck. 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.

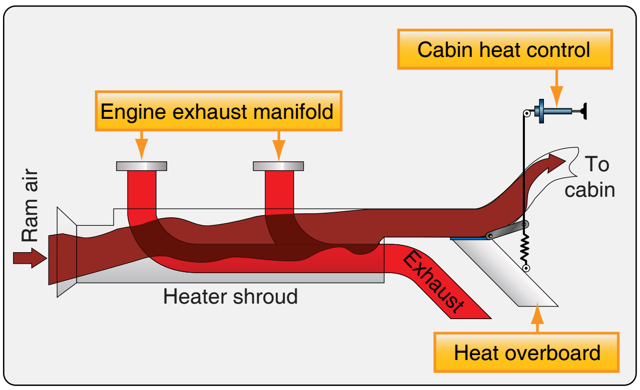

Figure 16-96. *The basic arrangement of an aircraft exhaust shroud heater.*

Exhaust Shroud Heaters

Most single-engine light aircraft use exhaust shroud heating systems to heat the cabin. Ambient air is directed into a metal shroud, or jacket, that encases part of the engine's exhaust system. The air is warmed by the exhaust and directed through a firewall heater valve into the cabin. This simple solution requires no electrical or engine power and it makes use of heat that would otherwise be wasted. *[Figures 16-96* and *16-97]*

A major concern of exhaust shroud heat systems is the possibility that exhaust gases could contaminate the cabin air. Even the slightest crack in an exhaust manifold could send enough carbon monoxide into the cabin to be fatal. Strict inspection procedures are in place to minimize this threat. Most involve pressurizing the exhaust system with air, while inspecting for leaks with a soapy solution. Some require the exhaust to be removed and pressurized while submerged under water to detect any leaks. Frequency of exhaust heat leak detection can be every 100 hours.

Occasionally, the exhaust system is slightly modified in a

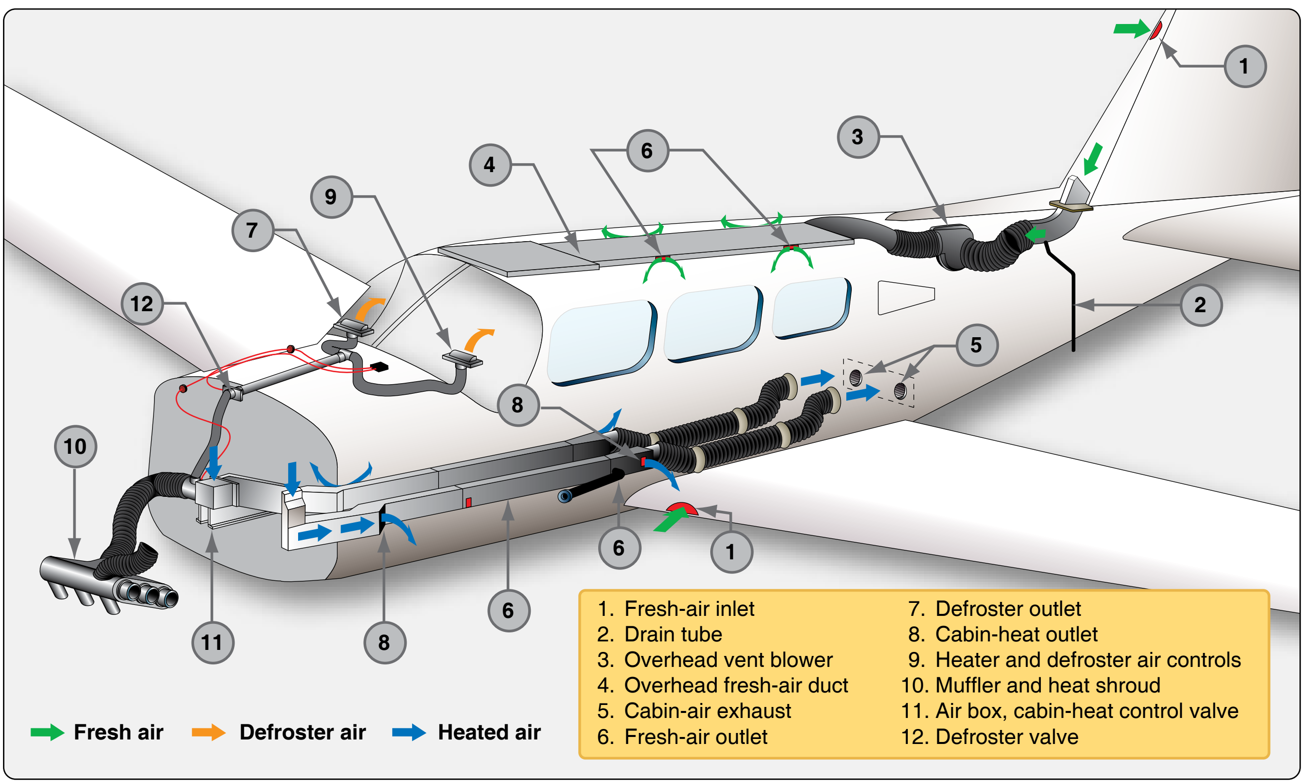

Figure 16-97. *The environmental system of a single-engine Piper aircraft with an exhaust shroud heating system.*

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]*

Regardless of age or condition, aircraft with exhaust shroud heating systems should contain a carbon monoxide detection device in the flight deck.

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.

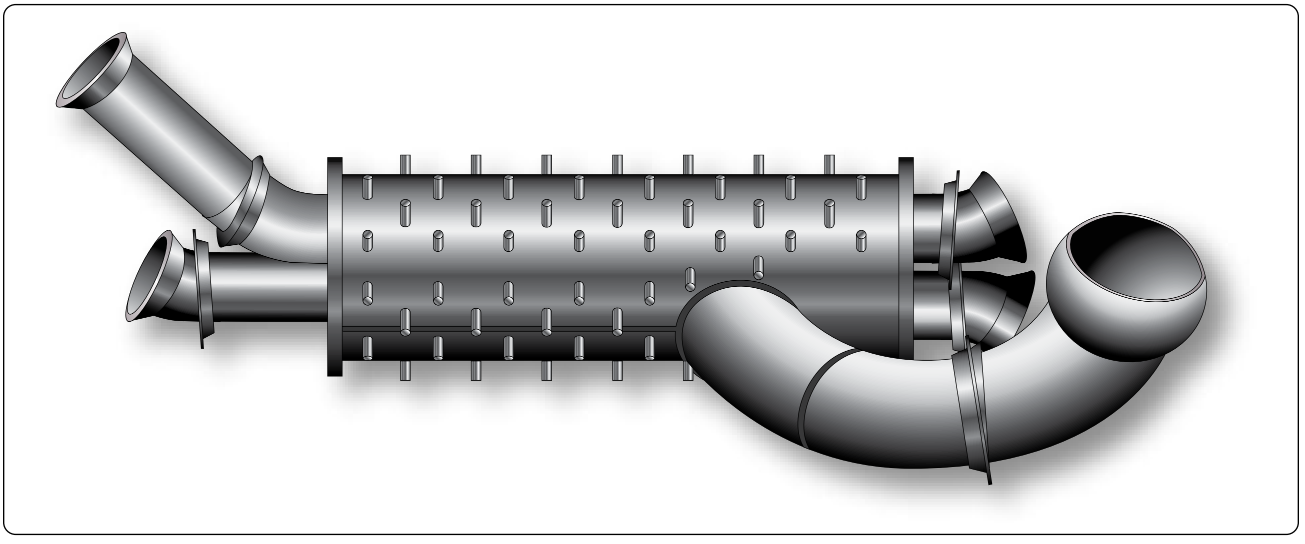

Figure 16-98. *An exhaust manifold with its shroud removed showing numerous welded studs used to increase heat transfer from the exhaust to the ambient air going to the cabin.*

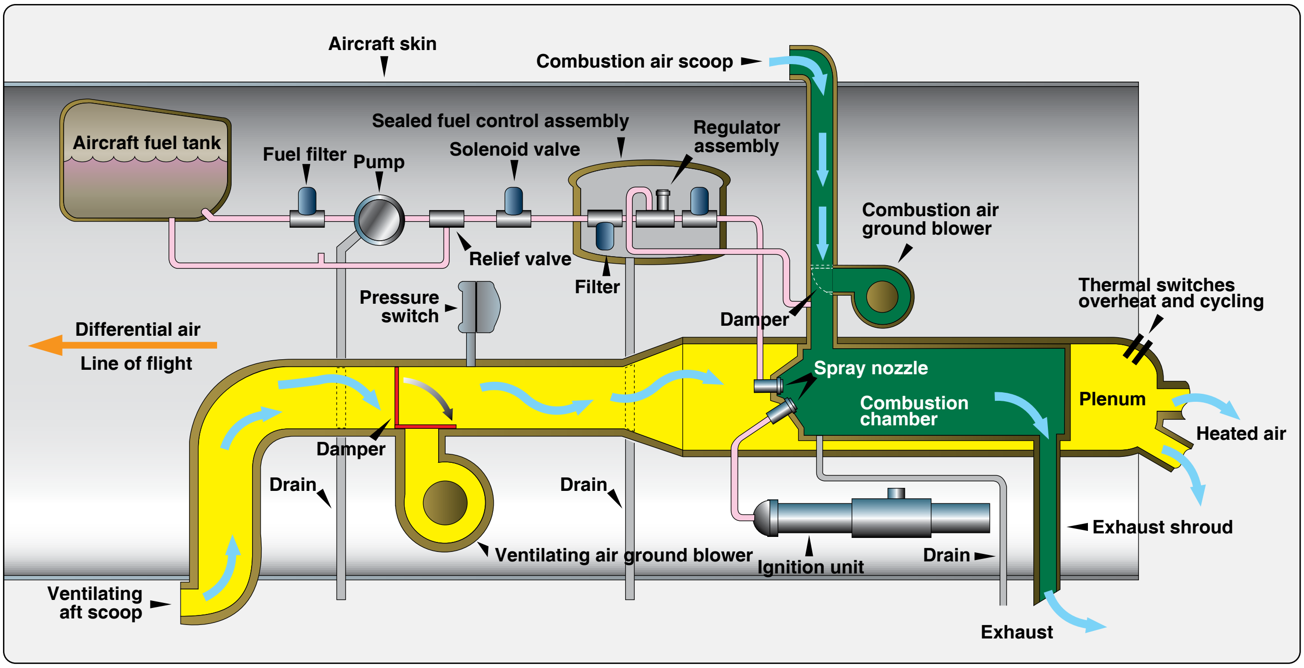

Figure 16-100. *A diagram of a typical combustion heater and its components.*

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 flight deck 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 flight deck, 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.

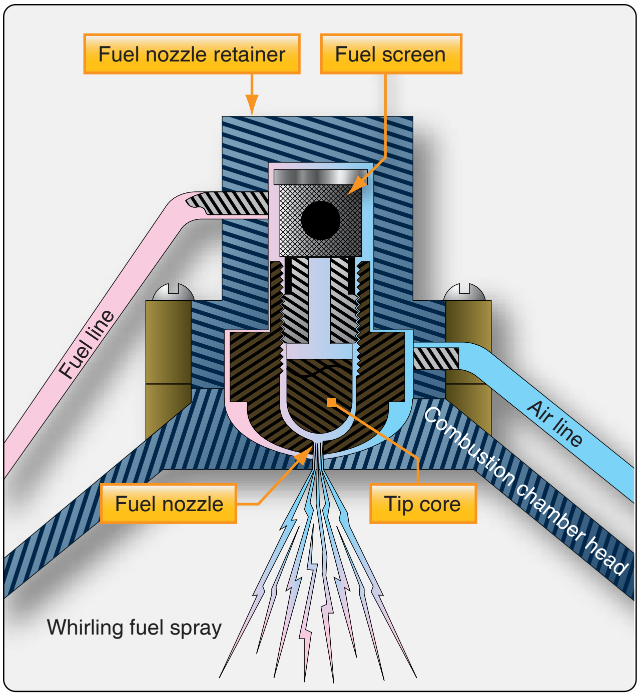

Figure 16-101. *The fuel nozzle located at the end of the combustion chamber sprays aircraft fuel, which is lit by a continuous sparking ignition system spark plug.*

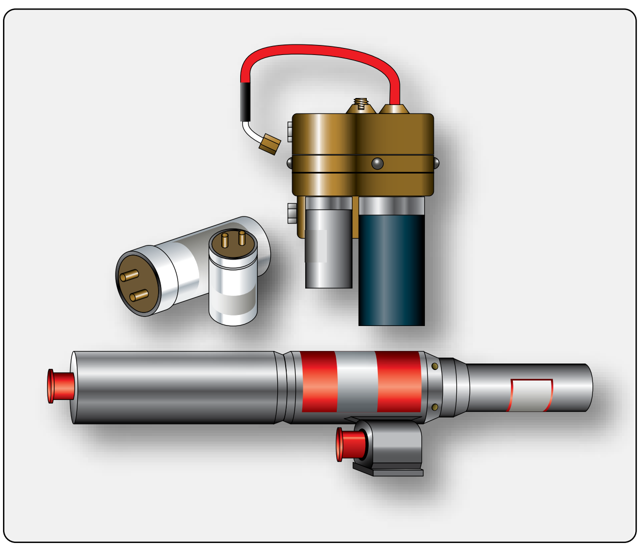

Figure 16-102. *Examples of ignition units used on combustion heaters.*

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 flight deck 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 & Inspection

Maintenance of combustion heaters consists of routine items, such as cleaning filters, checking spark plug wear, and ensuring inlets are not plugged. All maintenance and inspection of combustion heaters should be accomplished in accordance with the aircraft manufacturer's instructions. Combustion heater manufacturers also produce maintenance guidelines that should be followed. Intervals between the performance of maintenance items and the time between overhauls must be followed to help ensure a properly functioning heater is available when it is needed.

Inspection of the combustion heater should be performed on schedule as provided by the manufacturer or whenever a malfunction is suspected. Inlets and outlets should be clear. All controls should be checked for freedom of operation and function. Close observation for any sign of fuel leaks or cracks in the combustion chamber and/or shroud should be made. All components should be secure. An operational check can also be made. Follow the manufacturer's inspection criteria to ensure the combustion heater is in airworthy condition.

Chapter 17

Fire Protection Systems

Introduction

Because fire is one of the most dangerous threats to an aircraft, the potential fire zones of modern multiengine aircraft are protected by a fixed fire protection system. A fire zone is an area, or region, of an aircraft designed by the manufacturer to require fire detection and/or fire extinguishing equipment and a high degree of inherent fire resistance. The term "fixed" describes a permanently installed system in contrast to any type of portable fire extinguishing equipment, such as a hand-held Halon or water fire extinguisher. A complete fire protection system on modern aircraft, and on many older aircraft, includes a fire detection system and a fire extinguishing system. Typical zones on aircraft that have a fixed fire detection and/or fire extinguisher system are:

1. Engines and auxiliary power unit (APU).
2. Cargo and baggage compartments.
3. Lavatories on transport aircraft.
4. Electronic bays.
5. Wheel wells.
6. Bleed air ducts.

To detect fires or overheat conditions, detectors are placed in the various zones to be monitored. Fires are detected in reciprocating engine and small turboprop aircraft using one or more of the following:

1. Overheat detectors.
2. Rate-of-temperature-rise detectors.
3. Flame detectors.
4. Observation by crewmembers.

In addition to these methods, other types of detectors are used in aircraft fire protection systems but are seldom used to detect engine fires. For example, smoke detectors are better suited to monitor areas where materials burn slowly or smolder, such as cargo and baggage compartments. Other types of detectors in this category include carbon monoxide detectors and chemical sampling equipment capable of detecting combustible mixtures that can lead to accumulations of explosive gases.

The complete aircraft fire protection systems of most large turbine-engine aircraft incorporate several of these different detection methods.

1. Rate-of-temperature-rise detectors.
2. Radiation sensing detectors.
3. Smoke detectors.
4. Overheat detectors.
5. Carbon monoxide detectors.
6. Combustible mixture detectors.
7. Optical detectors.
8. Observation by crew or passengers.

The types of detectors most commonly used for fast detection of fires are the rate-of-rise, optical sensor, pneumatic loop, and electric resistance systems.

Classes of Fires

The following classes of fires that are likely to occur onboard aircraft, as defined in the U.S. National Fire Protection Association (NFPA) Standard 10, Standard for Portable Fire Extinguishers, 2007 Edition, are:

1. Class A—fires involving ordinary combustible materials, such as wood, cloth, paper, rubber, and plastics.
2. Class B—fires involving flammable liquids, petroleum oils, greases, tars, oil-based paints, lacquers, solvents, alcohols, and flammable gases.
3. Class C—fires involving energized electrical equipment in which the use of an extinguishing media that is electrically nonconductive is important.
4. Class D—fires involving combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.

Requirements for Overheat & Fire Protection Systems

Fire protection systems on current-production aircraft do not rely on observation by crew members as a primary method of fire detection. An ideal fire detector system includes as many of the following features as possible:

1. No false warnings under any flight or ground condition.
2. Rapid indication of a fire and accurate location of the fire.
3. Accurate indication that a fire is out.

4. Indication that a fire has re-ignited.
5. Continuous indication for duration of a fire.
6. Means for electrically testing the detector system from the aircraft flight deck.
7. Resists damage from exposure to oil, water, vibration, extreme temperatures, or handling.
8. Light in weight and easily adaptable to any mounting position.
9. Circuitry that operates directly from the aircraft power system without inverters.
10. Minimum electrical current requirements when not indicating a fire.
11. Flight deck light that illuminates, indicating the location of the fire, and with an audible alarm system.
12. A separate detector system for each engine.

Fire Detection/Overheat Systems

A fire detection system should signal the presence of a fire. Units of the system are installed in locations where there are greater possibilities of a fire. Three detector system types in common use are the thermal switch, thermocouple, and the continuous loop.

Thermal Switch System

A number of detectors, or sensing devices, are available. Many older-model aircraft still operating have some type of thermal switch system or thermocouple system. A thermal switch system has one or more lights energized by the aircraft power system and thermal switches that control operation of the light(s). These thermal switches are heat-sensitive units that complete electrical circuits at a certain temperature. They are connected in parallel with each other but in series with the indicator lights. *[Figure 17-1]* If the temperature rises above a set value in any one section of the circuit, the thermal switch closes, completing the light circuit to indicate a fire or overheat condition. No set number of thermal switches is required; the exact number is usually determined by the aircraft manufacturer. On some installations, all the thermal detectors are connected to one light; on others, there may be one thermal switch for each indicator light.

Some warning lights are push-to-test lights. The bulb is tested by pushing it in to check an auxiliary test circuit. The circuit shown in *Figure 17-1* includes a test relay. With the relay contact in the position shown, there are two possible paths for current flow from the switches to the light. This is an additional safety feature. Energizing the test relay completes a series circuit and checks all the wiring and the light bulb. Also included in the circuit shown in *Figure 17-1* is a dimming relay. By energizing the dimming relay, the circuit is altered to

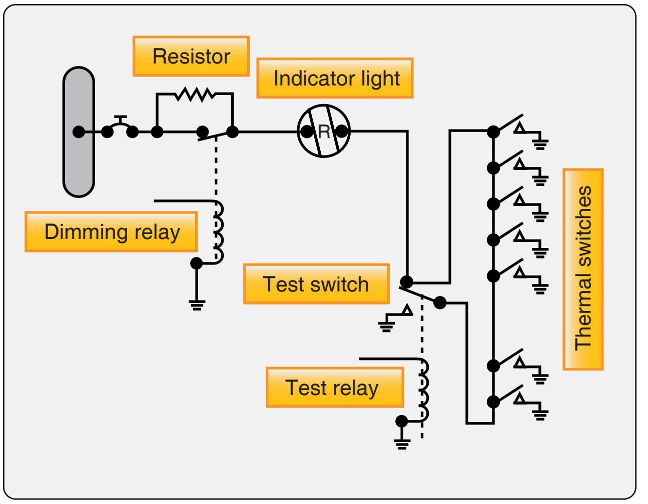

Figure 17-1. *Thermal switch fire circuit.*

include a resistor in series with the light. In some installations, several circuits are wired through the dimming relay, and all the warning lights may be dimmed at the same time.

Thermocouple System

The thermocouple fire warning system operates on an entirely different principle from the thermal switch system. A thermocouple depends on the rate of temperature rise and does not give a warning when an engine slowly overheats or a short circuit develops. The system consists of a relay box, warning lights, and thermocouples. The wiring system of these units may be divided into the following circuits:

1. Detector circuit.
2. Alarm circuit.
3. Test circuit.

These circuits are shown in *Figure 17-2*. The relay box contains two relays, the sensitive relay and the slave relay, and the thermal test unit. Such a box may contain from one to

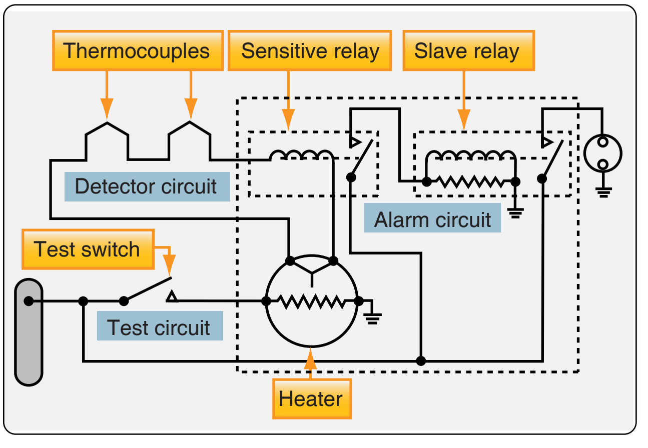

Figure 17-2. *Thermocouple fire warning circuit.*

eight identical circuits, depending on the number of potential fire zones. The relays control the warning lights. In turn, the thermocouples control the operation of the relays. The circuit consists of several thermocouples in series with each other and with the sensitive relay.

The thermocouple is constructed of two dissimilar metals, such as chromel and constantan. The point at which these metals are joined and exposed to the heat of a fire is called a hot junction. There is also a reference junction enclosed in a dead air space between two insulation blocks. A metal cage surrounds the thermocouple to give mechanical protection without hindering the free movement of air to the hot junction. If the temperature rises rapidly, the thermocouple produces a voltage because of the temperature difference between the reference junction and the hot junction. If both junctions are heated at the same rate, no voltage results. In the engine compartment, there is a normal, gradual rise in temperature from engine operation; because it is gradual, both junctions heat at the same rate and no warning signal is given. If there is a fire, however, the hot junction heats more rapidly than the reference junction. The ensuing voltage causes a current to flow within the detector circuit. Any time the current is greater than 4 milliamperes (0.004 ampere), the sensitive relay closes. This completes a circuit from the aircraft power system to the coil of the slave relay. The slave relay then closes and completes the circuit to the warning light to give a visual fire warning.

The total number of thermocouples used in individual detector circuits depends on the size of the fire zones and the total circuit resistance, which usually does not exceed 5 ohms. As shown in *Figure 17-2,* the circuit has two resistors. The resistor connected across the slave relay terminals absorbs the coil's self-induced voltage to prevent arcing across the points of the sensitive relay. The contacts of the sensitive relay are so fragile that they burn, or weld, if arcing is permitted.

When the sensitive relay opens, the circuit to the slave relay is interrupted and the magnetic field around its coil collapses. The coil then gets a voltage through self-induction but, with the resistor across the coil terminals, there is a path for any current flow as a result of this voltage, eliminating arcing at the sensitive relay contacts.

Continuous-Loop Systems

Transport aircraft almost exclusively use continuous thermal sensing elements for powerplant and wheel well protection. These systems offer superior detection performance and coverage, and they have the proven ruggedness to survive in the harsh environment of modern turbofan engines.

A continuous-loop detector or sensing system permits more complete coverage of a fire hazard area than any of the spot-type temperature detectors. Two widely used types of continuous-loop systems are the thermistor type detectors, such as the Kidde and the Fenwal systems, and the pneumatic pressure detector, such as the Lingberg system. (Lindberg system is also known as Systron-Donner and, more recently, Meggitt Safety Systems.)

Fenwal System

The Fenwal system uses a slender Inconel tube packed with thermally sensitive eutectic salt and a nickel wire center conductor. *[Figure 17-3]* Lengths of these sensing elements are connected in series to a control unit. The elements may be of equal or varying length and of the same or different temperature settings. The control unit, operating directly from the power source, impresses a small voltage on the sensing elements. When an overheat condition occurs at any point along the element length, the resistance of the eutectic salt within the sensing element drops sharply, causing current to flow between the outer sheath and the center conductor. This current flow is sensed by the control unit, which produces a signal to actuate the output relay and activate the alarms. When the fire has been extinguished or the critical temperature lowered below the set point, the Fenwal system automatically returns to standby alert, ready to detect any subsequent fire or overheat condition. The Fenwal system may be wired to employ a loop circuit. In this case, should an open circuit occur, the system still signals fire or overheat. If multiple open circuits occur, only that section between breaks becomes inoperative.

Kidde System

In the Kidde continuous-loop system, two wires are embedded in an Inconel tube filled with a thermistor core material. *[Figure 17-4]* Two electrical conductors go through the length of the core. One conductor has a ground connection to the tube, and the other conductor connects to

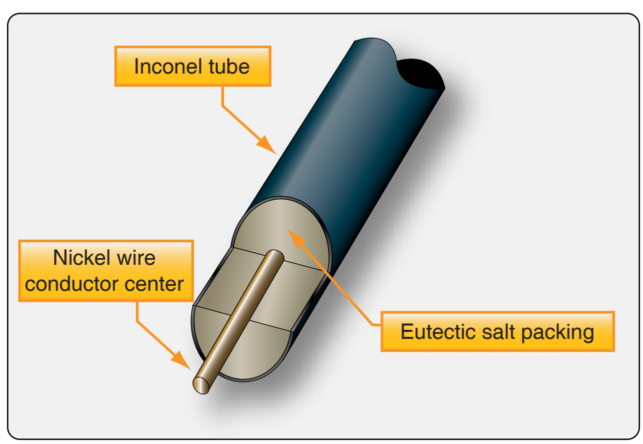

Figure 17-3. *Fenwal sensing element.*

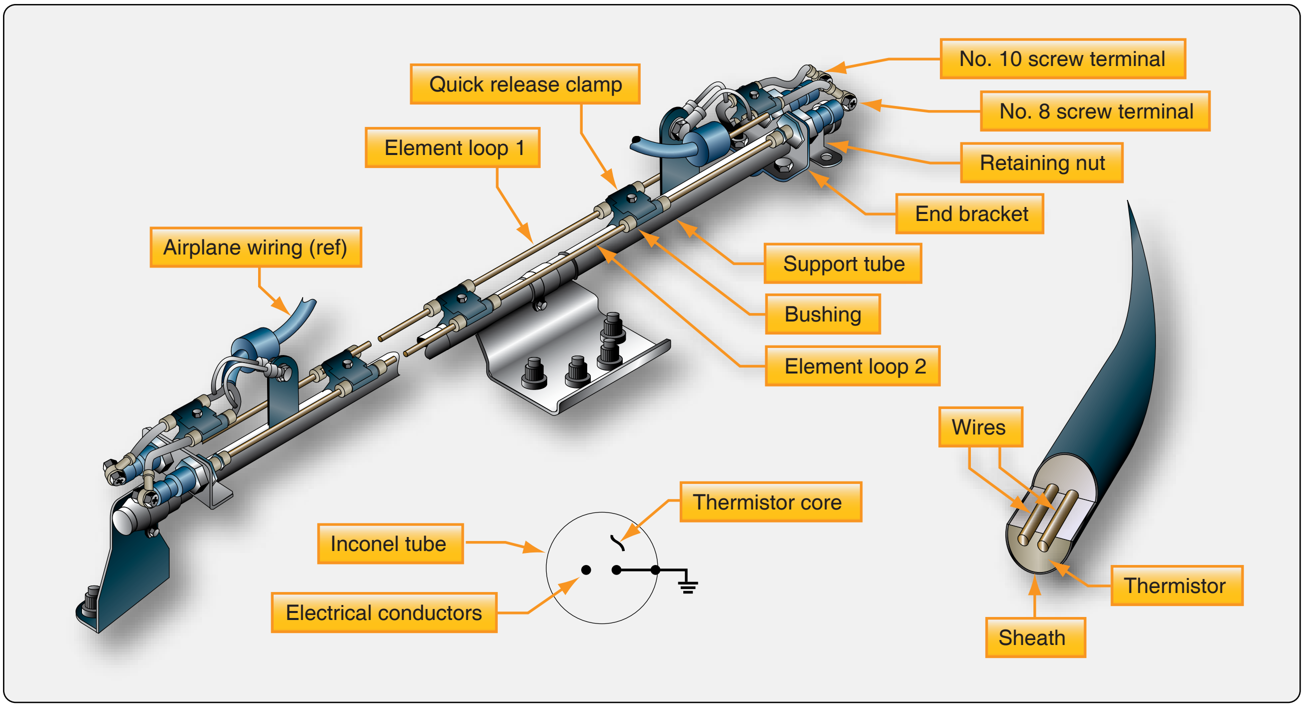

Figure 17-4. *Kidde continuous-loop system.*

the fire detection control unit. As the temperature of the core increases, electrical resistance to the ground decreases. The fire detection control unit monitors this resistance. If the resistance decreases to the overheat set point, an overheat indication occurs in the flight deck. Typically, a 10-second time delay is incorporated for the overheat indication. If the resistance decreases more to the fire set point, a fire warning occurs. When the fire or overheat condition is gone, the resistance of the core material increases to the reset point and the flight deck indications disappear. The rate of change of resistance identifies an electrical short or a fire. The resistance decreases more quickly with an electrical short than with a fire. In some aircraft, in addition to fire and overheat detection, the Kidde continuous-loop system can supply nacelle temperature data to the airplane condition monitoring function of the aircraft in-flight monitoring system (AIMS).

Sensing Element

The resistance of a sensor varies inversely as it is heated; as sensor temperature is increased, its resistance decreases. Each sensor is composed of two wires embedded in thermistor material that is encased in a heavy wall Inconel tube for high strength at elevated temperatures. The electrical connectors at each end of the sensor are ceramic insulated. The Inconel tubes are shrouded in a perforated stainless-steel tube and supported by Teflon-impregnated asbestos bushings at intervals. The shroud protects the sensor from breakage due to vibration, abrasion against airplane structure, and damage from maintenance activity.

The resistance of a sensor also varies inversely with its length, the increments of length being resistances in parallel. The heating of a short length of sensor out of a given length requires that the short length be heated above the temperature alarm point, so the total resistance of the sensor decreases to the alarm point. This characteristic permits integration of all temperatures throughout the length of the installation rather than sensing only the highest local temperature. The two wires encased within the thermistic material of each Inconel tube form a variable resistance network between themselves, between the detector wire and the Inconel tube, and between each adjacent incremental length of sensor. These variable resistance networks are monitored by the application of 28 volts direct current (DC) to the detector wire from the detector control unit.

Combination Fire & Overheat Warning

The analog signal from the thermistor-sensing element permits the control circuits to be arranged to give a two-level response from the same sensing element loop. The first is an overheat warning at a temperature level below the fire warning indicating a general engine compartment temperature rise, such as would be caused by leakage of hot bleed air or combustion gas into the engine compartment. It could also be an early warning of fire and would alert the crew to appropriate action to reduce the engine compartment temperature. The second-level response is at a level above that attainable by a leaking hot gas and is the fire warning.

Temperature Trend Indication

The analog signal produced by the sensing element loop as its temperature changes is converted to signals suitable for flight deck display to indicate engine bay temperature increases from normal. A comparison of the readings from each loop system also provides a check on the condition of the fire detection system, because the two loops should normally read alike.

System Test

The integrity of the continuous-loop fire detection system may be tested by actuating a test switch in the flight deck that switches one end of the sensing element loop from its control circuit to a test circuit built into the control unit, which simulates the sensing element resistance change due to fire. *[Figure 17-5]* If the sensing element loop is unbroken, the resistance detected by the control circuit is that of the simulated fire, and the alarm is activated. The test demonstrates, in addition to the continuity of the sensing element loop, the integrity of the alarm indicator circuit and the proper functioning of the control circuits. The thermistic properties of the sensing element remain unchanged for the life of the element (no irreversible changes take place when heated); the element functions properly as long as it is electrically connected to the control unit.

Fault Indication

Provision is made in the control unit to output a fault signal which activates a fault indicator whenever the short discriminator circuit detects a short in the sensing element loop. This is a requirement for transport category aircraft because such a short disables the fire detection system.

Dual-Loop Systems

Dual-loop systems are two complete basic fire detection systems with their output signals connected so that both must signal to result in a fire warning. This arrangement, called AND logic, results in greatly increased reliability against false fire warnings from any cause. Should one of the two loops be found inoperative at the preflight integrity test, a flight deck selector switch disconnects that loop and allows the signal from the other loop alone to activate the fire warning. Since the single operative loop meets all fire detector requirements, the aircraft can be safely dispatched and maintenance deferred to a more convenient time. However, should one of the two loops become inoperative in flight and a fire subsequently occur, the fire signaling loop activates a flight deck fault signal that alerts the flight crew to select single-loop operation to confirm the possible occurrence of fire.

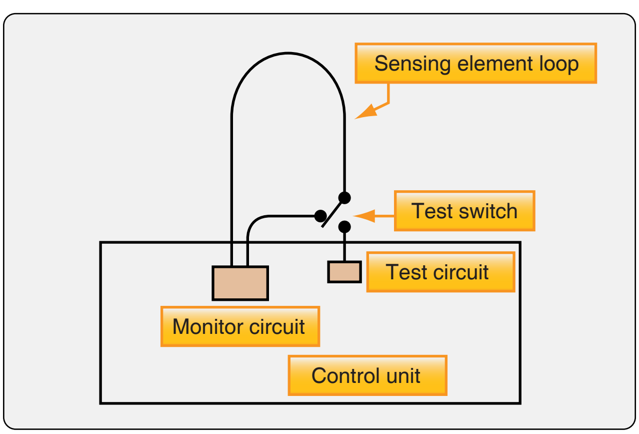

Figure 17-5. *Continuous loop fire detection system test circuit.*

Automatic Self-Interrogation

Dual-loop systems automatically perform the loop switching and decision-making function required of the flight crew upon appearance of the fault indication in the flight deck, a function called automatic self-interrogation. Automatic self-interrogation eliminates the fault indication and assures the immediate appearance of the fire indication should fire occur while at least one loop of the dual-loop system is operative. Should the control circuit from a single-loop signal fire, the self-interrogation circuit automatically tests the functioning of the other loop. If it tests operative, the circuit suppresses the fire signal because the operative loop would have signaled if a fire existed. If, however, the other loop tests inoperative, the circuit outputs a fire signal. The interrogation and decision takes place in milliseconds, so that no delay occurs if a fire actually exists.

Support Tube Mounted Sensing Elements

For those installations where it is desired to mount the sensing elements on the engine, and in some cases, on the aircraft structure, the support tube mounted element solves the problem of providing sufficient element support points and greatly facilitates the removal and reinstallation of the sensing elements for engine or system maintenance.

Most modern installations use the support tube concept of mounting sensing elements for better maintainability, as well as increased reliability. The sensing element is attached to a prebent stainless steel tube by closely spaced clamps and bushings, where it is supported from vibration damage and protected from pinching and excessive bending. The support tube-mounted elements can be furnished with either single or dual sensing elements.

Being prebent to the designed configuration assures its installation in the aircraft precisely in its designed location, where it has the necessary clearance to be free from the possibility of the elements chafing against engine or aircraft structure. The assembly requires only a few attachment points and, should its removal for engine maintenance be necessary, it is quickly and easily accomplished. Should the assembly require repair or maintenance, it is easily replaced with another assembly, leaving the repair for the shop. Should a sensing element be damaged, it is easily replaced in the assembly.

Fire Detection Control Unit (Fire Detection Card)

The control unit for the simplest type of system typically contains the necessary electronic resistance monitoring and alarm output circuits housed in a hermetically sealed aluminum case fitted with a mounting bracket and electrical connector. For more sophisticated systems, control modules are employed that contain removable control cards with circuitry for individual hazard areas and/or unique functions. In the most advanced applications, the detection system circuitry controls all aircraft fire protection functions, including fire detection and extinguishing for engines, APUs, cargo bays, and bleed-air systems.

Pressure Type Sensor Responder Systems

Some smaller turboprop aircraft are outfitted with pneumatic single point detectors. The design of these detectors is based on the principles of gas laws. The sensing element consists of a closed, helium-filled tube connected at one end to a responder assembly. As the element is heated, the gas pressure inside the tube increases until the alarm threshold is reached. At this point, an internal switch closes and reports an alarm to the flight deck. Continuous fault monitoring is included. This type of sensor is designed as a single-sensor detection system and does not require a control unit.

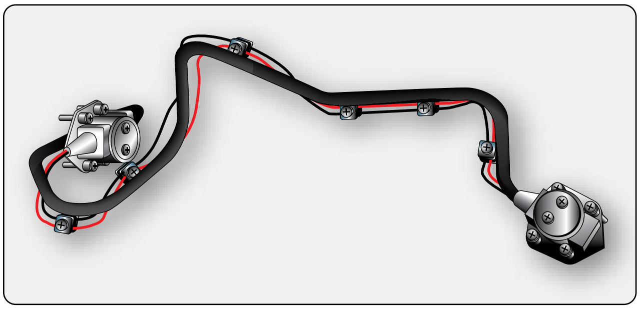

Figure 17-6. *Pneumatic dual fire/overheat detector assembly.*

Pneumatic Continuous-Loop Systems

The pneumatic continuous-loop systems are also known by their manufacturers' names Lindberg, Systron-Donner, and Meggitt Safety Systems. These systems are used for engine fire detection of transport type aircraft and have the same function as the Kidde system; however, they work on a different principle. They are typically used in a dual-loop design to increase reliability of the system.

The pneumatic detector has two sensing functions. It responds to an overall average temperature threshold and to a localized discrete temperature increase caused by impinging flame or hot gasses. Both the average and discrete temperature are factory set and are not field adjustable. *[Figure 17-6]*

Averaging Function

The fire/overheat detector serves as a fixed-volume device filled with helium gas. The helium gas pressure inside the detector increases in proportion to the absolute temperature and operates a pressure diaphragm that closes an electrical contact, actuating the alarm circuit. The pressure diaphragm within the responder assembly serves as one side of the electrical alarm contact and is the only moving part in the detector. The alarm switch is preset at an average temperature. Typical temperature ranges for average temperature settings are 200 °F (93 °C) to 850 °F (454 °C).

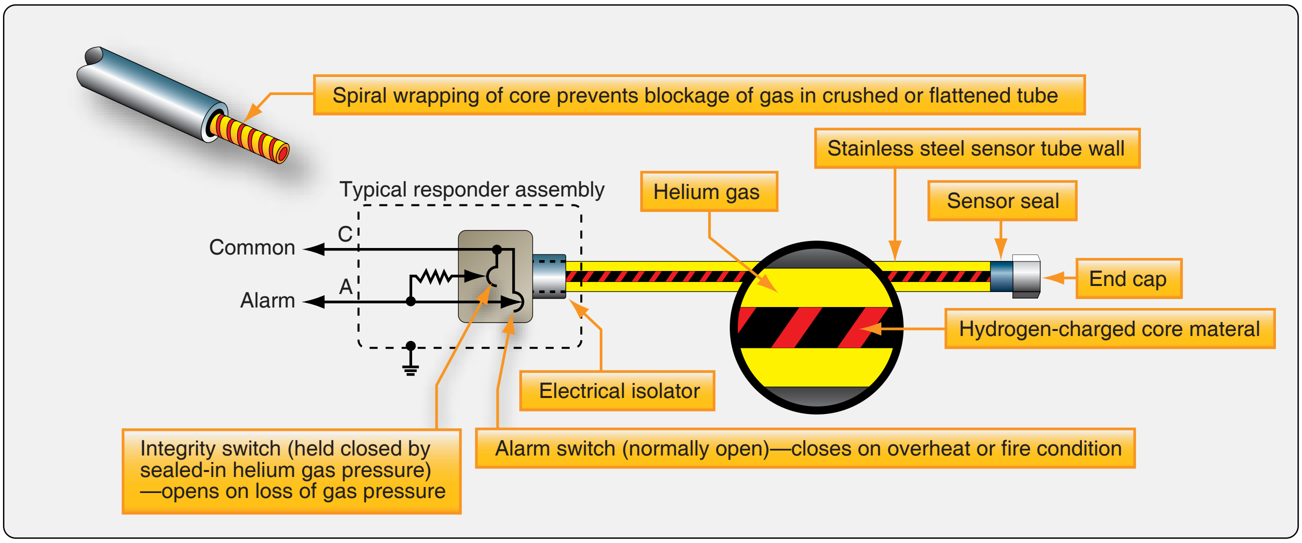

Figure 17-7. *Pneumatic pressure loop detector system.*

Discrete Function

The fire/overheat detector's sensor tube also contains a hydrogen-filled core material. *[Figure 17-7]* Large quantities of hydrogen gas are released from the detector core whenever a small section of the tube is heated to the preset discrete temperature or higher. The core outgassing increases the pressure inside the detector and actuates the alarm switch. Both the averaging and discrete functions are reversible. When the sensor tube is cooled, the average gas pressure is lowered, and the discrete hydrogen gas returns to the core material. The reduction of internal pressure allows the alarm switch to return to its normal position, opening the electrical alarm circuit.

Figure 17-8 shows a typical aircraft fire detection system in which a control module monitors two loops of up to four pneumatic detectors each, connected in parallel. The control module responds directly to an alarm condition and continuously monitors the wiring and integrity of each loop. The normally open alarm switch closes upon an overheat or fire condition, causing a short circuit between terminals A and C. During normal operation, a resistance value is maintained across the terminals by a normally closed integrity switch. Loss of sensor gas pressure opens the integrity switch, creating an open circuit across the terminals of the faulted detector. In addition to the pressure-activated alarm switch, there is a second integrity switch in the detector that is held closed by the averaging gas pressure at all temperatures down to –65 °F (–54 °C). If the detector should develop a leak, the loss of gas pressure would allow the integrity switch to open and signal a lack of detector integrity. The system then does not operate during test.

Fire Zones

Powerplant compartments are classified into zones based on the airflow through them.

1. Class A zone—area of heavy airflow past regular arrangements of similarly shaped obstructions. The power section of a reciprocating engine is usually of this type.
2. Class B zone—area of heavy airflow past aerodynamically clean obstructions. Included in this type are heat exchanger ducts, exhaust manifold shrouds, and areas where the inside of the enclosing cowling or other closure is smooth, free of pockets, and adequately drained so leaking flammables cannot puddle. Turbine engine compartments may be considered in this class if engine surfaces are aerodynamically clean and all airframe structural formers are covered by a fireproof liner to produce an aerodynamically clean enclosure surface.
3. Class C zone—area of relatively low airflow. An engine accessory compartment separated from the power section is an example of this type of zone.
4. Class D zone—area of very little or no airflow. These include wing compartments and wheel wells where little ventilation is provided.
5. Class X zone—area of heavy airflow and of unusual construction, making uniform distribution of the extinguishing agent very difficult. Areas containing deeply recessed spaces and pockets between large structural formers are of this type. Tests indicate agent requirements to be double those for Class A zones.

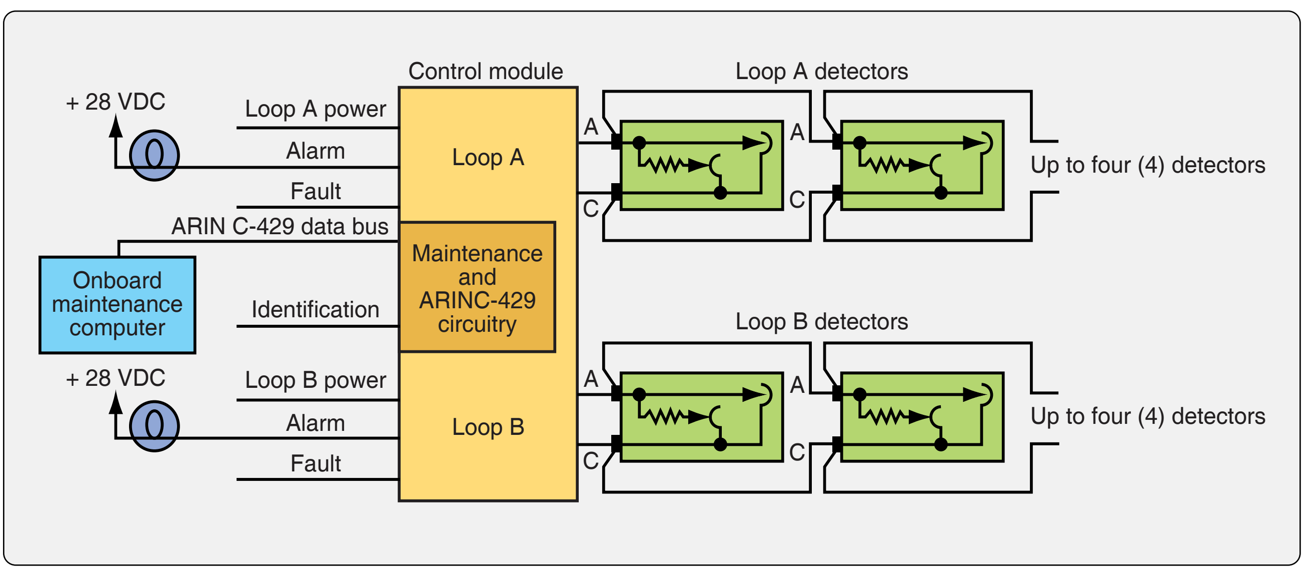

Figure 17-8. *Aircraft detection system control module.*

Smoke, Flame, & Carbon Monoxide Detection Systems

Smoke Detectors

A smoke detection system monitors the lavatories and cargo baggage compartments for the presence of smoke, which is indicative of a fire condition. Smoke detection instruments that collect air for sampling are mounted in the compartments in strategic locations. A smoke detection system is used where the type of fire anticipated is expected to generate a substantial amount of smoke before temperature changes are sufficient to actuate a heat detection system. Two common types used are light refraction and ionization.

Light Refraction Type

The light refraction type of smoke detector contains a photoelectric cell that detects light refracted by smoke particles. Smoke particles refract the light to the photoelectric cell and, when it senses enough change in the amount of light, it creates an electrical current that sets off a warning light. This type of smoke detector is referred to as a photoelectrical device.

Ionization Type

Some aircraft use an ionization type smoke detector. The system generates an alarm signal (both horn and indicator) by detecting a change in ion density due to smoke in the cabin. The system is connected to the 28-volt DC electrical power supplied from the aircraft. Alarm output and sensor sensitive checks are performed simply with the test switch on the control panel.

Flame Detectors

Optical sensors, often referred to as flame detectors, are designed to alarm when they detect the presence of prominent, specific radiation emissions from hydrocarbon flames. The two types of optical sensors available are infrared (IR) and ultraviolet (UV), based on the specific emission wavelengths that they are designed to detect. IR-based optical flame detectors are used primarily on light turboprop aircraft and helicopter engines. These sensors have proven to be very dependable and economical for these applications.

When radiation emitted by the fire crosses the airspace between the fire and the detector, it impinges on the detector front face and window. The window allows a broad spectrum of radiation to pass into the detector where it strikes the sensing device filter. The filter allows only radiation in a tight waveband centered on 4.3 micrometers in the IR band to pass on to the radiation-sensitive surface of the sensing device. The radiation striking the sensing device minutely raises its temperature causing small thermoelectric voltages to be generated. These voltages are fed to an amplifier whose output is connected to various analytical electronic processing circuits. The processing electronics are tailored exactly to the time signature of all known hydrocarbon flame sources and ignores false alarm sources, such as incandescent lights and sunlight. Alarm sensitivity level is accurately controlled by a digital circuit. *[Figure 17-9]*

Carbon Monoxide Detectors

Carbon monoxide is a colorless, odorless gas that is a byproduct of incomplete combustion. Its presence in the

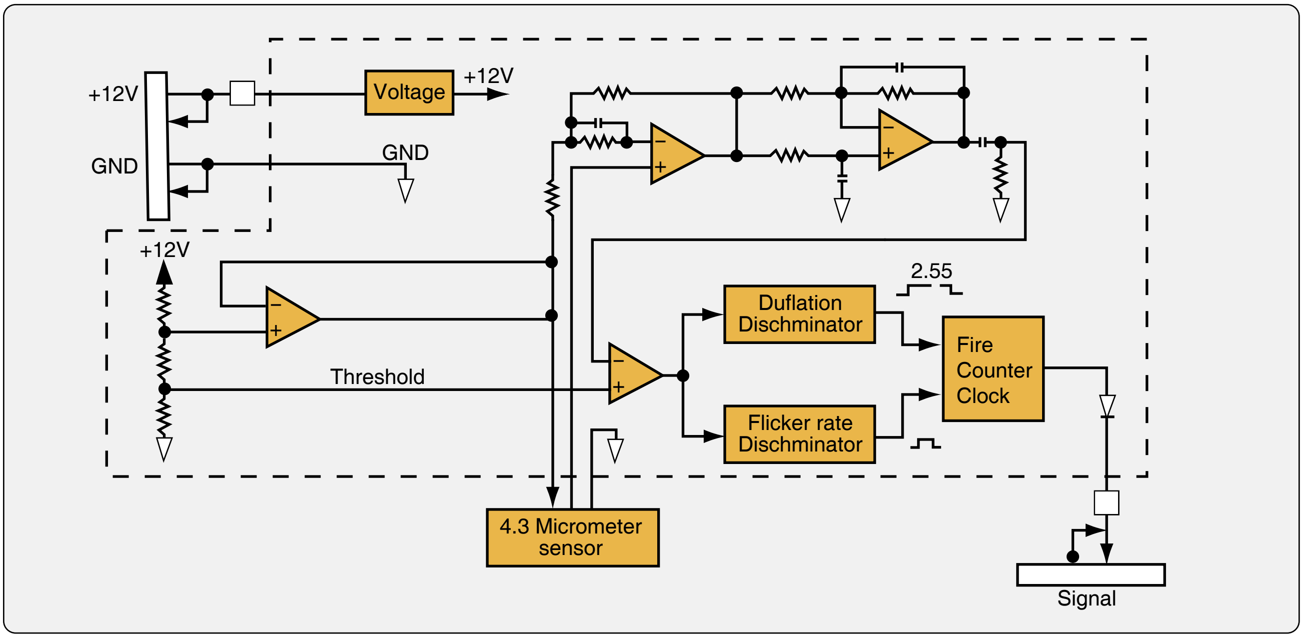

Figure 17-9. *Infrared (IR) based optical flame detector.*

breathing air of human beings can be deadly. To ensure crew and passenger safety, carbon monoxide detectors are used in aircraft cabins and flight decks. They are most often found on reciprocating engine aircraft with exhaust shroud heaters and on aircraft equipped with a combustion heater. Turbine bleed air, when used for heating the cabin, is tapped off of the engine upstream of the combustion chamber. Therefore, no threat of carbon monoxide presence is posed.

Carbon monoxide gas is found in varying degrees in all smoke and fumes of burning carbonaceous substances. Exceedingly small amounts of the gas are dangerous if inhaled. A concentration of as little as 2 parts in 10,000 may produce headache, mental dullness, and physical lethargy within a few hours. Prolonged exposure or higher concentrations may cause death.

There are several types of carbon monoxide detectors. Electronic detectors are common. Some are panel mounted and others are portable. Chemical color-change types are also common. These are mostly portable. Some are simple buttons, cards, or badges that have a chemical applied to the surface. Normally, the color of the chemical is tan. In the presence of carbon monoxide, the chemical darkens to grey or even black. The transition time required to change color is inversely related to the concentration of CO present. At 50 parts per million, the indication is apparent within 15 to 30 minutes. A concentration of 100 parts per million changes the color of the chemical in as little as 2–5 minutes. As concentration increases or duration of exposure is prolonged, the color evolves from grey to dark grey to black. If contaminated, installing a new indicating element allows a carbon monoxide portable test unit to be returned to service.

Extinguishing Agents & Portable Fire Extinguishers

There must be at least one hand held, portable fire extinguisher for use in the pilot compartment that is located within easy access of the pilot while seated. There must be at least one hand held fire extinguisher located conveniently in the passenger compartment of each airplane accommodating more than 6 and less than 30 passengers. Each extinguisher for use in a personnel compartment must be designed to minimize the hazard of toxic gas concentrations. The number of portable, hand held fire extinguishers for transport aircraft is shown in *Figure 17-10.*

Passenger capacity	No. of extinguishers
7 through 30	1
31 through 60	2
61 through 200	3
201 through 300	4
301 through 400	5
401 through 500	6
501 through 600	7
601 through 700	8

Figure 17-10. *Hand held fire extinguisher requirement for transport aircraft.*

Halogenated Hydrocarbons

For over 45 years, halogenated hydrocarbons (Halons) have been practically the only fire extinguishing agents used in civil transport aircraft. However, Halon is an ozone depleting and global warming chemical, and its production has been banned by international agreement. Although Halon usage has been banned in some parts of the world, aviation has been granted an exemption because of its unique operational and fire safety requirements. Halon has been the fire extinguishing agent of choice in civil aviation because it is extremely effective on a per unit weight basis over a wide range of aircraft environmental conditions. It is a clean agent (no residue), electrically nonconducting, and has relatively low toxicity.

Two types of Halons are employed in aviation: Halon 1301($CBrF_3$) a total flooding agent, and Halon 1211 ($CBrClF_2$) a streaming agent. Class A, B, or C fires are appropriately controlled with Halons. However, do not use Halons on a class D fire. Halon agents may react vigorously with the burning metal.

Note: While Halons are still in service and are appropriate agents for these classes of fires, the production of these ozone depleting agents has been restricted. Although not required, consider replacing Halon extinguishers with Halon replacement extinguishers when discharged. Halon replacement agents found to be compliant to date include the halocarbons HCFC Blend B, HFC-227ea, and HFC-236fa.

Inert Cold Gases

Carbon dioxide (CO_2) is an effective extinguishing agent. It is most often used in fire extinguishers that are available on the ramp to fight fires on the exterior of the aircraft, such as engine or APU fires. CO_2 has been used for many years to extinguish flammable fluid fires and fires involving electrical equipment. It is noncombustible and does not react with most substances. It provides its own pressure for discharge from the storage vessel, except in extremely cold climates where a booster charge of nitrogen may be added to winterize the system. Normally, CO_2 is a gas, but it is easily liquefied by compression and cooling. After liquification, CO_2 remains in a closed container as both liquid and gas. When CO_2 is then discharged to the atmosphere, most of the liquid expands to gas. Heat absorbed by the gas during vaporization cools the remaining liquid to –110 °F, and it becomes a finely divided white solid, dry ice snow.

Carbon dioxide is about 1½ times as heavy as air, which gives it the ability to replace air above burning surfaces and maintain a smothering atmosphere. CO_2 is effective as an extinguishing agent primarily because it dilutes the air and reduces the oxygen content so that combustion is no longer supported. Under certain conditions, some cooling effect is also realized. CO_2 is considered only mildly toxic, but it can cause unconsciousness and death by suffocation if the victim is allowed to breathe CO_2 in fire extinguishing concentrations for 20 to 30 minutes. CO_2 is not effective as an extinguishing agent on fires involving chemicals containing their own oxygen supply, such as cellulose nitrate (used in some aircraft paints). Also, fires involving magnesium and titanium cannot be extinguished by CO_2.

Dry Powders

Class A, B, or C fires can be controlled by dry chemical extinguishing agents. The only all purpose (Class A, B, C rating) dry chemical powder extinguishers contain mono-ammonium phosphate. All other dry chemical powders have a Class B, C U.S – UL fire rating only. Dry powder chemical extinguishers best control class A, B, and C fire but their use is limited due to residual residue and clean up after deployment.

Water

Class A type fires are best controlled with water by cooling the material below its ignition temperature and soaking the material to prevent re-ignition.

Flight Deck & Cabin Interiors

All materials used in the flight deck and cabin must conform to strict standards to prevent fire. In case of a fire, several types of portable fire extinguishers are available to fight the fire. The most common types are Halon 1211 and water.

Extinguisher Types

Portable fire extinguishers are used to extinguish fires in the cabin or flight deck. *Figure 17-11* shows a Halon fire extinguisher used in a general aviation aircraft. The Halon extinguishers are used on electrical and flammable liquid fires. Some transport aircraft also use water fire extinguisher for use on non-electrical fires.

The following is a list of extinguishing agents and the type (class) fires for which each is appropriate.

1. Water—class A. Water cools the material below its ignition temperature and soaks it to prevent reignition.
2. Carbon dioxide—class B or C. CO_2 acts as a blanketing agent. ***Note:*** CO_2 is not recommended for hand-held extinguishers for internal aircraft use.
3. Dry chemicals—class A, B, or C. Dry chemicals are the best control agents for these types of fires.
4. Halons—only class A, B, or C.
5. Halocarbon clean agents—only class A, B, or C.
6. Specialized dry powder—class D. (Follow the recommendations of the extinguisher's manufacturer because of the possible chemical reaction between the burning metal and the extinguishing agent.)

The following hand-held extinguishers are unsuitable as cabin or flight deck equipment.

- CO_2.
- Dry chemicals (due to the potential for corrosion damage to electronic equipment, the possibility of visual obscuration if the agent were discharged into the flight deck area, and the cleanup problems from their use).

Figure 17-11. *Portable fire extinguisher.*

- Specialized dry powder (it is suitable for use in ground operations).

Installed Fire Extinguishing Systems

Transport aircraft have fixed fire extinguishing systems installed in:

1. Turbine engine compartments.
2. APU compartments.
3. Cargo and baggage compartments.
4. Lavatories.

CO_2 Fire Extinguishing Systems

Older aircraft with reciprocating engines used CO_2 as an extinguishing agent, but all newer aircraft designs with turbine engines use Halon or equivalent extinguishing agent, such as halocarbon clean agents.

Halogenated Hydrocarbons Fire Extinguishing Systems

The fixed fire extinguisher systems used in most engine fire and cargo compartment fire protection systems are designed to dilute the atmosphere with an inert agent that does not support combustion. Many systems use perforated tubing or discharge nozzles to distribute the extinguishing agent. High rate of discharge (HRD) systems use open-end tubes to deliver a quantity of extinguishing agent in 1 to 2 seconds. The most common extinguishing agent still used today is Halon 1301 because of its effective firefighting capability and relatively low toxicity (UL classification Group 6). Noncorrosive Halon 1301 does not affect the material it contacts and requires no cleanup when discharged. Halon 1301 is the current extinguishing agent for commercial aircraft, but a replacement is under development. Halon 1301 cannot be produced anymore because it depletes the ozone layer. Halon 1301 will be used until a suitable replacement is developed. Some military aircraft use HCL-125 and the Federal Aviation Administration (FAA) is testing HCL-125 for use in commercial aircraft.

Containers

Fire extinguisher containers (HRD bottles) store a liquid halogenated extinguishing agent and pressurized gas (typically nitrogen). They are normally manufactured from stainless steel. Depending upon design considerations, alternate materials are available, including titanium. Containers are also available in a wide range of capacities. They are produced under Department of Transportation (DOT) specifications or exemptions. Most aircraft containers are spherical in design, which provides the lightest weight possible. However, cylindrical shapes are available where space limitations are a factor. Each container incorporates a temperature/pressure sensitive safety relief diaphragm that prevents container pressure from exceeding container test pressure in the event of exposure to excessive temperatures. *[Figures 17-12* and *17-13]*

Discharge Valves

Discharge valves are installed on the containers. A cartridge (squib) and frangible disc-type valve are installed in the outlet of the discharge valve assembly. Special assemblies having solenoid-operated or manually-operated seat-type valves are also available. Two types of cartridge disc-release techniques are used. Standard release-type uses a slug driven by explosive energy to rupture a segmented closure disc. For high temperature or hermetically sealed units, a direct explosive impact-type cartridge is used that applies fragmentation impact to rupture a prestressed corrosion resistant steel diaphragm. Most containers use conventional metallic gasket seals that facilitate refurbishment following discharge. *[Figure 17-14]*

Pressure Indication

A wide range of diagnostics is utilized to verify the fire extinguisher agent charge status. A simple visual indication gauge is available, typically a helical bourdon-type indicator that is vibration resistant. *[Figure 17-13]* A combination gauge switch visually indicates actual container pressure and also provides an electrical signal if container pressure is lost, precluding the need for discharge indicators. A ground checkable diaphragm-type low-pressure switch is commonly used on hermetically sealed containers. The Kidde system has a temperature compensated pressure switch that tracks the container pressure variations with temperatures by using a hermetically sealed reference chamber.

Figure 17-12. *Built-in non-portable fire extinguisher containers (HRD bottles) on an airliner.*

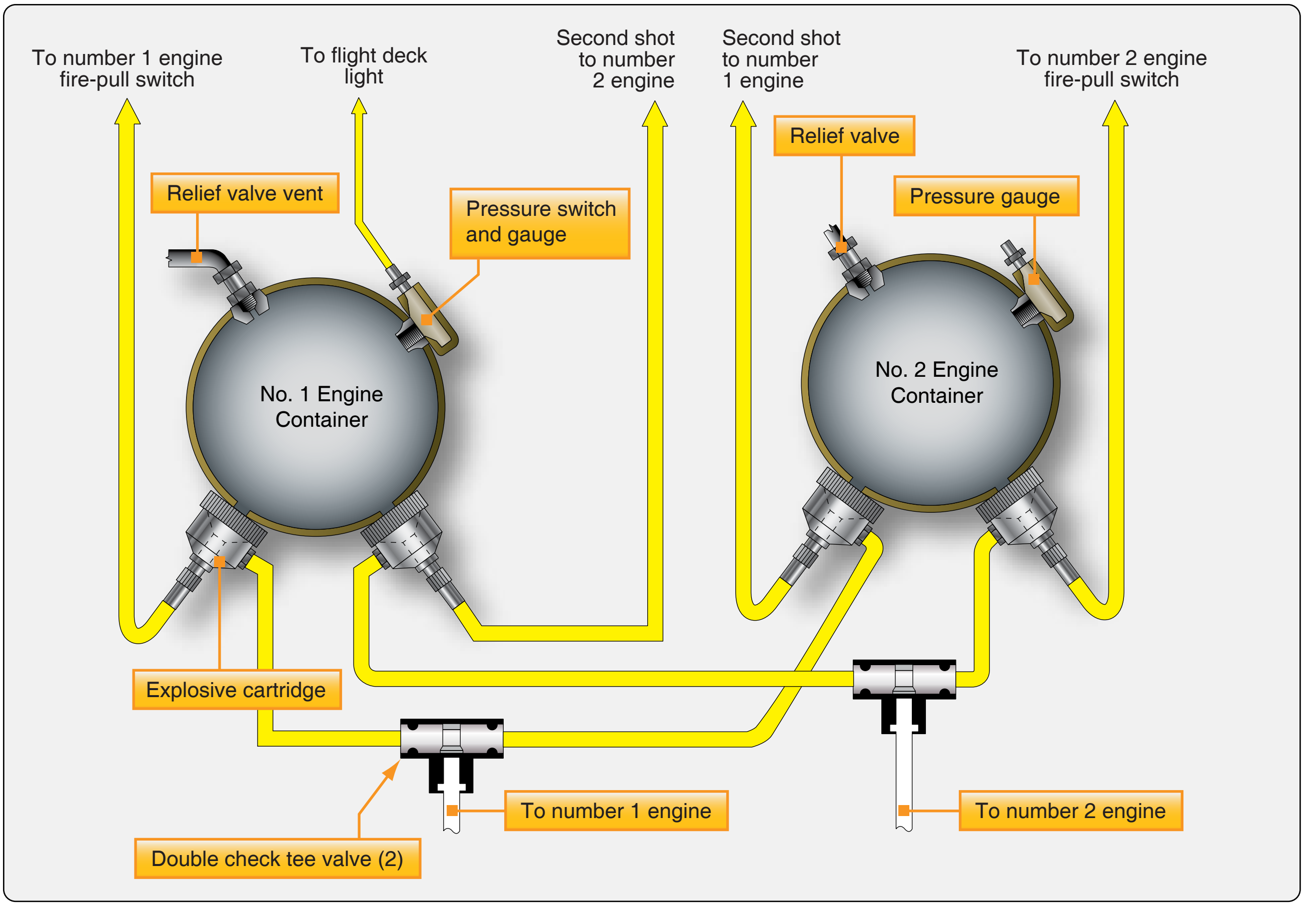

Figure 17-13. *Diagram of fire extinguisher containers (HRD bottles).*

Two-Way Check Valve

Two-way check valves are required in a two-shot system to prevent the extinguisher agent from a reserve container from backing up into the previous emptied main container. Valves are supplied with either MS-33514 or MS-33656 fitting configurations.

Discharge Indicators

Discharge indicators provide immediate visual evidence of container discharge on fire extinguishing systems. Two kinds of indicators can be furnished: thermal and discharge. Both types are designed for aircraft and skin mounting. *[Figure 17-15]*

Figure 17-14. *Discharge valve (left) and cartridge, or squib (right).*

Figure 17-15. *Discharge indicators.*

Thermal Discharge Indicator (Red Disc)

The thermal discharge indicator is connected to the fire container relief fitting and ejects a red disc to show when container contents have dumped overboard due to excessive heat. The agent discharges through the opening left when the disc blows out. This gives the flight and maintenance crews an indication that the fire extinguisher container needs to be replaced before next flight.

Yellow Disc Discharge Indicator

If the flight crew activates the fire extinguisher system, a yellow disc is ejected from the skin of the aircraft fuselage. This is an indication for the maintenance crew that the fire extinguishing system was activated by the flight crew, and the fire extinguishing container needs to be replaced before next flight.

Fire Switch

The engine and APU fire switches are typically installed on the center overhead panel or center console in the flight deck. *[Figure 17-16]* When an engine fire switch is activated, the following happens: the engine stops because the fuel control shuts off, the engine is isolated from the aircraft systems, and the fire extinguishing system is activated. Some aircraft use fire switches that need to be pulled and turned to activate the system, while others use a push-type switch with a guard. To prevent accidental activation of the fire switch, a lock is installed that releases the fire switch only when a fire has been detected. This lock can be manually released by the flight crew if the fire detection system malfunctions. *[Figure 17-17]*

Figure 17-16. *Engine and APU fire switches on the flight deck center overhead panel.*

Cargo Fire Detection

Transport aircraft need to have the following provisions for each cargo or baggage compartment:

1. The detection system must provide a visual indication to the flight crew within 1 minute after the start of a fire.
2. The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased.
3. There must be means to allow the crew to check, in flight, the functioning of each fire detector circuit.

Cargo Compartment Classification

Class A

A Class A cargo or baggage compartment is one in which the presence of a fire would be easily discovered by a crewmember while at his or her station and each part of the compartment is easily accessible in flight.

Class B

A Class B cargo, or baggage compartment, is one in which there is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher. When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent enters any compartment occupied by the crew or passengers. There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

Class C

A Class C cargo, or baggage compartment, is one not meeting the requirements for either a Class A or B compartment but in which:

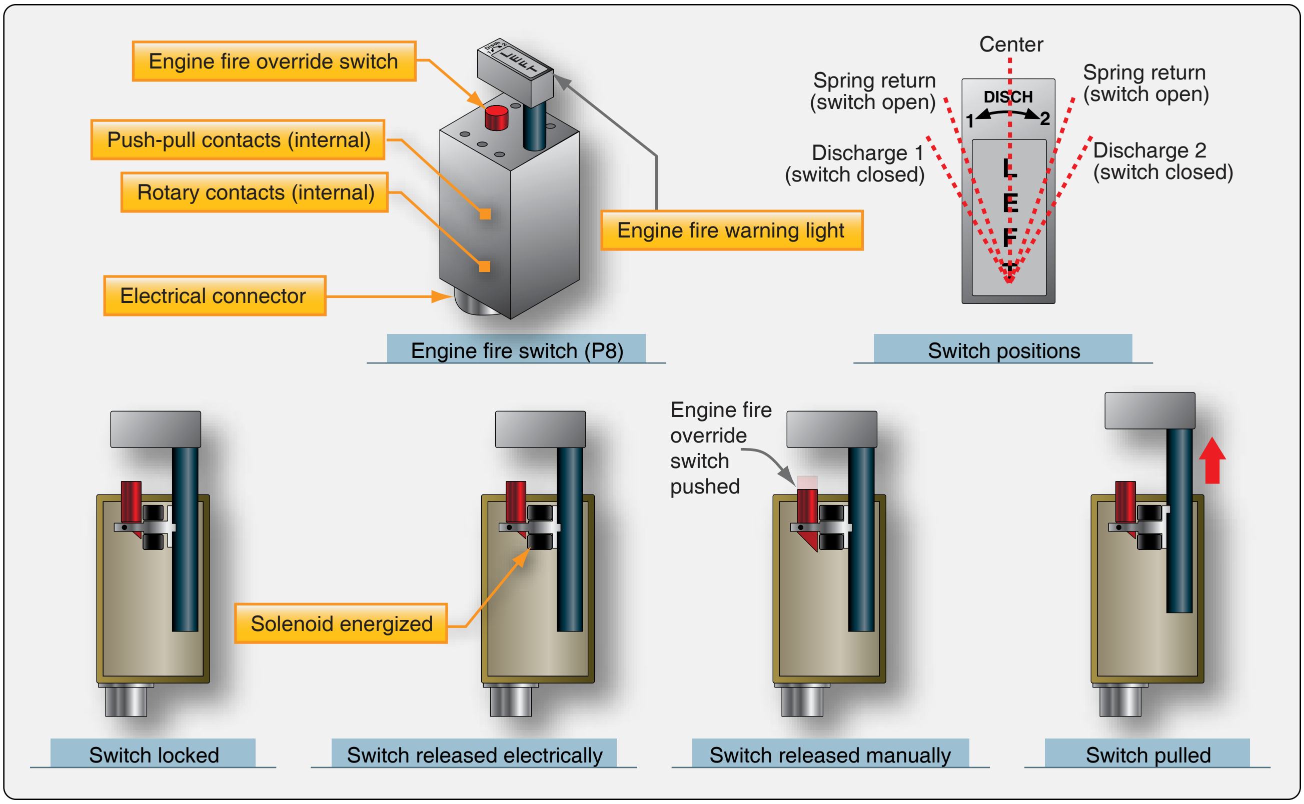

Figure 17-17. *Engine fire switch operation.*

1. There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.
2. There is an approved built-in fire extinguishing or suppression system controllable from the flight deck.
3. There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by the crew or passengers.
4. There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

Class E

Class E cargo compartment is one on airplanes used only for the carriage of cargo and in which:

1. There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station.
2. The controls for shutting off the ventilating airflow to, or within, the compartment are accessible to the flight crew in the crew compartment.
3. There are means to exclude hazardous quantities of smoke, flames, or noxious gases from the flight crew compartment.
4. The required crew emergency exits are accessible under any cargo loading condition.

Cargo & Baggage Compartment Fire Detection & Extinguisher System

The cargo compartment smoke detection system gives warnings in the flight deck if there is smoke in a cargo compartment. *[Figure 17-18]* Each compartment is equipped with a smoke detector. The smoke detectors monitor air in the cargo compartments for smoke. The fans bring air from the cargo compartment into the smoke detector. Before the air goes in the smoke detector, in-line water separators remove condensation and heaters increase the air temperature. *[Figure 17-19]*

Smoke Detector System

The optical smoke detector consists of source light emitting diodes (LEDs), intensity monitor photodiodes, and scatter detector photodiodes. Inside the smoke detection chamber, air flows between a source LED and a scatter detector photodiode. Usually, only a small amount of light from the LED gets to the scatter detector. If the air has smoke in it, the smoke particles reflect more light on the scatter detector. This causes an alarm signal. The intensity monitor photodiode makes sure that the source LED is on and keeps the output of the source LED constant. This configuration also finds

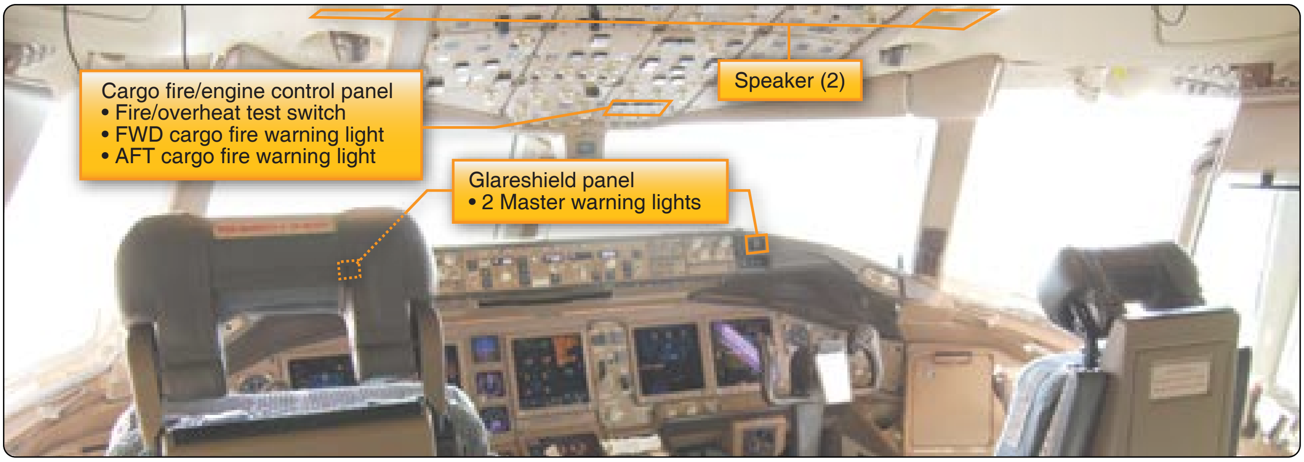

Figure 17-18. *Cargo fire detection warning.*

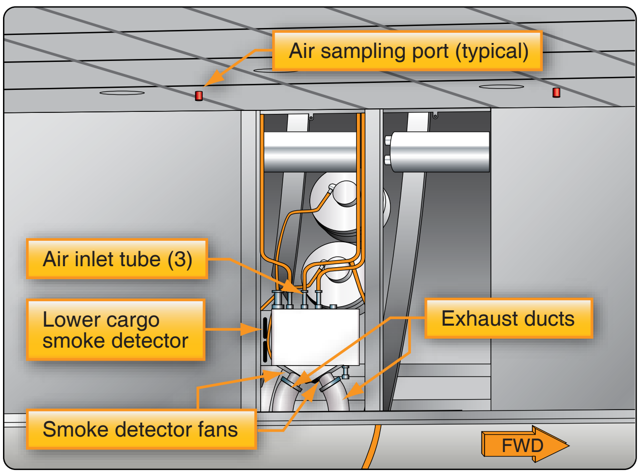

Figure 17-19. *Smoke detector installation.*

contamination of the LED and photodiodes. A defective diode, or contamination, causes the detector to change to the other set of diodes. The detector sends a fault message.

The smoke detector has multiple sampling ports. The fans draw air from the sampling ports through a water separator and a heater unit to the smoke detector. *[Figure 17-20]*

Cargo Compartment Extinguishing System

The cargo compartment extinguishing system is activated by the flight crew if the smoke detectors detect smoke in the cargo compartment. Some aircraft are outfitted with two types of fire extinguisher containers. The first system is the dump system that releases the extinguishing agent directly when the cargo fire discharge switch is activated. This action extinguishes the fire.

The second system is the metered system. After a time delay, the metered bottles discharge slowly and at a controlled rate through the filter regulator. Halon from the metered bottles replaces the extinguishing agent leakage. This keeps the correct concentration of extinguishing agent in the cargo compartment to keep the fire extinguished for 180 minutes.

The fire extinguishing bottles contain Halon 1301 or equivalent fire extinguishing agent pressurized with nitrogen. Tubing connects the bottles to discharge nozzles in the cargo compartment ceilings.

The extinguishing bottles are outfitted with squibs. The squib is an electrically operated explosive device. It is adjacent to

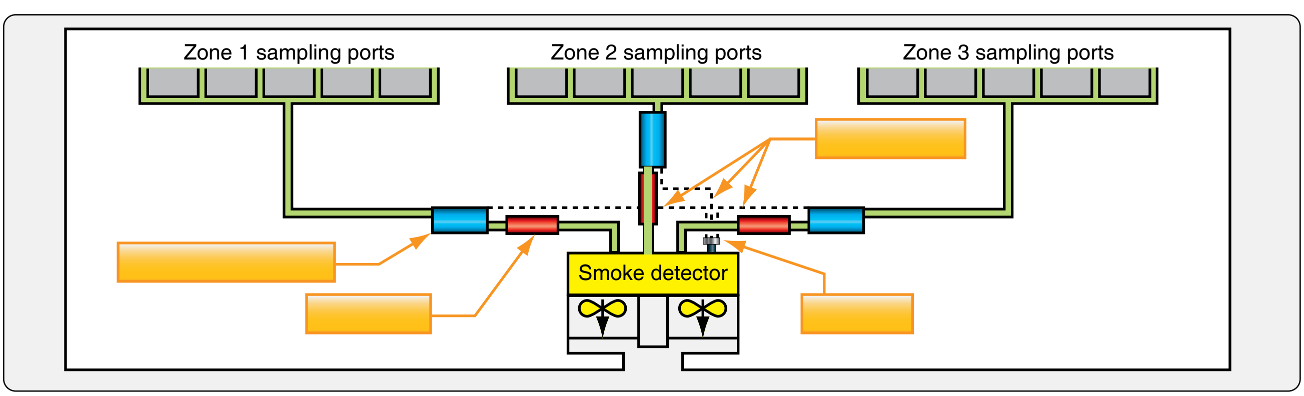

Figure 17-20. *Smoke detector system.*

a bottle diaphragm that can break. The diaphragm normally seals the pressurized bottle. When the cargo discharge switch is activated, the squib fires and the explosion breaks the diaphragm. Nitrogen pressure inside the bottle pushes the Halon through the discharge port into the cargo compartment. When the bottle discharges, a pressure switch is activated that sends an indication to the flight deck that a bottle has been discharged. Flow control valves are incorporated if the bottles can be discharged in multiple compartments. The flow control valves direct the extinguishing agent to the selected cargo compartment. *[Figure 17-21]*

The following indications occur in the flight deck if there is smoke in a cargo compartment:

- Master warning lights come on.
- Fire warning aural operates.
- A cargo fire warning message shows.
- Cargo fire warning light comes on.

The master warning lights and fire warning aural are prevented from operating during part of the takeoff operation.

Lavatory Smoke Detectors

Airplanes that have a passenger capacity of 20 or more are equipped with a smoke detector system that monitors the lavatories for smoke. Smoke indications provide a warning light in the flight deck or provide a warning light or audible warning at the lavatory and at flight attendant stations that would be readily detected by a flight attendant. Each lavatory must have a built-in fire extinguisher that discharges automatically. The smoke detector is located in the ceiling of the lavatory. *[Figure 17-22]*

Lavatory Smoke Detector System

Refer to *Figure 17-23*. The lavatory smoke detector is powered by the 28-volt DC left/right main DC bus. If there is smoke in the sensing chamber of the smoke detector, the alarm LED (red) comes on. The timing circuit makes an intermittent ground. The warning horn and lavatory call

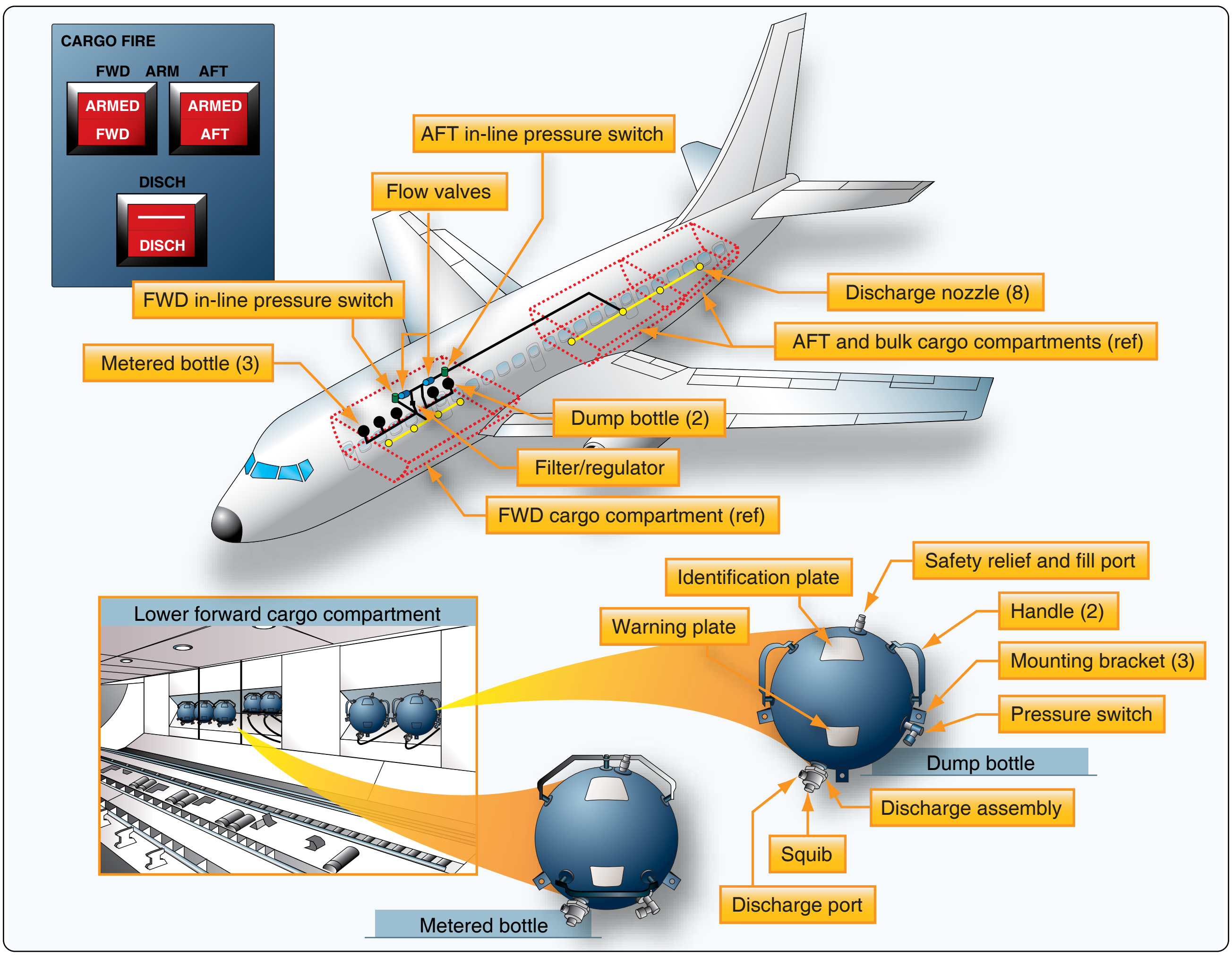

Figure 17-21. *Cargo and baggage compartment extinguishing system.*

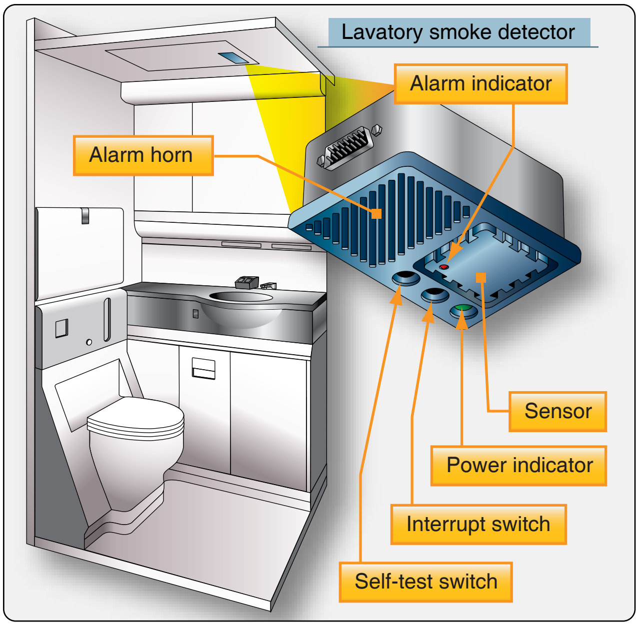

Figure 17-22. *Lavatory smoke detector diagram.*

light operate intermittently. The smoke detection circuit makes a ground for the relay. The energized relay makes a ground signal for the overhead electronics unit (OEU) in the central monitoring systems (CMS). This interface gives these indications: lavatory master call light flashes, cabin system control panel (CSCP) and cabin area control panel (CACP) pop-up window shows, and the lavatory call chime operates. Push the lavatory call reset switch or the smoke detector interrupt switch to cancel the smoke indications. If there is still smoke in the lavatory, the alarm LED (red) stays on. All smoke indications go away automatically when the smoke is gone.

Lavatory Fire Extinguisher System

The lavatory compartment is outfitted with a fire extinguisher bottle to extinguish fires in the waste compartment. The fire extinguisher is a bottle with two nozzles. The bottle contains pressurized Halon 1301 or equivalent fire extinguishing agent. When the temperature in the waste compartment reaches approximately 170 °F, the solder that seals the nozzles melt and the Halon is discharged. Weighing the bottle is often the only way to determine if the bottle is empty or full. *[Figure 17-24]*

Fire Detection System Maintenance

Fire detector sensing elements are located in many high-activity areas around aircraft engines. Their location, together with their small size, increases the chance of damage to the sensing elements during maintenance. General maintenance of a fire detection system typically includes the inspection and servicing of damaged sections, containment of loose material that could short detector terminals, correcting connection joints and shielding, and replacement of damaged sensing elements. An inspection and maintenance program for all types of continuous-loop systems should include the following visual checks.

Note: These procedures are examples and should not be used to replace the applicable manufacturer's instructions.

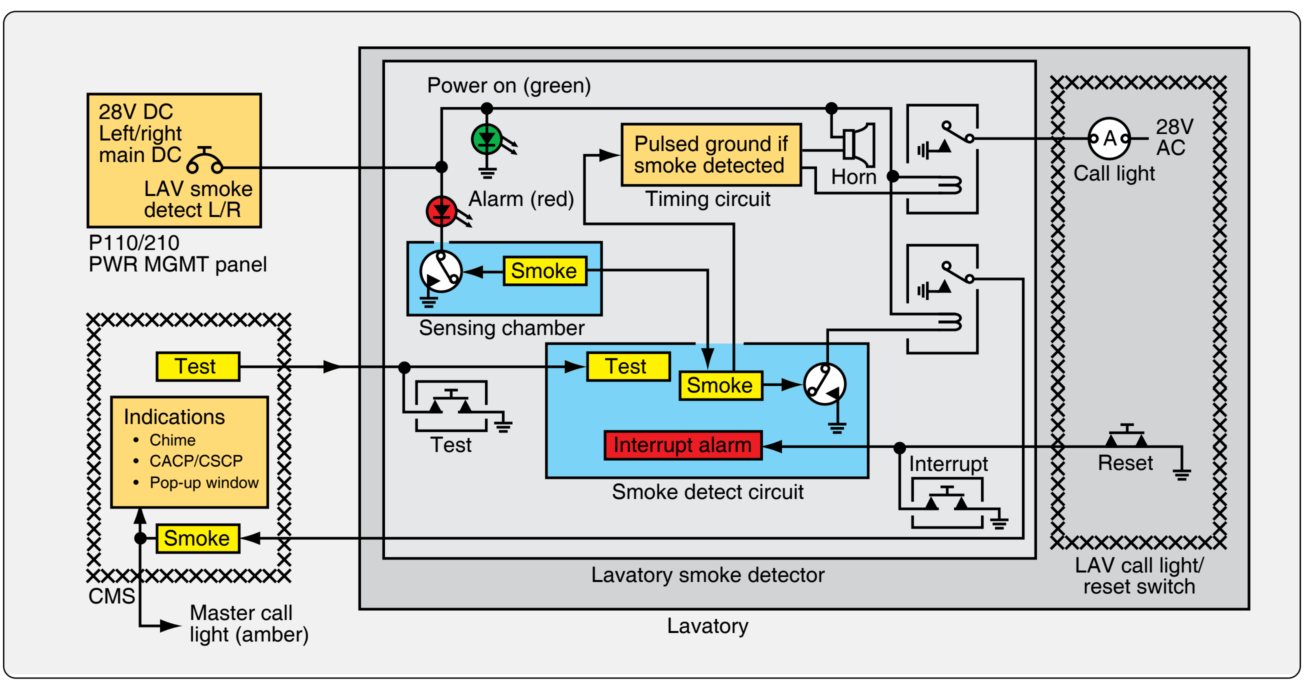

Figure 17-23. *Lavatory smoke detector diagram.*

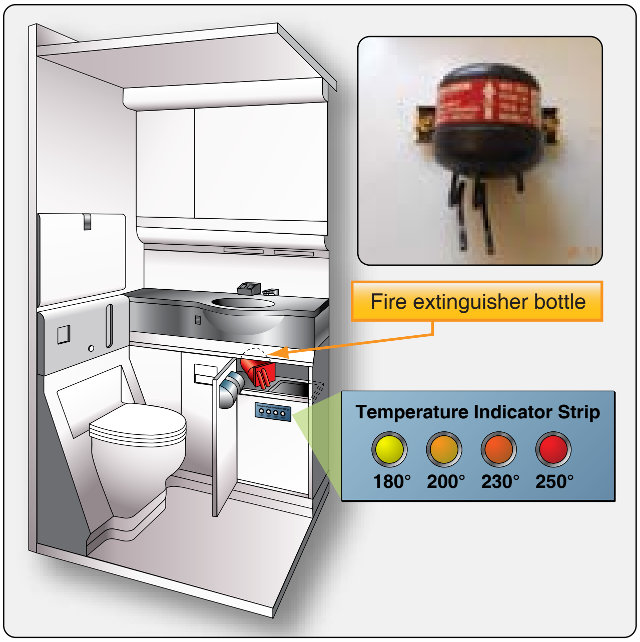

Figure 17-24. *Lavatory fire extinguishing bottle.*

Sensing elements of a continuous-loop system should be inspected for the following:

1. Cracked or broken sections caused by crushing or squeezing between inspection plates, cowl panels, or engine components.
2. Abrasion caused by rubbing of the element on cowling, accessories, or structural members.
3. Pieces of safety wire, or other metal particles, that may short the spot-detector terminals.
4. Condition of rubber grommets in mounting clamps that may be softened from exposure to oils or hardened from excessive heat.
5. Dents and kinks in sensing element sections. Limits on the element diameter, acceptable dents and kinks, and degree of smoothness of tubing contour are specified by manufacturers. No attempt should be made to straighten any acceptable dent or kink, since stresses may be set up that could cause tubing failure. *[Figure 17-25]*
6. Nuts at the end of the sensing elements should be inspected for tightness and safety wire. *[Figure 17-26]* Loose nuts should be retorqued to the value specified by the manufacturer's instructions. Some types of sensing element connection joints require the use of copper crush gaskets. These should be replaced any time a connection is separated.
7. If shielded flexible leads are used, they should be inspected for fraying of the outer braid. The braided sheath is made up of many fine metal strands woven into a protective covering surrounding the inner insulated wire. Continuous bending of the cable or rough treatment can break these fine wires, especially those near the connectors.

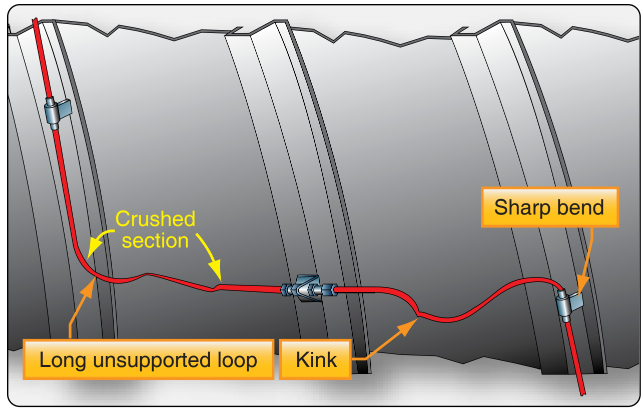

Figure 17-25. *Sensing element defects.*

8. Sensing element routing and clamping should be inspected carefully. *[Figure 17-27]* Long, unsupported sections may permit excessive vibration that can cause breakage. The distance between clamps on straight runs, usually about 8 to 10 inches, is specified by each manufacturer. At end connectors, the first support clamp usually is located about 4 to 6 inches from the end connector fittings. In most cases, a straight run of one inch is maintained from all connectors before a bend is started, and an optimum bend radius of 3 inches is normally adhered to.
9. Interference between a cowl brace and a sensing element can cause rubbing. This interference may cause wear and short the sensing element.
10. Grommets should be installed on the sensing element so that both ends are centered on its clamp. The split end of the grommet should face the outside of the nearest bend. Clamps and grommets should fit the element snugly. *[Figure 17-28]*

Fire Detection System Troubleshooting

The following troubleshooting procedures represent the most common difficulties encountered in engine fire detection systems:

1. Intermittent alarms are most often caused by an intermittent short in the detector system wiring. Such shorts may be caused by a loose wire that occasionally touches a nearby terminal, a frayed wire brushing against a structure, or a sensing element rubbing against a structural member long enough to wear through the insulation. Intermittent faults often can be located by moving wires to recreate the short.