

Chapter 15

Ice & Rain Protection

Ice Control Systems

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

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

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

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

Ice or frost forming on aircraft creates two basic hazards:

1. The resulting malformation of the airfoil that could decrease the amount of lift.

2. The additional weight and unequal formation of the ice that could cause unbalancing of the aircraft, making it hard to control.

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

Icing Effects

Ice buildup increases drag and reduces lift. It causes destructive vibration and hampers true instrument readings. Control surfaces become unbalanced or frozen. Fixed slots are filled and movable slots jammed. Radio reception is hampered, and engine performance is affected. Ice, snow, and slush have a direct impact on the safety of flight. Not only because of degraded lift, reduced takeoff performance, and/or maneuverability of the aircraft, but when chunks break off, they can also cause engine failures and structural damage. Fuselage aft-mounted engines are particularly susceptible to this foreign object damage (FOD) phenomenon. Wing-mounted engines are not excluded however. Ice can be present on any part of the aircraft and, when it breaks off, there is some probability that it could go into an engine. The worst case is that ice on the wing breaks off during takeoff due to the flexing of the wing and goes directly into the engine, leading to surge, vibration, and complete thrust loss. Light snow that is loose on the wing surfaces and the fuselage can also cause engine damage leading to surge, vibration, and thrust loss.



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

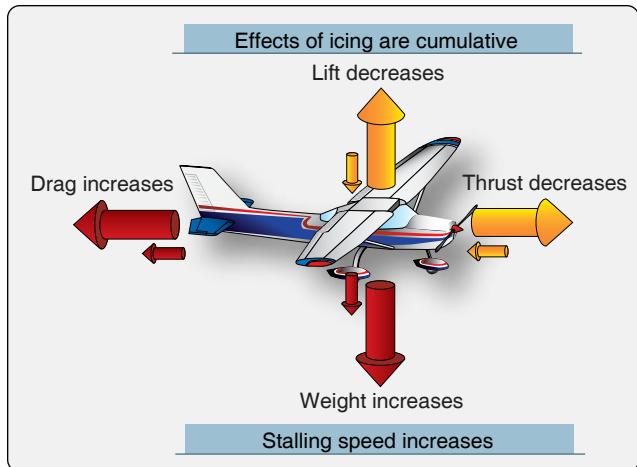


Figure 15-2. Effects of structural icing.

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

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

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

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

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

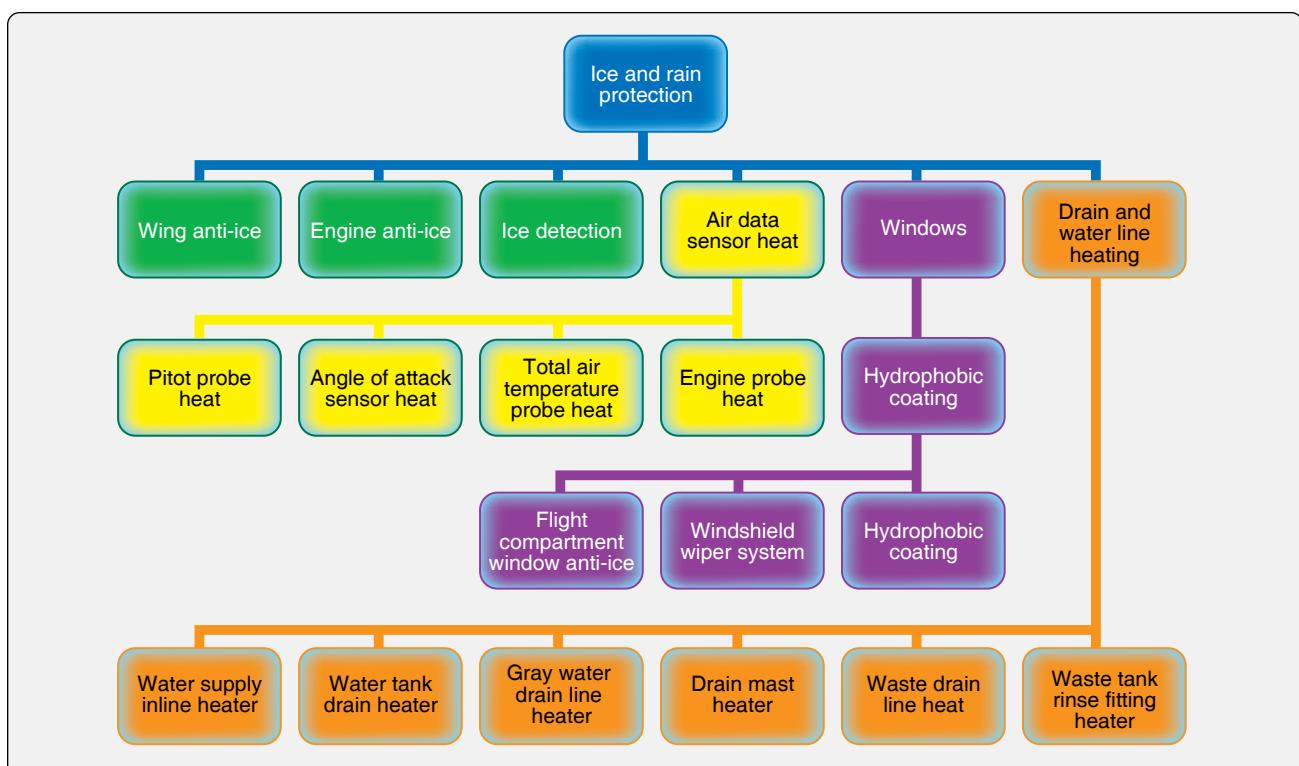


Figure 15-3. Ice and rain protection systems.

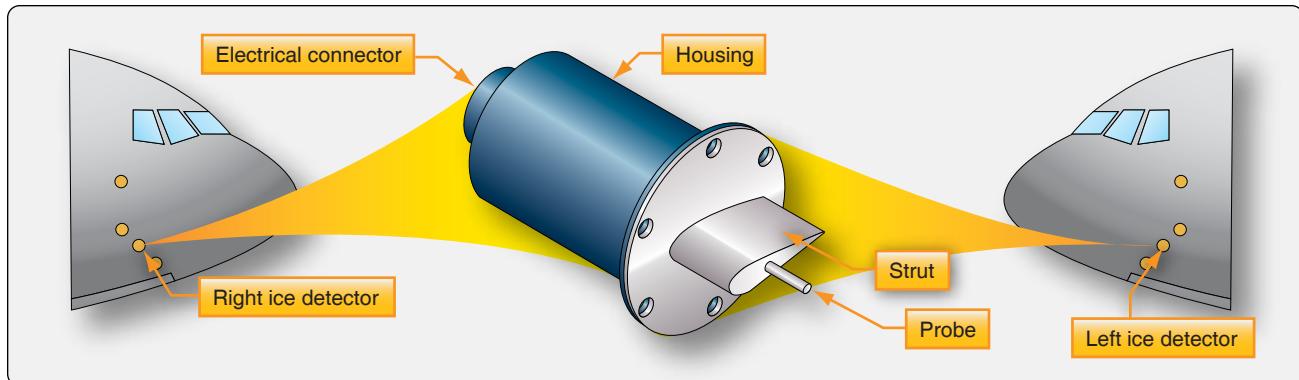


Figure 15-4. An ice detector alerts the flight crew of icing conditions and, on some aircraft, automatically activates ice protection systems. One or more detectors are located on the forward fuselage.

Ice Detector System

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

Ice Prevention

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

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

Equipment is designed for anti-icing or for deicing. Anti-icing equipment is turned on before entering icing conditions and is designed to prevent ice from forming. A surface may be anti-iced by keeping it dry, by heating to a temperature that

evaporates water upon impingement, or by heating the surface just enough to prevent freezing, maintaining it running wet. Deicing equipment is designed to remove ice after it begins to accumulate typically on the wings and stabilizer leading edges. Ice may be controlled on aircraft structure by the methods described in Figure 15-5.

Wing & Stabilizer Anti-Icing Systems

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

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

Figure 15-5. Typical ice control methods.



Figure 15-6. Aircraft with thermal WAI system.

Thermal Pneumatic Anti-icing

Thermal systems used for the purpose of preventing the formation of ice or for deicing airfoil leading edges usually use heated air ducted spanwise along the inside of the leading edge of the airfoil and distributed around its inner surface. These thermal pneumatic anti-icing systems are used for

wings, leading edge slats, horizontal and vertical stabilizers, engine inlets, and more. There are several sources of heated air, including hot bleed air from the turbine compressor, engine exhaust heat exchangers, and ram air heated by a combustion heater.

Wing Anti-Ice (WAI) System

Thermal wing anti-ice (WAI or TAI) systems for business jet and large-transport category aircraft typically use hot air bled from the engine compressor. [Figure 15-6] Relatively large amounts of very hot air can be bled off the compressor, providing a satisfactory source of anti-icing heat. The hot air is routed through ducting, manifolds, and valves to components that need to be anti-iced. Figure 15-7 shows a typical WAI system schematic for a business jet. The bleed air is routed to each wing leading edge by an ejector in each wing inboard area. The ejector discharges the bleed air into piccolo tubes for distribution along the leading edge. Fresh ambient air is introduced into the wing leading edge by two flush-mounted ram air scoops in each wing leading edge, one at the wing root and one near the wingtip. The ejectors entrain ambient air, reduce the temperature of the bleed air,

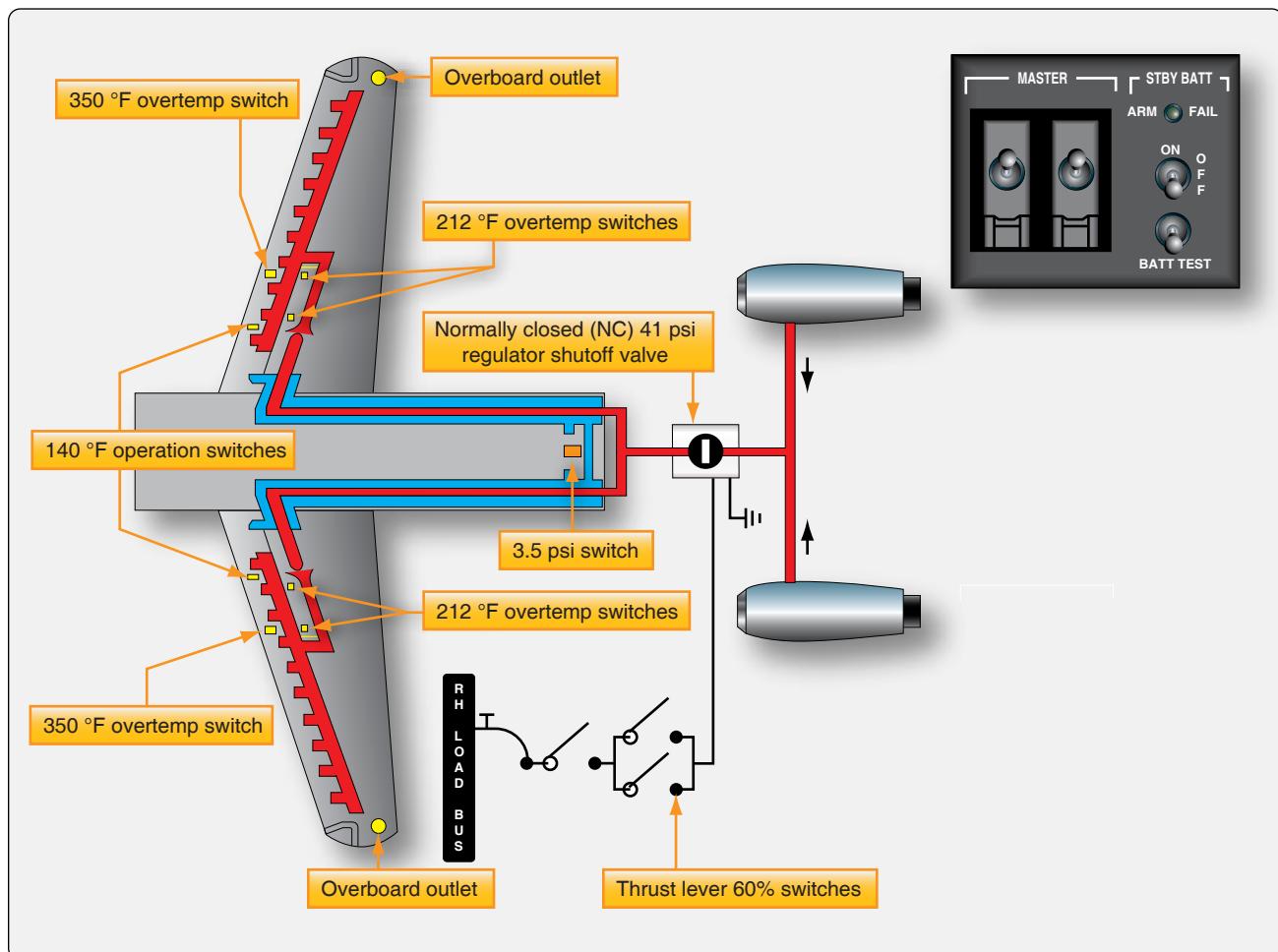


Figure 15-7. Thermal WAI system.

and increase the mass airflow in the piccolo tubes. The wing leading edge is constructed of two skin layers separated by a narrow passageway. [Figure 15-8] The air directed against the leading edge can only escape through the passageway, after which it is vented overboard through a vent in the bottom of the wingtip.

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

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

When installing a section of duct, make certain that the seal bears evenly against and is compressed by the adjacent joint's flange. When specified, the ducts should be pressure tested at the pressure recommended by the manufacturer of the aircraft concerned. Leak checks are made to detect defects in the duct that would permit the escape of heated air. The rate of leakage at a given pressure should not exceed that recommended in the aircraft maintenance manual.

Air leaks can often be detected audibly and are sometimes revealed by holes in the lagging or thermal insulation material. However, if difficulty arises in locating leaks, a soap-and-water solution may be used. All ducting should be inspected for security, general condition, or distortion. Lagging or insulating blankets must be checked for security and must be free of flammable fluids, such as oil or hydraulic fluid.

Leading Edge Slat Anti-Ice System

Aircraft that utilize leading edge slats often use bleed air from the engine compressor to prevent the formation of frost on these surfaces. On a modern transport category aircraft, the pneumatic system supplies bleed air for this purpose. WAI valves control the air flow from the pneumatic system to WAI ducts. The WAI ducts carry the air to the slats. Holes in the bottom of each slat let the air out.

The airfoil and cowl ice protection system (ACIPS) computer card controls the WAI valves, and pressure sensors send duct air pressure data to the computer. The aircrew can select an auto or manual mode with the WAI selector. In the auto mode, the system turns on when the ice detection system detects ice. The off and on positions are used for manual control of the WAI system. The WAI system is only used in the air, except for ground tests. The weight on wheels system and/or airspeed data disarms the system when the aircraft is on the ground. [Figure 15-9]

WAI Valve

The WAI valve controls the flow of bleed air from the pneumatic system to the WAI ducts. The valve is electrically controlled and pneumatically actuated. The torque motor controls operation of the valve. With no electrical power to the torque motor, air pressure on one side of the actuator holds the valve closed. Electrical current through the torque motor allows air pressure to open the valve. As the torque motor current increases, the valve opening increases. [Figure 15-10]

WAI Pressure Sensor

The WAI pressure sensor senses the air pressure in the WAI duct after the WAI valve. The ACIPS computer card uses the pressure information to control the WAI system.

WAI Ducts

The WAI ducts move air from the pneumatic system through the wing leading edge to the leading-edge slats. Figure 15-9 shows that only leading edge slat sections 3, 4, and 5 on the left wing and 10, 11, and 12 on the right wing receive bleed air for WAI. Sections of the WAI ducting are perforated. The holes allow air to flow into the space inside the leading-edge slats. The air leaves the slats through holes in the bottom of each slat. Some WAI ducts have connecting "T" ducts that telescope to direct air into the slats while

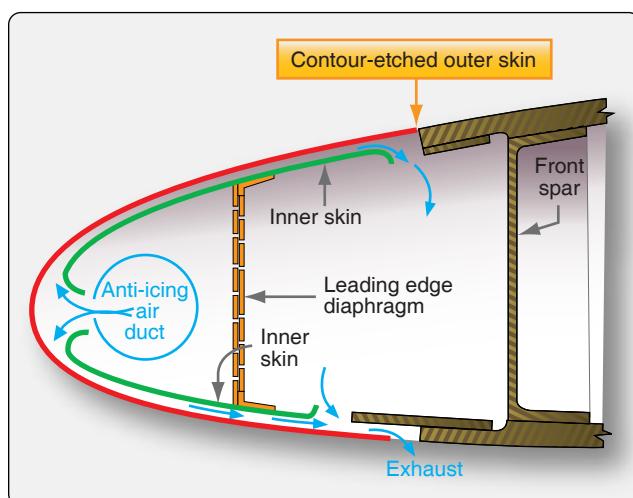


Figure 15-8. Heated wing leading edge.

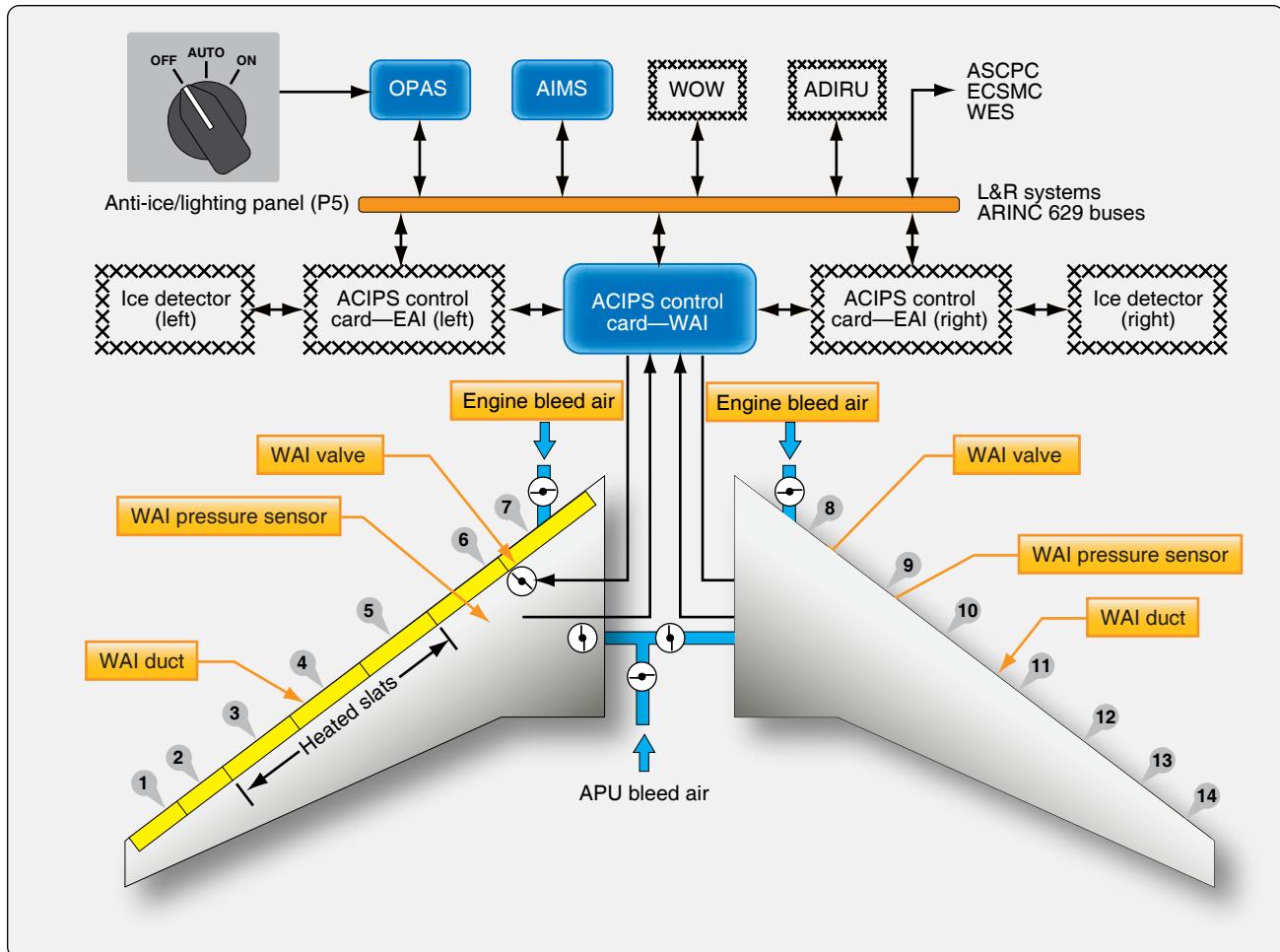


Figure 15-9. Wing leading edge slat anti-icing system.

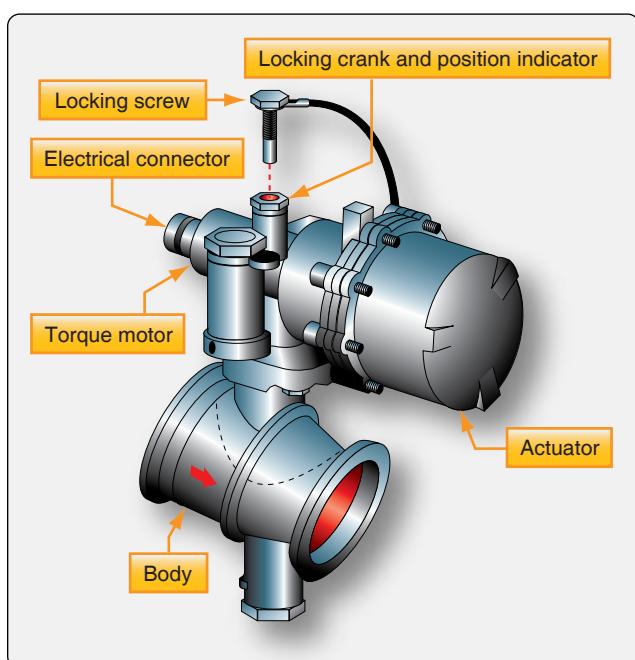


Figure 15-10. A wing anti-icing valve.

extended. The telescoping section attached to the slat on one end, slides over the narrow diameter “T” section that is connected into the WAI duct. A seal prevents any loss of air. This arrangement allows warm air delivery to the slats while retracted, in transit, and fully deployed. [Figure 15-11]

WAI Control System

Modern aircraft use several onboard computers to control aircraft systems. The WAI system is controlled by the ACIPS computer card. The ACIPS computer card controls both WAI valves. The required positions of the WAI valves change as bleed air temperature and altitude change. The left and right valves operate at the same time to heat both wings equally. This keeps the airplane aerodynamically stable in icing conditions. The WAI pressure sensors supply feedback information to the WAI ACIPS computer card for WAI valve control and position indication. If either pressure sensor fails, the WAI ACIPS computer card sets the related WAI valve to either fully open or fully closed. If either valve fails closed, the WAI computer card keeps the other valve closed.

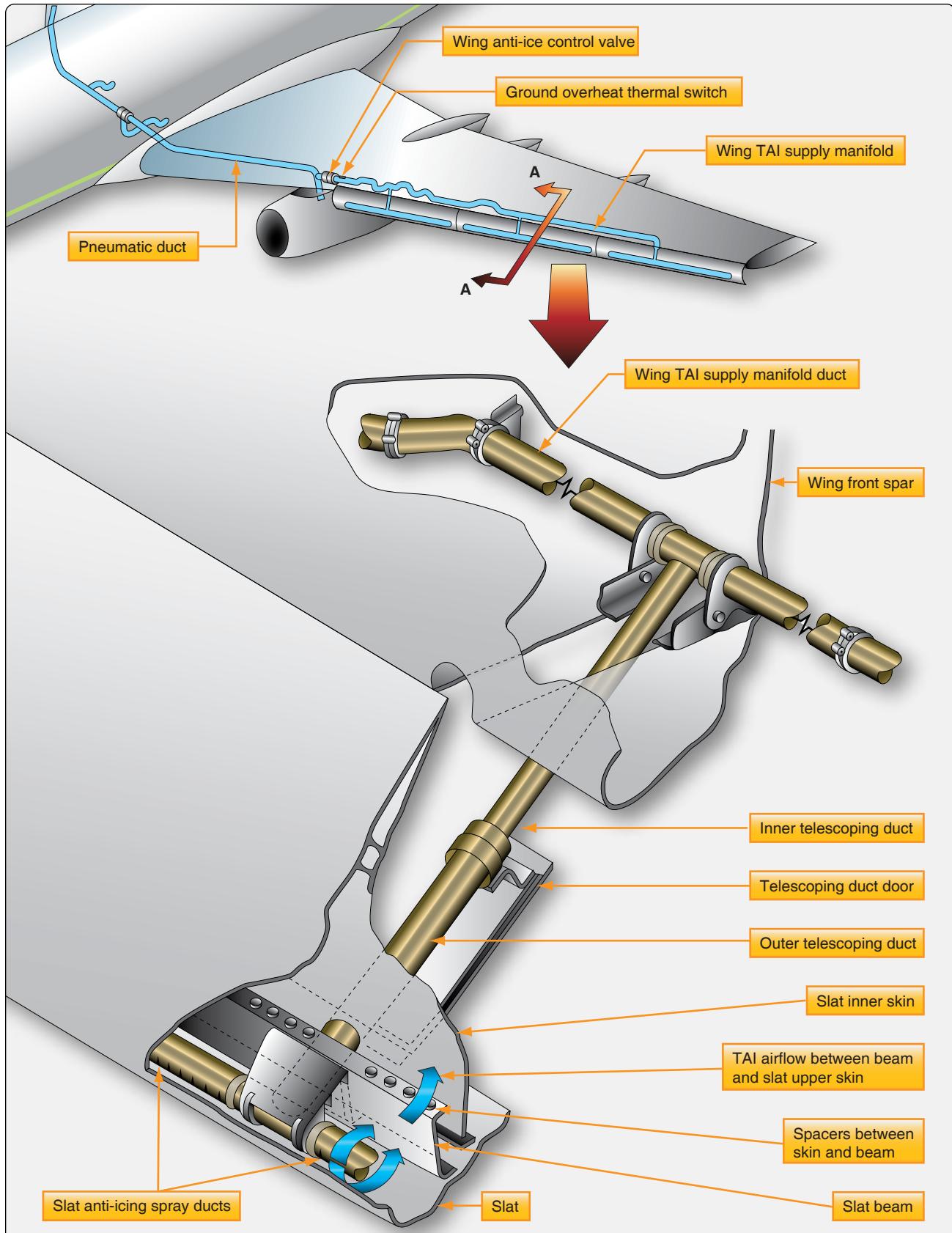


Figure 15-11. WAI ducting.

There is one selector for the WAI system. The selector has three positions: auto, on, and off. With the selector in auto and no operational mode inhibits, the WAI ACIPS computer card sends a signal to open the WAI valves when either ice detector detects ice. The valves close after a 3-minute delay when the ice detector no longer detects ice. The time delay prevents frequent on/off cycles during intermittent icing conditions. With the selector on and no operational mode inhibits, the WAI valves open. With the selector off, the WAI valves close. The operational mode for the WAI valves can be inhibited by many different sets of conditions. [Figure 15-12]

- Airplane on the ground (except during an initiated or periodic built-in test equipment (BITE) test).
 - Total Air Temperature (TAT) is more than 50 °F (10 °C) and the time since takeoff is less than 5 minutes.
 - Auto slat operation.
 - Air-driven hydraulic pump operation.
 - Engine start.
 - Bleed air temperature less than 200 °F (93 °C).

The operational mode is inhibited if all of these conditions occur:

- Auto mode is selected.
 - Takeoff mode is selected.
 - Airplane has been in the air less than 10 minutes.

With auto or on selected, the operational mode is inhibited if any of these conditions occur:

The WAI valves stay closed as long as the operational mode inhibit is active. If the valves are already open, the operational mode inhibit causes the valves to close.

WAI Indication System

The aircrew can monitor the WAI system on the onboard computer maintenance page. [Figure 15-13] The following information is shown:

- WING MANIFOLD PRESS—pneumatic duct pressure in PSIG.

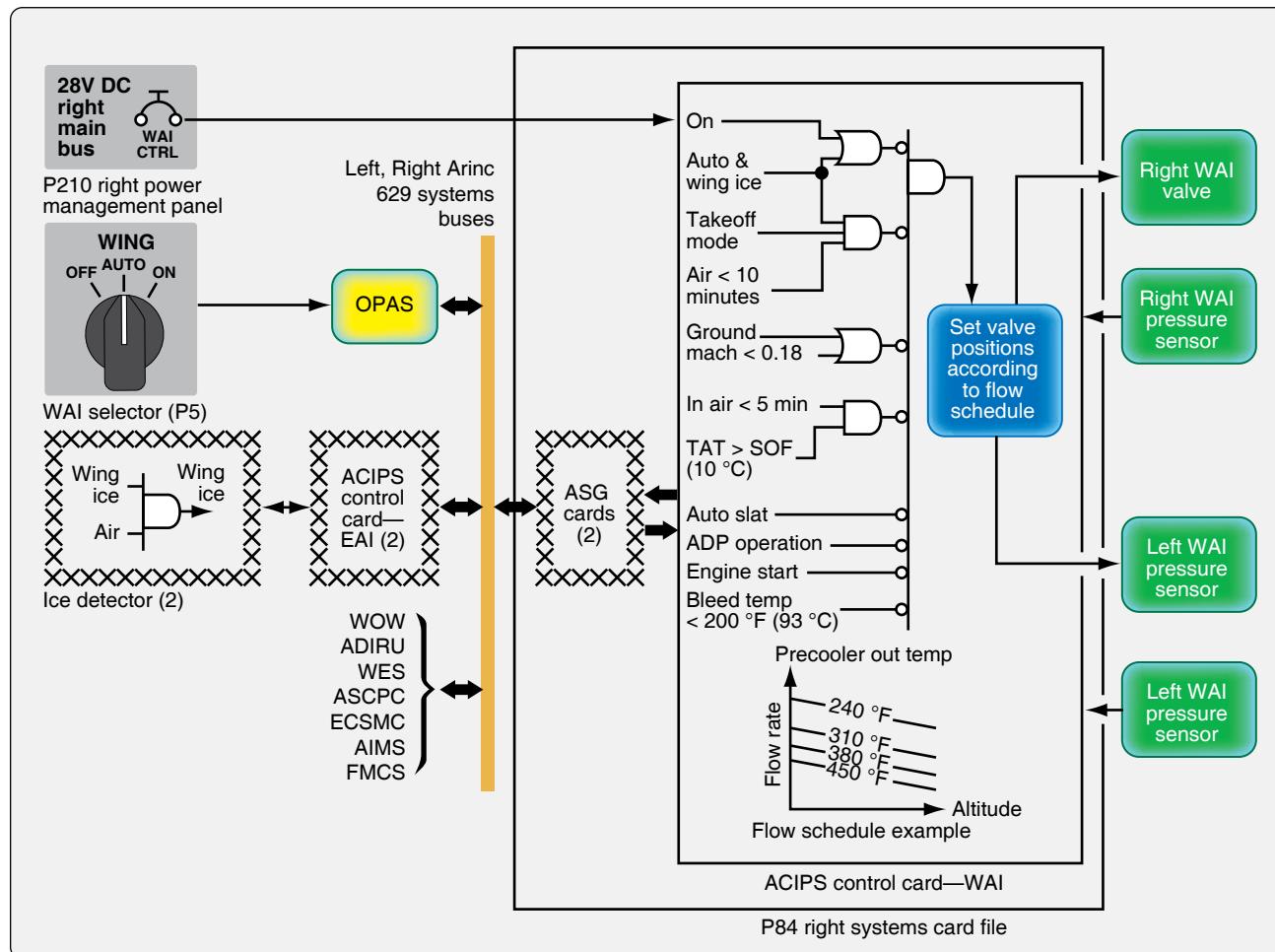


Figure 15-12. WAI inhibit logic schematic.

ICE PROTECTION	ENG TYPE --	
ALTITUDE 10,000	L	R
TAT -2	ENGINE/WING	ENGINE/WING
ICE DETECTION:		
ENGINE ANTI-ICE:		
FINCASE DUCT LEAK SIGNAL	NORMAL	NORMAL
VALVE	REGULATING	REGULATING
SUPPLY AIR TEMP	884	884
AIR PRESSURE	13	13
AIR FLOW	13	13
WING ANTI-ICE:		
WING MANIFOLD PRESSURE	50	50
VALVE	REGULATING	REGULATING
AIR PRESSURE	19	19
AIR FLOW	85	85

Figure 15-13. Ice protection onboard computer maintenance page.

- VALVE—WAI valve open, closed, or regulating.
- AIR PRESS—pressure downstream of the WAI valves in PSIG.
- AIR FLOW—air flow through the WAI valves in pounds per minute.

WAI System Built-In Test Equipment (BITE) Test

BITE circuits in the WAI ACIPS computer card continuously monitor the WAI system. Faults that affect the dispatch of the aircraft cause status messages. Other faults cause central maintenance computer system (CMCS) maintenance messages. The BITE in the WAI ACIPS computer card also performs automatic power-up and periodic tests. Faults found during these tests that affect dispatch cause status messages. Other faults cause CMCS maintenance messages. The power-up test occurs when the card gets power. BITE does a test of the card hardware and software functions and the valve and pressure sensor interfaces. The valves do not move during this test.

The periodic test occurs when all these conditions are true:

- The airplane has been on the ground between 1 and 5 minutes.
- The WAI selector is set to auto or on.
- Air-driven hydraulic pumps are not in intermittent operation.
- Bleed pressure is sufficient to open the WAI valves.
- The time since the last periodic test is more than 24 hours.
- During this test, the WAI valves cycle open and closed. This test makes sure that valve malfunctions are detected.

Thermal Electric Anti-Icing

Electricity is used to heat various components on an aircraft so that ice does not form. This type of anti-ice is typically limited to small components due to high amperage draw. Effective thermal electric anti-icing is used on most air data probes, such as pitot tubes, static air ports, TAT and AOA probes, ice detectors, and engine P2/T2 sensors. Water lines, waste water drains, and some turboprop inlet cowls are also heated with electricity to prevent ice from forming. Transport category and high-performance aircraft use thermal electric anti-icing in windshields.

In devices that use thermal electric anti-icing, current flows through an integral conductive element that produces heat. The temperature of the component is elevated above the freezing point of water, so ice cannot form. Various schemes are used, such as an internal coil wire, externally wrapped blankets or tapes, as well as conductive films and heated gaskets. A basic discussion of probe heat follows. Windshield heat and portable water heat anti-icing are discussed later in this chapter. Propeller deice boots, which also are used for anti-icing, are also thermal electric and discussed in this chapter.

Data probes that protrude into the ambient airstream are particularly susceptible to ice formation in flight. *Figure 15-14* illustrates the types and location probes that use thermal electric heat on one airliner. A pitot tube, for example, contains an internal electric element that is controlled by a switch in the flight deck. Use caution checking the function of the pitot heat when the aircraft is on the ground. The tube gets extremely hot since it must keep ice from forming at altitude in temperatures near -50 °F at speeds possibly over 500 miles per hour. An ammeter or load meter in the circuit can be used to safely determine functionality.

Simple probe heat circuits exist on GA aircraft with a switch and a circuit breaker to activate and protect the device. Advanced aircraft may have more complex circuitry in which control is by computer and flight condition of the aircraft is considered before thermal electric heaters are activated automatically. *Figure 15-15* shows such a circuit for a pitot tube. The primary flight computer (PFC) supplies signals for the air data card (ADC) to energize ground and air heat control relays to activate probe heat. Information concerning speed of the aircraft, whether it is in the air or on the ground, and if the engines are running, are factors considered by the ADC logic. Similar controls are used for other probe heaters.

Chemical Anti-Icing

Chemical anti-icing is used in some aircraft to anti-ice the leading edges of the wing, stabilizers, windshields, and propellers. The wing and stabilizer systems are often called weeping wing systems or are known by their trade name of

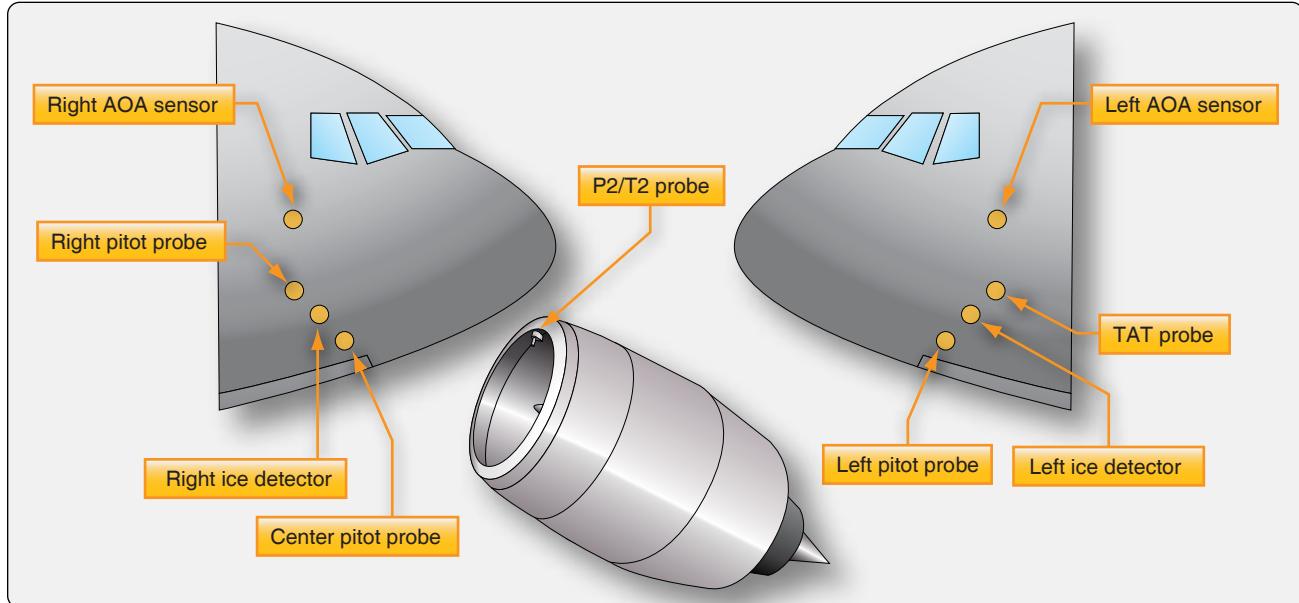


Figure 15-14. Probes with thermal electric anti-icing on one commercial airliner.

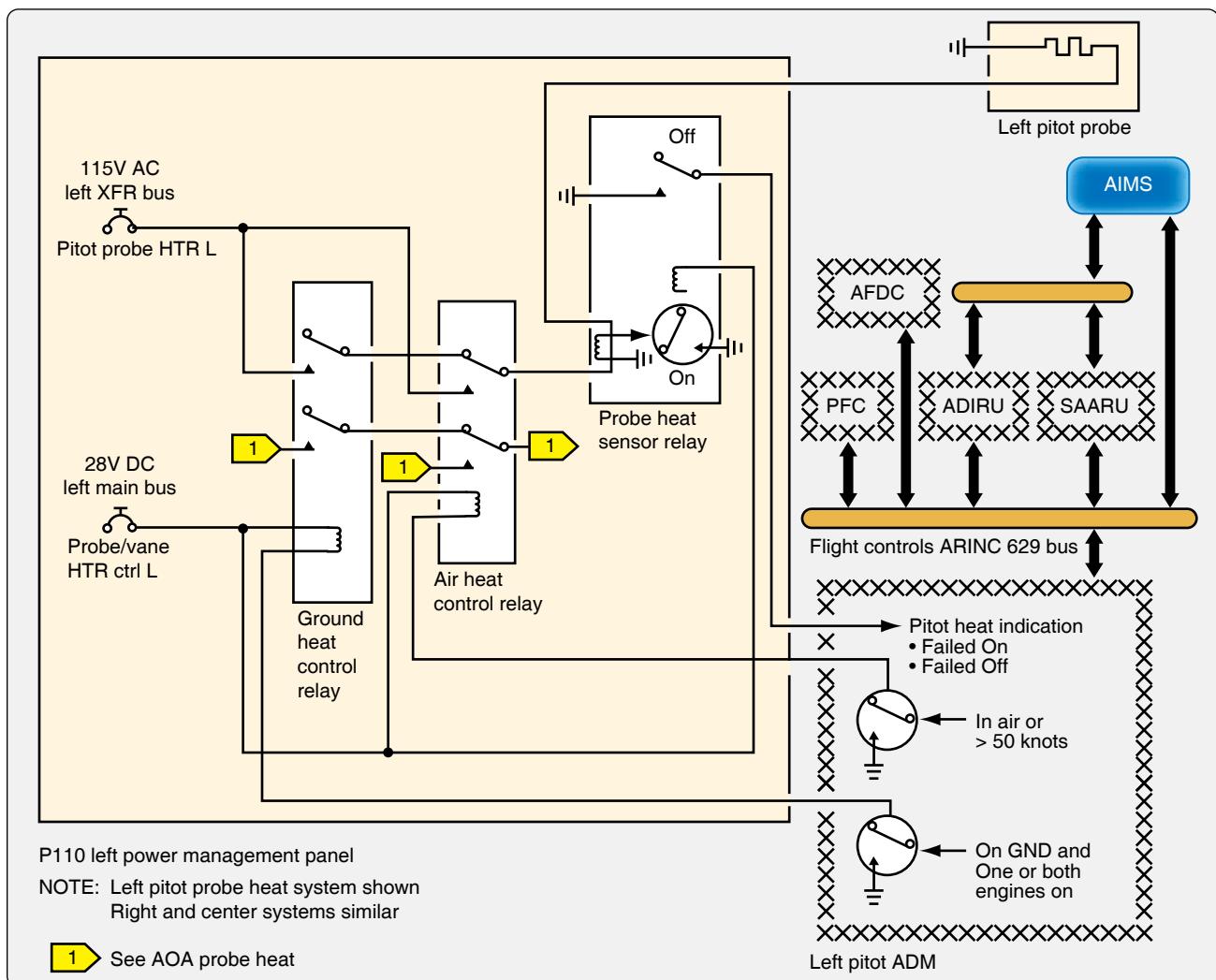


Figure 15-15. Pitot probe heat system.

TKS™ systems. Ice protection is based upon the freezing point depressant concept. An antifreeze solution is pumped from a reservoir through a mesh screen embedded in the leading edges of the wings and stabilizers. Activated by a switch in the flight deck, the liquid flows over the wing and tail surfaces, preventing the formation of ice as it flows. The solution mixes with the supercooled water in the cloud, depresses its freezing point, and allows the mixture to flow off of the aircraft without freezing. The system is designed to anti-ice, but it is also capable of deicing an aircraft as well. When ice has accumulated on the leading edges, the antifreeze solution chemically breaks down the bond between the ice and airframe. This allows aerodynamic forces to carry the ice away. Thus, the system clears the airframe of accumulated ice before transitioning to anti-ice protection. *Figure 15-16* shows a chemical anti-ice system.

The TKS™ weeping wing system contains formed titanium panels that are laser drilled with over 800 tiny holes (.0025-inch diameter) per square inch. These are mated

with non-perforated stainless-steel rear panels and bonded to wing and stabilizer leading edges. As fluid is delivered from a central reservoir and pump, it seeps through the holes. Aerodynamic forces cause the fluid to coat the upper and lower surfaces of the airfoil. The glycol-based fluid prevents ice from adhering to the aircraft structure.

Some aircraft with weeping wing systems are certified to fly into known icing conditions. Others use it as a hedge against unexpected ice encountered in flight. The systems are basically the same. Reservoir capacity permits 1-2 hours of operation. TKS™ weeping wings are used primarily on reciprocating aircraft that lack a supply of warm bleed air for the installation of a thermal anti-ice system. However, the system is simple and effective leading to its use on some turbine powered corporate aircraft as well.

Wing & Stabilizer Deicing Systems

GA aircraft and turboprop commuter-type aircraft often use a pneumatic deicing system to break off ice after it has formed

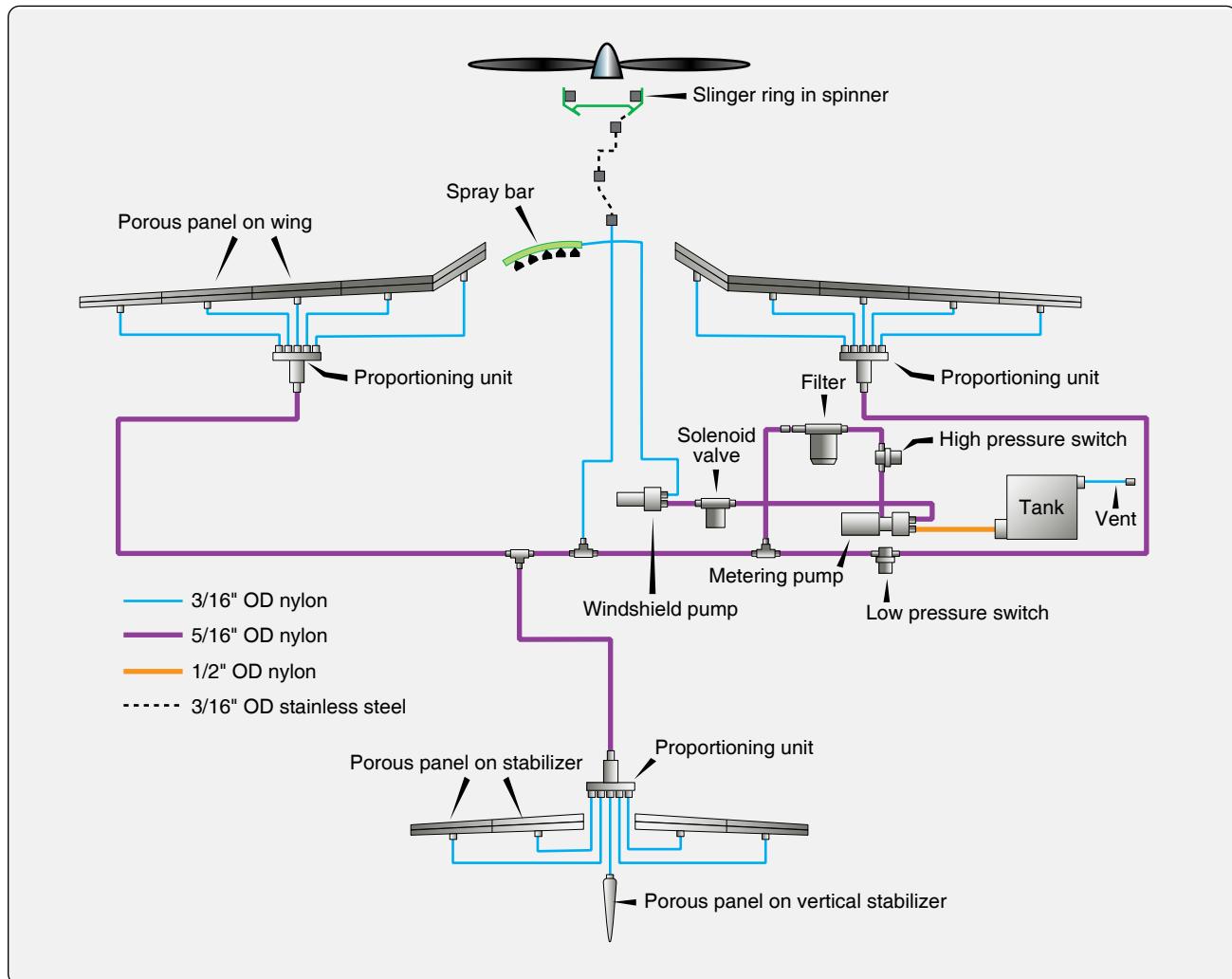


Figure 15-16. Chemical deicing system.

on the leading-edge surfaces. The leading edges of the wings and stabilizers have inflatable boots attached to them. The boots expand when inflated by pneumatic pressure, which breaks away ice accumulated on the boot. Most boots are inflated for 6 to 8 seconds. They are deflated by vacuum suction. The vacuum is continuously applied to hold the boots tightly against the aircraft while not in use.

Sources of Operating Air

The source of operating air for deice boot systems varies with the type of powerplant installed on the aircraft. Reciprocating engine aircraft typically use a dedicated engine-driven air pump mounted on the accessory drive gear box of the engine. The suction side of the pump is used to operate the gyroscopic instruments installed on the aircraft. It is also used to hold the deice boots tight to the aircraft when they are not inflated. The pressure side of the pump supplies air to inflate the deice boots, which breaks up ice that has formed on the wing and stabilizer leading edges. The pump operates continuously. Valves, regulators, and switches in the flight deck are used to control the flow of source air to the system.

Turbine Engine Bleed Air

The source of deice boot operating air on turbine engine aircraft is typically bleed air from the engine compressor(s). A relatively low volume of air on an intermittent basis is required to operate the boots. This has little effect on engine power enabling use of bleed air instead of adding a separate engine-driven air pump. Valves controlled by switches in the flight deck deliver air to the boots when requested.

Pneumatic Deice Boot System for GA Aircraft

GA aircraft, especially twin-engine models, are commonly equipped with pneumatic deicer systems. Rubber boots are attached with glue to the leading edges of the wings and stabilizers. These boots have a series of inflatable tubes. During operation, the tubes are inflated and deflated in an alternating cycle. [Figure 15-17] This inflation and deflation causes the ice to crack and break off. The ice is then carried away by the airstream. Boots used in GA aircraft typically inflate and deflate along the length of the wing. In larger turbo prop aircraft, the boots are installed in sections along the wing with the different sections operating alternately and symmetrically about the fuselage. This is done so that any disturbance to airflow caused by an inflated tube is kept to a minimum by inflating only short sections on each wing at a time.

GA System Operation

Figure 15-18 shows a deice system used on a GA twin-engine aircraft with reciprocating engines. In normal flight, all of the components in the deice system are de-energized. Discharge air from the dry air pumps is dumped overboard through the

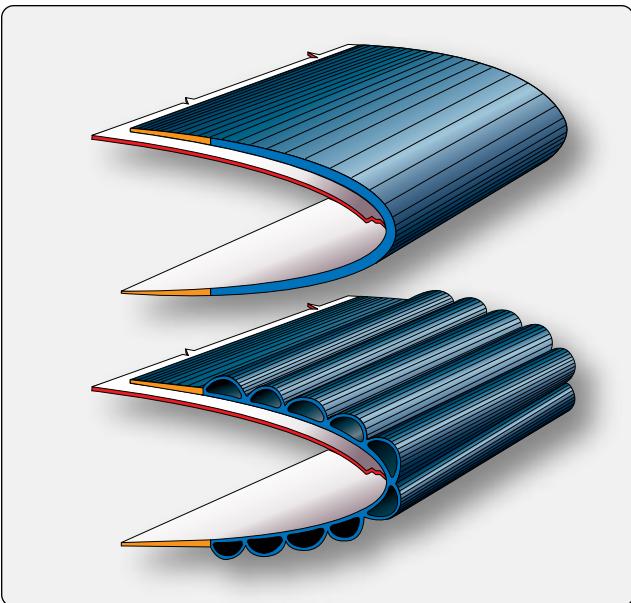


Figure 15-17. Cross-section of a pneumatic deicing boot uninflated (top) and inflated (bottom).

deice control valves. The deflate valve is open connecting the deice boots to the suction side of the pump through the check valve manifold and the vacuum regulator. The gyroscopic instruments are also connected to the vacuum side of the dry air pump. The vacuum regulator is set to supply the optimum suction for the gyros, which is sufficient to hold the boots tightly against the airfoil surfaces.

When the switch shown in Figure 15-19 is pushed ON, the solenoid-operated deice control valves in each nacelle open and the deflate valve energizes and closes. Pressurized air from the discharge side of the pumps is routed through the control valves to the deice boot. When the system reaches 17 psi, pressure switches located on the deflate valve de-energize the deice control valve solenoids. The valves close and route pump air output overboard. The deflate valve opens and the boots are again connected to vacuum.

On this simple system, the pilot must manually start this inflation/deflation cycle by pushing the switch each time deice is required. Larger aircraft with more complex systems may include a timer, which will cycle the system automatically until turned OFF. The use of distributor valves is also common. A distributor valve is a multi-position control valve controlled by the timer. It routes air to different deice boots in a sequence that minimizes aerodynamic disturbances as the ice breaks off the aircraft. Boots are inflated symmetrically on each side of the fuselage to maintain control in flight while deicing occurs. Distributor valves are solenoid operated and incorporate the deflate valve function to reconnect the deice boots with the vacuum side of the pump after all have been inflated.

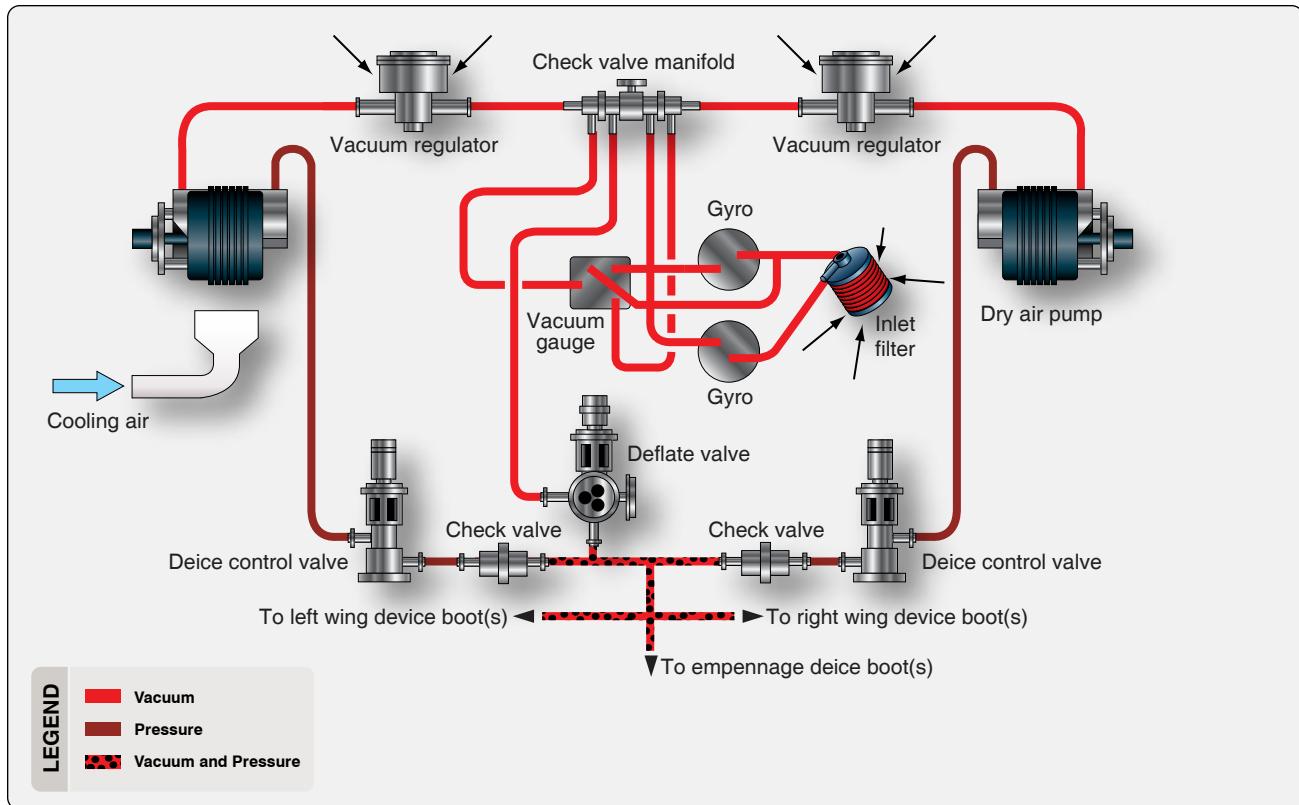


Figure 15-18. Pneumatic deicing system for a twin engine GA aircraft with reciprocating engines.



Figure 15-19. Wing deice switch.

Combining functional components of a deice system into a single unit is fairly common. Figure 15-20 illustrates the right side of a large aircraft deice boot system. The left side is the same. In addition to the distributor valves, which combine functions of a control valve and deflate valve, the system also uses a combination unit. This unit combines the functions of a shutoff control valve for all pump supply air, as well as a pressure regulator for the system. It also contains a secondary air filter.

Deice System for Turboprop Aircraft

Figure 15-21 shows a pneumatic deice system used on a turboprop aircraft. The source of pneumatic air is engine bleed air, which is used to inflate two inboard wing boots, two

outboard boots, and horizontal stabilizer boots. Additional bleed air is routed through the brake deice valve to the brakes. A three-position switch controls the operation of the boots. This switch is spring loaded to the center OFF position. When ice has accumulated, the switch should be selected to the single-cycle (up) position and released. [Figure 15-22] Pressure-regulated bleed air from the engine compressors supply air through bleed air flow control units and pneumatic shutoff valves to a pneumatic control assembly that inflates the wing boots. After an inflation period of 6 seconds, an electronic timer switches the distributor in the control assembly to deflate the wing boots, and a 4-second inflation begins in the horizontal stabilizer boots. After these boots have been inflated and deflated, the cycle is complete, and all boots are again held down tightly against the wings and horizontal stabilizer by vacuum. The spring-loaded switch must be selected up again for another cycle to occur.

Each engine supplies a common bleed air manifold. To ensure the operation of the system, if one engine is inoperative, a flow control unit with check valve is incorporated in the bleed air line from each engine to prevent the loss of pressure through the compressor of the inoperative engine. If the boots fail to function sequentially, they may be operated manually by selecting the DOWN position of the same deice cycle switch. Depressing and holding it in the manual

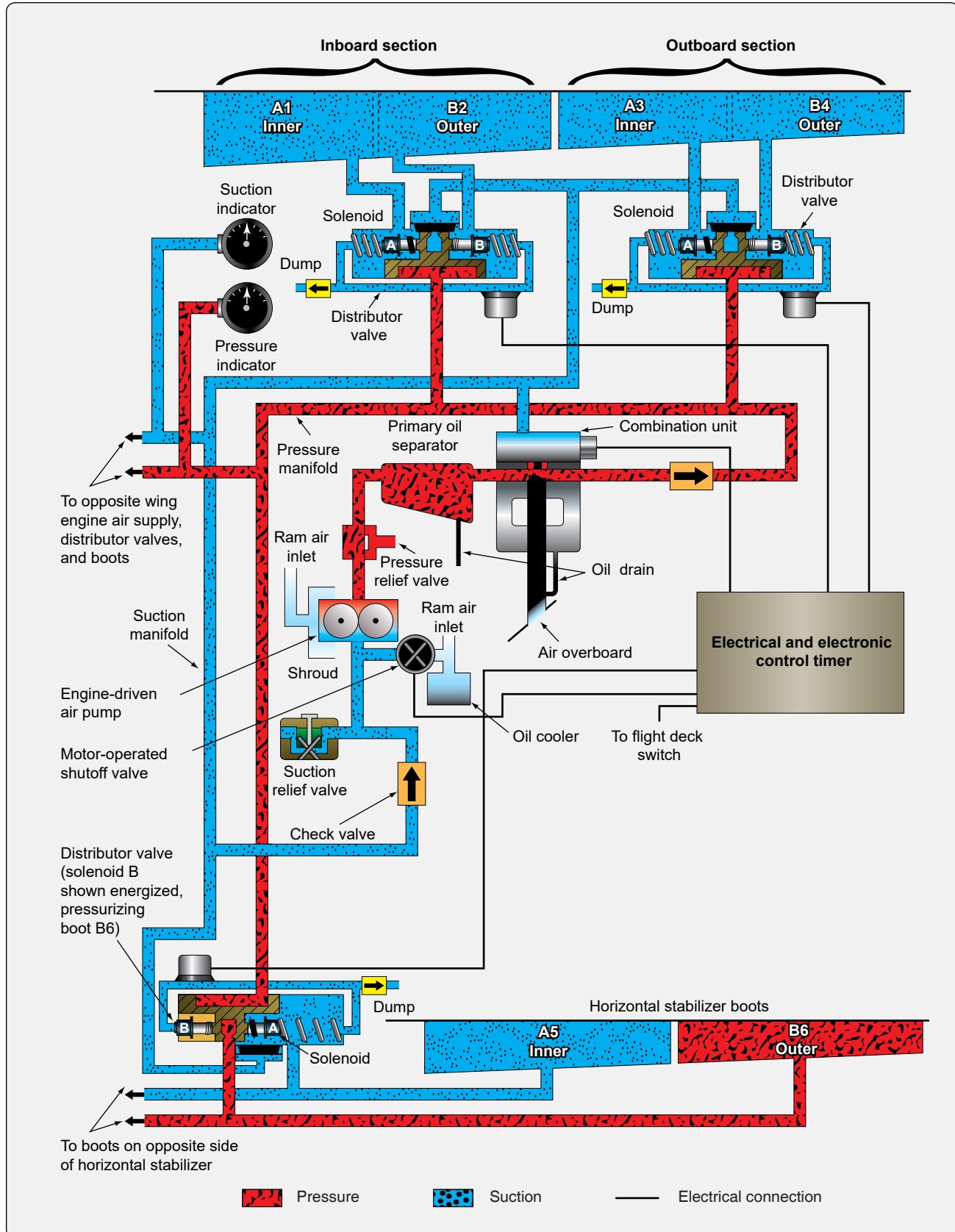


Figure 15-20. Right-side deice boot system on a large aircraft (left side similar).

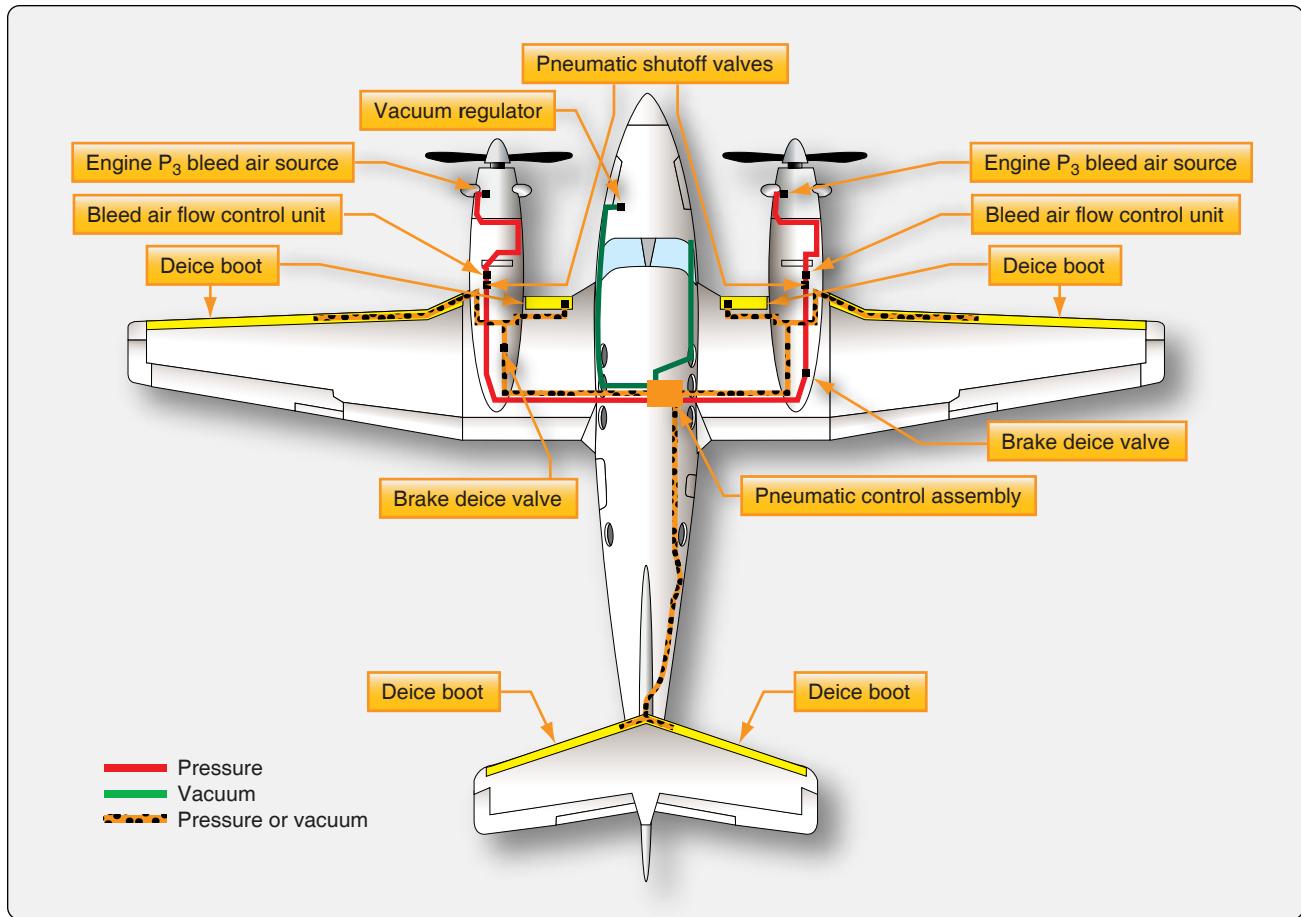


Figure 15-21. Wing deice system for turboprop aircraft.



Figure 15-22. Ice protection panel on a turboprop aircraft with deice boots.

DOWN position inflates all the boots simultaneously. When the switch is released, it returns to the (spring-loaded) off position, and each boot is deflated and held by vacuum. When operated manually, the boot should not be left inflated for more than 7 to 10 seconds, as a new layer of ice may begin to form on the expanded boots and become un-removable. If one engine is inoperative, the loss of its pneumatic pressure

does not affect boot operation. Electric power to the boot system is required to inflate the boots in either single-cycle or manual operation. When electric power is lost, the vacuum holds the boots tightly against the leading edge.

Deicing System Components

Several components are used to construct all deice boot systems. The components may differ slightly in name and location within the system depending on the aircraft. Components may also combine functions to save space and weight. The basic functions of filtering, pressure regulation, distribution, and attachment to a vacuum when boots are not in use must all be present. Check valves must also be installed to prevent back flow in the system. Manifolds are common on multiengine aircraft to allow sourcing of low pressure air from both engine pumps. Note that air-pump pressure is typically expelled overboard when not needed. Bleed air is shut off by a valve when not needed for deice boot operation on turbine engine aircraft. A timer, or control unit with an automatic mode, exists on many aircraft to repeat the deice cycle periodically.

Wet-Type Engine-Driven Air Pump

To provide pressure for the deice boots, older aircraft may use a wet-type engine-driven air pump mounted on the accessory drive gear case of the engine. Some modern aircraft may also use a wet-type air pump because of its durability. The pump is typically a four vane, positive displacement pump. Engine oil passes from the accessory case through the pump mounting base flange to lubricate the pump. Some of the oil is entrained in the output air and must be removed by an oil separator before it is sent through other components in the deice system. When installing a wet-type pump, care should be taken to ensure that the oil passage in the gasket, pump, and mounting flange are aligned to ensure lubrication. [Figure 15-23]

Dry-Type Engine-Driven Air Pump

Most modern GA aircraft are equipped with a dry-type engine-driven air pump. It is also mounted on the engine accessory drive case; however, it is not lubricated with engine oil. The pump is constructed with carbon rotor vanes and bearings. The carbon material wears at a controlled rate to provide adequate lubrication without the need for oil. This keeps output air oil-free; thus, the use of an oil separator is not required. Caution should be used to prevent oil, grease, or degreasing fluids from entering the pump or the air system to ensure proper pump and system operation. [Figure 15-24] Dry-type and wet-type pumps are virtually maintenance free. Mounting bolts should be checked for security as should all hose connections. Wet-type pumps have a longer time before requiring overhaul, but dry-type pumps give the assurance that the deice system will not be contaminated with oil.

Oil Separator

An oil separator is required for each wet-type air pump. Pump output air flows through the separator where most of the oil is removed and sent back to the engine though a drain line. Some systems may include a secondary separator to ensure oil free air is delivered to the deice system. There are no moving parts in an oil separator. A convoluted (coiled or twisted) interior allows the air to pass, while the oil condenses and drains back to the engine. The only maintenance required on the separator is flushing the interior of the unit with a specified solvent. This should be done at intervals prescribed in the applicable maintenance manual. [Figure 15-25]

Control Valve

A control valve is a solenoid operated valve that allows air from the pump to enter the deice system. When energized by the deice switch in the flight deck, the valve opens. The control valve dumps pump air overboard when the deice system is not in use. Many control valves are built in combination with pressure relief valves that keeps the deice system safe from over pressure. [Figure 15-26]

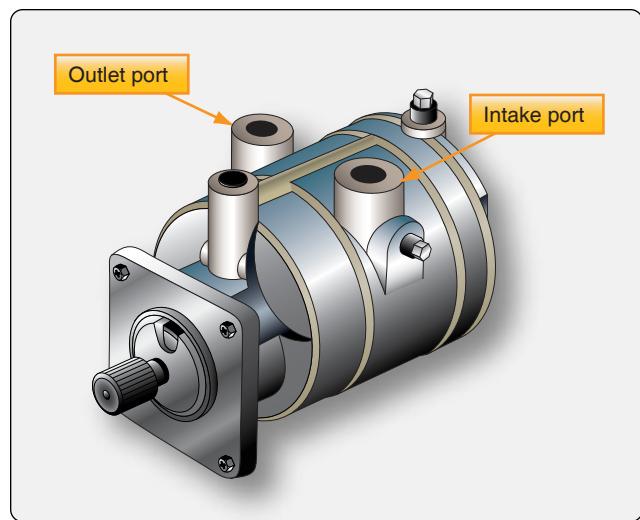


Figure 15-23. A wet-type air pump with engine oil lubricating ports in the mounting flange.



Figure 15-24. Dry-type engine-driven air pump.

Deflate Valve

All deice boot systems require a means for connecting vacuum from the air pump to the boots when the boots are not in use. This ensures the boots are held tightly deflated against the aircraft structure to provide the significant change in size and shape needed to break off accumulated ice when the boots inflate. One single deflate valve is used on simple deice boot systems. The deflate valve is solenoid operated. It is located at a point in the system where when closed, air is delivered to the boots. When open, vacuum is applied. Often, the deflate function is built into another unit, such as a distributor valve discussed next.

Distributor Valve

A distributor valve is a type of control valve used in relatively complex deice boot systems. It is an electrically-operated solenoid valve controlled by the deice boot system timer



Figure 15-25. An oil separator used with a wet-type engine-driven air pump.

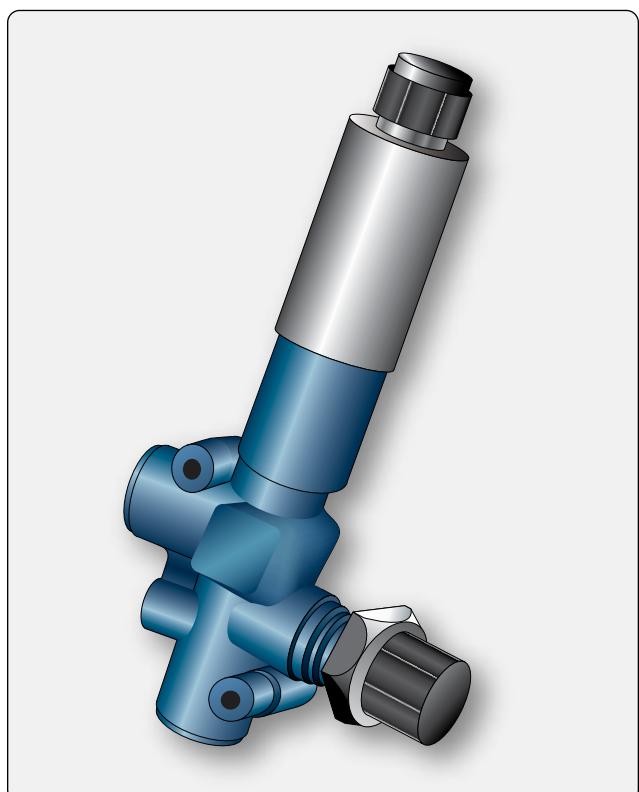


Figure 15-26. A solenoid operated deice control valve.

or control unit. On some systems, a distributor valve is assigned to each set of deice boots it controls. It differs from a control valve in that it has the deflate valve function built into it. Therefore, the distributor valve transfers connection of the boots from the pressure side of the air pump to the vacuum side of the pump once the proper inflation time has elapsed. The valve also dumps the unneeded air from the pump overboard.

Another type of distributor valve exists that handles the inflation and deflation of numerous sets of deice boots in a single unit. It also connects the boots to vacuum and dumps pump air when deice is not needed. A servo motor is used to position the multi-position valve. These centralized units are controlled by a timer or control unit. They inflate and deflate all of the boots on the aircraft. The timer may be built into the unit on some models.

Timer/Control Unit

All but the simplest of deice systems contain a timer or control unit. This device controls the action of the distributor valve(s) to ensure all boots are inflated in the proper sequence and for the correct duration. Six seconds of inflation is common to break off accumulated ice. The boot then must be immediately deflated so that ice does not adhere to the inflated geometry of the boot. This could cause it to fail to deflate or break off ice when the boot is re-inflated. The timer, or control unit, can also be made to cycle through the inflation and deflation of all boots periodically, thus relieving the flight crew of repetitive manual activation of the system. The function and capabilities of timers and control units vary. Consult the manufacturer's maintenance information for the performance characteristics of the timer/control unit on the aircraft in question.

The timer, or control unit, may be an independent device, or it may be built-in as part of another deice system component, such as a central distribution valve.

Note: A modern system design may use a pressure switch to signal deflation of the deice boots. When pressure builds in the boots to a preset amount, the switch signals the control valve to close and connect the boots to vacuum. However, this system retains a control unit for automatic cycling of the system at a set time interval.

Regulators & Relief Valves

Both the pressure and vacuum developed by an air pump must be regulated for use in the deice boot system. Typical boot inflation air pressure is between 15 and 20 psi. Vacuum pressure is set for the requirements of the gyroscopic instruments operated by the vacuum side of the air pump. Measured in inches of mercury, normal vacuum pressure (suction) is 4.5 to 5.5 "Hg.

Deice boot system air pressure is controlled by a pressure regulator valve located somewhere in the system downstream of the pump or oil separator, if installed. The regulator may be a stand-alone unit, or it may be combined into another deice system component. Regardless, the spring-loaded valve relieves pressure overboard when it exceeds the limit for which the system is designed.

A vacuum regulator is installed in the vacuum manifold on the suction side of the air pump to maintain the vacuum at the designed level. Also known as a suction regulating valve or similar, the spring-loaded valve contains a filter for the ambient air drawn through the valve during operation. This filter must be changed or kept clean per manufacturer's instructions. [Figure 15-27]

Manifold Assembly

In all pneumatic deice boot systems, it is necessary for check valves to be installed to prevent backflow of air in the system. The location(s) depends on system design. Sometimes, the check valve is built into another system component. On twin-engine aircraft, it is common to unite the air supplied from each engine-driven pump to provide redundancy. Check valves are required to guard against backflow should one pump fail. A manifold assembly is commonly used to join both sides of the system. [Figure 15-28] It contains the required check valves in a single assembly.

Inlet Filter

The air used in a deice boot system is ambient air drawn in upstream of the gyroscopic instruments on the suction side of the engine-driven air pump. This air must be free of contaminants for use spinning the gyros, as well as for inflation of the deice boots. To ensure clean air, an inlet filter is installed as the air intake point for the system. This filter must be regularly maintained as per manufacturer's



Figure 15-28. A manifold assembly used in multiengine aircraft deice systems.

instructions. Figure 15-29 shows a typical inlet air filter. Figure 15-30 shows the relationship of the vacuum regulator and inlet air filter to other system components.

Construction & Installation of Deice Boots

Deicer boots are made of soft, pliable rubber, or rubberized fabric, and contain tubular air cells. The outer ply of the deicer boot is of conductive neoprene to provide resistance to deterioration by the elements and many chemicals. The neoprene also provides a conductive surface to dissipate static electricity charges. These charges, if allowed to accumulate, would eventually discharge through the boot to the metal skin beneath, causing static interference with the radio equipment. [Figure 15-31]

On modern aircraft, the deicer boots are bonded with an adhesive to the leading edge of wing and tail surfaces. The trailing edges of this type boot are tapered to provide a smooth airfoil. Elimination of fairing strips, screws, and rivnuts used



Figure 15-27. A vacuum regulator.



Figure 15-29. Air filter for vacuum system.

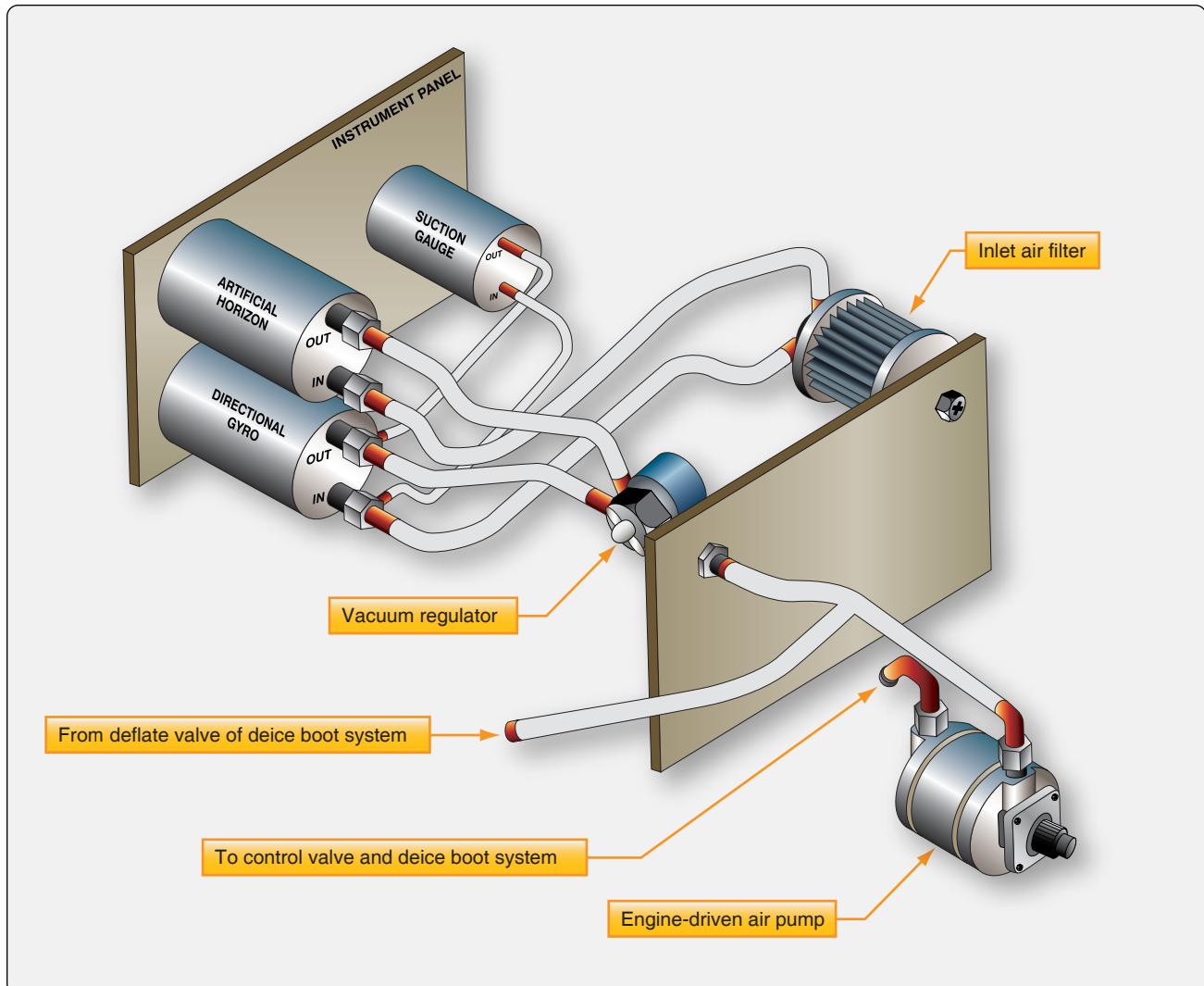


Figure 15-30. Location of the inlet air filter in relationship to other components in a gyro instrument/pneumatic deice boot system.



Figure 15-31. Deicing boots inflated (left) and deflated (right).

on older types of deicing boots reduces the weight of the deice system. The deicer boot air cells are connected to system pressure and vacuum lines by non-kinking flexible hose.

When gluing the deice boots to the leading edge of wings and stabilizers, the manufacturer's instruction must be strictly followed. The glue is typically a contact cement normally spread on both the airfoil and the boot and allowed to become tacky before mating the surfaces. Clean, paint-free surfaces are required for the glue to adhere properly. Removal of old boots is performed by re-softening the cement with solvent.

Inspection, Maintenance, & Troubleshooting of Rubber Deicer Boot Systems

Maintenance on pneumatic deicing systems varies with each aircraft model. The instructions of the airframe or system components manufacturer should be followed in all cases. Depending on the aircraft, maintenance usually consists of operational checks, adjustments, troubleshooting, and inspection.

Operational Checks

An operational check of the system can be made by operating the aircraft engines or by using an external source of air. Most systems are designed with a test plug to permit ground checking the system without operating the engines. When using an external air source, make certain that the air pressure does not exceed the test pressure established for the system. Before turning the deicing system on, observe the vacuum-operated instruments. If any of the gauges begin to operate, it is an indication that one or more check valves have failed to close and that reverse flow through the instruments is occurring. Correct the difficulty before continuing the test. If no movement of the instrument pointers occurs, turn on the deicing system. With the deicer system controls in their proper positions, check the suction and pressure gauges for

proper indications. The pressure gauge fluctuates as the deicer tubes inflate and deflate. A relatively steady reading should be maintained on the vacuum gauge. It should be noted that not all systems use a vacuum gauge. If the operating pressure and vacuum are satisfactory, observe the deicers for actuation. With an observer stationed outside the aircraft, check the inflation sequence to be certain that it agrees with the sequence indicated in the aircraft maintenance manual. Check the timing of the system through several complete cycles. If the cycle time varies more than is allowable, determine the difficulty and correct it. Inflation of the deicers must be rapid to provide efficient deicing. Deflation of the boot being observed should be completed before the next inflation cycle. [Figure 15-32]

Adjustments

Examples of adjustments that may be required include adjusting the deicing system control cable linkages, adjusting system pressure relief valves, and deicing system vacuum (suction) relief valves. A pressure relief valve acts as a safety device to relieve excess pressure in the event of regulator valve failure. To adjust this valve, operate the aircraft engines and adjust a screw on the valve until the deicing pressure gauge indicates the specified pressure at which the valve should relieve. Vacuum relief valves are installed in a system that uses a vacuum pump to maintain constant suction during varying vacuum pump speeds. To adjust a vacuum relief valve, operate the engines. While watching the vacuum (suction) gauge, an assistant should adjust the suction relief valve adjusting screw to obtain the correct suction specified for the system.

Troubleshooting

Not all troubles that occur in a deicer system can be corrected by adjusting system components. Some troubles must be corrected by repair or replacement of system components or



Figure 15-32. Test equipment used to test a wing deice system (left), and test equipment installed in the aircraft for testing (right).

by tightening loose connections. Several troubles common to pneumatic deicing systems are shown in the left-hand column of the chart in *Figure 15-33*. Note the probable causes and the remedy of each trouble listed in the chart. In addition to using troubleshooting charts, operational checks are sometimes necessary to determine the possible cause of trouble.

Inspection

During each preflight and scheduled inspection, check the deicer boots for cuts, tears, deterioration, punctures, and security; during periodic inspections, go a little further and check deicer components and lines for cracks. If weather cracking of rubber is noted, apply a coating of conductive cement. The cement, in addition to sealing the boots against weather, dissipates static electricity so that it does not

puncture the boots by arcing to the metal surfaces.

Deice Boot Maintenance

The life of the deicers can be greatly extended by storing them when they are not needed and by observing these rules when they are in service:

1. Do not drag gasoline hoses over the deicers.
2. Keep deicers free of gasoline, oil, grease, dirt, and other deteriorating substances.
3. Do not lay tools on or lean maintenance equipment against the deicers.
4. Promptly repair or resurface the deicers when abrasion or deterioration is noted.
5. Wrap deice boots in paper or canvas when storing.

Problem	Causes (most of which can be identified with a 343 Test Kit)	Corrective action(s)
Boots do not inflate	<ul style="list-style-type: none"> • Open circuit breaker • Faulty deflate valve Solenoid inoperable: <ol style="list-style-type: none"> 1. Improper voltage at solenoid 2. Blocked air vent in solenoid 3. Inoperative plunger Diaphragm not seated <ol style="list-style-type: none"> 1. Blocked vent orifice located in rivet bottom at center of diaphragm 2. Dirty diaphragm seal area 3. Diaphragm ruptured Two faulty deice control valves or faulty two-stage regulators Faulty check valve Relay not functioning Leak in system boots 	<ul style="list-style-type: none"> • Reset circuit breaker • Check deflate valves as follows: <ul style="list-style-type: none"> Solenoid inoperable: <ol style="list-style-type: none"> 1. Correct electrical system 2. Clean with alcohol or replace 3. Clean with alcohol or replace Diaphragm not seated <ol style="list-style-type: none"> 1. Clean with .010 diameter wire and alcohol 2. Clean with blunt instrument and alcohol 3. Replace valve Clean or replace valve assembly as noted above Replace check valve Check wiring or replace relay Repair as needed
Slow boot inflation	<ul style="list-style-type: none"> • Lines blocked or disconnected • Low air pump capacity • One or more deice control valves not functioning properly • Deflate valve not fully closed • Ball check in deflate valve inoperative • Leaks in system or boots 	<ul style="list-style-type: none"> • Check and replace lines • Replace air pump • Clean or replace valve assembly as noted above • Clean or replace valve assembly as noted above • Clean check valve or replace deflate valve • Repair as needed
System will not cycle	<ul style="list-style-type: none"> • Pressure in system not reaching specified psi to activate pressure switch • Leak in system or boots • Pressure switch on deflate valve inoperative 	<ul style="list-style-type: none"> • Clean or replace deice control valve as noted above • Clean or replace deflate valve, as noted above • Repair as needed, tighten all hose connections • Replace switch
Slow deflation	<ul style="list-style-type: none"> • Low vacuum • Faulty deflate valve (indicated by temporary reduction in suction gauge reading) 	<ul style="list-style-type: none"> • Repair as needed • Clean or replace valve assembly as noted above
No vacuum for boot hold down	<ul style="list-style-type: none"> • Malfunctioning deflate valve or deice valve • Leak in system or boots 	<ul style="list-style-type: none"> • Clean or replace valve assembly as noted above • Repair as needed
Boots will not deflate during cycle	<ul style="list-style-type: none"> • Faulty deflate valve 	<ul style="list-style-type: none"> • Check and replace valve
Boots appear to inflate on aircraft climb	<ul style="list-style-type: none"> • Vacuum source for boot holddown inoperative • Lines running through pressurized cabin loose or disconnected 	<ul style="list-style-type: none"> • Check operation of ball check in deflate valve • Check for loose or disconnected vacuum lines and repair

Figure 15-33. Troubleshooting guide for wing deice system.

Thus far, preventive maintenance has been discussed. The actual work on the deicers consists of cleaning, resurfacing, and repairing. Cleaning should ordinarily be done at the same time the aircraft is washed, using a mild soap and water solution. Grease and oil can be removed with a cleaning agent, such as naphtha, followed by soap and water scrubbing. Whenever the degree of wear is such that it indicates that the electrical conductivity of the deicer surface has been destroyed, it may be necessary to resurface the deicer. The resurfacing substance is a black, conductive neoprene cement. Prior to applying the resurfacing material, the deicer must be cleaned thoroughly and the surface roughened. Cold patch repairs can be made on a damaged deicer. The deicer must be relieved of its installed tension before applying the patch. The area to be patched must be clean and buffed to roughen the surface slightly. Patches are glued in place. Follow manufacturer's instructions for all repairs.

Electric Deice Boots

A few modern aircraft are equipped with electric deice boots on wing sections or on the horizontal stabilizer. These boots contain electric heating elements which are bonded

to the leading edges similarly to pneumatic deice boots. When activated, the boots heat up and melt the ice off of leading edge surfaces. The elements are controlled by a sequence timer in a deice controller. Ice detector and ram air temperature probe inputs initiate operation when other flight condition parameters exist. The boot elements turn ON and OFF in paired sections to avoid aerodynamic imbalance. The system is inoperative while the aircraft is on the ground. *Figure 15-34* illustrated such a system. A benefit of electric deice boots is the conservation of engine bleed air. Current draw is limited to only those periods when de-ice is required.

Propeller Deice System

The formation of ice on the propeller leading edges, cuffs, and spinner reduces the efficiency of the powerplant system. Deice systems using electrical heating elements and systems using chemical deicing fluid are used.

Electrothermal Propeller Device System

Many propellers are deiced by an electrically heated boot on each blade. The boot, firmly cemented in place, receives current from a slip ring and brush assembly on the spinner

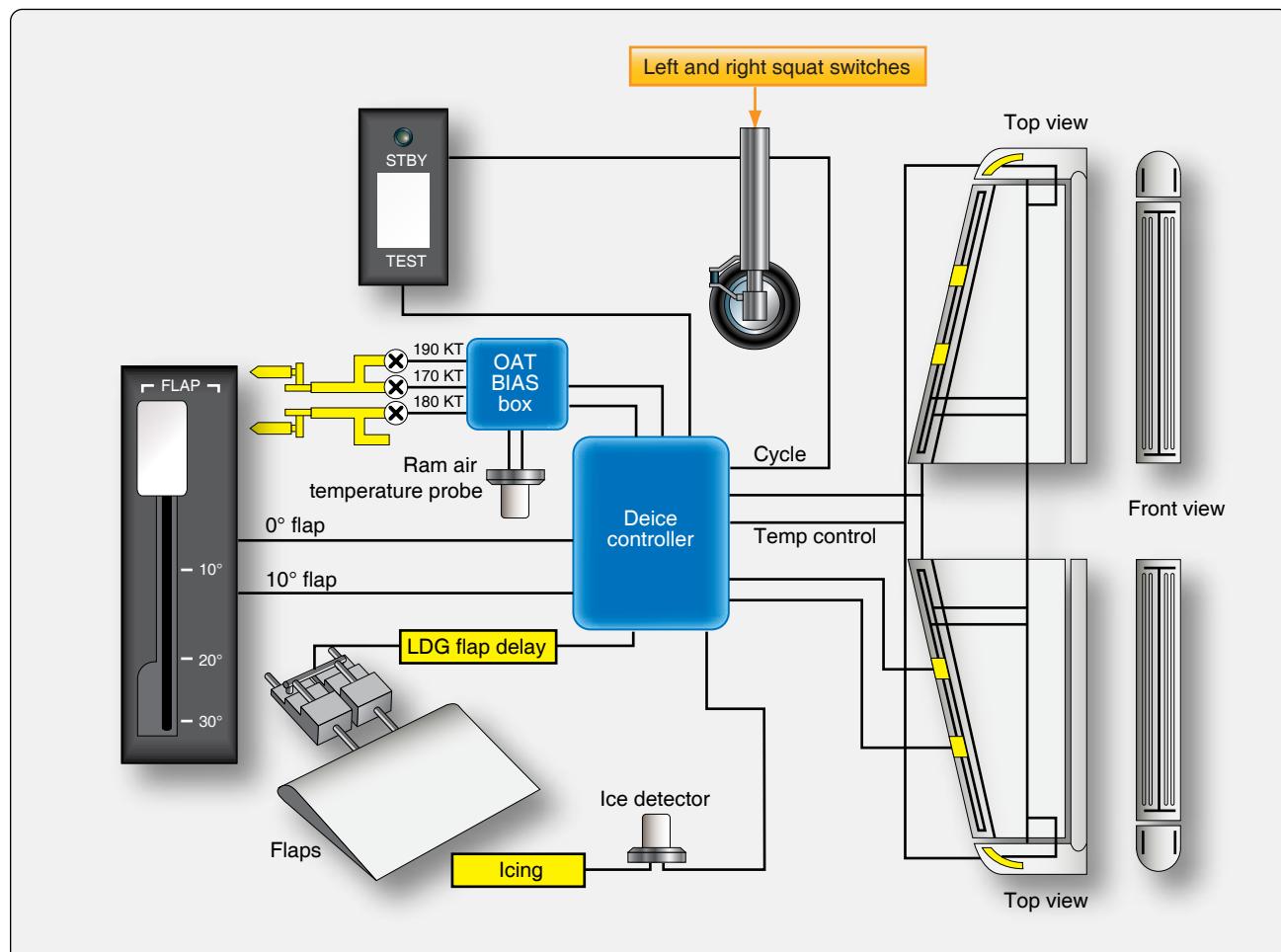


Figure 15-34. Electric stabilizer deice system.

bulkhead. The slip ring transmits current to the deice boot. The centrifugal force of the spinning propeller and air blast breaks the ice particles loose from the heated blades. [Figure 15-35]

On one aircraft model, the boots are heated in a preset sequence, which is an automatic function controlled by a timer. This sequence is as follows: 30 seconds for the right prop outer elements; 30 seconds for the right prop inner elements; 30 seconds for the left prop outer elements; and, 30 seconds for the left prop inner elements. Once the system is turned on for automatic is activated, it cycles continuously. A manual bypass of the timer is incorporated. [Figure 15-36]

Chemical Propeller Deice

Some aircraft models, especially single-engine GA aircraft, use a chemical deicing system for the propellers. Ice usually appears on the propeller before it forms on the wing. The glycol-based fluid is metered from a tank by a small electrically driven pump through a microfilter to the slinger rings on the prop hub. The propeller system can be a stand-alone system, or it can be part of a chemical wing and

stabilizer deicing system such as the TKSTTM weeping system.

Ground Deicing of Aircraft

The presence of ice on an aircraft may be the result of direct precipitation, formation of frost on integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear following taxiing through snow or slush. In accordance with the Federal Aviation Administration (FAA) Advisory Circular (AC) 120-60, the aircraft must be free of all frozen contaminants adhering to the wings, control surfaces, propellers, engine inlets, or other critical surfaces before takeoff.

Any deposits of ice, snow, or frost on the external surfaces of an aircraft may drastically affect its performance. This may be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the airfoil surfaces, or it may be due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges, valves, microswitches, or by the ingestion of ice into the engine. When aircraft are hangared to melt snow or frost,

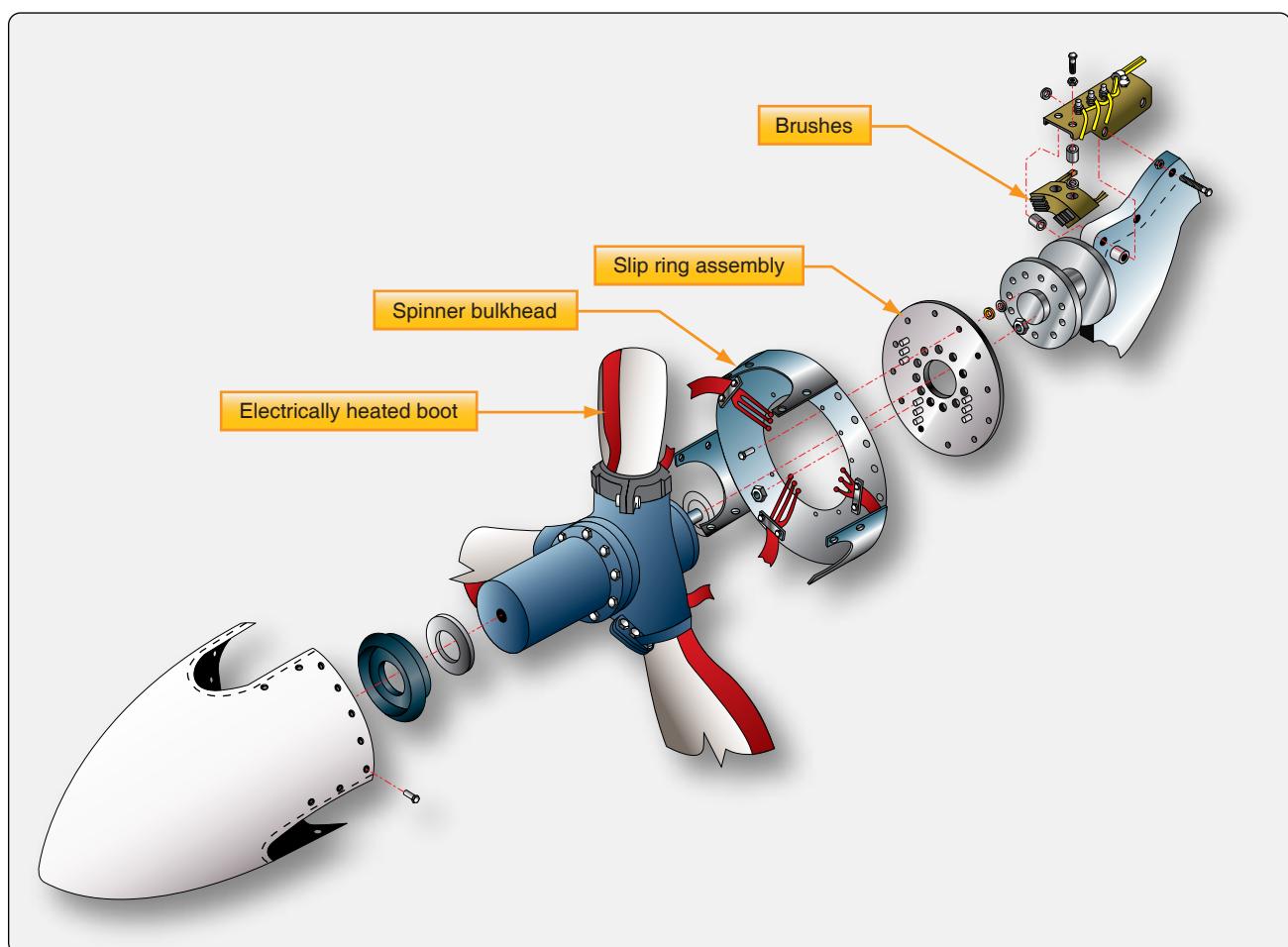


Figure 15-35. Electro thermal propeller deice system components.

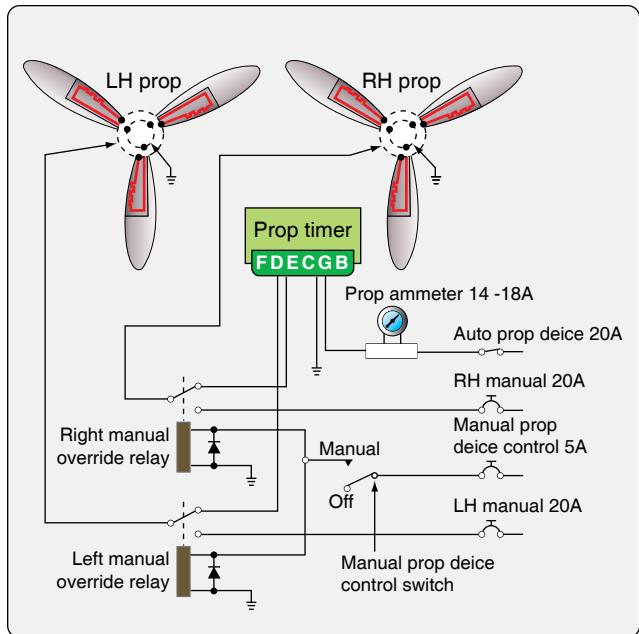


Figure 15-36. Propeller electrical deice system schematic.

any melted snow or ice may freeze again if the aircraft is subsequently moved into subzero temperatures. Any measures taken to remove frozen deposits while the aircraft is on the ground must also prevent the possible refreezing of the liquid.

Frost Removal

Frost deposits can be removed by placing the aircraft in a warm hangar or by using a frost remover or deicing fluid. These fluids normally contain ethylene glycol and isopropyl alcohol and can be applied either by spray or by hand. It should be applied within 2 hours of flight. Deicing fluids may adversely affect windows or the exterior finish of the aircraft, only the type of fluid recommended by the aircraft manufacturer should be used. Transport category aircraft are often deiced on the ramp or a dedicated deicing location at the airport. Deicing trucks are used to spray the deicing and/or anti-icing fluid on aircraft surfaces. [Figure 15-37]

Deicing & Anti-icing of Transport Type Aircraft

Deicing Fluid

The deicing fluid must be accepted according to its type for holdover times, aerodynamic performance, and material compatibility. The coloring of these fluids is also standardized. In general, glycol is colorless, Type-I fluids are orange, Type-II fluids are white/pale yellow, and Type-IV fluids are green. The color for Type-III fluid has not yet been determined.

When aircraft surfaces are contaminated by frozen moisture, they must be deiced prior to dispatch. When freezing precipitation exists, and there is a risk of contamination of



Figure 15-37. An American Airlines aircraft being deiced at Syracuse Hancock International Airport.

the surface at the time of dispatch, aircraft surfaces must be anti-iced. If both deicing and anti-icing are required, the procedure may be performed in one or two steps. The selection of a one- or two-step process depends upon weather conditions, available equipment, available fluids, and the holdover time to be achieved.

Holdover Time (HOT)

Holdover Time (HOT) is the estimated time that deicing/anti-icing fluid prevents the formation of frost or ice and the accumulation of snow on the critical surfaces of an aircraft. HOT begins when the final application of deicing/anti-icing fluid commences and expires when the deicing/anti-icing fluid loses its effectiveness. Figure 15-38 shows a holdover timetable for Type IV fluid.

Critical Surfaces

Basically, all surfaces that have an aerodynamic, control, sensing, movement, or measuring function must be clean. These surfaces cannot necessarily be cleaned and protected in the same conventional deicing/anti-icing manner as the wings. Some areas require only a cleaning operation, while others need protection against freezing. The procedure of deicing may also vary according to aircraft limitations. The use of hot air may be required when deicing (e.g., landing gear or propellers).

Figure 15-39 shows critical areas on an aircraft that should not be sprayed directly. Some critical elements and procedures that are common for most aircraft are:

- Deicing/anti-icing fluids must not be sprayed directly on wiring harnesses and electrical components (e.g., receptacles, junction boxes), onto brakes, wheels, exhausts, or thrust reversers.
- Deicing/anti-icing fluid shall not be directed into the orifices of pitot heads, static ports, or directly onto

FAA Type IV Holdover Time Guidelines																	
OAT		SAE type IV fluid concentration neat fluid water (vol. %/vol.%)	Approximate holdover times under various weather conditions (hours:minutes)														
°C	°F		Frost*	Freezing Fog	Snow◊	Freezing drizzle***	Light free rain	Rain on cold soaked wing	Other*								
above 0	above 32	100/0	18:00	1:05–2:15	0:35–1:05	0:40–1:10	0:25–0:40	0:10–0:50 0:05–0:35	CAUTION: no holdover time guidelines exist								
		72/25	6:00	1:05–1:45	0:30–1:05	0:35–0:50	0:15–0:30										
		50/50	4:00	0:15–0:35	0:05–0:20	0:10–0:20	0:05–0:10										
0 through -3	32 through 27	100/0	12:00	1:05–2:15	0:30–0:55	0:40–1:10	0:15–0:40	CAUTION: clear ice may require touch for confirmation									
		75/25	5:00	1:05–2:15	0:25–0:50	0:35–0:50	0:15–0:30										
		50/50	3:00	1:15–0:35	0:05–0:15	0:10–0:20	0:05–0:15										
below -3 through -14	below 27 through 7	100/0	12:00	0:20–0:50	0:20–0:40	**0:20–0:45	**0:10–0:25										
		75/25	5:00	0:25–0:50	0:15–0:25	**0:15–0:30	**0:10–0:20										
		100/0	12:00	0:15–0:40	0:15–0:30												
below -25	below -13	100/0	SAE type IV fluid may be used below -25 °C (-13 °F) if the freezing point of the fluid is at least 7 °C (13 °F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE type I when SAE type IV fluid cannot be used.														
°C = degrees Celsius °F = degrees Fahrenheit OAT= outside air temperature VOL = volume		The responsibility for the application of these data remains with the user. * During conditions that apply to aircraft protection for ACTIVE FROST. ** No holdover time guidelines exist for this condition below -10 °C (14 °F). *** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible. ‡ Snow pellets, ice pellets, heavy snow, moderate and heavy freezing rain, hail. ◊ Snow includes snow grains.															
CAUTIONS: <ul style="list-style-type: none"> The time of protection will be shortened in heavy weather conditions: heavy precipitation rates or high moisture contents. High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may be reduced when aircraft skin temperature is lower than OAT. 																	

Figure 15-38. FAA deice holdover time guidelines.

- airstream direction detectors probes/angle of attack airflow sensors.
- All reasonable precautions shall be taken to minimize fluid entry into engines, other intakes/outlets, and control surface cavities.
 - Fluids shall not be directed onto flight deck or cabin windows as this can cause crazing of acrylics or penetration of the window seals.
 - Any forward area from which fluid can blow back onto windscreens during taxi or subsequent takeoff shall be free of residues prior to departure.
 - If Type II, III, or IV fluids are used, all traces of the fluid on flight deck windows should be removed prior to departure, particular attention being paid to windows fitted with wipers.
 - Landing gear and wheel bays shall be kept free from buildup of slush, ice, or accumulations of blown snow.
 - When removing ice, snow, slush, or frost from aircraft surfaces, care shall be taken to prevent it entering and accumulating in auxiliary intakes or control surface

hinge areas (e.g., manually remove snow from wings and stabilizer surfaces forward toward the leading edge and remove from ailerons and elevators back towards the trailing edge).

Ice & Snow Removal

Probably the most difficult deposit to deal with is deep, wet snow when ambient temperatures are slightly above the freezing point. This type of deposit should be removed with a soft brush or squeegee. Use care to avoid damage to antennas, vents, stall warning devices, vortex generators, etc., that may be concealed by the snow. Light, dry snow in subzero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a deicing fluid. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of deicing operations, inspect the aircraft to ensure that its condition is satisfactory for flight. All external surfaces should be examined for signs of residual snow or

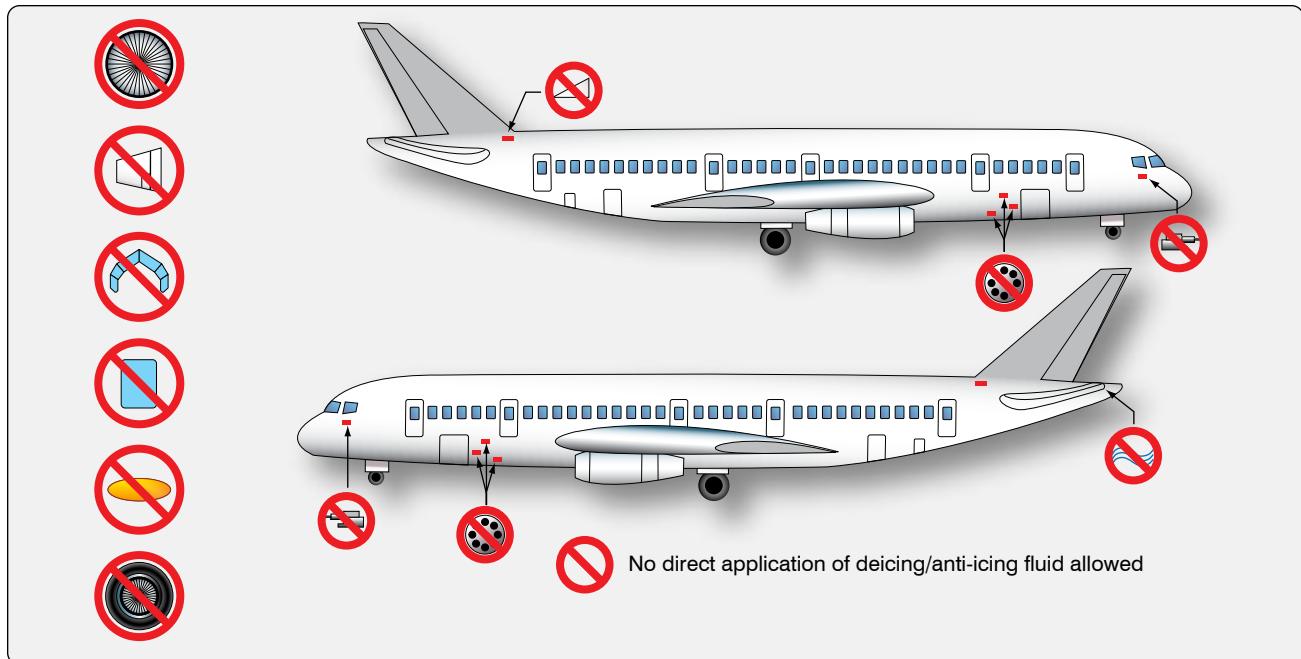


Figure 15-39. No direct application of deicing/anti-icing fluid allowed.

ice, particularly in the vicinity of control gaps and hinges. Check the drain and pressure sensing ports for obstructions. When it becomes necessary to physically remove a layer of snow, all protrusions and vents should be examined for signs of damage. Control surfaces should be moved to ascertain that they have full and free movement. The landing gear mechanism, doors and bay, and wheel brakes should be inspected for snow or ice deposits and the operation of up-locks and microswitches checked.

Snow or ice can enter turbine engine intakes and freeze in the compressor. If the compressor cannot be turned by hand for this reason, hot air should be blown through the engine until the rotating parts are free.

Rain Control Systems

There are several different ways to remove the rain from the windshields. Most aircraft use one or a combination of the following systems: windshield wipers, chemical rain repellent, pneumatic rain removal (jet blast), or windshields treated with a hydrophobic surface seal coating.

Windshield Wiper Systems

In an electrical windshield wiper system, the wiper blades are driven by an electric motor(s) that receive(s) power from the aircraft's electrical system. On some aircraft, the pilot's and copilot's windshield wipers are operated by separate systems to ensure that clear vision is maintained through one of the windows should one system fail. Each windshield wiper assembly consists of a wiper, wiper arm, and a wiper motor/converter. Almost all windshield wiper systems use

electrical motors. Some older aircraft might be equipped with hydraulic wiper motors. [Figure 15-40]

Maintenance performed on windshield wiper systems consists of operational checks, adjustments, and troubleshooting. An operational check should be performed whenever a system component is replaced or whenever the system is suspected of not working properly. During the check, make sure that the windshield area covered by the wipers is free of foreign matter and is kept wet with water. Adjustment of a windshield wiper system consists of adjusting the wiper blade tension, the angle at which the blade sweeps across the windshield, and proper parking of the wiper blades.

Chemical Rain Repellent

Water poured onto clean glass spreads out evenly. Even when the glass is held at a steep angle or subjected to air velocity, the glass remains wetted by a thin film of water. However, when glass is treated with certain chemicals, a transparent film is formed that causes the water to behave very much like mercury on glass. The water draws up into beads that cover only a portion of the glass and the area between beads is dry. The water is readily removed from the glass. This principle lends itself quite naturally to removing rain from aircraft windshields. The high-velocity slipstream continually removes the water beads, leaving a large part of the window dry.

A rain repellent system permits application of the chemical repellent by a switch or push button in the flight deck. The proper amount of repellent is applied regardless of how

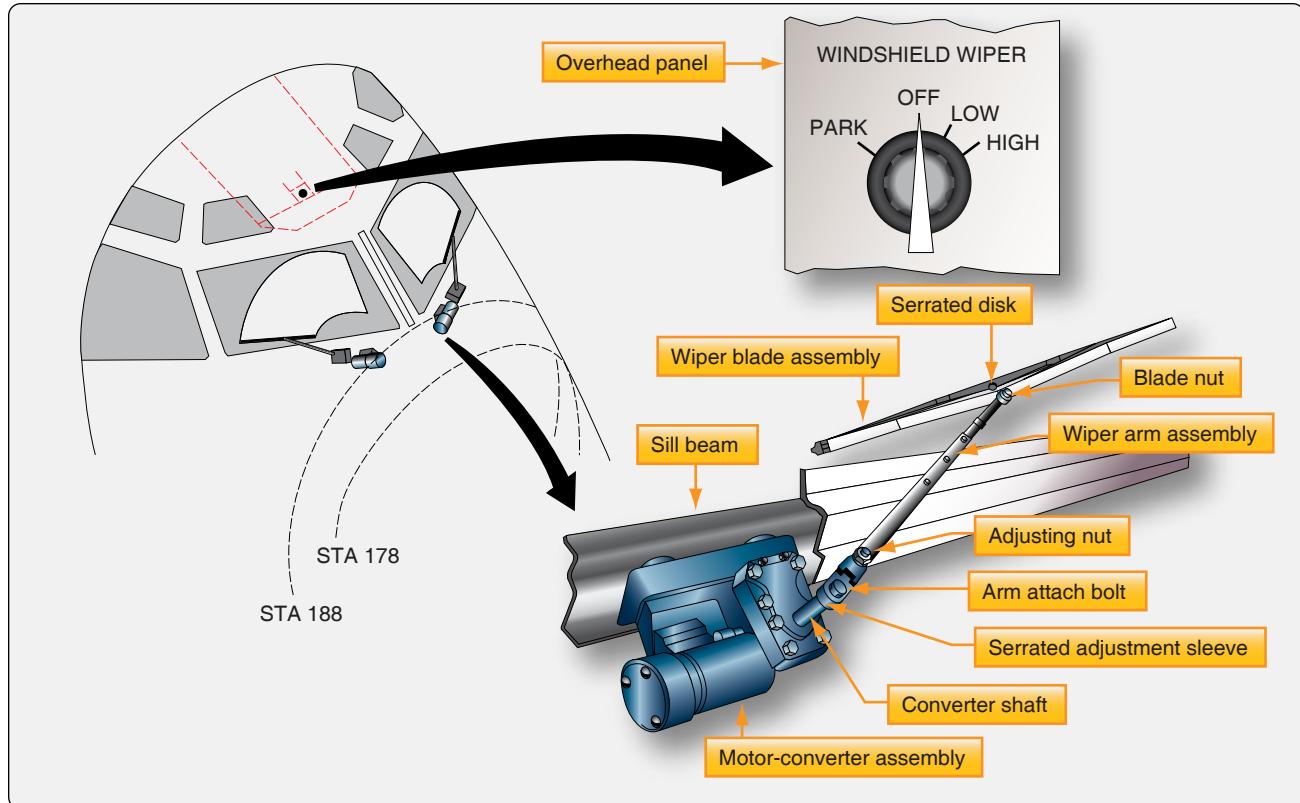


Figure 15-40. Windshield wiper assembly/installation on a transport category aircraft. The motor-converter is mounted under the aircraft skin.

long the switch is held. On some systems, a solenoid valve controlled by a time delay module meters the repellent to a nozzle which sprays it on the outside of the windshield. Two such units exist—one each for the forward glass of the pilot and copilot. [Figure 15-41]

This system should only be used in very wet conditions. The rain repellent system should not be operated on dry windows because heavy undiluted repellent restricts window visibility. Should the system be operated inadvertently, do not operate the windshield wipers or rain clearing system as this tends to increase smearing. Also, the rain repellent residues caused by application in dry weather or very light rain can cause staining or minor corrosion of the aircraft skin. To prevent this, any concentrated repellent or residue should be removed by a thorough fresh water rinse at the earliest opportunity. After application, the repellent film slowly deteriorates with continuing rain impingement. This makes periodic reapplication necessary. The length of time between applications depends upon rain intensity, the type of repellent used, and whether windshield wipers are used.

Windshield Surface Seal Coating

Some aircraft models use a surface seal coating, also called hydrophobic coating that is on the outside of the pilot's/

copilot's windshield. [Figure 15-42] The word hydrophobic means to repel or not absorb water. The windshield hydrophobic coating is on the external surface of the windows (windshields). The coatings cause raindrops to bead up and roll off, allowing the flight crew to see through the windshield with very little distortion. The hydrophobic windshield coating reduces the need for wipers and gives the flight crew better visibility during heavy rain.

Most new aircraft windshields are treated with surface seal coating. The manufacturer's coating process deeply penetrates the windshield surface providing hydrophobic action for quite some time. When effectiveness declines, products made to be applied in the field are used. These liquid treatments rubbed onto the surface of the windshield maintain the beading action of rain water. They must be applied periodically or as needed.

Pneumatic Rain Removal Systems

Windshield wipers characteristically have two basic problem areas. One is the tendency of the slipstream aerodynamic forces to reduce the wiper blade loading pressure on the window, causing ineffective wiping or streaking. The other is in achieving fast enough wiper oscillation to keep up with high rain impingement rates during heavy rain falls. As a result, most aircraft wiper systems fail to provide satisfactory vision in heavy rain.

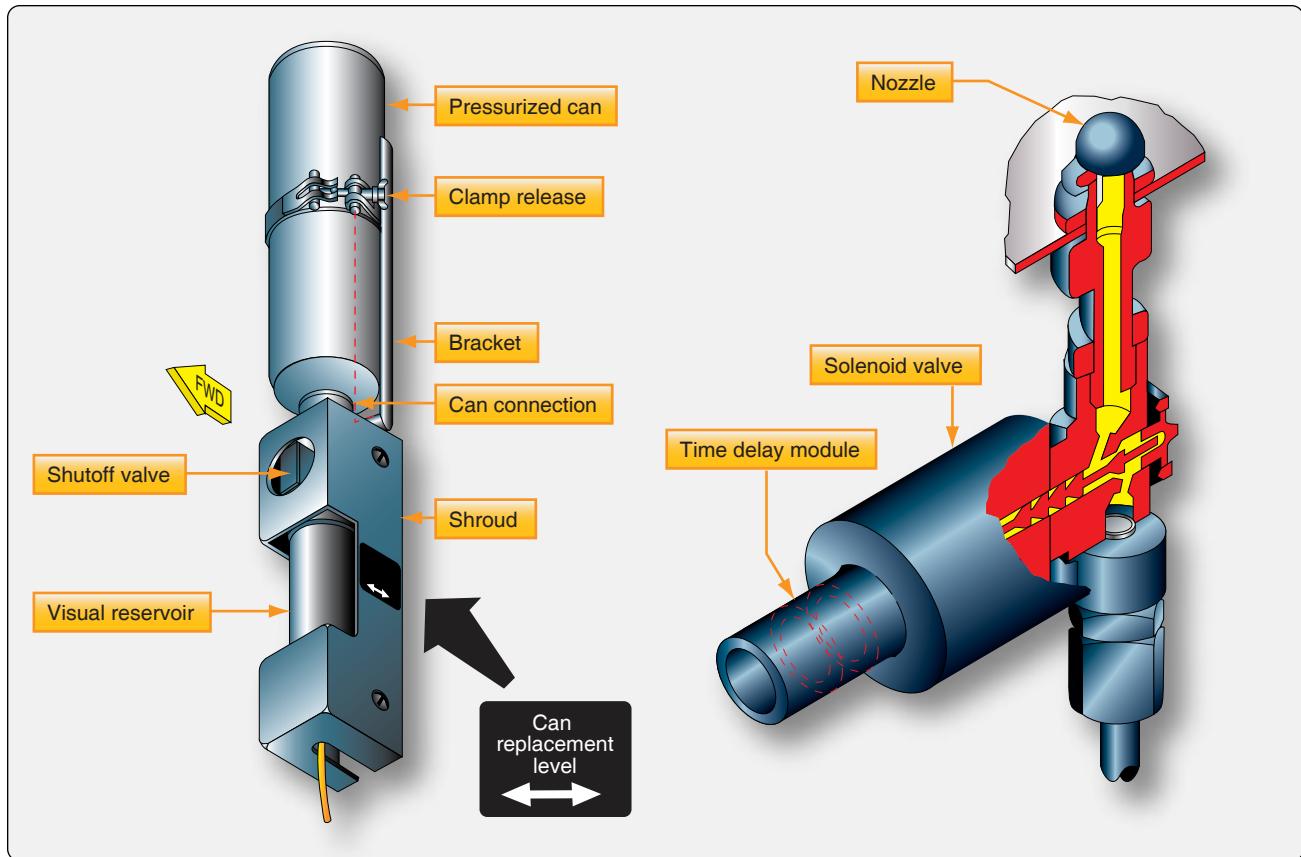


Figure 15-41. Flight deck rain repellent canister and reservoir.

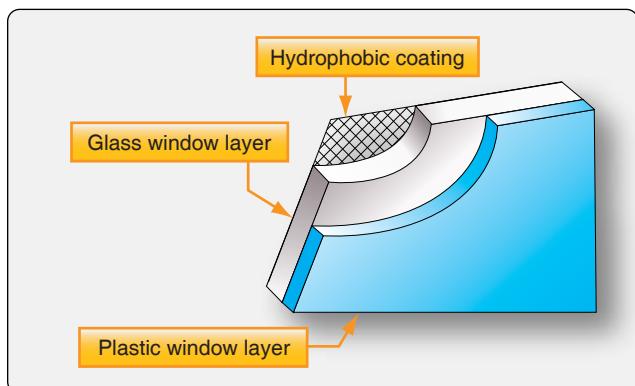


Figure 15-42. Hydrophobic coating on windshield.

The rain removal system shown in *Figure 15-43* controls windshield icing and removes rain by directing a flow of heated air over the windshield. This heated air serves two purposes. First, the air breaks the rain drops into small particles that are then blown away. Secondly, the air heats the windshield to prevent the moisture from freezing. The air can be supplied by an electric blower or by bleed air.

Windshield Frost, Fog, & Ice Control Systems

In order to keep windshield areas free of ice, frost, and fog, window anti-icing, deicing, and defogging systems are used. These can be electric, pneumatic, or chemical depending on the type and complexity of the aircraft. A few of these systems are discussed in this section.

Electric

High performance and transport category aircraft windshields are typically made of laminated glass, polycarbonate, or similar ply material. Typically, clear vinyl plies are also included to improve performance characteristics. The laminations create the strength and impact resistance of the windshield assembly. These are critical features for windshields as they are subject to a wide range of temperatures and pressures. They must also withstand the force of a 4-pound bird strike at cruising speed to be certified. The laminated construction facilitates the inclusion of electric heating elements into the glass layers, which are used to keep the windshield clear of ice, frost, and fog. The elements can be in the form of resistance wires or a transparent conductive material may be used as one of the window plies. To ensure enough heating is applied to the outside of the windshield, heating elements are placed on the inside of the outer glass

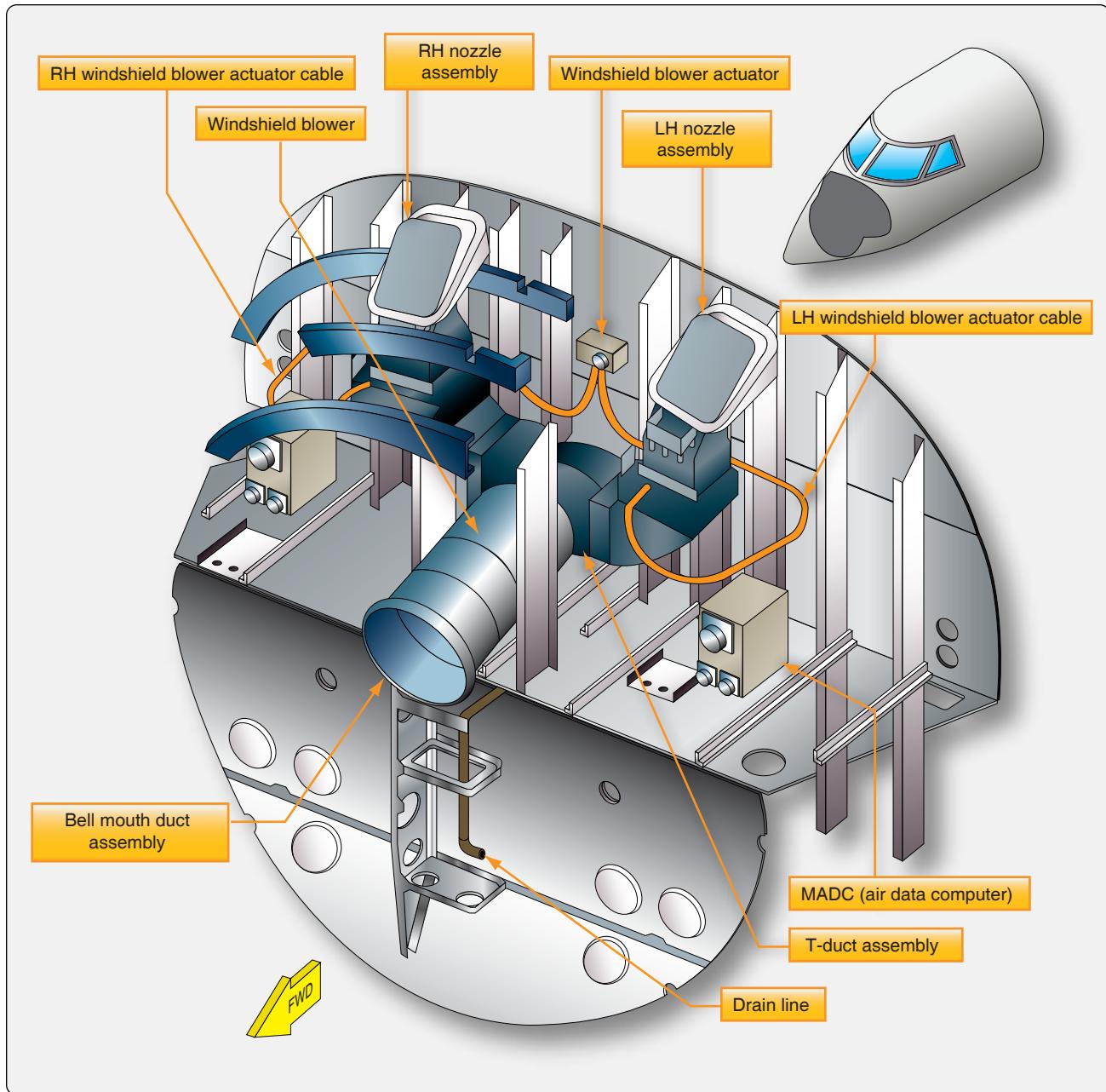


Figure 15-43. Windshield rain and frost removal system.

ply. Windshields are typically bonded together by the application of pressure and heat without the use of cement. Figure 15-44 illustrates the plies in one transport category aircraft windshield.

Whether resistance wires or a laminated conductive film is used, aircraft window heat systems have transformers to supply power and feedback mechanisms, such as thermistors, to provide a window heat control unit with information used to keep operating temperature within acceptable limits. Some systems are automatic while others are controlled by flight deck switches. Separate circuits for pilot and co-pilot are common to ensure visibility in case of a malfunction. Consult

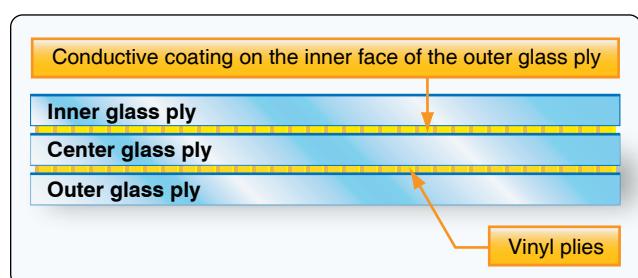


Figure 15-44. Cross-section of a transport category windshield.

the manufacturer's maintenance information for details on the particular window heat system in question.

Some windshield heating systems can be operated at two heat

levels. On these aircraft, NORMAL heating supplied heat to the broadest area of windshield. HIGH heating supplies a higher intensity of heat to a smaller but more essential viewing area. Typically, this window heating system is always on and set in the NORMAL position. *Figure 15-45* illustrates a simplified windshield heat system of this type.

Pneumatic

Some laminated windshields on older aircraft have a space between the plies that allows the flow of hot air to be directed between the glass to keep it warm and fog free. The source of air is bleed air or conditioned air from the environmental control system. Small aircraft may utilize ducted warm air, which is released to flow over the windshield inner surface to defrost and defog. These systems are similar to those used in automobiles. The source of air could be ambient (defog only), the aircraft's heating system, or a combustion heater. While these pneumatic windshield heat systems are effective for the aircraft on which they are installed, they are not approved for flying into known icing conditions and, as such, are not effective for anti-icing.

Large aircraft equipped with pneumatic jet blast rain repellent systems achieve some anti-icing effects from operating this system although electric windshield heat is usually used.

Chemical

As previously mentioned in this chapter, chemical anti-icing systems exist generally for small aircraft. This type of anti-icing is also used on windshields. Whether alone or part of a TKS™ system or similar, the liquid chemical is sprayed through a nozzle onto the outside of the windshield which prevents ice from forming. The chemical can also deice the windshield of ice that may have already formed. Systems such as these have a fluid reservoir, pump, control valve, filter, and relief valve. Other components may exist. *Figure 15-46* shows a set of spray tubes for application of chemical anti-icing on an aircraft windshield.

Water & Waste Tank Ice Prevention

Transport type aircraft have water and waste systems on board, and electrical heaters are often used to prevent the formation of ice in the water lines of these systems. Water

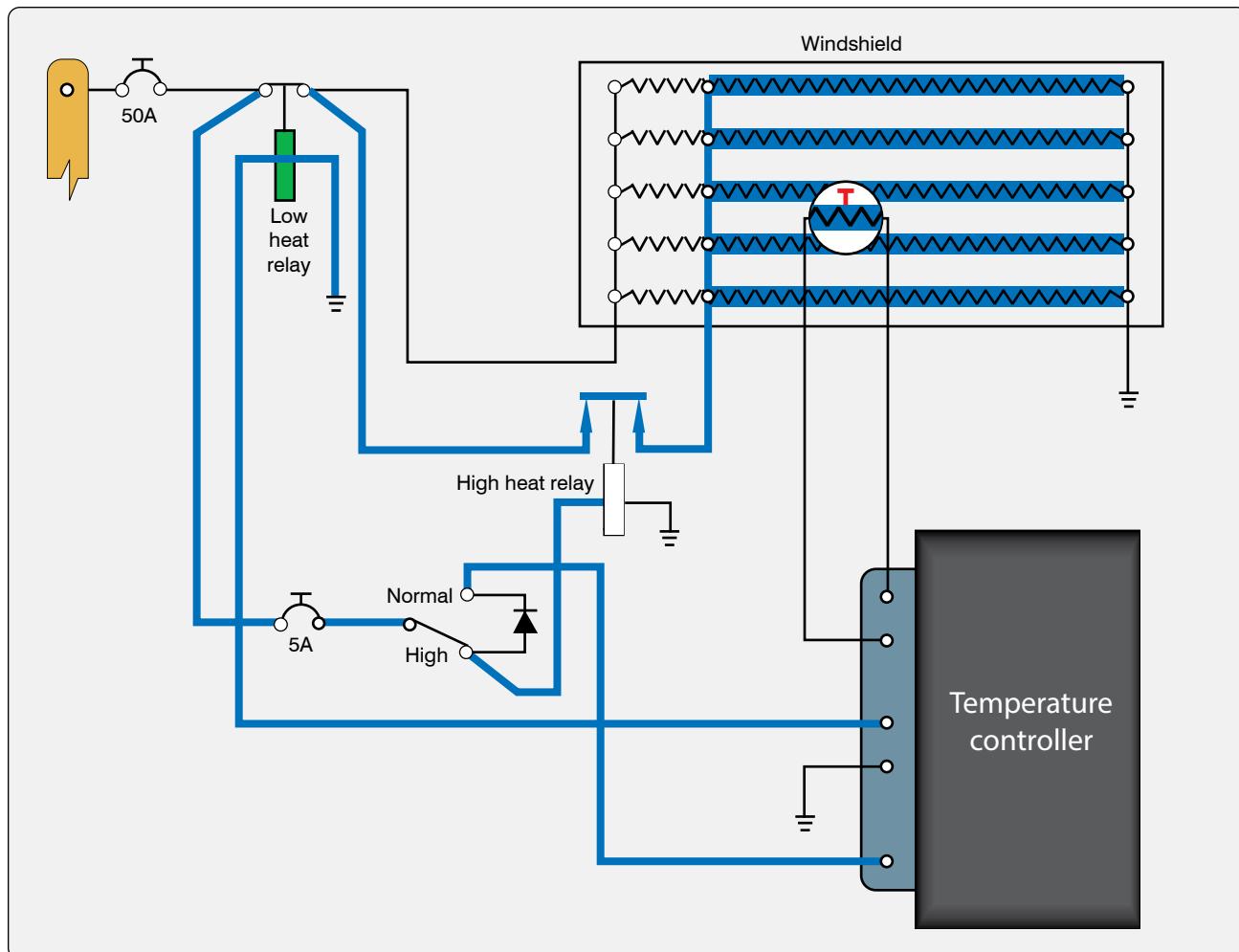


Figure 15-45. Electric windshield heat schematic.



Figure 15-46. Chemical deicing spray tubes.

lines carry water from the potable tanks to the lavatories and galleys. The waste water tanks collect the gray water from the galleys and lavatories. Heater blankets, inline heaters, or heater boots are often used to heat the water supply lines, water tank drain hoses, waste drain lines, waste tank rinse fittings, and drain masts. Thermostats in the water lines supply temperature data to the control unit that turns the electrical heaters on and off. When the temperature falls below freezing, the electrical heaters turn on and stay on until the temperature reaches a safe temperature. *Figure 15-47* is a schematic of a water supply line heater system, and *Figure 15-48* shows the location of the waste water tanks and heater blankets.

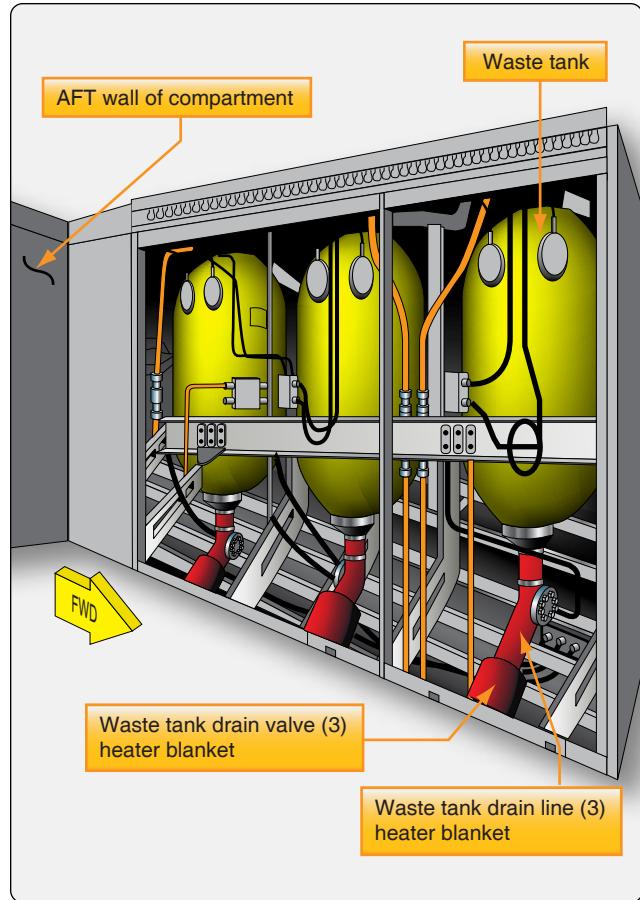


Figure 15-48. Waste water tanks and heater blankets.

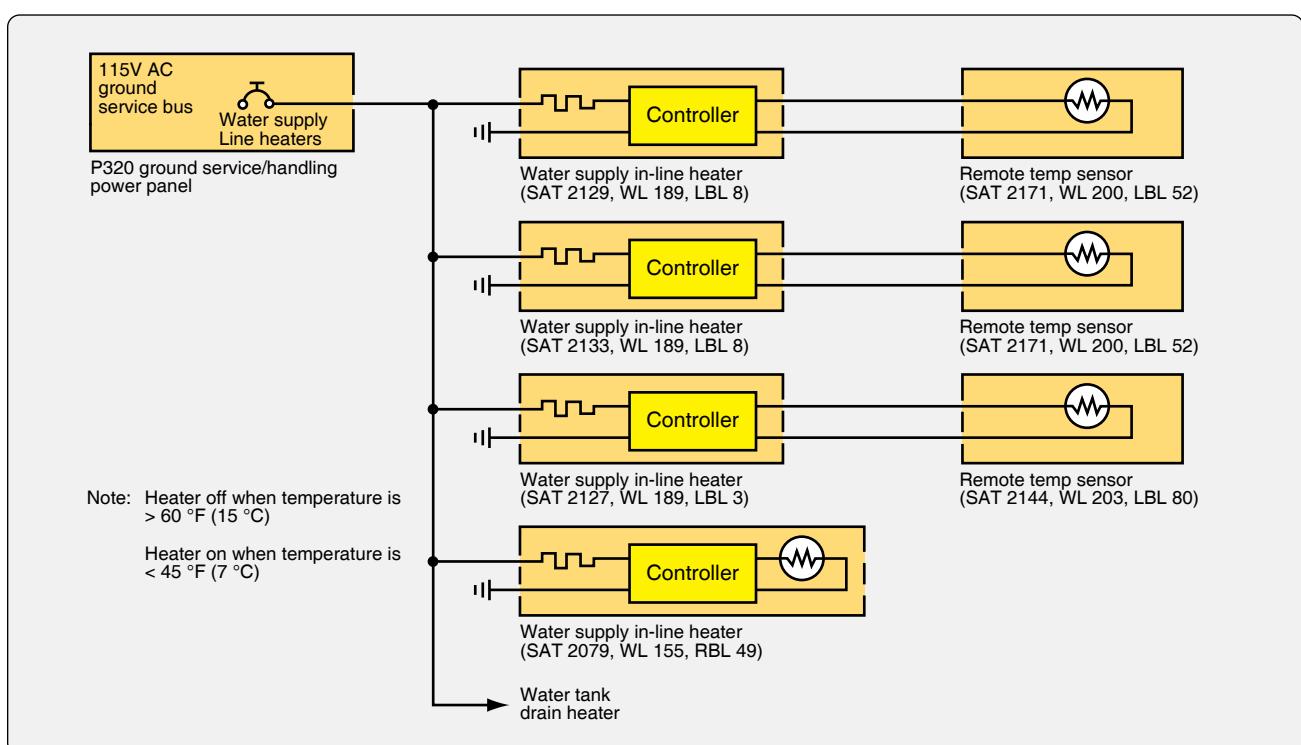


Figure 15-47. Water supply line heater system.

Chapter 16

Cabin Environmental Control Systems

Physiology of Flight

Composition of the Atmosphere

The mixture of gases that make up the earth's atmosphere is commonly called air. It is composed principally of 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent is made up of various gases in smaller quantities. Some of these are important to human life, such as carbon dioxide, water vapor, and ozone. *Figure 16-1* indicates the respective percentage of the quantity of each gas in its relation to the total mixture.

As altitude increases, the total quantity of all the atmospheric gases reduces rapidly. However, the relative proportions of nitrogen and oxygen remain unchanged up to about 50 miles above the surface of the earth. The percentage of carbon dioxide is also fairly stable. The amounts of water vapor and ozone vary.

Nitrogen is an inert gas that is not used directly by man for life processes; however, many compounds containing nitrogen are essential to all living matter.

The small quantity of carbon dioxide in the atmosphere is utilized by plants during photosynthesis. Thus, the food supply for all animals, including man, depends on it. Carbon dioxide also helps control breathing in man and other animals.

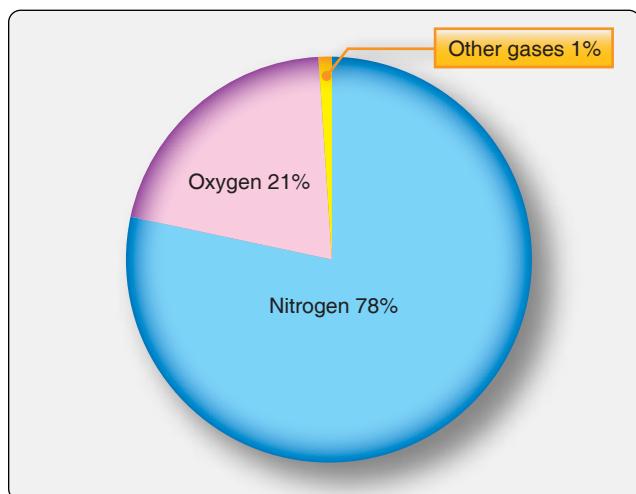


Figure 16-1. The percentage of the various gases that comprise the atmosphere.

The amount of water vapor in the atmosphere is variable but, even under humid conditions at sea level, it rarely exceeds 5 percent. Water also occurs in the atmosphere as ice crystals. All forms of water in the atmosphere absorb far more energy from the sun than do the other gases. Water plays an important role in the formation of weather.

Ozone is a form of oxygen. It contains three oxygen atoms per molecule, rather than the usual two. Most of the atmosphere's ozone is formed by the interaction of oxygen and the sun's rays near the top of the stratosphere in an area called the ozone layer. This is important to living organisms because ozone filters out most of the sun's harmful ultraviolet (UV) radiation. Ozone is also produced by electrical discharges, such as lightning strikes. It has a faint odor, somewhat like that of weak chlorine, that may be detected after a thunderstorm. Auroras and cosmic rays may also produce ozone. Ozone is of great consequence to living creatures on earth and to the circulation of the upper atmosphere.

Human Respiration & Circulation

Oxygen & Hypoxia

The second most prevalent substance in the atmosphere, oxygen, is essential for most living processes. Without oxygen, humans and animals die very rapidly. A reduction in the normal oxygen supply alters the human condition. It causes important changes in body functions, thought processes, and the maintainable degree of consciousness. The resultant sluggish condition of mind and body produced by insufficient oxygen is called hypoxia.

There are several scenarios that can result in hypoxia. During aircraft operations, it is brought about by a decrease in the pressure of oxygen in the lungs at high altitudes. The air contains the typical 21 percent of oxygen, but the rate at which oxygen can be absorbed into the blood depends upon the oxygen pressure. Greater pressure pushes the oxygen from the lung alveoli into the bloodstream. As the pressure is reduced, less oxygen is forced into and absorbed by the blood.

At sea level, oxygen pressure in the lungs is approximately three pounds per square inch (psi). This is sufficient to saturate the blood with oxygen and permit the mind and body to function normally. As altitude is increased, this pressure

decreases. Below 7,000 feet above sea level, the available oxygen quantity and pressure remain sufficient for saturation of the blood with oxygen. Above 7,000 feet, however, the oxygen pressure becomes increasingly insufficient to saturate the blood. At 10,000 feet mean sea level (MSL), saturation of the blood with oxygen is only about 90 percent of normal. Long durations at this altitude can result in headache and fatigue, both symptoms of hypoxia. At 15,000 feet MSL, oxygen transfer to the bloodstream drops to 81 percent of saturation. This typically results in sleepiness, headache, blue lips and fingernails, and increased pulse and respiration. Worse yet, vision and judgment become impaired and safe operation of an aircraft becomes compromised. Higher in the atmosphere, decreasing pressure causes even less oxygen to enter the bloodstream; only 68 percent saturation at 22,000 feet MSL. Remaining at 25,000 feet MSL for 5 minutes, where oxygen transfer to the blood is reduced to approximately 50 percent saturation, causes unconsciousness. [Figure 16-2]

Hyperventilation

Another physiological phenomenon of interest to aviators is hyperventilation. Its symptoms greatly resemble hypoxia. When various cells in the body use oxygen and food delivered to them by the blood, carbon dioxide is a by-product. Blood carries this carbon dioxide to the lungs where it is exhaled.

Carbon dioxide functions in the body to regulate the depth and frequency of breathing. A high level of carbon dioxide in the blood triggers rapid, deep breathing to expel it. This also promotes the intake of a greater amount of oxygen for active cells to use. A low carbon dioxide level causes more relaxed breathing resulting in less oxygen intake. Therefore, an oxygen/carbon dioxide balance exists in the blood.

Occasionally, fear, panic, or pain triggers excessive rapid breathing in a person. With it comes a reduction of carbon

Altitude MSL (feet)	Oxygen pressure (psi)
0	3.08
5,000	2.57
10,000	2.12
15,000	1.74
20,000	1.42
25,000	1.15
30,000	0.92
35,000	0.76
40,000	0.57

Figure 16-2. Oxygen pressure in the atmosphere at various altitudes.

dioxide in the blood, even though the body does not need this. The lower carbon dioxide level signals the body that there is enough oxygen available and blood vessels constrict, causing hypoxia-like symptoms because insufficient oxygen is being delivered to the cells. Note that the onset of hypoxia described in the previous section occurs without the rapid breathing that accompanies hyperventilation. Hyperventilation can often be alleviated by having the person calm down and breathe normally, which restores the oxygen/carbon dioxide balance in the bloodstream.

Carbon Monoxide Poisoning

Carbon monoxide is a colorless, odorless gas produced by incomplete combustion of hydrocarbon fuels, such as those used in aviation. The human body does not require this gas to function. Its presence, however, can prevent a sufficient level of oxygen to be maintained in the body, resulting in hypoxia. This is also known as carbon monoxide poisoning. As with all forms of oxygen deprivation, extended exposure to carbon monoxide can result in unconsciousness and even death.

Hemoglobin is the substance in the blood that attaches to oxygen in the lungs and circulates it to cells in the body for use. Carbon monoxide more readily attaches itself to hemoglobin than oxygen. If carbon monoxide is present in the lungs, hemoglobin attaches to it and not oxygen. This results in cells not receiving the amount of oxygen they need. The insufficient oxygen level results in hypoxia-like symptoms.

A real danger of carbon monoxide poisoning is that long exposure to slight traces of carbon monoxide can result in oxygen deprivation just as easily as short-term exposure to a concentrated amount. The onset of its effects can be very subtle.

Carbon monoxide detectors are used in flight decks and cabins to provide the crew a warning of the silent danger. There are many types of carbon monoxide detectors available to alert aviators of the presence of this gas. Some are made to be permanently installed in the instrument panel, while others are portable. The simplest carbon monoxide detectors are chemical tabs mounted on cardboard that hang on or adhere to something in the flight deck. When carbon monoxide is present, the tab changes color due to a chemical reaction. More sophisticated detectors provide a digital output in parts per million of carbon monoxide present or illuminate a light and/or an audible alarm sounds. [Figure 16-3] If contaminated, a carbon monoxide portable test unit can be returned to service by installing a new indicating element.

Aircraft that utilize exhaust shroud-type heating systems or combustion heaters are more likely to have carbon monoxide introduced into the cabin from these devices. It is very



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

important to discover the source of carbon monoxide if it is detected. Various leak checks and testing for cracks are performed regularly whenever a combustion source is also the source for cabin heat.

Aircraft Oxygen Systems

The negative effects of reduced atmospheric pressure at flight altitudes, forcing less oxygen into the blood, can be overcome. There are two ways this is commonly done: increase the pressure of the oxygen or increase the quantity of oxygen in the air mixture.

Large transport-category and high-performance passenger aircraft pressurize the air in the cabin. This serves to push more of the normal 21 percent oxygen found in the air into the blood for saturation. Techniques for pressurization are discussed later in this chapter. When utilized, the percentage of oxygen available for breathing remains the same; only the pressure is increased.

By increasing the quantity of oxygen available in the lungs, less pressure is required to saturate the blood. This is the basic function of an aircraft oxygen system. Increasing the level of oxygen above the 21 percent found in the atmosphere can offset the reduced pressure encountered as altitude increases. Oxygen may be regulated into the air that is breathed so as to maintain a sufficient amount for blood saturation. Normal mental and physical activity can be maintained at indicated altitudes of up to about 40,000 feet with the sole use of supplemental oxygen.

Oxygen systems that increase the quantity of oxygen in

breathing air are most commonly used as primary systems in small and medium size aircraft designed without cabin pressurization. Pressurized aircraft utilize oxygen systems as a means of redundancy should pressurization fail. Portable oxygen equipment may also be aboard for first aid purposes.

Forms of Oxygen & Characteristics

Gaseous Oxygen

Oxygen is a colorless, odorless, and tasteless gas at normal atmospheric temperatures and pressures. It transforms into a liquid at -183°C (its boiling point). Oxygen combines readily with most elements and numerous compounds. This combining is called oxidation. Typically, oxidation produces heat. When something burns, it is actually rapidly combining with oxygen. Oxygen itself does not burn because it does not combine with itself, except to form oxygen or ozone. But, pure oxygen combines violently with petroleum products creating a significant hazard when handling these materials in close proximity to each other. Nevertheless, oxygen and various petroleum fuels combine to create the energy produced in internal combustion engines.

Pure gaseous oxygen, or nearly pure gaseous oxygen, is stored and transported in high-pressure cylinders that are typically painted green. Technicians should be cautious to keep pure oxygen away from fuel, oil, and grease to prevent unwanted combustion. Not all oxygen in containers is the same. Aviator's breathing oxygen is tested for the presence of water. This is done to avoid the possibility of it freezing in the small passage ways of valves and regulators. Ice could prevent delivery of the oxygen when needed. Aircraft often operate in subzero temperatures, increasing the possibility of icing. The water level should be a maximum of .02ml per liter of oxygen. The words "Aviator's Breathing Oxygen" should be marked clearly on any cylinders containing oxygen for this purpose. [Figure 16-4]

Production of gaseous oxygen for commercial or aircraft cylinders is often through a process of liquefying air. By controlling temperature and pressure, the nitrogen in the air can be allowed to boil off leaving mostly pure oxygen. Oxygen may also be produced by the electrolysis of water. Passing electric current through water separates the oxygen from the hydrogen. One further method of producing gaseous oxygen is by separating the nitrogen and oxygen in the air through the use of a molecular sieve. This membrane filters out nitrogen and some of the other gases in air, leaving nearly pure oxygen for use. Onboard oxygen sieves, or oxygen concentrators as they are sometimes called, are used on some military aircraft. Their use in civil aviation is expected.

Use of portable pulse oximeters has become more common in aviation. These devices measure the oxygen saturation



Figure 16-4. “Aviator’s breathing oxygen” is marked on all oxygen cylinders designed for this purpose.

level of the blood. With this information, adjustments to the oxygen flow rates of onboard oxygen equipment can be made to prevent hypoxia. *Figure 16-5* shows an oximeter into

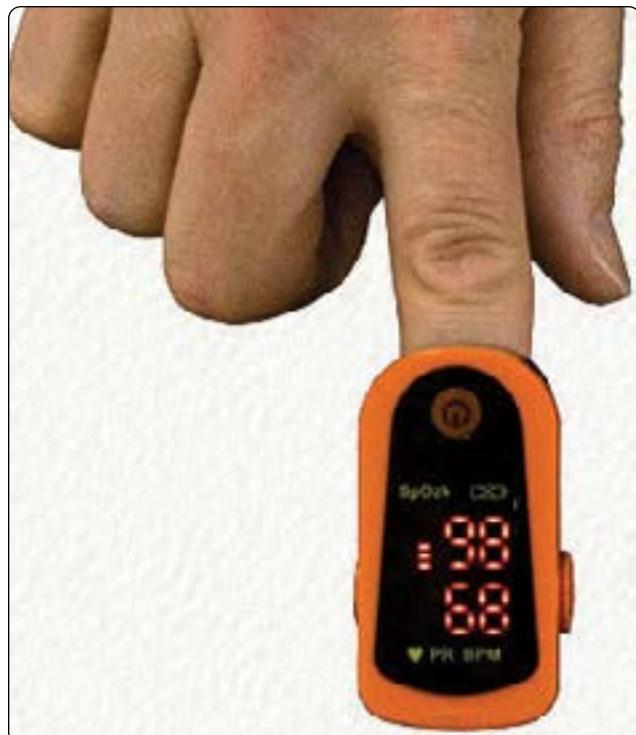


Figure 16-5. A portable pulse-type oximeter displays percentage of oxygen saturation of the blood and heart rate. Pilots can adjust oxygen supply levels to maintain saturation and avoid hypoxia.



Figure 16-6. A spherical liquid oxygen onboard container used by the military.

which a finger is inserted to measure oxygen saturation of the blood in percentage. Heart rate is also displayed.

Liquid Oxygen

Liquid oxygen (LOX) is a pale blue, transparent liquid. Oxygen can be made liquid by lowering the temperature to below -183°C or by placing gaseous oxygen under pressure. A combination of these is accomplished with a Dewar bottle. This special container is used to store and transport liquid oxygen. It uses an evacuated, double-walled insulation design to keep the liquid oxygen under pressure at a very low temperature. [Figure 16-6] A controlled amount of oxygen is allowed to vaporize and is plumbed into a gaseous oxygen delivery system downstream of a converter that is part of the container assembly.

A small quantity of LOX can be converted to an enormous amount of gaseous oxygen, resulting in the use of very little storage space compared to that needed for high-pressure gaseous oxygen cylinders. However, the difficulty of handling LOX, and the expense of doing so, has resulted in the container system used for gaseous oxygen to proliferate throughout civilian aviation. LOX is used in military aviation and some medical helicopter applications for patient oxygen.

Chemical or Solid Oxygen

Sodium chlorate has a unique characteristic. When ignited, it produces oxygen as it burns. This can be filtered and delivered through a hose to a mask that can be worn and breathed directly by the user. Solid oxygen candles, as they are called, are formed chunks of sodium chlorate wrapped inside insulated stainless-steel housings to control the heat produced when activated. The chemical oxygen supply is

often ignited by a spring-loaded firing pin that when pulled, releases a hammer that smashes a cap creating a spark to light the candle. Electric ignition via a current-induced hot wire also exists. Once lit, a sodium chlorate oxygen generator cannot be extinguished. It produces a steady flow of breathable oxygen until it burns out, typically generating 10–20 minutes of oxygen. [Figure 16-7]

Solid oxygen generators are primarily used as backup oxygen devices on pressurized aircraft. They are one-third as heavy as gaseous oxygen systems that use heavy storage tanks for the same quantity of oxygen available. Sodium chlorate chemical oxygen generators also have a long shelf life, making them

perfect as a standby form of oxygen. They are inert below 400 °F and can remain stored with little maintenance or inspection until needed, or until their expiration date is reached.

The feature of not extinguishing once lit limits the use of solid oxygen since it becomes an all-or-nothing source. The generators must be replaced if used, which can greatly increase the cost of using them as a source of oxygen for short periods of time. Moreover, chemical oxygen candles must be transported with extreme caution and as hazardous materials. They must be properly packed, and their ignition devices deactivated.

Onboard Oxygen Generating Systems (OBOGS)

The molecular sieve method of separating oxygen from the other gases in air has application in flight, as well as on the ground. The sieves are relatively light in weight and relieve the aviator of a need for ground support for the oxygen supply. Onboard oxygen generating systems on military aircraft pass bleed air from turbine engines through a sieve that separates the oxygen for breathing use. Some of the separated oxygen is also used to purge the sieve of the nitrogen and other gases that keep it fresh for use. Use of this type of oxygen production in civilian aircraft is anticipated. [Figure 16-8]

Oxygen Systems & Components

Built-in and portable oxygen systems are used in civilian aviation. They use gaseous or solid oxygen (oxygen generators) as suits the purpose and aircraft. LOX systems and molecular sieve oxygen systems are not discussed, as current applications on civilian aircraft are limited.

Gaseous Oxygen Systems

The use of gaseous oxygen in aviation is common; however, applications vary. On a light aircraft, it may consist of a small

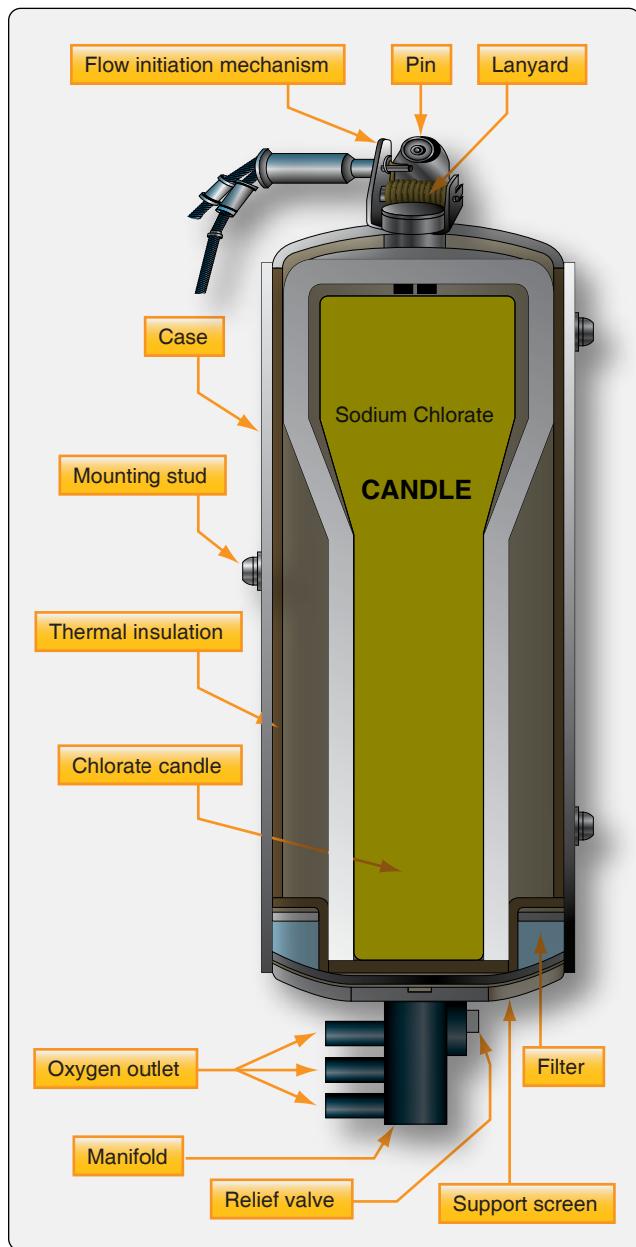


Figure 16-7. A sodium chlorate solid oxygen candle is at the core of a chemical oxygen generator.



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



Figure 16-9. This test stand is used for hydrostatic testing of oxygen cylinders. The water-filled cylinder is lowered into the barrel on the left where it is pressurized to the proper level as monitored via gauges mounted on the control panel. A displacement container on the top left of the control board collects water from the barrel to measure the expansion of the cylinder when pressurized to ensure it is within limits.

carry-on portable cylinder with a single mask attached via a hose to a regulator on the bottle. Larger portable cylinders may be fitted with a regulator that divides the outlet flow for 2–4 people. Built-in oxygen systems on high performance and light twin-engine aircraft typically have a location where oxygen cylinders are installed to feed a distribution system via tubing and a regulator. The passenger compartment may have multiple breathing stations plumbed so that each passenger can individually plug in a hose and mask if oxygen is needed. A central regulator is normally controlled by the flight crew who may have their own separate regulator and oxygen cylinder. Transport category aircraft may use an elaborate built-in gaseous oxygen system as a backup system to cabin pressurization. In all of these cases, oxygen is stored as a gas at atmospheric temperature in high-pressure cylinders. It is distributed through a system with various components that are described in this section.

Oxygen Storage Cylinders

Gaseous oxygen is stored and transported in high-pressure cylinders. Traditionally, these have been heavy steel tanks rated for 1800–1850 psi of pressure and capable of maintaining pressure up to 2,400 psi. While these performed adequately, lighter weight tanks were sought. Some newer cylinders are comprised of a lightweight aluminum shell wrapped by Kevlar®. These cylinders are capable of carrying the same amount of oxygen at the same pressure as steel tanks but weigh much less. Also available are heavy-walled all-aluminum cylinders. These units are common as carry-on portable oxygen used in light aircraft.

Most oxygen storage cylinders are painted green, but yellow and other colors may be used as well. They are certified to Department of Transportation (DOT) specifications. To ensure serviceability, cylinders must be hydrostatically tested periodically. In general, a hydrostatic test consists of filling the container with water and pressurizing it to $\frac{5}{3}$ of its certified rating. It should not leak, rupture, or deform beyond an established limit. *Figure 16-9* shows a hydrostatic cylinder testing apparatus.

Most cylinders also have a limited service life after which they can no longer be used. After a specified number of filling cycles or calendar age, the cylinders must be removed from service. The most common high-pressure steel oxygen cylinders used in aviation are the 3AA and the 3HT. They come in various sizes but are certified to the same specifications. Cylinders certified under DOT-E-8162 are also popular for their extremely light weight. These cylinders typically have an aluminum core around which Kevlar® is wrapped. The DOT-E 8162 approved cylinders are now approved under DOT-SP-8162 specifications. The SP certification has extended the required time between hydrostatic testing to 5 years (previously 3 years). [*Figure 16-10*]

The manufactured date and certification number is stamped on each cylinder near the neck. Subsequent hydrostatic test dates are also stamped there as well. Composite cylinders use placards rather than stamping. The placard must be covered with a coat of clear epoxy when additional information is added, such as a new hydrostatic test date.

Oxygen cylinders are considered empty when the pressure inside drops below 50 psi. This ensures that air containing water vapor has not entered the cylinder. Water vapor could cause corrosion inside the tank, as well as presenting the possibility of ice forming and clogging a narrow passageway in the cylinder valve or oxygen system. Any installed tank allowed to fall below this pressure should be removed from service.

Certification Type	Material	Rated pressure (psi)	Required hydrostatic test	Service life (years)	Service life (fillings)
DOT 3AA	Steel	1,800	5	Unlimited	N/A
DOT 3HT	Steel	1,850	3	24	4,380
DOT-E-8162	Composite	1,850	3	15	N/A
DOT-SP-8162	Composite	1,850	5	15	N/A
DOT 3AL	Aluminum	2,216	5	Unlimited	N/A

Figure 16-10. Common cylinders used in aviation with some certification and testing specifications.

Oxygen Systems & Regulators

The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements, and whether the aircraft has a pressurization system. Systems are often characterized by the type of regulator used to dispense the oxygen: continuous-flow and demand flow. In some aircraft, a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the larger transport aircraft. Many aircraft have a combination of both systems that may be augmented by portable equipment.

Continuous-Flow Systems

In its simplest form, a continuous-flow oxygen system allows oxygen to exit the storage tank through a valve and passes it through a regulator/reducer attached to the top of the tank. The flow of high-pressure oxygen passes through a section of the regulator that reduces the pressure of the oxygen, which is then fed into a hose attached to a mask worn by the user. Once the valve is opened, the flow of oxygen is continuous. Even when the user is exhaling, or when the mask is not in use, a preset flow of oxygen continues until the tank valve is closed. On some systems, fine adjustment to the flow can be made with an adjustable flow indicator that is installed in the hose in line to the mask. A portable oxygen setup for a light aircraft exemplifies this type of continuous-flow system and is shown in *Figure 16-11*.

A more sophisticated continuous-flow oxygen system uses a regulator that is adjustable to provide varying amounts of oxygen flow to match increasing need as altitude increases. These regulators can be manual or automatic in design. Manual continuous-flow regulators are adjusted by the crew as altitude changes. Automatic continuous-flow regulators have a built in aneroid. As the aneroid expands with altitude, a mechanism allows more oxygen to flow through the regulator to the users. [*Figure 16-12*]

Many continuous-flow systems include a fixed location for the oxygen cylinders with permanent delivery plumbing installed to all passenger and crew stations in the cabin.

In large aircraft, separate storage cylinders for crew and passengers are typical. Fully integrated oxygen systems usually have separate, remotely mounted components to reduce pressure and regulate flow. A pressure relief valve is also typically installed in the system, as is some sort of filter and a gauge to indicate the amount of oxygen pressure



Figure 16-11. A typical portable gaseous oxygen cylinder complete with valve, pressure gauge, regulator/reducer, hose, adjustable flow indicator, and rebreather cannula. A padded carrying case/bag can be strapped to the back of a seat in the cabin to meet certification and testing specifications.



Figure 16-12. A manual continuous flow oxygen system may have a regulator that is adjusted by the pilot as altitude varies. By turning the knob, the left gauge can be made to match the flight altitude thus increasing and decreasing flow as altitude changes.

remaining in the storage cylinder(s). *Figure 16-13* diagrams the type of continuous-flow system that is found on small to medium sized aircraft.

Built-in continuous-flow gaseous oxygen systems accomplish a final flow rate to individual user stations through the use of a calibrated orifice in each mask. Larger diameter orifices are usually used in crew masks to provide greater flow than that for passengers. Special oxygen masks provide even greater flow via larger orifices for passengers traveling with medical conditions requiring full saturation of the blood with oxygen.

Allowing oxygen to continuously flow from the storage cylinder can be wasteful. Lowest sufficient flow rates can be accomplished through the use of rebreather apparatus. Oxygen and air that is exhaled still contains usable oxygen. By capturing this oxygen in a bag, or in a cannula with oxygen absorbing reservoirs, it can be inhaled with the next breath, reducing waste. [Figure 16-14]

The passenger section of a continuous-flow oxygen system may consist of a series of plug-in supply sockets fitted to the cabin walls adjacent to the passenger seats to which oxygen masks can be connected. Flow is inhibited until a passenger manually plugs in. When used as an emergency system in pressurized aircraft, depressurization automatically triggers the deployment of oxygen ready continuous-flow masks at each passenger station. A lanyard attached to the mask turns on the flow to each mask when it is pulled toward the passenger for use. The masks are normally stowed overhead in the passenger service unit (PSU). [Figure 16-15] Deployment of the emergency continuous-flow passenger oxygen masks may also be controlled by the crew. [Figure 16-16]

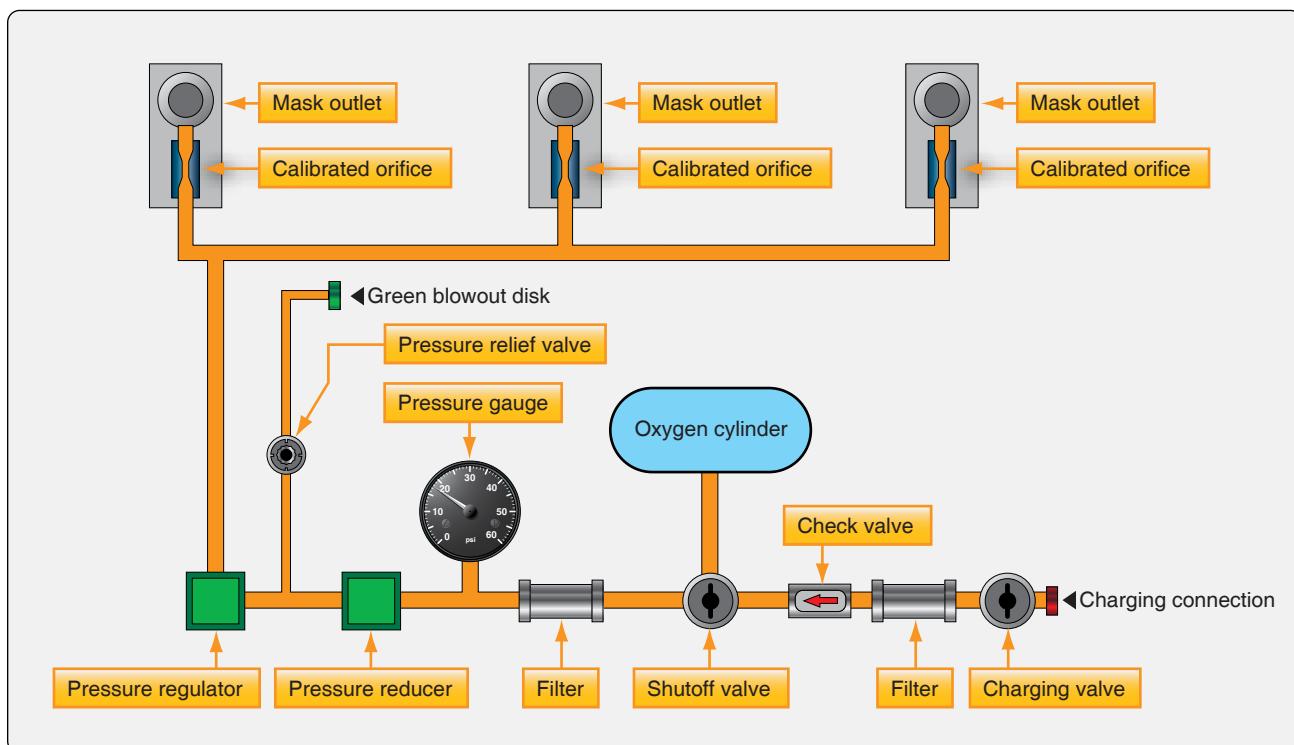


Figure 16-13. Continuous flow oxygen system found on small to medium size aircraft.

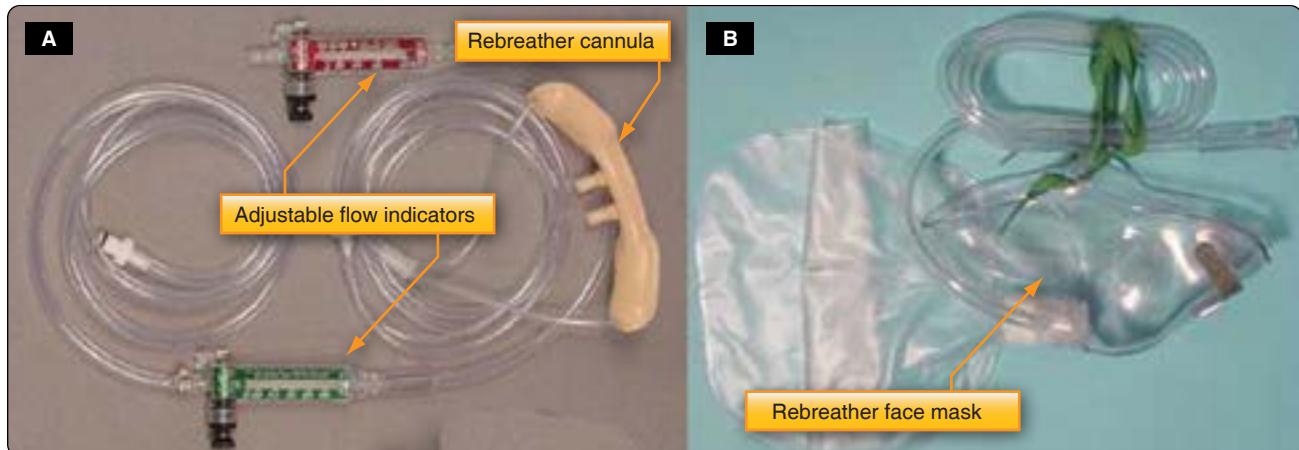


Figure 16-14. A rebreather cannula (A) and rebreather bag (B) capture exhaled oxygen to be inhaled on the next breath. This conserves oxygen by permitting lower flow rates in continuous flow systems. The red and green devices are optional flow indicators that allow the user to monitor oxygen flow rate.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



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

Continuous-flow oxygen masks are simple devices made to direct flow to the nose and mouth of the wearer. They fit snugly but are not air tight. Vent holes allow cabin air to mix with the oxygen and provide escape for exhalation. In a rebreather mask, the vents allow the exhaled mixture that is not trapped in the rebreather bag to escape. This is appropriate, because this is the air-oxygen mixture that has been in the lungs the longest, so it has less recoverable oxygen to be breathed again. [Figure 16-17]

Demand-Flow or Pressure-Demand Systems

When oxygen is delivered only as the user inhales, or on demand, it is known as a demand-flow system or a pressure-demand system. During the hold and exhalation periods of breathing, the oxygen supply is stopped. Thus, the duration of the oxygen supply is prolonged as none is wasted. Demand-flow systems are used most frequently by



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



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

the crew on high performance and air transport category aircraft. [Figure 16-18]

Demand-flow systems are similar to continuous-flow systems in that a cylinder delivers oxygen through a valve when opened. The tank pressure gauge, filter(s), pressure relief valve, and any plumbing installed to refill the cylinder while installed on the aircraft are all similar to those in a continuous-flow system. The high-pressure oxygen also passes through a pressure reducer and a regulator to adjust the pressure and flow to the user. But, demand-flow oxygen regulators differ significantly from continuous-flow oxygen regulators. They work in conjunction with close-fitting demand-type masks to control the flow of oxygen. [Figure 16-19]

In a demand-flow oxygen system, the system pressure-reducing valve is sometimes called a pressure regulator. This device lowers the oxygen pressure from the storage cylinder(s) to roughly 60–85 psi and delivers it to individual regulators dedicated for each user. A pressure reduction also occurs at the inlet of the individual regulator by limiting the size of the inlet orifice. There are two types of individual regulators: the diluter-demand type and the pressure-demand type. [Figure 16-20]

The diluter-demand type regulator holds back the flow of oxygen until the user inhales with a demand-type oxygen mask. The regulator dilutes the pure oxygen supply with cabin air each time a breath is drawn. With its control toggle switch set to normal, the amount of dilution depends on the cabin altitude. As altitude increases, an aneroid allows more oxygen and less cabin air to be delivered to the user by adjusting flows through a metering valve. At approximately 34,000 feet, the diluter-demand regulator meters 100 percent oxygen. This should not be needed unless cabin pressurization fails. Additionally, the user may select 100 percent oxygen delivery at any time by positioning the oxygen selection lever on the regulator. A built-in emergency switch also delivers 100 percent oxygen, but in a continuous flow as the demand function is bypassed. [Figure 16-21]

Pressure-demand oxygen systems operate similarly to diluter-demand systems, except that oxygen is delivered through the individual pressure regulator(s) under higher pressure. When the demand valve is unseated, oxygen under pressure forces its way into the lungs of the user. The demand function still operates, extending the overall supply of oxygen beyond that of a continuous-flow system. Dilution with cabin air also occurs if cabin altitude is less than 34,000 feet.

Pressure-demand regulators are used on aircraft that regularly fly at 40,000 feet and above. They are also found on many airliners and high-performance aircraft that may not typically fly that high. Forcing oxygen into the lungs under pressure ensures saturation of the blood, regardless of altitude or cabin altitude.

Both diluter-demand and pressure-demand regulators also come in mask-mounted versions. The operation is essentially the same as that of panel-mounted regulators. [Figure 16-22]

Flow Indicators

Flow indicators, or flow meters, are common in all oxygen systems. They usually consist of a lightweight object, or apparatus, that is moved by the oxygen stream. When flow exists, this movement signals the user in some way. [Figure 16-23] Many flow meters in continuous-flow oxygen systems also double as flow rate adjusters. Needle valves

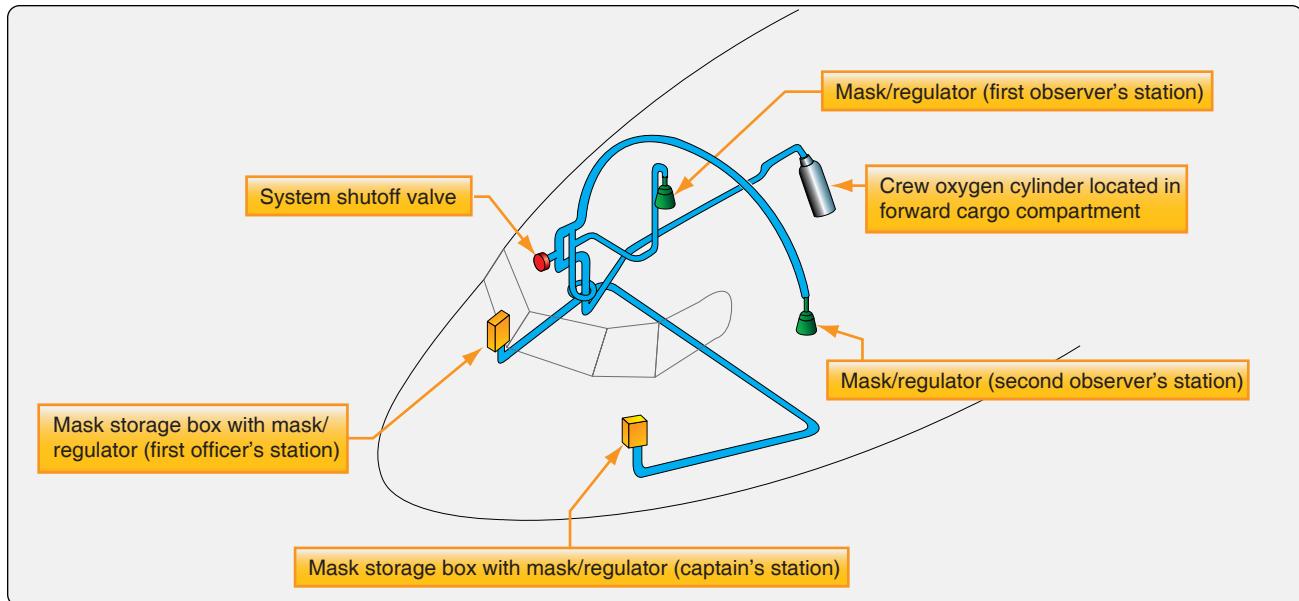


Figure 16-18. Location of demand-flow oxygen components on a transport category aircraft.

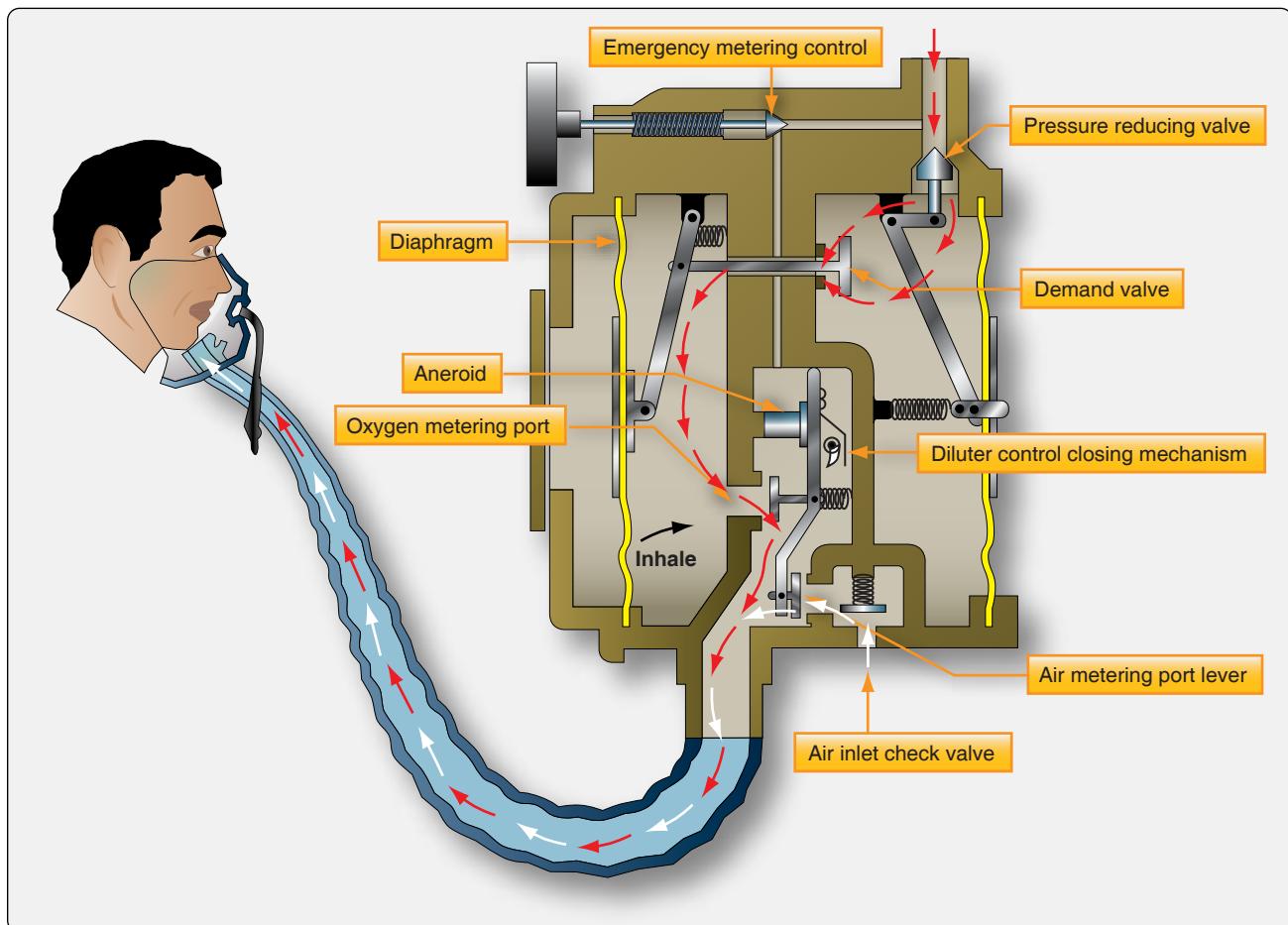


Figure 16-19. A demand regulator and demand-type mask work together to control flow and conserve oxygen. Demand-flow masks are close fitting so that when the user inhales, low pressure is created in the regulator, which allows oxygen to flow. Exhaled air escapes through ports in the mask, and the regulator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



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

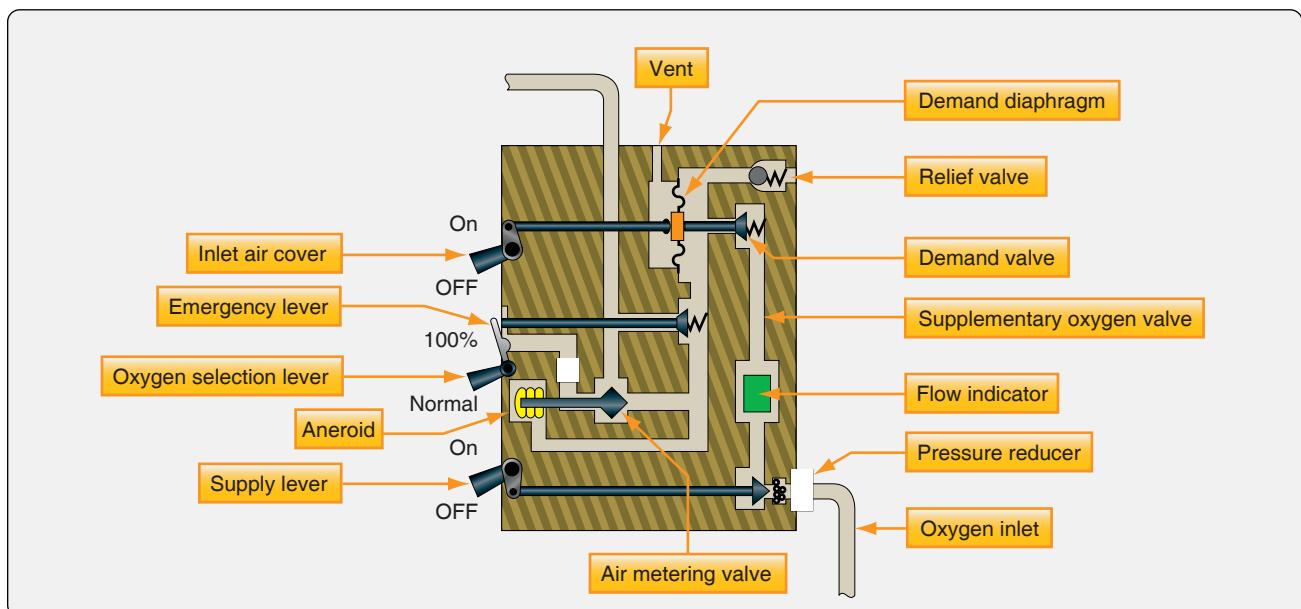


Figure 16-21. A diluter-demand regulator operates when low pressure caused by inhalation moves the demand diaphragm. A demand valve connected to the diaphragm opens, letting oxygen flow through the metering valve. The metering valve adjusts the mixture of cabin air and pure oxygen via a connecting link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

fitted into the flow indicator housing can fine-adjust the oxygen delivery rate. Demand-flow oxygen systems usually have flow indicators built into the individual regulators at each user station. Some contain a blinking device that activates when the user inhales and oxygen is delivered. Others move a colored pith object into a window. Regardless, flow indicators provide a quick verification that an oxygen system is functioning.

Different flow indicators are used to provide verification that the oxygen system is functioning. Other demand-flow

indicators are built into the oxygen regulators. [Figure 16-23]

A recent development in general aviation oxygen systems is the electronic pulse demand oxygen delivery system (EDS). A small, portable EDS unit is made to connect between the oxygen source and the mask in a continuous-flow oxygen system. It delivers timed pulses of oxygen to the wearer on demand, saving oxygen normally lost during the hold and exhale segments of the breathing cycle. Advanced pressure sensing and processing allows the unit to deliver oxygen only when an inhalation starts. It can also sense differences in



Figure 16-22. A mask-mounted version of a miniature diluter-demand regulator designed for use in general aviation (left), a mechanical quick-donning diluter-demand mask with the regulator on the mask (center), and an inflatable quick-donning mask (right). Squeezing the red grips directs oxygen into the hollow straps.



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



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

users' breathing cycles and physiologies and adjust the flow of oxygen accordingly. A built-in pressure-sensing device adjusts the amount of oxygen released as altitude changes. [Figure 16-24]

Permanently mounted EPD systems are also available. They typically integrate with an electronic valve/regulator on the oxygen cylinder and come with an emergency bypass switch to provide continuous-flow oxygen should the system malfunction. A liquid crystal display (LCD) monitor/control panel displays numerous system operating parameters and allows adjustments to the automatic settings. This type of electronic metering of oxygen has also been developed for passenger emergency oxygen use in airliners. [Figure 16-25]

Oxygen Plumbing & Valves

Tubing and fittings make up most of the oxygen system plumbing and connect the various components. Most lines are metal in permanent installations. High-pressure lines are usually stainless steel. Tubing in the low-pressure parts of the oxygen system is typically aluminum. Flexible plastic hosing



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

is used to deliver oxygen to the masks; its use is increasing in permanent installations to save weight.

Installed oxygen tubing is usually identified with color-coded tape applied to each end of the tubing, and at specified intervals along its length. The tape coding consists of a green band overprinted with the words "BREATHING OXYGEN" and a black rectangular symbol overprinted on a white background border strip. [Figure 16-26]

Tubing-to-tubing fittings in oxygen systems are often designed with straight threads to receive flared tube connections. Tubing-to-component fittings usually have straight threads on the tubing end and external pipe threads (tapered) on the other end for attachment to the component. The fittings are typically made of the same material as the tubing (i.e., aluminum or steel). Flared and flareless fittings are both used, depending on the system.

Five types of valves are commonly found in high-pressure gaseous oxygen systems: filler, check, shutoff, pressure reducer, and pressure relief. They function as they would in any other system with one exception: oxygen system shutoff valves are specifically designed to open slowly.

The ignition point for any substances is lower in pure oxygen than it is in air. When high-pressure oxygen is allowed to rush into a low-pressure area, its velocity could reach the speed of sound. If it encounters an obstruction (a valve seat, an elbow, a piece of contaminant, etc.), the oxygen compresses. With this compression, known as adiabatic compression (since it



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

builds so quickly no heat is lost to its surroundings), comes high temperature. Under pressure, this high temperature exceeds the ignition point of the material the oxygen encounters and a fire or explosion results. A stainless-steel line, for example, would not normally burn and is used for carrying numerous fluids under high pressure. But under high pressure and temperature in the presence of 100 percent oxygen, even stainless steel can ignite.

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

Additionally, technicians should always open all oxygen valves slowly. Keeping oxygen from rushing into a low-pressure area should be a major concern when working with high-pressure gaseous oxygen systems.

Oxygen cylinder valves and high-pressure systems are often provided with a relief valve should the desired pressure be exceeded. Often, the valve is ported to an indicating or blowout disc. This is located in a conspicuous place, such as the fuselage skin, where it can be seen during walk-around inspection. Most blowout discs are green. The absence of the green disc indicates the relief valve has opened, and the cause should be investigated before flight. [Figure 16-28]

Chemical Oxygen Systems

The two primary types of chemical oxygen systems are the portable type, much like a portable carry-on gaseous oxygen cylinder, and the fully integrated supplementary oxygen



Figure 16-28. An oxygen blowout plug on the side of the fuselage indicates when pressure relief has occurred and should be investigated.

system used as backup on pressurized aircraft in case of pressurization failure. [Figure 16-29] This latter use of solid chemical oxygen generators is most common on airliners. The generators are stored in the overhead PSU attached to hoses and masks for every passenger on board the aircraft. When a depressurization occurs, or the flight crew activates a switch, a compartment door opens, and the masks and hoses fall out in front of the passengers. The action of pulling the mask down to a usable position actuates an electric current, or ignition hammer, that ignites the oxygen candle and initiates the flow of oxygen. Typically, 10 to 20 minutes of oxygen is available for each user. This is calculated to be enough time for the aircraft to descend to a safe altitude for unassisted breathing.

Chemical oxygen systems are unique in that they do not produce the oxygen until it is time to be used. This allows safer transportation of the oxygen supply with less maintenance. Chemical oxygen-generating systems also require less space

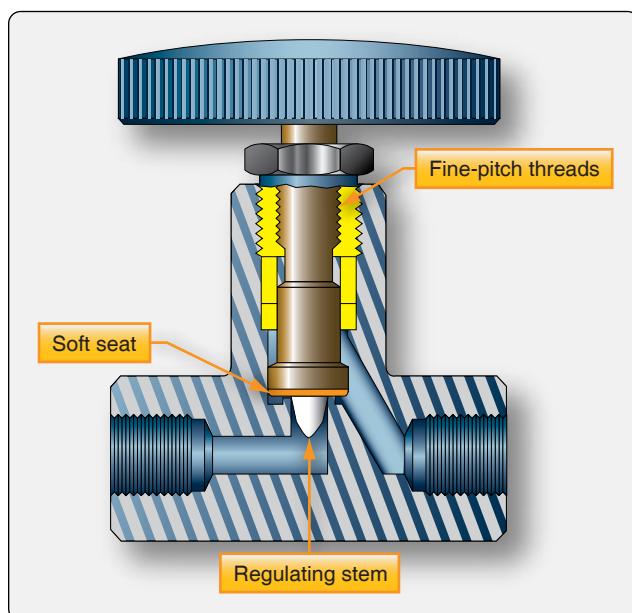


Figure 16-27. This high-pressure oxygen system shutoff valve has fine-pitch threads and a regulating stem to slow the flow of oxygen through the valve. A soft valve seat is also included to assure the valve closes completely.



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

and weigh less than gaseous oxygen systems supplying the same number of people. Long runs of tubing, fittings, regulators, and other components are avoided, as are heavy gaseous oxygen storage cylinders. Each passenger row grouping has its own fully independent chemical oxygen generator. The generators, which often weigh less than a pound, are insulated and can burn completely without getting hot. The size of the orifice opening in the hose-attach nipples regulates the continuous flow of oxygen to the users.

LOX Systems

LOX systems are rarely used in civilian aviation. They may be encountered on former military aircraft now in the civilian fleet. As mentioned, the storage of LOX requires a special container system. The plumbing arrangement to convert the liquid to a usable gas is also unique. It basically consists of a controlled heat exchange assembly of tubing and valves. Overboard pressure relief is provided for excessive temperature situations. Once gaseous, the LOX system is the same as it is in any comparable gaseous oxygen delivery system. Use of pressure-demand regulators and masks is common. Consult the manufacturer's maintenance manual for further information if a LOX system is encountered.

Oxygen System Servicing

Servicing Gaseous Oxygen

Gaseous oxygen systems are prevalent in general, corporate, and airline aviation. The use of lightweight aluminum and composite storage cylinders has improved these simple and reliable life support systems. All gaseous oxygen systems require servicing and maintenance. Various procedures and requirements to perform these functions are covered in this section.

Leak Testing Gaseous Oxygen Systems

Leaks in a continuous-flow oxygen system may be difficult to detect because the system is open at the user end. Blocking the flow of oxygen allows pressure to build and leak check procedures can be followed that are similar to those used in the high-pressure sections of the systems. Detection of leaks should be performed with oxygen-safe leak check fluid. This is a soapy liquid free from elements that might react with pure oxygen or contaminate the system. As with leak detection on an inflated tire or tube assembly, the oxygen leak detection solution is applied to the outside of fittings and mating surfaces. The formation of bubbles indicates a leak. [Figure 16-30]

Careful assembly of oxygen components and fittings without overtightening or undertightening is required. If a leak is found at a fitting, it should be checked for the proper torque. Tightening may not always stop the leak. If the fitting is



Figure 16-30. Oxygen system leak check solution.

torqued properly and a leak still exists, pressure must be released from the system and the fitting must be examined for flaws or contamination. If necessary, the fitting must be replaced. All system components, lines, and fittings must be replaced with the proper parts, which should be cleaned and inspected thoroughly before installation. Follow the manufacturer's instructions and repeat the leak check when completed.

Use caution when maintaining the high-pressure portion of a gaseous oxygen system. An open tank valve pressurizes the lines and components with up to 1,850 pounds per square inch (psi) of oxygen. Identify the high-pressure section of the system as that portion upstream of the reducer or regulator that has stainless steel tubing. No attempt should be made to tighten a leaky oxygen fitting while the system is charging. The oxygen supply should be isolated in the cylinder and the system depressurized to reduce the consequences of a spark or to minimize spillage and injury should a complete fitting failure occur.

Draining an Oxygen System

The biggest factor in draining an oxygen system is safety. The oxygen must be released into the atmosphere without causing a fire, explosion, or hazard. Draining outside is highly recommended. The exact method of draining can vary. The basic procedure involves establishing a continuous flow in a safe area until the system is empty.

If the cylinder valve is operative, close the valve to isolate the oxygen supply in the cylinder. All that remains is to empty the lines and components. This can be done without disassembling the system by letting oxygen flow from the delivery point(s). If the environment is safe to receive the oxygen, positioning

a demand-flow regulator to the emergency setting delivers a continuous flow of oxygen to the mask when plugged in. Hang the mask(s) out of a window while the system drains. Plug in all mask(s) to allow oxygen to drain from a continuous-flow oxygen system. Systems without check valves can be drained by opening the refill valve.

Filling an Oxygen System

Filling procedures for oxygen systems vary. Many general aviation aircraft are set up to simply replace an empty cylinder with one that is fully charged. This is also the case with a portable oxygen system. High performance and air transport category aircraft often have built-in oxygen systems that contain plumbing designed to refill gaseous oxygen cylinders while they are in place. A general discussion of the procedure to fill this type of installation follows.

Before charging any oxygen system, consult the aircraft manufacturer's maintenance manual. The type of oxygen to be used, safety precautions, equipment to be used, and the procedures for filling and testing the system must be observed. Several general precautions should also be observed when servicing a gaseous oxygen system. Oxygen valves should be opened slowly, and filling should proceed slowly to avoid overheating. The hose from the refill source to the oxygen fill valve on the aircraft should be purged of air before it is used to transfer oxygen into the system. Pressures should also be checked frequently while refilling. Additionally, all items used for oxygen systems must be free of any grease or oil, as this will cause a fire.

Airline and fixed-base operator maintenance shops often use oxygen filler carts to service oxygen systems. These contain several large oxygen supply cylinders connected to the fill cart manifold. This manifold supplies a fill hose that attaches to the aircraft. Valves and pressure gauges allow awareness and control of the oxygen dispensing process. [Figure 16-31] Be sure all cylinders on the cart are aviator's breathing oxygen and that all cylinders contain at least 50 psi of oxygen pressure. Each cylinder should also be within its hydrostatic test date interval. After a cart cylinder has dispensed oxygen, the remaining pressure should be recorded. This is usually written on the outside of the cylinder with chalk or in a cylinder pressure log kept with the cart. As such, the technician can tell at a glance the status of each oxygen bottle.

No pump or mechanical device is used to transfer oxygen from the fill cart manifold to the aircraft system. Objects under pressure flow from high pressure to low pressure. Thus, by connecting the cart to the aircraft and systematically opening oxygen cylinders with increasingly higher pressure, a slow increase in oxygen flow to the aircraft can be managed.

The following is a list of steps to safely fill an aircraft oxygen system from a typical oxygen refill cart.

1. Check hydrostatic dates on all cylinders, especially those that are to be filled on the aircraft. If a cylinder is out of date, remove and replace it with a specified unit that is serviceable.
2. Check pressures on all cylinders on the cart and in the aircraft. If pressure is below 50 psi, replace the cylinder(s). On the aircraft, this may require purging the system with oxygen when completed. Best practices dictate that any low-pressure or empty cylinder(s) on the cart should also be removed and replaced when discovered.
3. Take all oxygen handling precautions to ensure a safe environment around the aircraft.
4. Ground the refill cart to the aircraft.
5. Connect the cart hose from the cart manifold to the aircraft fill port. Purge the air from the refill hose with oxygen before opening the refill valve on the aircraft. Some hoses are equipped with purge valves to do this while the hose is securely attached to the aircraft. Other hoses need to be purged while attached to the refill fitting but not fully tightened.
6. Observe the pressure on the aircraft bottle to be filled. Open it. On the refill cart, open the cylinder with the closest pressure to the aircraft cylinder that exceeds it.
7. Open the aircraft oxygen system refill valve. Oxygen will flow from cart cylinder (manifold) into the aircraft cylinder.
8. When the cylinder pressures equalize, close the cylinder on the cart, and open the cart cylinder with the next highest pressure. Allow it to flow into the



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

- aircraft cylinder until the pressures equalize and flow ceases. Close the cart cylinder and proceed to the cart cylinder with the next highest pressure.
9. Continue the procedure in step 8 until the desired pressure in the aircraft cylinder is achieved.
 10. Close the aircraft refill valve and close all cylinders on the cart.
 11. The aircraft oxygen cylinder valve(s) should be left in the proper position for normal operations. Remotely mounted cylinders are usually left open.
 12. Disconnect the refill line from the refill port on the aircraft. Cap or cover both.
 13. Remove the grounding strap.

Temperature has a significant effect on the pressure of gaseous oxygen. Manufacturers typically supply a fill chart or a placard at the aircraft oxygen refill station to guide technicians in compensating for temperature/pressure variations. Technicians should consult the chart and fill cylinders to the maximum pressure listed for the prevailing ambient temperature. [Figure 16-32]

When it is hot, oxygen cylinders are filled to a higher pressure than 1,800 psi or 1,850 psi, the standard maximum pressure ratings of most high-pressure aircraft oxygen cylinders. This is allowable because at altitude the temperature and pressure of the oxygen can decrease significantly. Filling cylinders to temperature-compensated pressure values ensures a full supply of oxygen is available when needed. When filling cylinders on a cold day, compensation for temperature and pressure changes dictates that cylinders be filled to less than the maximum rated capacity to allow for pressure increases as temperature rises. Strict adherence to the temperature/pressure compensation chart values is mandatory to ensure safe storage of aircraft oxygen.

Some aircraft have temperature compensation features built into the refill valve. After setting the ambient temperature on the valve dial, the valve closes when the correct amount of oxygen pressure has been established in the aircraft cylinder. A chart can be used to ensure proper servicing.

Purging an Oxygen System

The inside of an oxygen system becomes completely saturated with oxygen during use. This is desirable to deliver clean, odor-free oxygen to the users and to prevent corrosion caused by contamination. An oxygen system needs to be purged if it has been opened or depleted for more than 2 hours, or if it is suspected that the system has been contaminated. Purging is accomplished to evacuate contaminants and to restore oxygen saturation to the inside of the system.

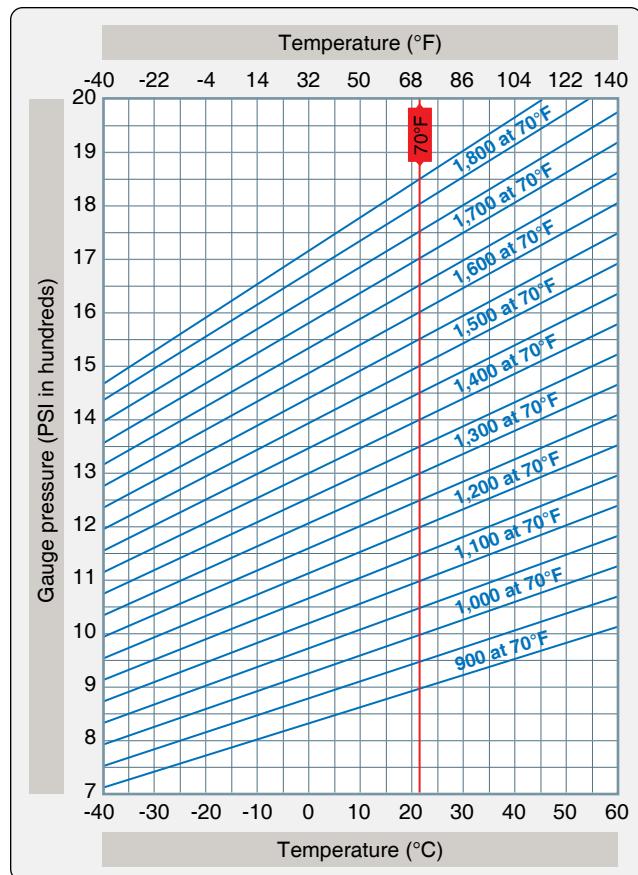


Figure 16-32. A temperature-compensating pressure refill chart is used by the technician to ensure proper oxygen cylinder pressure in the aircraft system.

The main cause of contamination in an oxygen system is moisture. In very cold weather, the small amount of moisture contained in the breathing oxygen can condense. With repeated charging, a significant amount of moisture may collect. Additionally, systems that are opened contain the moisture from the air that has entered. Damp charging equipment, or poor refill procedures, can also introduce water into the system. Always follow manufacturer's instructions when performing maintenance, refilling, or purging an oxygen system.

Cumulative condensation in an oxygen system cannot be entirely avoided. Purging is needed periodically. The procedure for purging may vary somewhat with each aircraft model. Generally speaking, oxygen is run through a sound oxygen system for a number of minutes at a given pressure to perform the purging. This can be as little as 10 minutes at normal delivery pressure. Other systems may require up to 30 minutes of flow at an elevated pressure. Regardless, the removal of contaminants and the resaturation of the inside of the system with oxygen is the basis for purging. It is acceptable to use nitrogen, or dry air, to blow through lines

and components when performing maintenance. However, a final purging with pure oxygen is required before the system is serviceable for use.

It is important to ensure storage cylinders are refilled if they are used during the purging process. Be certain that there are no open lines and all safety caps are installed before returning the aircraft to service.

Filling LOX Systems

The use of LOX in civilian aviation is rare. The most common and safest way to fill a LOX system is to simply exchange the storage unit for one that is full. However, filling LOX on the aircraft is possible.

A portable fill cart is used, and all of the same precautions must be observed as when servicing a high-pressure gaseous oxygen system. Additionally, protection from cold burns is necessary. Due to the amount of gaseous oxygen released during the process, refilling should be accomplished outside. The servicing cart is attached to the aircraft system through a fill valve. The buildup/vent valve on the LOX container assembly is placed in the vent position. The valve on the service cart is then opened. LOX flows into the aircraft system; some vaporizes and cools the entire setup. This gaseous oxygen flows overboard through the vent valve while the system fills. When a steady stream of LOX flows from the vent valve, the system is filled. The valve is then switched to the buildup position. The aircraft refill valve and cart supply valves are closed, and the hose is removed.

Back seated valves can freeze in the open position due to the low temperature involved while LOX is being transferred. Valves should be opened completely and then closed slightly so as to not be back seated.

Inspection of Masks & Hoses

The wide varieties of oxygen masks used in aviation require periodic inspection. Mask and hose integrity ensure effective delivery of oxygen to the user when it is needed. Sometimes this is in an emergency situation. Leaks, holes, and tears are not acceptable. Most discrepancies of this type are remedied by replacement of the damaged unit.

Some continuous-flow masks are designed for disposal after use. Be sure there is a mask for each potential user on board the aircraft. Masks designed to be reused should be clean, as well as functional. This reduces the danger of infection and prolongs the life of the mask. Various mild cleaners and antiseptics that are free of petroleum products can be used. A supply of individually wrapped alcohol swabs are often kept in the flight deck.

Built-in microphones should be operational. Donning straps and fittings should be in good condition and function so that the mask is held firm to the user's face. The diameter of mask hoses in a continuous-flow system is quite a bit smaller than those used in a demand-flow system. This is because the inside diameter of the hose aids in controlling flow rate. Masks for each kind of system are made to only connect to the proper hose.

Smoke masks are required on transport aircraft and are used on some other aircraft as well. These cover the eyes, as well as the user's nose and mouth. Smoke masks are usually available within easy grasp of the crew members. They are used when the situation in the flight deck demands the increased level of protection offered. Smoke mask hoses plug into demand regulators in the same port used for regular demand type masks and operate in the same manner. Most include a built-in microphone. [Figure 16-33] Some portable oxygen systems are also fitted with smoke masks.

Replacing Tubing, Valves, & Fittings

The replacement of aircraft oxygen system tubing, valves, and fittings is similar to the replacement of the same components in other aircraft systems. There is, however, an added emphasis on cleanliness and compatible sealant use.

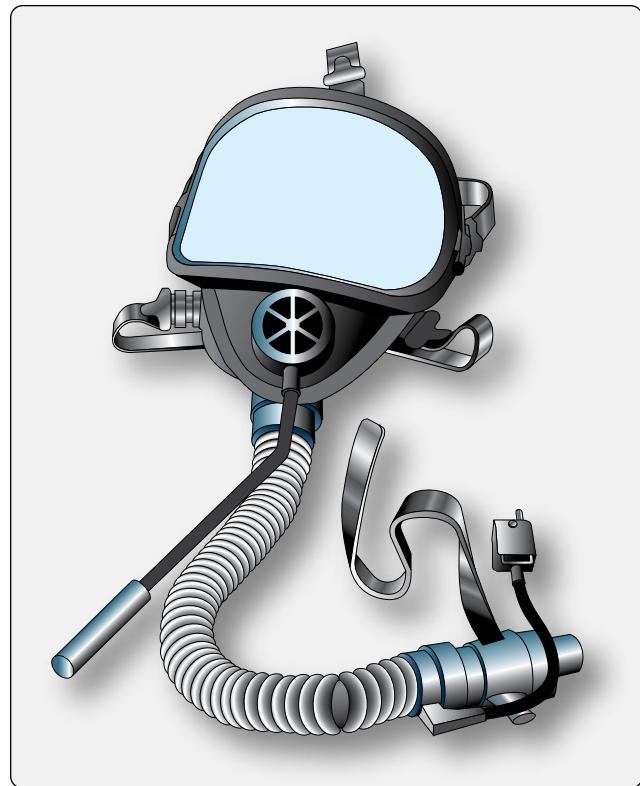


Figure 16-33. Smoke masks cover the eyes as well as the nose and mouth of the user.

Any oxygen system component should be cleaned thoroughly before installation. Often tubing comes with leftover residue from the bending or flaring processes. Cleaning should be accomplished with nonpetroleum-based cleansers. Trichlorethylene, acetone, and similar cleaners can be used to flush new tubing. Tubing should be blown or baked dry before installation. Follow the manufacturer's procedures for cleaning oxygen system components.

Some oxygen components make use of tapered pipe fittings. This type of connection is usually sealed with the application of thread lubricant/sealant. Typical thread sealers are petroleum based and should not be used; only oxygen compatible thread lubricant/sealers should be used. Alternatively, Teflon® tape is also used on oxygen pipe fitting connections. Be sure to begin wrapping the Teflon® tape at least two threads from the end of the fitting. This prevents any tape from coming loose and entering the oxygen system.

Prevention of Oxygen Fires or Explosions

Precautions must be observed when working with or around pure oxygen. It readily combines with other substances, some in a violent and explosive manner. As mentioned, it is extremely important to keep distance between pure oxygen and petroleum products. When allowed to combine, an explosion can result. Additionally, there are a variety of inspection and maintenance practices that should be followed to ensure safety when working with oxygen and oxygen

systems. Care should be used and, as much as possible, maintenance should be done outside.

When working on an oxygen system, it is essential that the warnings and precautions given in the aircraft maintenance manual be carefully observed. Before any work is attempted, an adequate fire extinguisher should be on hand. Cordon off the area and post "NO SMOKING" placards. Ensure that all tools and servicing equipment are clean and avoid power on checks and use of the aircraft electrical system.

Oxygen System Inspection & Maintenance

When working around oxygen and oxygen systems, cleanliness enhances safety. Clean, grease-free hands, clothes, and tools are essential. A good practice is to use only tools dedicated for work on oxygen systems. There should be absolutely no smoking or open flames within a minimum of 50 feet of the work area. Always use protective caps and plugs when working with oxygen cylinders, system components, or plumbing. Do not use any kind of adhesive tape. Oxygen cylinders should be stored in a designated, cool, ventilated area in the hangar away from petroleum products or heat sources.

Oxygen system maintenance should not be accomplished until the valve on the oxygen supply cylinder is closed and pressure is released from the system. Fittings should be unscrewed slowly to allow any residual pressure to dissipate. All oxygen lines should be marked and should have at least

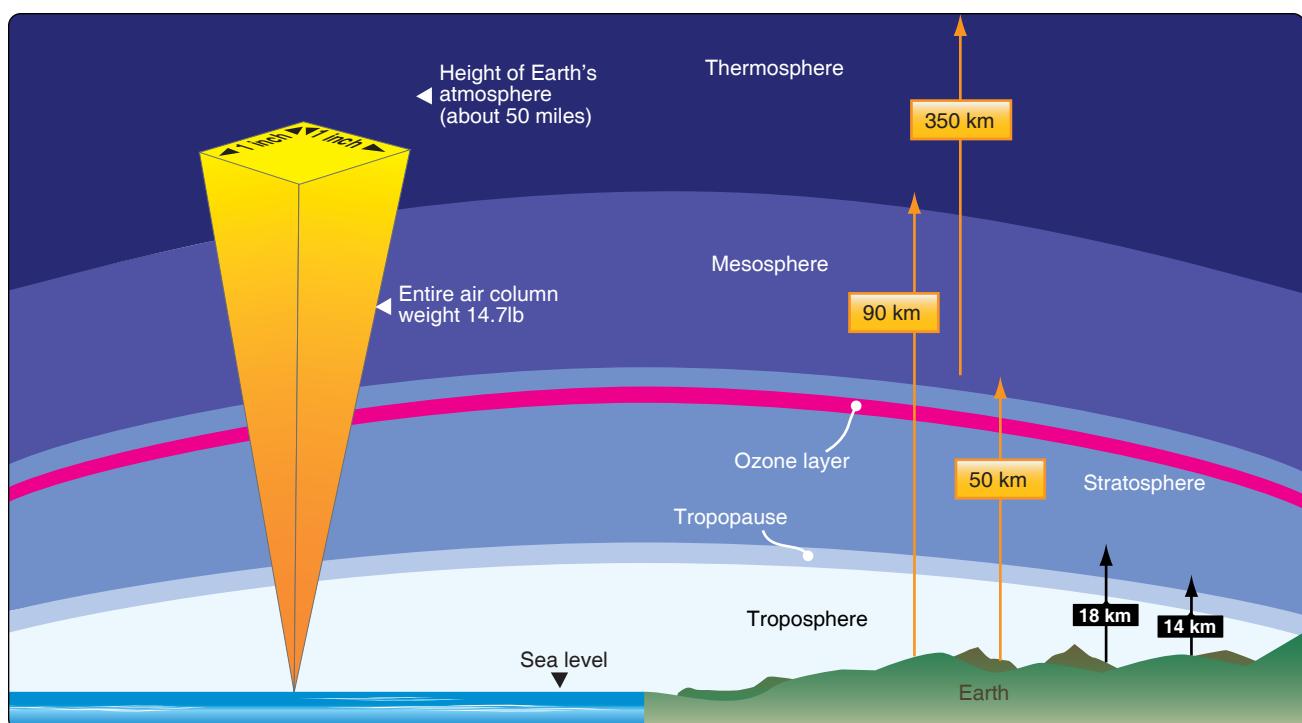


Figure 16-34. The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.

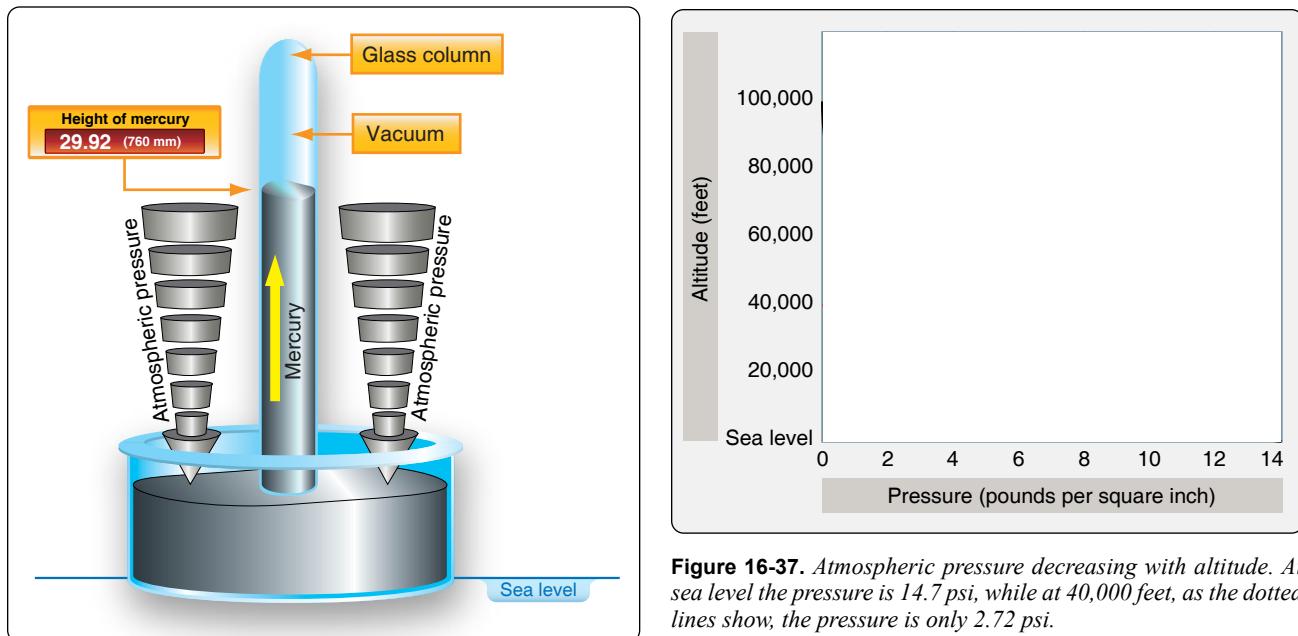


Figure 16-35. The weight of the atmosphere pushes down on the mercury in the reservoir of a barometer, which causes mercury to rise in the column. At sea level, mercury is forced up into the column approximately 29.92 inches. Therefore, it is said that barometric pressure is 29.92 inches of mercury at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

2 inches of clearance from moving parts, electrical wiring, and all fluid lines. Adequate clearance must also be provided from hot ducts and other sources that might heat the oxygen. A pressure and leak check must be performed each time the system is opened for maintenance. Do not use any lubricants, sealers, cleaners, etc., unless specifically approved for oxygen system use.

Aircraft Pressurization Systems

Pressure of the Atmosphere

The gases of the atmosphere (air), although invisible, have weight. A one square inch column of air stretching from sea level into space weighs 14.7 pounds. Therefore, it can be stated that the pressure of the atmosphere, or atmospheric pressure, at sea level is 14.7 psi. [Figure 16-34]

Atmospheric pressure is also known as barometric pressure

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

and is measured with a barometer. [Figure 16-35] Expressed in various ways, such as in inches of mercury or millimeters of mercury, these measurements come from observing the height of mercury in a column when air pressure is exerted on a reservoir of mercury into which the column is set. The column must be evacuated so air inside does not act against the mercury rising. A column of mercury 29.92 inches high weighs the same as a column of air that extends from sea level to the top of the atmosphere and has the same cross-section as the column of mercury.

Aviators often interchange references to atmospheric pressure between linear displacement (e.g., inches of mercury) and units of force (e.g., psi). Over the years, meteorology has shifted its use of linear displacement representation of atmospheric pressure to units of force. However, the unit of force nearly universally used today to represent atmospheric pressure in meteorology is the hectopascal (hPa). A hectopascal is a metric (SI) unit that expresses force in newtons per square meter. 1,013.2 hPa is equal to 14.7 psi. [Figure 16-36]

Atmospheric pressure decreases with increasing altitude. The

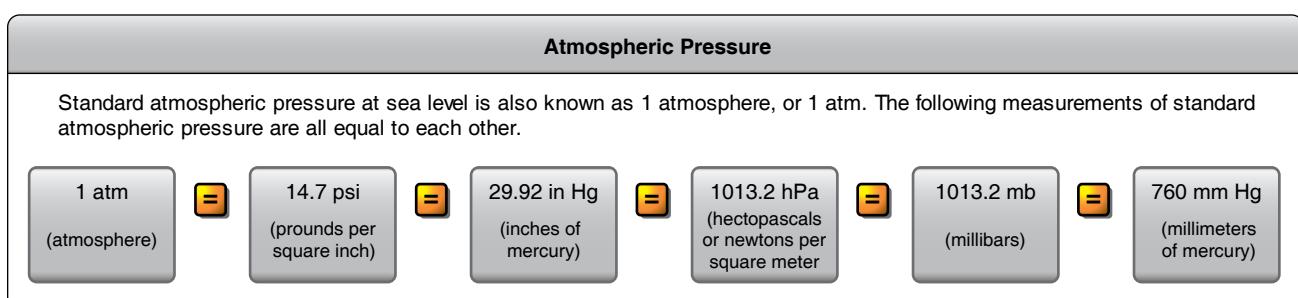


Figure 16-36. Various equivalent representations of atmospheric pressure at sea level.

simplest explanation for this is that the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in *Figure 16-37*. The decrease in pressure is a rapid one and, at 50,000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value.

Temperature & Altitude

Temperature variations in the atmosphere are of concern to aviators. Weather systems produce changes in temperature near the earth's surface. Temperature also changes as altitude is increased. The troposphere is the lowest layer of the atmosphere. On average, it ranges from the earth's surface to about 38,000 feet above it. Over the poles, the troposphere extends to only 25,000–30,000 feet and, at the equator, it may extend to around 60,000 feet. This oblong nature of the troposphere is illustrated in *Figure 16-38*.

Most civilian aviation takes place in the troposphere in which temperature decreases as altitude increases. The rate of change is somewhat constant at about -2°C or -3.5°F for every 1,000 feet of increase in altitude. The upper boundary of the troposphere is the tropopause. It is characterized as a zone of relatively constant temperature of -57°C or -69°F .

Above the tropopause lies the stratosphere. Temperature increases with altitude in the stratosphere to near 0°C before decreasing again in the mesosphere, which lies above it. The stratosphere contains the ozone layer that protects the earth's inhabitants from harmful UV rays. Some civilian flights and numerous military flights occur in the stratosphere. *Figure 16-39* diagrams the temperature variations in different layers of the atmosphere.

When an aircraft is flown at high altitude, it burns less

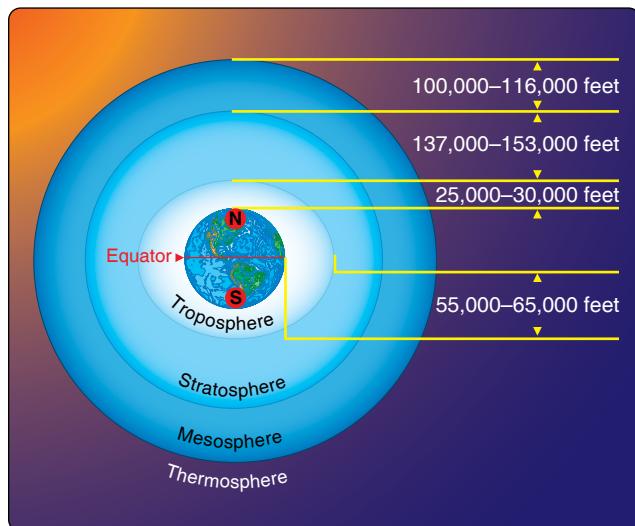


Figure 16-38. The troposphere extends higher above the earth's surface at the equator than it does at the poles.

fuel for a given airspeed than it does for the same speed at a lower altitude. This is due to decreased drag that results from the reduction in air density. Bad weather and turbulence can also be avoided by flying in the relatively smooth air above storms and convective activity that occur in the lower troposphere. To take advantage of these efficiencies, aircraft are equipped with environmental systems to overcome extreme temperature and pressure levels. While supplemental oxygen and a means of staying warm suffice, aircraft pressurization and air conditioning systems have been developed to make high altitude flight more comfortable. *Figure 16-40* illustrates the temperatures and pressures at various altitudes in the atmosphere.

Pressurization Terms

The following terms should be understood for the discussion of pressurization and cabin environmental systems that follows:

1. Cabin altitude—given the air pressure inside the cabin, the altitude on a standard day that has the same pressure as that in the cabin. Rather than saying the pressure inside the cabin is 10.92 psi, it can be

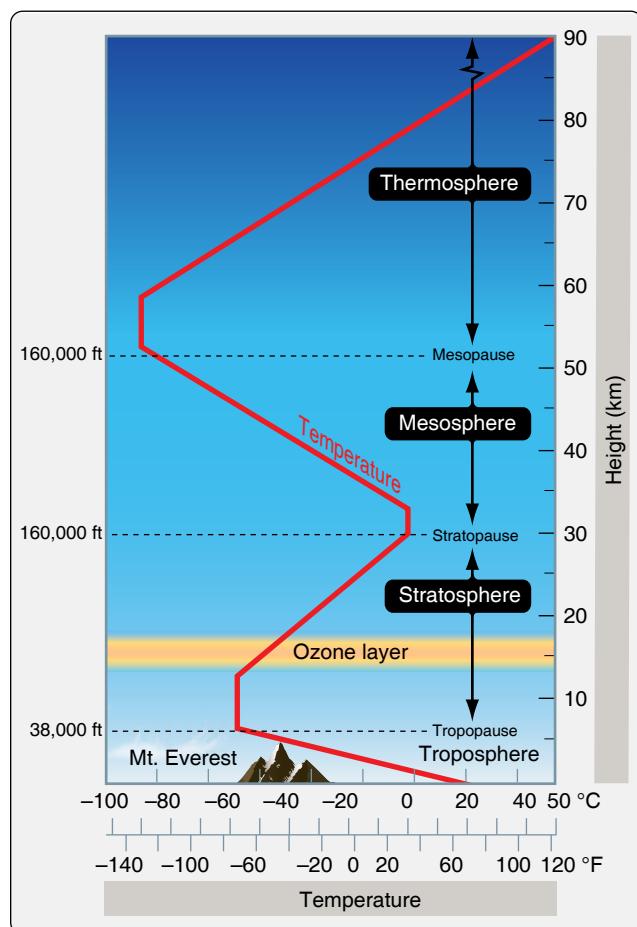


Figure 16-39. The atmospheric layers with temperature changes depicted by the red line.

Altitude feet	Pressure			Temperature	
	psi	hPa	in Hg	°F	°C
0	14.69	1013.2	29.92	59.0	15
1,000	14.18	977.2	28.86	55.4	13
2,000	13.66	942.1	27.82	51.9	11
3,000	13.17	908.1	26.82	48.3	9.1
4,000	12.69	875.1	25.84	44.7	7.1
5,000	12.23	843.1	24.90	41.2	5.1
6,000	11.77	812.0	23.98	37.6	3.1
7,000	11.34	781.8	23.09	34.0	1.1
8,000	10.92	752.6	22.23	30.5	-0.8
9,000	10.51	724.3	21.39	26.9	-2.8
10,000	10.10	696.8	20.58	23.3	-4.8
12,000	9.34	644.4	19.03	16.2	-8.8
14,000	8.63	595.2	17.58	9.1	-12.7
16,000	7.96	549.2	16.22	1.9	-16.7
18,000	7.34	506.0	14.94	-5.2	-29.7
20,000	6.76	465.6	13.75	-12.3	-24.6
22,000	6.21	427.9	12.64	-19.5	-28.6
24,000	5.70	392.7	11.60	-26.6	-32.5
26,000	5.22	359.9	10.63	-33.7	-36.5
28,000	4.78	329.3	9.72	-40.9	-40.5
30,000	4.37	300.9	8.89	-48.0	-44.4
32,000	3.99	274.5	8.11	-55.1	-48.4
34,000	3.63	250.0	7.38	-62.2	-52.4
36,000	3.30	227.3	6.71	-69.4	-56.3
38,000	3.00	206.5	6.10	-69.4	-56.5
40,000	2.73	187.5	5.54	-69.4	-56.5
45,000	2.14	147.5	4.35	-69.4	-56.5
50,000	1.70	116.0	3.42	-69.4	-56.5

Figure 16-40. Cabin environmental systems establish conditions quite different from those found outside the aircraft.

said that the cabin altitude is 8,000 feet (MSL).

2. Cabin differential pressure—the difference between the air pressure inside the cabin and the air pressure outside the cabin. Cabin pressure (psi) – ambient pressure (psi) = cabin differential pressure (psid or Δ psi).
3. Cabin rate of climb—the rate of change of air pressure inside the cabin, expressed in feet per minute (fpm) of cabin altitude change.

Pressurization Issues

Pressurizing an aircraft cabin assists in making flight possible in the hostile environment of the upper atmosphere. The degree of pressurization and the operating altitude of any aircraft are limited by critical design factors. A cabin pressurization system must accomplish several functions if it is to ensure adequate passenger comfort and safety. It must be capable of maintaining a cabin pressure altitude of approximately 8,000 feet or lower regardless of the cruising altitude of the aircraft. This is to ensure that passengers and

crew have enough oxygen present at sufficient pressure to facilitate full blood saturation. A pressurization system must also be designed to prevent rapid changes of cabin pressure, which can be uncomfortable or injurious to passengers and crew. Additionally, a pressurization system should circulate air from inside the cabin to the outside at a rate that quickly eliminates odors and to remove stale air. Cabin air must also be heated or cooled on pressurized aircraft. Typically, these functions are incorporated into the pressurization source.

To pressurize, a portion of the aircraft designed to contain air at a pressure higher than outside atmospheric pressure must be sealed. A wide variety of materials facilitate this. Compressible seals around doors combine with various other seals, grommets, and sealants to essentially establish an air tight pressure vessel. This usually includes the cabin, flight compartment, and the baggage compartments. Air is then pumped into this area at a constant rate sufficient to raise the pressure slightly above that which is needed. Control is maintained by adjusting the rate at which the air is allowed to flow out of the aircraft.

A key factor in pressurization is the ability of the fuselage to withstand the forces associated with the increase in pressure inside the structure versus the ambient pressure outside. This differential pressure can range from 3.5 psi for a single-engine reciprocating aircraft, to approximately 9 psi on high performance jet aircraft. [Figure 16-41] If the weight of the aircraft structure were of no concern, this would not be a problem. Making an aircraft strong for pressurization, yet also light, has been an engineering challenge met over numerous years beginning in the 1930s. The development of jet aircraft and their ability to exploit low drag flight at higher altitude made the problem even more pronounced. Today, the proliferation of composite materials in aircraft structure continues this engineering challenge.

In addition to being strong enough to withstand the pressure differential between the air inside and the air outside the cabin, metal fatigue from repeated pressurization and depressurization weakens the airframe. Some early pressurized aircraft structures failed due to this and resulted in fatal accidents. The FAA's aging aircraft program was instituted to increase inspection scrutiny of older airframes that may show signs of fatigue due to the pressurization cycle.

Aircraft of any size may be pressurized. Weight considerations when making the fuselage strong enough to endure pressurization usually limit pressurization to high performance light aircraft and larger aircraft. A few pressurized single-engine reciprocating aircraft exist, as well as many pressurized single-engine turboprop aircraft.

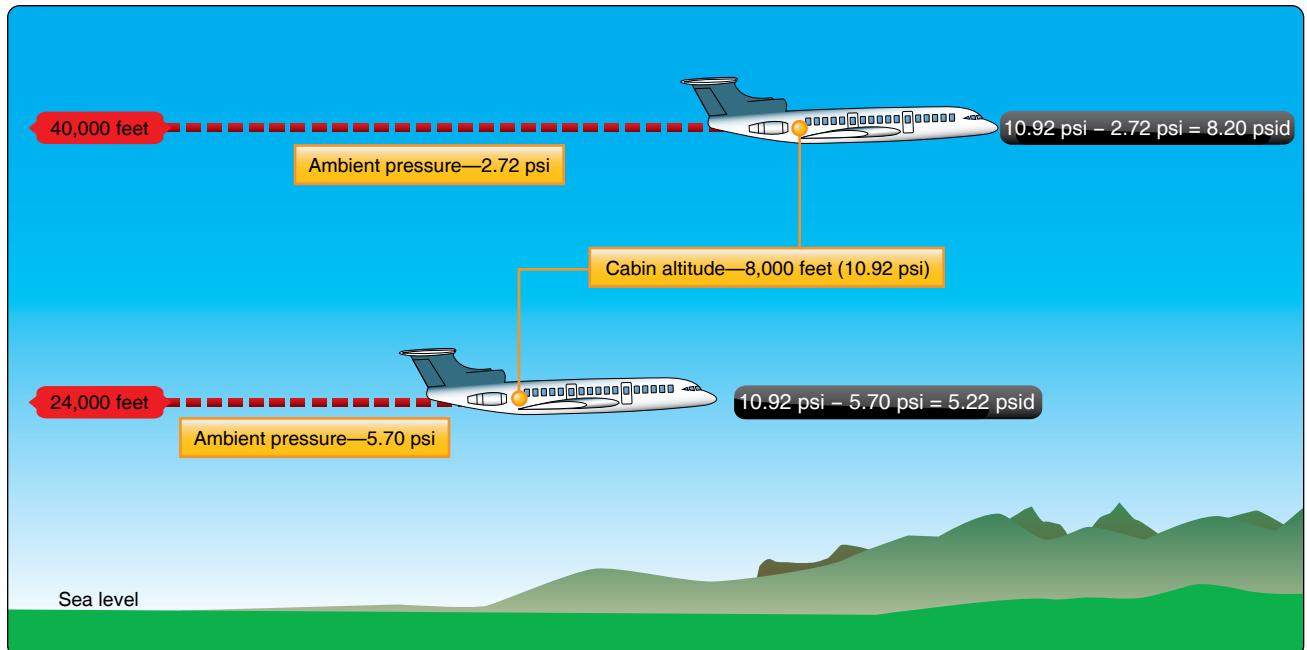


Figure 16-41. Differential pressure (psid) is calculated by subtracting the ambient air pressure from the cabin air pressure.

Sources of Pressurized Air

The source of air to pressurize an aircraft varies mainly with engine type. Reciprocating aircraft have pressurization sources different from those of turbine-powered aircraft. The compression of air raises its temperature. A means for keeping pressurization air cool enough is built into most pressurization systems. It may be in the form of a heat exchanger, using cold ambient air to modify the temperature of the air from the pressurization source. A full air cycle air conditioning system with expansion turbine may also be used. The latter provides the advantage of temperature control on the ground and at low altitudes where ambient air temperature may be higher than comfortable for the passengers and crew.

Reciprocating Engine Aircraft

There are three typical sources of air used to pressurize reciprocating aircraft: supercharger, turbocharger, and engine-driven compressor. Superchargers and turbochargers are installed on reciprocating engines to permit better performance at high altitude by increasing the quantity and pressure of the air in the induction system. Some of the air produced by each of these can be routed into the cabin to pressurize it.

A supercharger is mechanically driven by the engine. Despite engine performance increases due to higher induction system pressure, some of the engine output is utilized by the supercharger. Furthermore, superchargers have limited capability to increase engine performance. If supplying both the intake and the cabin with air, the engine performance ceiling is lower than if the aircraft were not pressurized.

Superchargers must be located upstream of the fuel delivery to be used for pressurization. They are found on older reciprocating engine aircraft, including those with radial engines. [Figures 16-42 and 16-43]

Turbochargers, sometimes known as turbosuperchargers, are driven by engine exhaust gases. They are the most common source of pressurization on modern reciprocating engine aircraft. The turbocharger impeller shaft extends through the bearing housing to support a compression impeller in a separate housing. By using some of the turbocharger

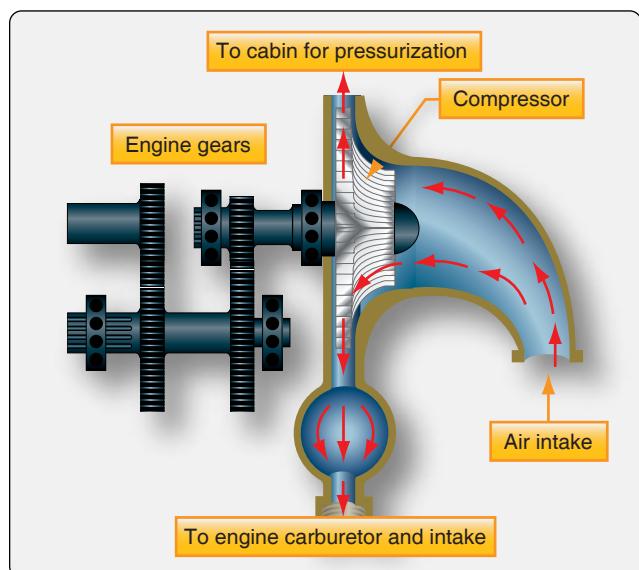


Figure 16-42. A reciprocating engine supercharger can be used as a source of pressurization if it is upstream of carburetion.