CHAPTER 7

ICE AND RAIN PROTECTION

GENERAL

Rain, snow, and ice are transportation's ancient 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.

The two types of ice encountered during flight are rime and glaze. Rime ice forms a rough surface on the aircraft leading edges. It is rough because the temperature of the air is very low and freezes the water before it has time to spread. Glaze ice forms a smooth, thick coating over the leading edges of the aircraft. When the temperature is just slightly below freezing, the water has more time to flow before it freezes.

Ice may be expected to form whenever there is visible moisture in the air and the temperature is near or below freezing. An exception is carburetor icing which can occur during warm weather with no visible moisture present. If ice is allowed to accumulate on the wings and empennage leading edges, it destroys the lift characteristics of the airfoil. Ice or rain accumulations on the windshield interfere with vision.

Icing Effects

Ice on an aircraft affects its performance and efficiency in many ways. 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 (figure 7–1).

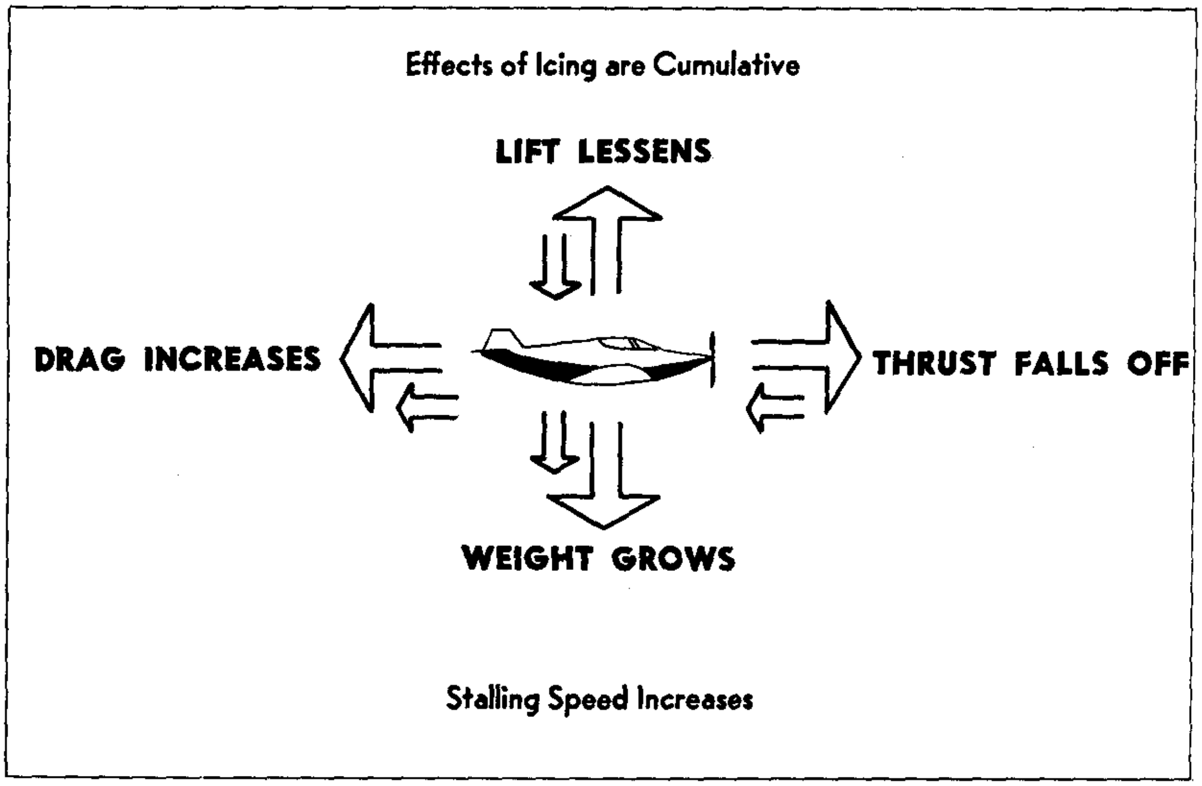

FIGURE 7–1. Effects of structural icing.

The methods used to prevent icing (anti-icing) or to eliminate ice that has formed (deicing) vary with the aircraft make and model. In this Chapter ice prevention and ice elimination using pneumatic pressure, application of heat, and the application of fluid will be discussed.

Ice Prevention

Several means to prevent or control ice formation are used in aircraft today: (1) Heating surfaces using hot air, (2) heating by electrical elements, (3) breaking up ice formations, usually by inflatable boots, and (4) alcohol spray. A surface may be anti-iced either 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; or the surface may be deiced by allowing ice to form and then removing it.

Ice prevention or elimination systems ensure safety of flight when icing conditions exist. Ice may be controlled on aircraft structure by the following methods.

Location of Ice	*Method of Control*
1. Leading edge of the wing	Pneumatic, Thermal
2. Leading edges of vertical and horizontal stabilizers	Pneumatic, Thermal
3. Windshields, windows, and radomes	Electrical, Alcohol
4. Heater and Engine air inlets	Electrical
5. Stall warning transmitters	Electrical
6. Pitot tubes	Electrical
7. Flight controls	Pneumatic, Thermal
8. Propeller blade leading edges	Electrical, Alcohol
9. Carburetors	Thermal, Alcohol
10. Lavatory drains	Electrical

PNEUMATIC DEICING SYSTEMS

Pneumatic deicing systems use rubber deicers, called boots or shoes, attached to the leading edge of the wing and stabilizers. The deicers are composed of a series of inflatable tubes. During operation, the tubes are inflated with pressurized air, and deflated in an alternating cycle as shown in figure 7–2. This inflation and deflation causes the ice to **crack and break off. The ice is then carried away by the airstream.**

Deicer tubes are inflated by an engine-driven air pump (vacuum pump), or by air bled from gas turbine engine compressors. The inflation sequence is controlled by either a centrally located distributor valve or by solenoid operated valves located adjacent to the deicer air inlets.

Deicers 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 will be kept to a minimum by inflating only short sections on each wing at a time.

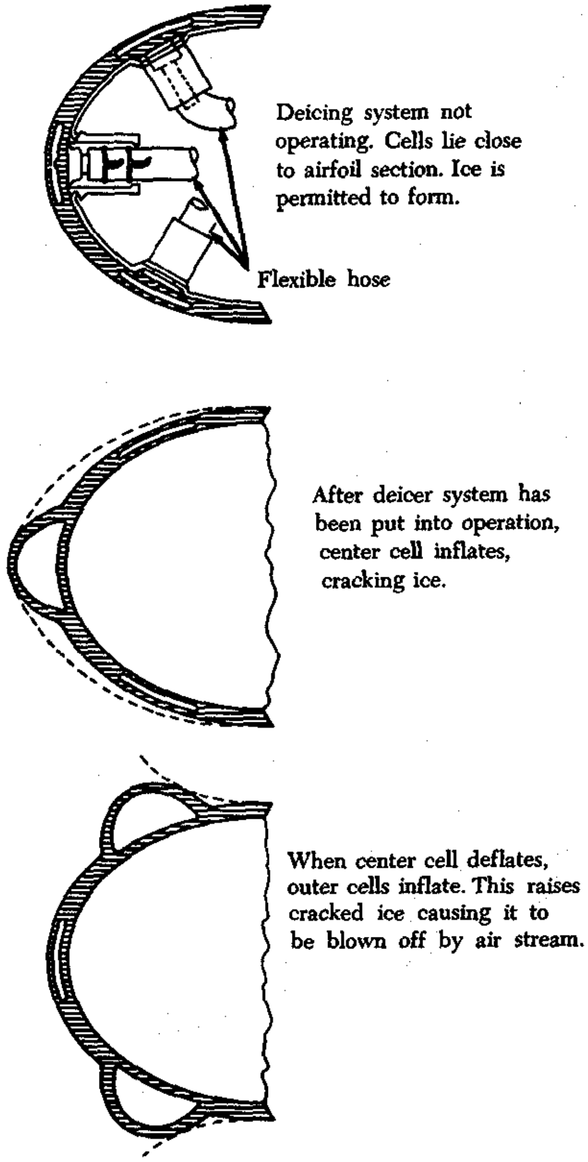

FIGURE 7–2. Deicer boot inflation cycle.

DEICER BOOT CONSTRUCTION

Deicer boots are made of soft, pliable rubber or rubberized fabric and contain tubular air cells. The outer ply of the deicer 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.

Deicer boots are attached to the leading edge of wing and tail surfaces with cement or fairing strips and screws, or a combination of both.

Deicer boots which are secured to the surface with fairing strips and screws or a combination of fairing strips, screws, and cement have a bead and bead wire on each lengthwise edge. On this type installation, screws pass through a fairing strip and the deicer boot just ahead of the bead wire and fit into Rivnuts located permanently in the skin of the aircraft.

The new type deicer boots (figure 7–3) are completely bonded to the surface with cement. The trailing edges of this type boot are tapered to provide a smooth airfoil. By eliminating the fairing strips and screws, this type installation cuts down on the weight of the deicer system.

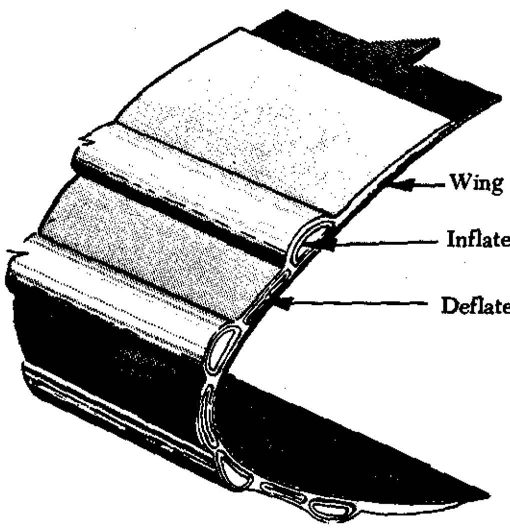

FIGURE 7–3. Deicer boot cross section.

The deicer boot air cells are connected to system pressure and vacuum lines by nonkinking flexible hose.

In addition to the deicer boots, the major components of a representative pneumatic deicing system are a source of pressurized air, an oil separator, air pressure and suction relief valves, a pressure regulator and shutoff valve, an inflation timer, and a distributor valve or a control valve. A schematic of a typical system is shown in figure 7–4.

In this system, air pressure for system operation is supplied by air bled from the engine compressor. The bleed air from the compressor is ducted to a pressure regulator. The regulator reduces the pressure of the turbine bleed air to the deicer system pressure. An ejector, located downstream of the regulator, provides the vacuum necessary to keep the boots deflated.

The air pressure and suction relief valves and regulators maintain the pneumatic system pressure and suction at the desired settings. The timer is essentially a series of switch circuits actuated successively by a solenoid-operated rotating step switch. The timer is energized when the deicing switch is placed in the "on" position.

When the system is operated, the deicer port in the distributor valve is closed to vacuum and system operating pressure is applied to the deicers connected to that port. At the end of the inflation period the deicer pressure port is shut off, and air in the deicer flows overboard through the exhaust port. When the air flowing from the deicers reaches a low pressure (approximately 1 p.s.i.), the exhaust port is closed. Vacuum is re-applied to exhaust the remaining air from the deicer.

This cycle is repeated as long as the system is operating. If the system is turned off, the system timer automatically returns to its starting position.

A pneumatic deicing system that uses an engine-driven air pump is shown in figure 7–5. The right hand side of the system is illustrated, however, the left hand side is identical. Notice that inflatable deicers are provided for the wing leading edges and the horizontal stabilizer leading edges. Included in the system are two engine-driven air (vacuum) pumps, two primary oil separators, two combination units, six distributor valves, an electronic timer, and the control switches on the deicing control panel. To indicate system pressure, a suction indicator and a pressure indicator are included in the system.

Pneumatic System Operation

As shown in figure 7–5, the deicer boots are arranged in sections. The right-hand wing boots include two sections: (1) An inboard (inner boot

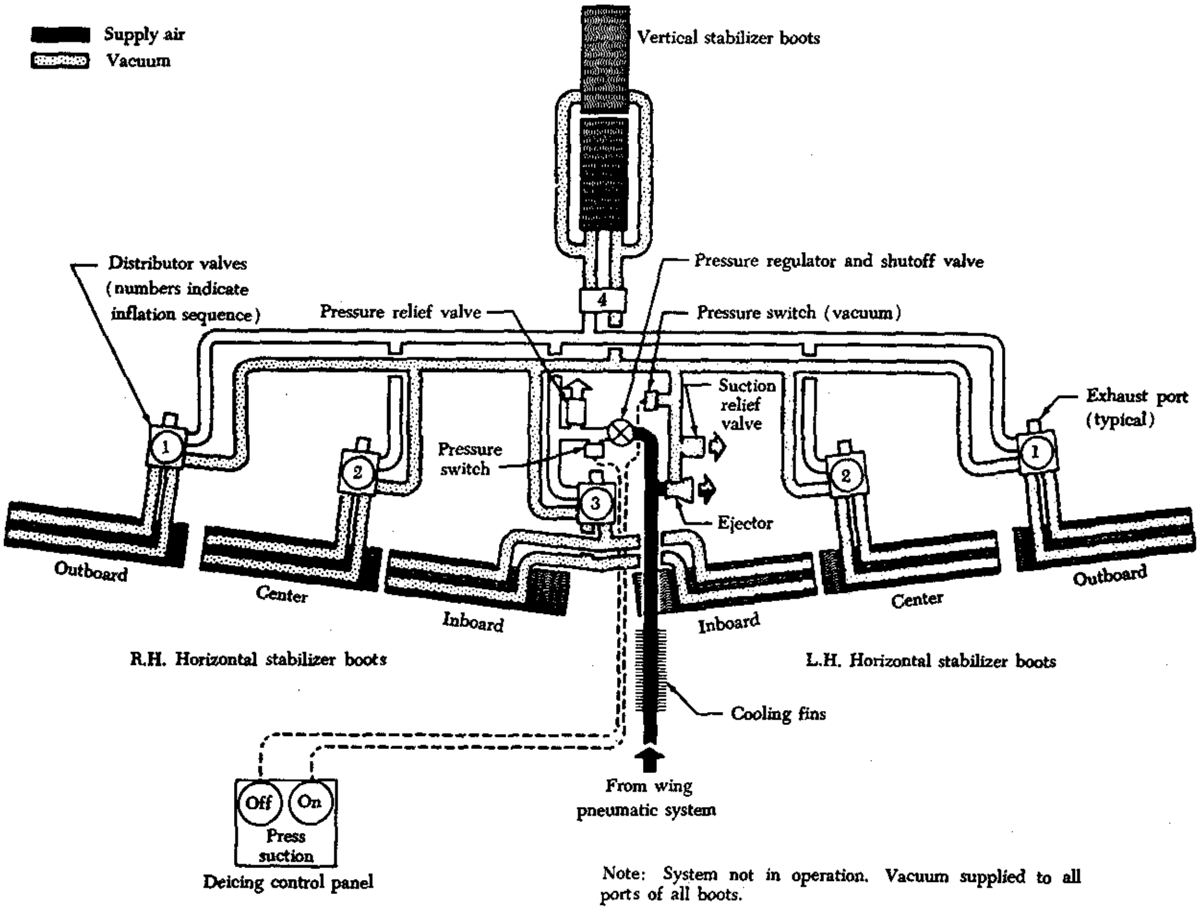

FIGURE 7-4. Schematic of a pneumatic deicing system.

A1 and outer boot B2) section and (2) an outboard (inner boot A3 and outer boot B4) section. The right-hand horizontal stabilizer has two boot sections (inner boot A5 and outer boot B6). A distributor valve serves each wing boot section and another distributor valve serves both horizontal stabilizer boot sections. Notice that each distributor valve has a pressure inlet port, a suction outlet port, a dump port, and two additional ports (A and B). Distributor valve A and B ports are connected to related boot A and B ports. Pressure and suction can be alternated through A and B ports by the movement of a distributor valve solenoid servo valve. Note also that each distributor valve is connected to a common pressure manifold and a common suction manifold. When the pneumatic deicing system is on, pressure or suction is applied by either or both engine-driven air (vacuum) pumps. The suction side of each pump is connected to the suction manifold. The pressure side of each pump is connected through a pressure relief valve to the pressure manifold. The pressure relief valve maintains the pressure in the pressure manifold at 17 p.s.i. The pressurized air then passes to the primary oil separator. The oil separator removes any oil from the air. Oil-free air is then delivered to the combination unit. The combination unit directs, regulates to 15 p.s.i., and filters the air supply to the distributor valves.

When the pneumatic deicing system is off, air pump suction, regulated at 4 in. Hg by an adjustable suction relief valve, holds the deicing boots deflated. Air pump pressure is then directed overboard by the combination unit.

DEICING SYSTEM COMPONENTS

Engine-Driven Air Pump

The engine-driven air pump is of the rotary, four vane, positive displacement type and is mounted on

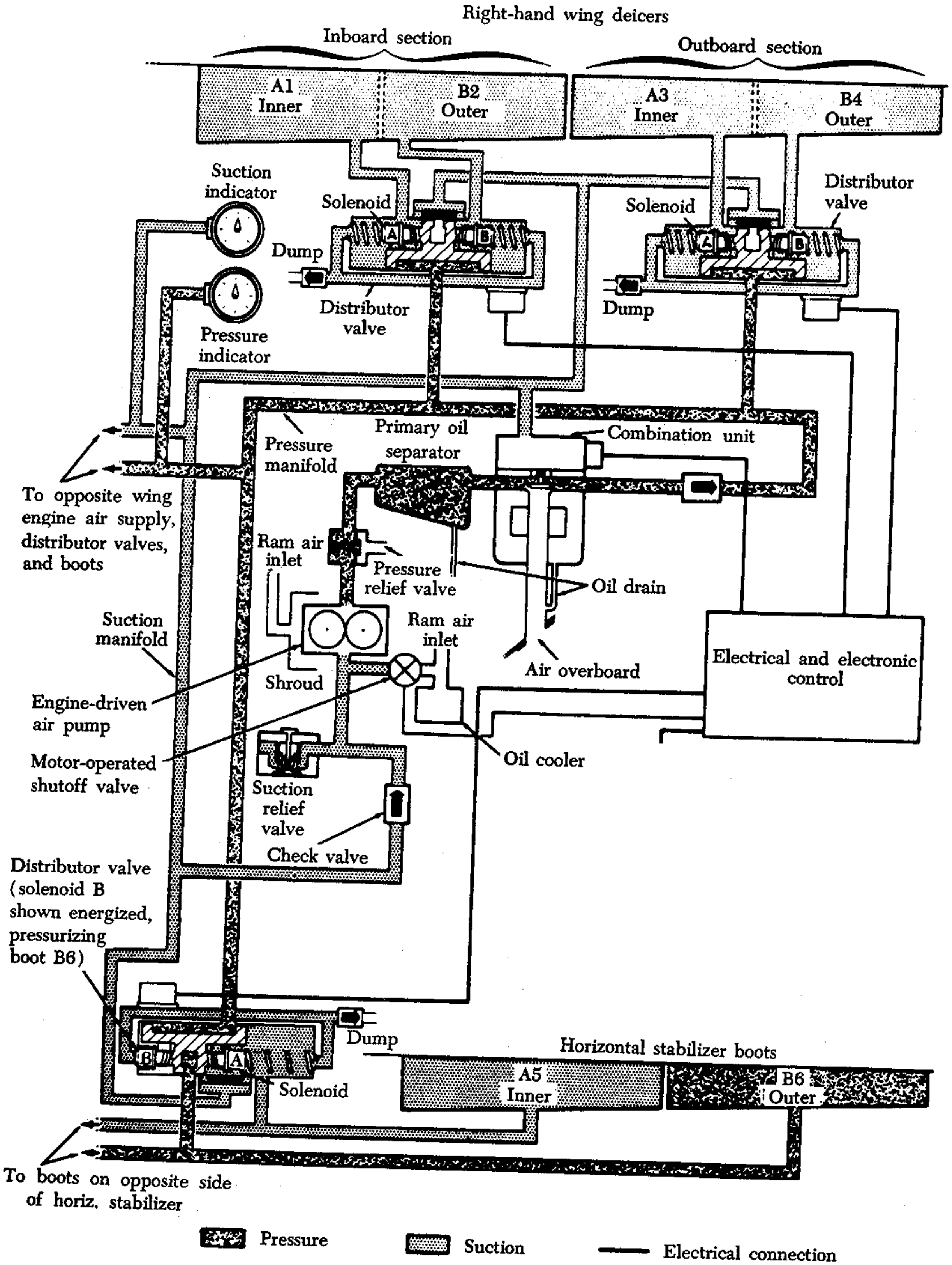

FIGURE 7–5. A pneumatic deicing system using an engine-driven air pump.

the accessory drive gear box of the engine. The compression side of each pump supplies air pressure to inflate the wing and tail deicer boots. Suction is supplied from the inlet side of each pump to hold down the boots, when not being inflated, while in flight. One type of pump uses engine oil for lubrication and is mounted so that the drive gear is mated with the drive gear in the accessory drive gear box. The oil taken in the pump for lubrication and sealing is discharged through the pressure side, to the oil separator. At this point, most of the oil is separated from the air and fed back to the engine oil sump. When installing a new pump, care should be taken to ensure that the oil passages in the gasket, pump, and engine mounting pad are aligned (figure 7–6). If this oil passage does not line up, the new pump will be damaged from lack of lubrication.

Another type of vacuum pump, called a dry pump, depends on specially compounded carbon parts to provide pump lubrication. The pump is constructed with carbon vanes for the rotor. This material is also used for the rotor bearings. The carbon vane material wears at a controlled rate to provide adequate lubrication. This eliminates the need for external lubricants.

When using the dry type of pump, oil, grease, or degreasing fluids must be prevented from entering the system. This is important at installation and during subsequent maintenance.

Maintenance of the engine-driven pump is limited to inspection for loose connections and security of mounting.

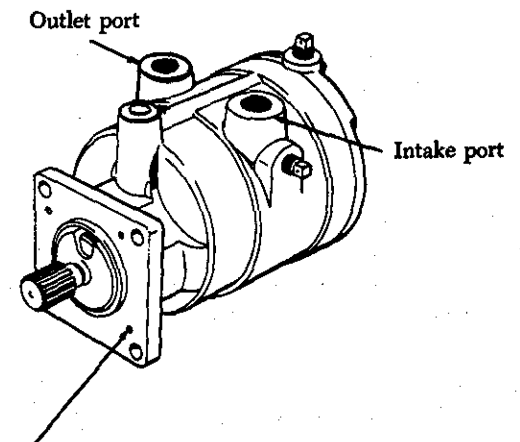

FIGURE 7–6. Lubrication of wet type vacuum pump.

Safety Valves

An air pressure safety valve is installed on the pressure side of some types of engine-driven air pumps. Schematically, this valve is placed on the air pressure side of the pump between the primary oil separators and the pump. The safety valve exhausts excessive air at high pump r.p.m. when a predetermined pressure is reached. The valve is preset and is not adjustable.

Oil Separator

An oil separator is provided for each wet-type air pump. Each separator has an air inlet port, an air outlet port, and an oil drain line which is routed back to the engine oil sump. Since the air pump is internally lubricated, it is necessary to provide this means of separating oil from the pressurized air. The oil separator removes approximately 75% of the oil from the air.

The only maintenance required on the oil separator is flushing the interior of the unit with a suitable cleaning solvent. This should be done at intervals prescribed by the applicable maintenance manual.

Combination Regulator, Unloading Valve, and Oil Separator

The combination regulator, unloading valve, and oil separator consists of a diaphragm-controlled, spring-loaded unloading valve, an oil filter and drain; a diaphragm type air pressure regulator valve with an adjustment screw; and a solenoid selector valve. The assembly has an air pressure inlet port, an exhaust port, an outlet to the solenoid distributor valves, an outlet to the suction side of the engine-driven air pumps, and an oil drain. The combination unit has three functions: (1) To remove all residual oil left in the air by the primary oil separator before it enters the pressure manifold; (2) to control, direct, and regulate air pressure in the system; and (3) to discharge air to the atmosphere when the deicer system is not in use, thereby allowing the air pump to operate at no pressure load.

Maintenance of this unit consists of changing the filter element as prescribed by the applicable maintenance manual.

The pressure regulator may be adjusted, if the deicer system pressure gage does not register the specified pressure. The adjusting screw should be turned counterclockwise to increase the pressure and clockwise to decrease the system pressure.

Suction Regulating Valve

An adjustable suction regulating valve is installed in each engine nacelle. One side of each valve is piped to the inlet (suction) side of the engine-driven air pump and the other side to the main suction manifold line. The purpose of the suction valve is to maintain the deicer system suction automatically.

Maintenance of this valve consists of removing the air intake filter screen and cleaning it with a cleaning solvent as prescribed by the applicable maintenance manual.

This valve may be adjusted to obtain the desired deicing system suction. The deicer system suction is increased by turning the adjusting screw counterclockwise and decreased by turning it clockwise.

Solenoid Distributor Valve

The solenoid distributor valve is normally located near the group of deicer boots which it serves. Each distributor valve incorporates a pressure inlet port, suction outlet port, two ports ("A" and "B") to the boots, and a port piped overboard to a low pressure area. Each distributor also has two solenoids, A and B. The pressure inlet port is integral with the manifold pressure line, thereby making approximately 15 p.s.i. pressure available at all times when the deicer system is operating. The suction port is connected to the main suction line. This allows approximately 4 in. Hg suction available at all times in the distributor valve. Ports "A" and "B" connect suction and pressure to the boots, as controlled by the distributor valve. The port piped to the low pressure area allows the air under pressure in the boots to be dumped overboard as controlled by the distributor valve servo.

The distributor valve normally allows suction to be supplied to the boots for holddown in flight. However, when the solenoid in the distributor valve is energized by the electronic timer cycle control, it moves a servo valve, changing the inlet to that section of the boot from suction to pressure. This allows the boot to inflate fully for a predetermined time. This interval is controlled by the electronic timer. When the solenoid is de-energized, the airflow through the valve is cut off. The air then discharges out of the boot through an integral check valve until the pressure reaches approximately 1 in. Hg, the boot is ported to the suction manifold and the remaining air is evacuated, thus again holding the boot down by suction.

Electronic Timer

An electronic timer is used to control the operating sequence and the time intervals of the deicing system. When the deicing system is turned on, the electronic timer energizes a solenoid in the unloading valve. The solenoid closes a servo valve, thereby directing air pressure to the unloading valve and closing it until the regulator valve of the combination unit takes over. The regulator valve then tends to keep the entire manifold system at approximately 15 p.s.i. pressure and unloads any surplus air at the separator by dumping it overboard. The pressure manifold line is then routed to the distributor valves. The electronic timer then controls the operating sequence of the distributor valves.

PNEUMATIC DEICING SYSTEM MAINTENANCE

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 gages 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 gages for proper indications. The pressure gage will fluctuate as the deicer tubes inflate and deflate. A relatively steady reading should be maintained on the vacuum gage. It should be noted that not all systems use a vacuum gage. 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.

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 gage 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) gage, 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 by tightening loose connections. Several troubles common to pneumatic deicing systems are shown in the left-hand column of the chart in figure 7–7. 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; and 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 will not puncture the boots by arcing to the metal surfaces.

Deicer 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 re-surface the deicers when abrasion or deterioration is noted.

(5) Wrap the deicer in paper or canvas when storing it.

Thus far preventive maintenance has been discussed. The actual work on the deicers consists of cleaning, re-surfacing, and repairing. Cleaning should ordinarily be done at the same time the aircraft is washed, using a mild soap and water solution. Grease and oil can be removed with a cleaning agent, such as naptha, followed by soap and water scrubbing.

Whenever the degree of wear is such that it indicates that the electrical conductivity of the deicer surface has been destroyed, it may be necessary to re-surface the deicer. The re-surfacing substance is a black, conductive neoprene cement. Prior to applying the re-surfacing 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.

One disadvantage of a pneumatic deicer system is the disturbance of airflow over the wing and tail caused by the inflated tubes. This unwanted feature

Trouble	Probable Cause	Remedy
Pressure gage oscillates.	Faulty lines or connections.	Repair or replace lines. Tighten loose connections.
	Deicing boots torn or punctured.	Repair faulty boots.
	Faulty gage.	Replace gage.
	Faulty air relief valve.	Adjust or replace relief valve.
	Faulty air regulator.	Adjust or replace regulator.
Pressure gage oscillates; peaks at a specified pressure while instrument vacuum gage shows no reading.	Vacuum check valves installed improperly.	Re-install correctly.
	Vacuum relief valve improperly adjusted or faulty.	Adjust or replace valve as necessary.
	Faulty lines between pump and gage.	Tighten, repair, or replace faulty lines or connections.
Pressure gage shows no pressure while vacuum gage shows normal reading.	Faulty pressure gage line.	Repair or replace line.
	Faulty pressure gage.	Replace gage.
	Pressure relief valve faulty.	Adjust or replace as necessary.
	Pressure regulator faulty.	Adjust or replace as necessary.
Cycling period irregular.	Loose or faulty tubing and connection.	Tighten, repair, or replace as necessary.
	Boots torn or punctured.	Repair faulty boots.
	Faulty electronic timer.	Replace timer.

FIGURE 7–7. Troubleshooting pneumatic deicing systems.

of the deicer boot system has led to the development of other methods of ice control, one of which is the thermal anti-icing system.

THERMAL ANTI-ICING SYSTEMS

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. However, electrically heated elements are also used for anti-icing and deicing airfoil leading edges.

There are several methods used to provide heated air. These include bleeding hot air from the turbine compressor, engine exhaust heat exchangers, and ram air heated by a combustion heater.

In installations where protection is provided by preventing the formation of ice, heated air is supplied continuously to the leading edges as long as the anti-icing system is "on." When a system is designed to deice the leading edges, much hotter air is supplied for shorter periods on a cyclic system.

The systems incorporated in some aircraft include an automatic temperature control. The temperature is maintained within a predetermined range by mixing heated air with cold air.

A system of valves is provided in some installations to enable certain parts of the anti-icing system to be shut off. In the event of an engine failure these valves also permit supplying the entire anti-icing system with heated air from one or more of the remaining engines. In other installations the valves are arranged so that when a critical portion of the wing has been deiced, the heated air can be diverted to a less critical area to clear it of ice. Also, should icing conditions of unusual severity be encountered, the entire flow of air can be directed to the most critical areas.

The portions of the airfoils which must be protected from ice formation are usually provided with a closely spaced double skin (see figure 7–8). The heated air carried through the ducting is passed into the gap. This provides sufficient heat to the outer skin to melt the layer of ice next to the skin or to prevent its formation. The air is then exhausted to the atmosphere at the wing tip or at points where ice formation could be critical; for example, at the leading edge of control surfaces.

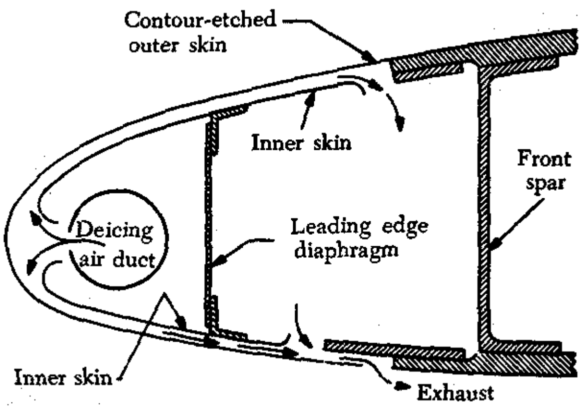

FIGURE 7–8. A typical heated leading edge.

When the air is heated by combustion heaters, usually one or more heaters are provided for the wings. Another heater is located in the tail area to provide hot air for the leading edges of the vertical and horizontal stabilizers.

When the engine is the source of heat, the air is routed to the empennage through ducting which is usually located under the floor.

Anti-Icing Using Combustion Heaters

Anti-icing systems using combustion heaters usually have a separate system for each wing and the empennage. A typical system of this type has the required number of combustion heaters located in each wing and in the empennage. A system of ducting and valves controls the airflow.

The anti-icing system is automatically controlled by overheat switches, thermal cycling switches, a balance control, and a duct pressure safety switch. The overheat and cycling switches allow the heaters to operate at periodic intervals, and they also stop heater operation completely if overheating occurs. A complete description of combustion heaters and their operation is discussed in Chapter 14, Cabin Atmosphere Control Systems, of this handbook. The balance control is used to maintain equal heating in both wings. The duct pressure safety switch interrupts the heater ignition circuits if ram air pressure falls below a specified amount. This protects the heaters from overheating when not enough ram air is passing through.

An airflow diagram of a typical wing and empennage anti-icing system using combustion heaters is shown in figure 7–9.

Anti-Icing Using Exhaust Heaters

Anti-icing of the wing and tail leading edges is accomplished by a controlled flow of heated air from heat muffs around a reciprocating engine's tail pipe. In some installations this assembly is called an augmentor. As illustrated in figure 7–10, an adjustable vane in each augmentor aft section can be controlled through a range of positions from closed to open. Partially closing each vane restricts the flow of cooling air and exhaust gases. This causes the temperature to rise in the heat muff forward of the vane. This provides a source of heat for the anti-icing system.

Normally, heated air from either engine supplies the wing leading edge anti-icing system in the same wing section. During single engine operation, a crossover duct system interconnects the left and right wing leading edge ducts. This duct supplies heated air to the wing section normally supplied by the inoperative engine. Check valves in the crossover duct prevent the reverse flow of heated air and also prevent cold air from entering the anti-icing system from the inoperative engine.

Figure 7–11 is a schematic of a typical anti-icing system that uses exhaust heaters. Note that, normally, the wing and tail anti-icing system is controlled electrically by operating the heat anti-ice button. When the button is in the "off" position, the outboard heat source valves and the tail anti-ice valve are closed. While the anti-ice system is off, the inboard heat source valves are controlled by the cabin temperature control system. Furthermore the augmentor vanes can be controlled by the augmentor vane switch.

Pushing the heat anti-ice button to the "on" position opens the heat source valves and the tail anti-icing valve. A holding coil keeps the button in the "on" position. In addition, the augmentor vane control circuits are automatically armed. The vanes can be closed by positioning the augmentor vane switch

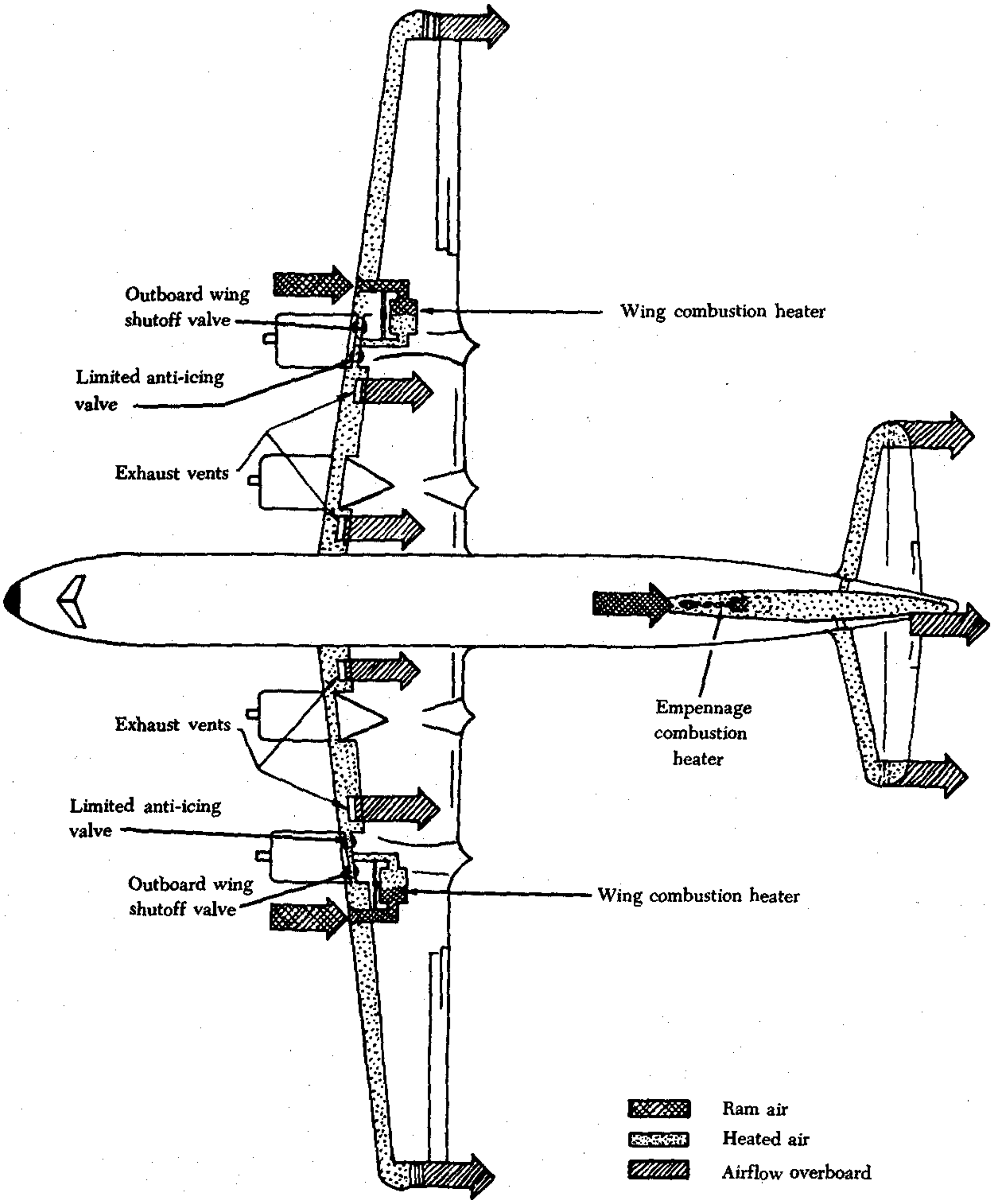

FIGURE 7–9. Airflow diagram of a typical anti-icing system.

to "close." This provides for maximum heat from the system. A safety circuit, controlled by thermostatic limit switches (not shown) in the anti-icing system ducts, releases the anti-ice button to the "off" position whenever a duct becomes overheated. When overheating occurs, the heat source valves and the tail anti-icing shutoff valve close and the augmentor vanes go to the trail (open) position.

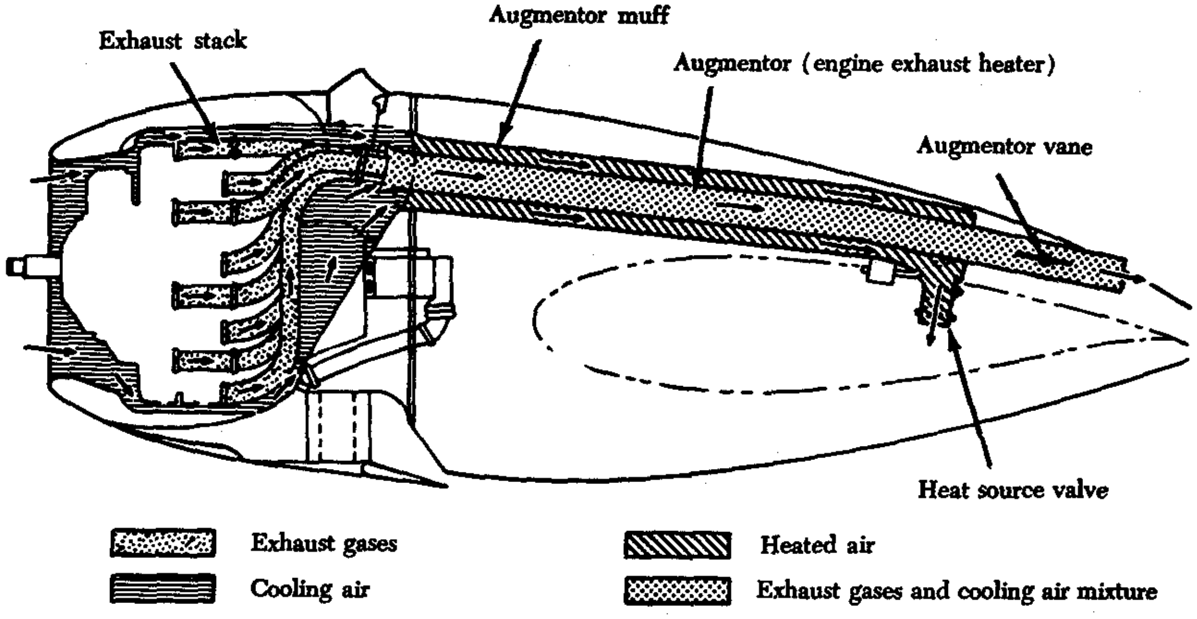

FIGURE 7–10. Heat source for thermal anti-icing system.

The heat source valves can be closed manually by the manual heat anti-ice shutoff handle. Manual operation may be necessary if the electrical control circuits for the valves fail. In this system, the handle is connected to the valves by a cable system and clutch mechanism. Once the heat source valves have been operated manually, they cannot be operated electrically until the manual override system is re-set. Most systems provide for re-setting of the manual override system in flight.

Anti-Icing Using Engine Bleed Air

Heated air for anti-icing is obtained by bleeding air from the engine compressor. The reason for the use of such a system is that relatively large amounts of very hot air can be tapped off the compressor, providing a satisfactory source of anti-icing and deicing heat.

A typical system of this type is shown in figure 7–12. This system is divided into six sections. Each section includes (1) a shutoff valve, (2) a temperature indicator, and (3) an overheat warning light.

The shutoff valve for each anti-icing section is a pressure regulating type. The valve controls the flow of air from the bleed air system to the ejectors, where it is ejected through small nozzles into mixing chambers. The hot bleed air is mixed with ambient air. The resultant mixed air at approximately 350° F. flows through passages next to the leading edge skin. Each of the shutoff valves is pneumatically actuated and electrically controlled. Each shutoff valve acts to stop anti-icing and to control airflow when anti-icing is required. A thermal switch connected to the control solenoid of the shutoff valve causes the valve to close and shut off the flow of bleed air when the temperature in the leading edge reaches approximately 185° F. When the temperature drops, the valve opens, and hot bleed air enters the leading edge.

The temperature indicator for each anti-icing section is located on the anti-icing control panel. Each indicator is connected to a resistance-type temperature bulb located in the leading edge area. The temperature bulb is placed so that it senses the temperature of the air in the area aft of the leading edge skin, not the hot air passed next to the skin.

Overheat warning systems are provided to protect the aircraft structure from damage due to excessive heat. If the normal cyclic system fails, temperature sensors operate to open the circuit controlling the anti-ice shutoff valves. The valves close pneumatically to shut off the flow of hot air.

PNEUMATIC SYSTEM DUCTING

The ducting usually consists of aluminum alloy, titanium, stainless steel, or molded fiber glass tubes.

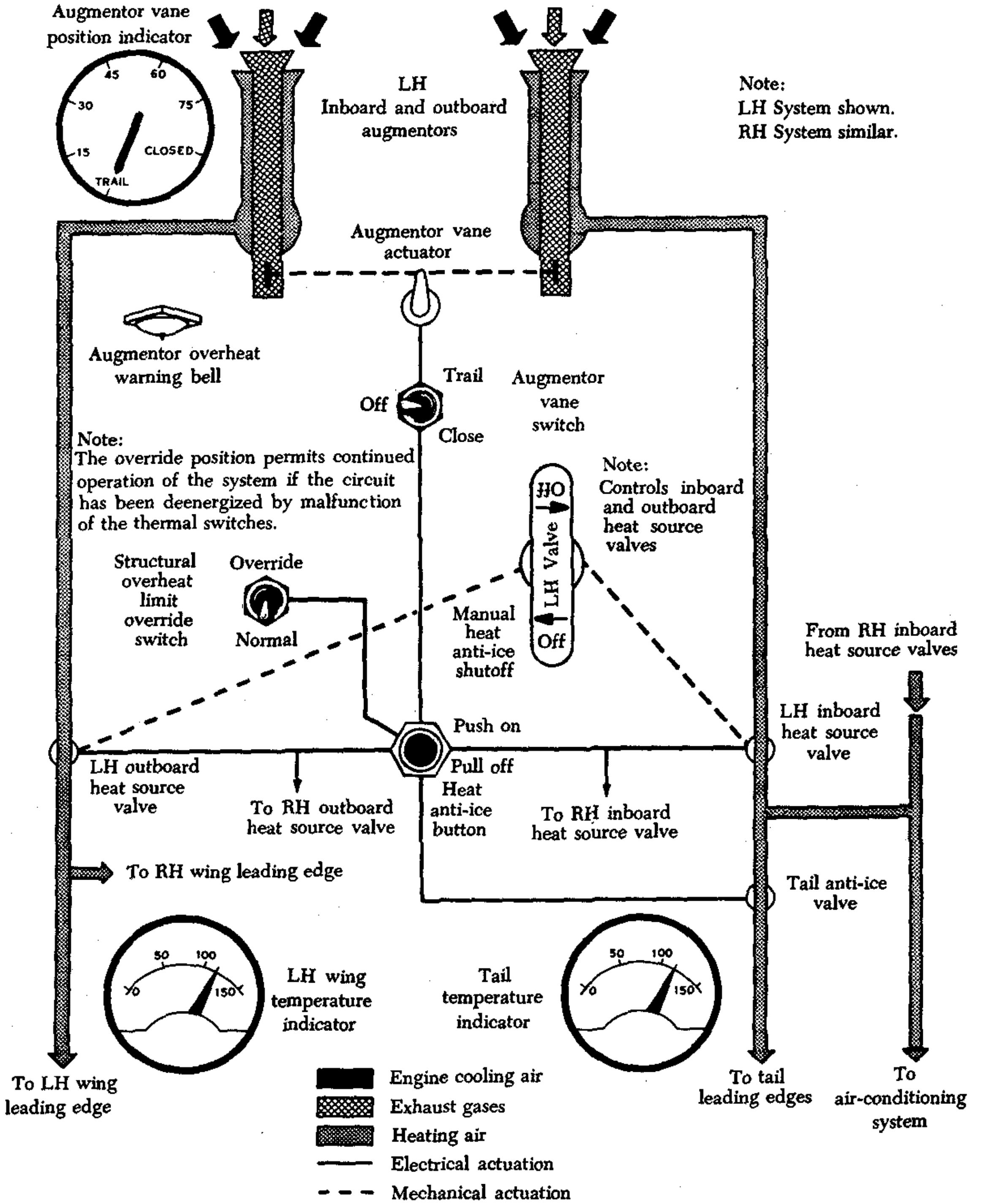

FIGURE 7-11. Wing and tail anti-icing system schematic.

The tube, or duct, sections are attached to each other by bolted end flanges or by band-type vee-clamps. The ducting is lagged with a fire-resistant, heat insulating material, such as fiber glass.

In some installations the ducting is interposed with thin stainless steel expansion bellows. These

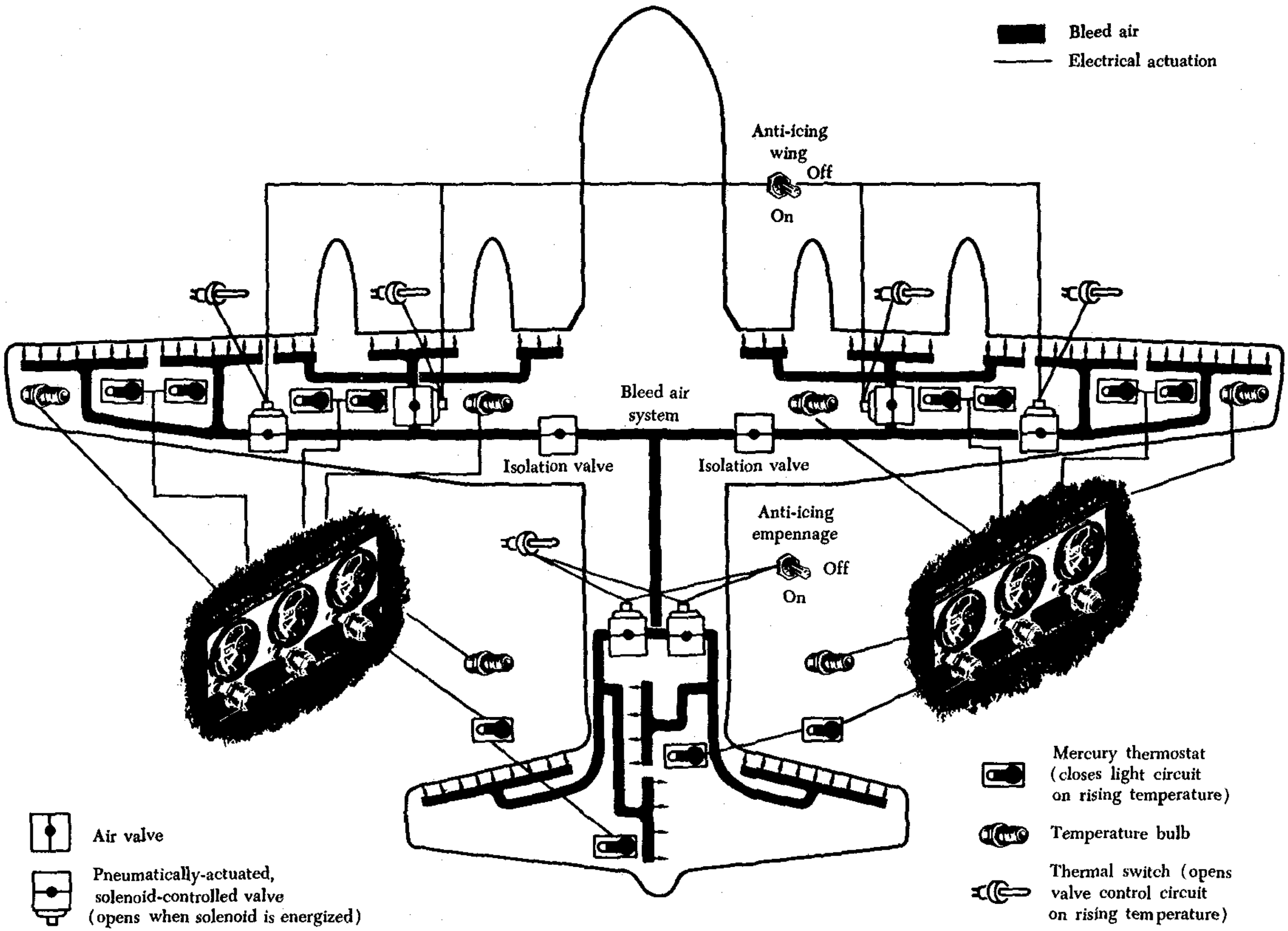

FIGURE 7-12. Schematic of a typical thermal anti-icing system.

bellows are located at strategic positions to absorb any distortion or expansion of the ducting which 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. Pressure testing is particularly important with pressurized aircraft, since a leak in the ducting may result in the inability to maintain cabin pressure. However, pressure tests are more often made to detect defects in the duct which would permit the escape of heated air. The rate of leakage at a given pressure should not exceed that recommended in the aircraft maintenance or service 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.

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.

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

When aircraft are hangared to melt snow or frost, any melted snow or ice may freeze again if the aircraft is subsequently moved into subzero temperatures. Any measures taken to remove frozen deposits while the aircraft is on the ground must also prevent the possible re-freezing 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 hrs. of flight.

Deicing fluids may adversely affect windows or the exterior finish of the aircraft. Therefore, only the type of fluid recommended by the aircraft manufacturer should be used.

Removing Ice and Snow Deposits

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 brush or squeegee. Use care to avoid damage to antennas, vents, stall warning devices, vortex generators, etc., which may be concealed by the snow.

Light, dry snow in subzero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment.

Moderate or heavy ice and residual snow deposits should be removed with a deicing fluid. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of deicing operations, inspect the aircraft to ensure that its condition is satisfactory for flight. All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control gaps and hinges. Check the drain and pressure sensing ports for obstructions. When it becomes necessary to physically remove a layer of snow, all protrusions and vents should be examined for signs of damage.

Control surfaces should be moved to ascertain that they have full and free movement. The landing gear mechanism, doors, and bay, and wheel brakes should be inspected for snow or ice deposits and the operation of uplocks 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.

WINDSHIELD ICING CONTROL SYSTEMS

In order to keep window areas free of ice, frost, etc., window anti-icing, deicing, defogging, and demisting systems are used. The systems vary according to the type of aircraft and its manufacturer. Some windshields are built with double panels having a space between, which will allow the circulation of heated air between the surfaces to control icing and fogging. Others use windshield wipers and anti-icing fluid which is sprayed on.

One of the more common methods for controlling ice formation and fog on modern aircraft windows is the use of an electrical heating element built into the window. When this method is used with pressurized aircraft, a layer of tempered glass gives strength to withstand pressurization. A layer of transparent conductive material (stannic oxide) is the heating element and a layer of transparent vinyl plastic adds a nonshattering quality to the window. The vinyl and glass plies (figure 7–13) are bonded by the application of pressure and heat. The bond is achieved without the use of a cement as vinyl has a natural affinity for glass. The conductive coating dissipates static electricity from the windshield in addition to providing the heating element.

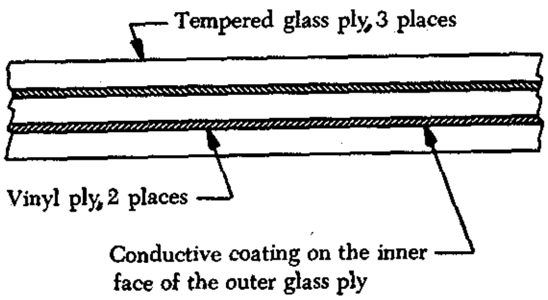

FIGURE 7–13. Section through a laminated windshield.

On some aircraft, thermal electric switches automatically turn the system on when the air temperature is low enough for icing or frosting to occur. The system may stay on all the time during such temperatures, or on some aircraft it may operate with a pulsating on-and-off pattern. Thermal overheat switches automatically turn the systems off in case of an overheating condition which could damage the transparent area.

An electrically heated windshield system includes:

(1) Windshield autotransformers and heat control relays.
(2) Heat control toggle switches.
(3) Indicating lights.
(4) Windshield control units.
(5) Temperature-sensing elements (thermistors) laminated in the panel.

A typical system is shown in figure 7–14. The system receives power from the 115 v. a.c. buses through the windshield heat control circuit breakers. When the windshield heat control switch is set to "high," 115 v., 400 Hz a.c. is supplied to the left and right amplifiers in the windshield control unit.

The windshield heat control relay is energized, thereby applying 200 v., 400 Hz a.c. to the windshield heat autotransformers. These transformers provide 218 v. a.c. power to the windshield heating current bus bars through the windshield control unit relays. The sensing element in each windshield has a positive temperature coefficient of resistance and forms one leg of a bridge circuit. When the windshield temperature is above calibrated value, the sensing element will have a higher resistance value than that needed to balance the bridge. This decreases the flow of current through the amplifiers and the relays of the control unit are de-energized. As the temperature of the windshield drops, the resistance value of the sensing elements also drops and the current through the amplifiers will again reach sufficient magnitude to operate the relays in the control unit, thus energizing the windshield heaters.

When the windshield heat control switch is set to "low," 115 v., 400 Hz a.c. is supplied to the left and right amplifiers in the windshield control unit and to the windshield heat autotransformers. In this condition, the transformers provide 121 v. a.c. power to the windshield heating current bus bars through the windshield control unit relays. The sensing elements in the windshield operate in the same manner as described for high-heat operation to maintain proper windshield temperature control.

The temperature control unit contains two hermetically sealed relays and two three-stage electronic amplifiers. The unit is calibrated to maintain a windshield temperature of 40° – 49° C. (105° – 120° F.). The sensing element in each windshield panel has a positive temperature coefficient of resistance and forms one leg of a bridge which controls the flow of current in its associated ampli-

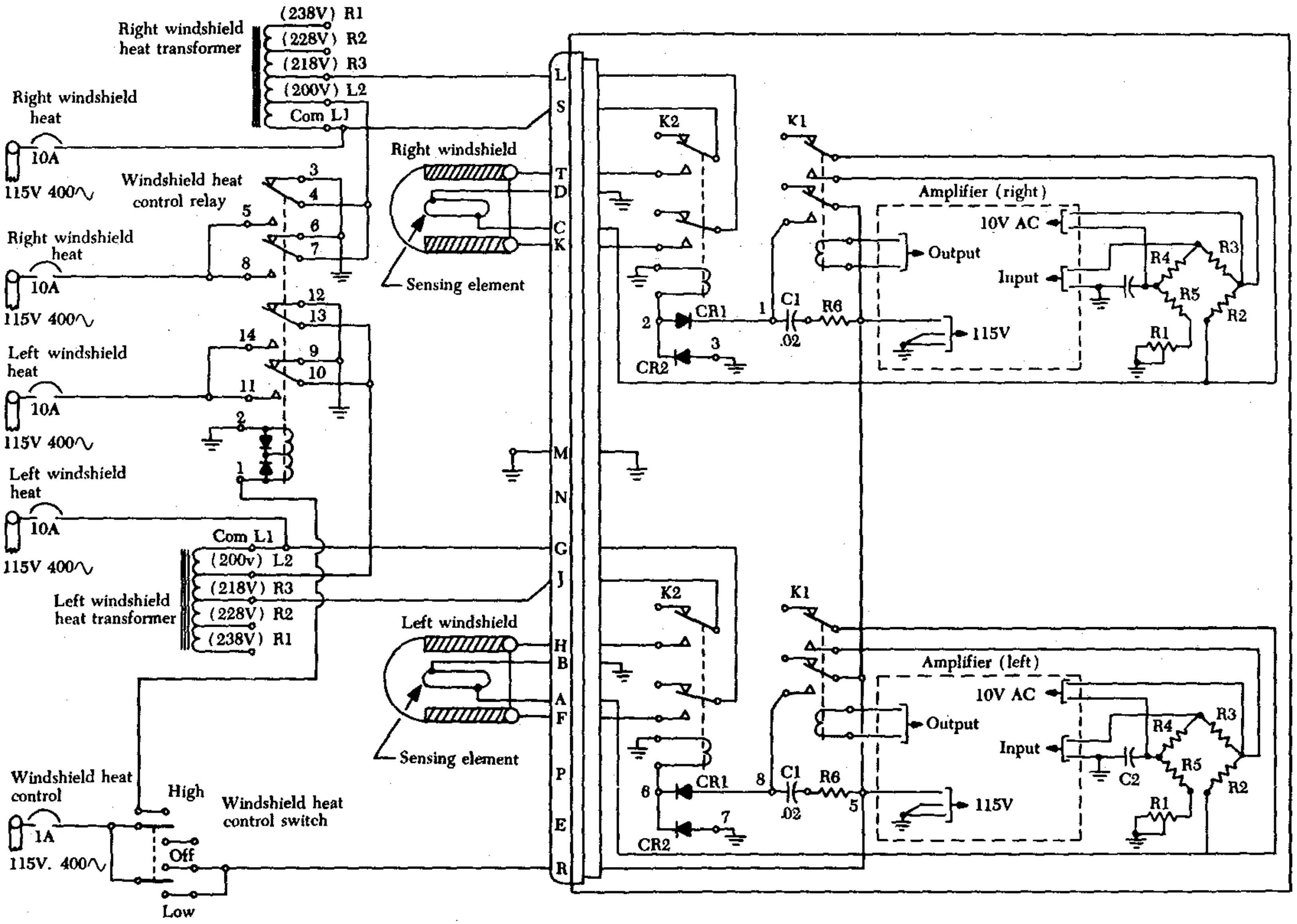

FIGURE 7–14. Windshield temperature control circuit.

fier. The final stage of the amplifier controls the hermetically sealed relay which provides a.c. power to the windshield heating current bus bars. When the windshield temperature is above calibrated value, the sensing elements will have a higher resistance value than that needed to balance the bridge. This decreases the flow of current through the amplifiers and the relays of the control unit are de-energized. As the temperature of the windshield drops, the resistance value of the sensing elements also drops and the current through the amplifiers will again reach sufficient magnitude to operate the relays in the control unit, thus energizing the circuit.

There are several problems associated with electrically heated windshields. These include delamination, scratches, arcing, and discoloration.

Delamination (separation of the plies) although undesirable, is not harmful structurally provided it is within the limits established by the aircraft manufacturer, and is not in an area where it affects the optical qualities of the panel.

Arcing in a windshield panel usually indicates that there is a breakdown in the conductive coating. Where chips or minute surface cracks are formed in the glass plies, simultaneous release of surface compression and internal tension stresses in the highly tempered glass can result in the edges of the crack and the conductive coating parting slightly. Arcing is produced where the current jumps this gap, particularly where these cracks are parallel to the window bus bars. Where arcing exists, there is invariably a certain amount of local overheating which, depending upon its severity and location, can cause further damage to the panel. Arcing in the vicinity of a temperature-sensing element is a particular problem since it could upset the heat control system.

Electrically heated windshields are transparent to directly transmitted light but they have a distinctive color when viewed by reflected light. This color will vary from light blue, yellow tints, and light pink depending upon the manufacturer of the window panel. Normally, discoloration is not a problem unless it affects the optical qualities.

Windshield scratches are more prevalent on the outer glass ply where the windshield wipers are indirectly the cause of this problem. Any grit trapped by a wiper blade can convert it into an extremely effective glass cutter when the wiper is set in motion. The best solution to scratches on the windshield is a preventive one; clean the windshield wiper blades as frequently as possible. Incidentally, windshield wipers should never be operated on a dry panel, since this increases the chances of damaging the surface.

Assuming that visibility is not adversely affected, scratches or nicks in the glass plies are allowed within the limitations set forth in the appropriate service or maintenance manuals. Attempting to improve visibility by polishing out nicks and scratches is not recommended. This is because of the unpredictable nature of the residual stress concentrations set up during the manufacture of tempered glass. Tempered glass is stronger than ordinary annealed glass due to the compression stresses in the glass surface which have to be overcome before failure can occur from tension stresses in the core. Polishing away any appreciable surface layer can destroy this balance of internal stresses and can even result in immediate failure of the glass.

Determining the depth of scratches has always presented some difficulty. An optical micrometer can be used for this purpose. It is essentially a microscope supported on small legs rather than the more familiar solid base mounting. When focused on any particular spot, the focal length of the lens (distance from the lens to the object) can be read from a micrometer scale on the barrel of the instrument. The depth of a scratch or fissure in a windshield panel, for example, can thus be determined by obtaining focal length readings to the surface of the glass and to the bottom of the scratch. The difference between these two readings gives the depth of the scratch. The optical micrometer can be used on flat, convex, and concave surfaces of panels whether they are installed on the aircraft or not.

Window Defrost System

The window defrost system directs heated air from the cabin heating system (or from an auxiliary heater, depending on the aircraft) to the pilot's and copilot's windshield and side windows by means of a series of ducts and outlets. In warm weather when heated air is not needed for defrosting, the system can be used to defog the windows. This is done by blowing ambient air on the windows using the blowers.

Windshield and Carburetor Alcohol Deicing Systems

An alcohol deicing system is provided on some aircraft to remove ice from the windshield and the carburetor. Figure 7–15 illustrates a typical two-engine system in which three deicing pumps (one for each carburetor and one for the windshield) are used. Fluid from the alcohol supply tank is controlled by a solenoid valve which is energized when any of the alcohol pumps are on. Alcohol flow from the solenoid valve is filtered and directed to the alcohol pumps and distributed through a system of plumbing lines to the carburetors and windshield.

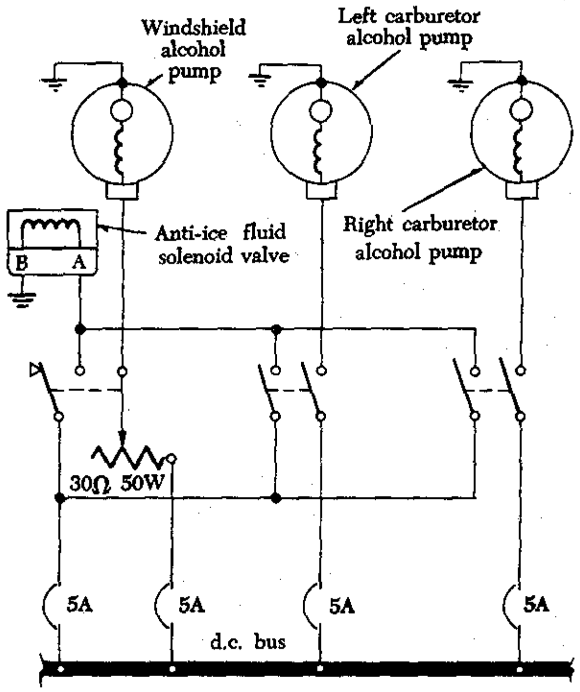

FIGURE 7–15. Carburetor and windshield deicing system.

Toggle switches control the operation of the carburetor alcohol pumps. When the switches are placed in the "on" position, the alcohol pumps are turned on and the solenoid-operated alcohol shutoff valve is opened. Operation of the windshield deicer pump and the solenoid-operated alcohol shutoff valve is controlled by a rheostat-type switch, located in the pilot's station. When the rheostat is moved away from the "off" position, the shutoff valve is opened and the alcohol pump will pump fluid to the windshield at the rate selected by the rheostat. When the rheostat is returned to the "off" position, the shutoff valve closes and the pump stops operating.

Pitot Tube Anti-Icing

To prevent the formation of ice over the opening in the pitot tube, a built-in electric heating element is provided. A switch, located in the cockpit, controls power to the heater. Use caution when ground checking the pitot tube since the heater must not be operated for long periods unless the aircraft is in flight. Additional information concerning pitot tubes is found in Chapter 2 of this handbook, Aircraft Instrument Systems.

Heating elements should be checked for functioning by ensuring that the pitot head begins to warm up when power is applied. If an ammeter or loadmeter is installed in the circuit, the heater operation can be verified by noting the current consumption when the heater is turned on.

WATER AND TOILET DRAIN HEATERS

Heaters are provided for toilet drain lines, water lines, drain masts, and waste water drains when they are located in an area that is subjected to freezing temperatures in flight. The types of heaters used are integrally heated hoses, ribbon, blanket, or patch heaters that wrap around the lines, and gasket heaters (see figure 7–16). Thermostats are provided in heater circuits where excessive heating is undesirable or to reduce power consumption. The heaters have a low voltage output and continuous operation will not cause overheating.

RAIN ELIMINATING SYSTEMS

When rain forms on a windshield during flight, it becomes a hazard and must be eliminated. To provide a clear windshield, rain is eliminated by wiping it off or blowing it off. A third method of rain removal involves chemical rain repellants. Rain is blown from the windshield of some aircraft by air from jet nozzles located beneath the windshield. On other aircraft, windshield wipers are used to eliminate the rain. The windshield wipers of an aircraft accomplish the same function as those of an automobile. In each instance, rubber blades wipe across the windshield to remove rain and slushy ice.

Electrical Windshield Wiper Systems

In an electrical windshield wiper system, the wiper blades are driven by an electric motor(s) which 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.

Figure 7–17 shows a typical electrical windshield wiper installation. An electrically operated wiper is installed on each windshield panel. Each wiper is driven by a motor-converter assembly. The converters change the rotary motion of the motor to reciprocating motion to operate the wiper arms. A shaft protruding from the assembly provides an attachment for the wiper arm.

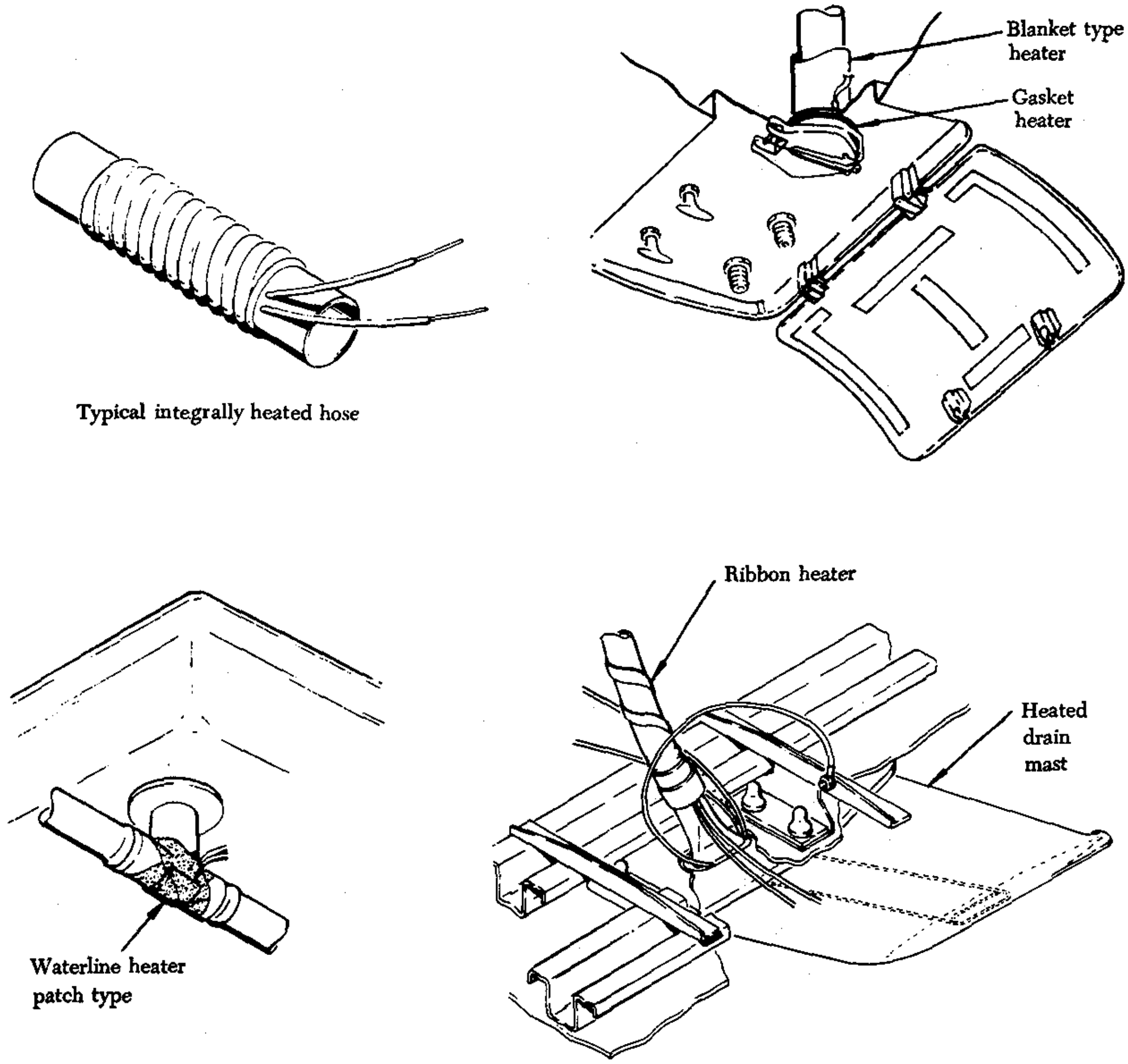

FIGURE 7-16. Typical water and drain line heaters.

The windshield wiper is controlled by setting the wiper control switch to the desired wiper speed. When the "high" position is selected (figure 7-18), relays 1 and 2 are energized. With both relays energized, field 1 and field 2 are energized in parallel. The circuit is completed and the motors operate at an approximate speed of 250 strokes per minute. When the "low" position is selected, relay 1 is energized. This causes field 1 and field 2 to be energized in series. The motor then operates at approximately 160 strokes per minute. Setting the switch to the "off" position, allows the relay contacts to return to their normal positions. However, the wiper motor will continue to run until the wiper arm reaches the "park" position. When both relays are open and the park switch is closed, the excitation to the motor is reversed. This causes the wiper to move off the lower edge of the windshield, opening the cam-operated park switch. This de-energizes the motor and releases the brake solenoid applying the brake. This ensures that the motor will not coast and re-close the park switch.

Hydraulic Windshield Wiper Systems

Hydraulic windshield wipers are driven by pressure from the aircraft's main hydraulic system. Figure 7-19 shows the components making up a representative hydraulic windshield wiper system.

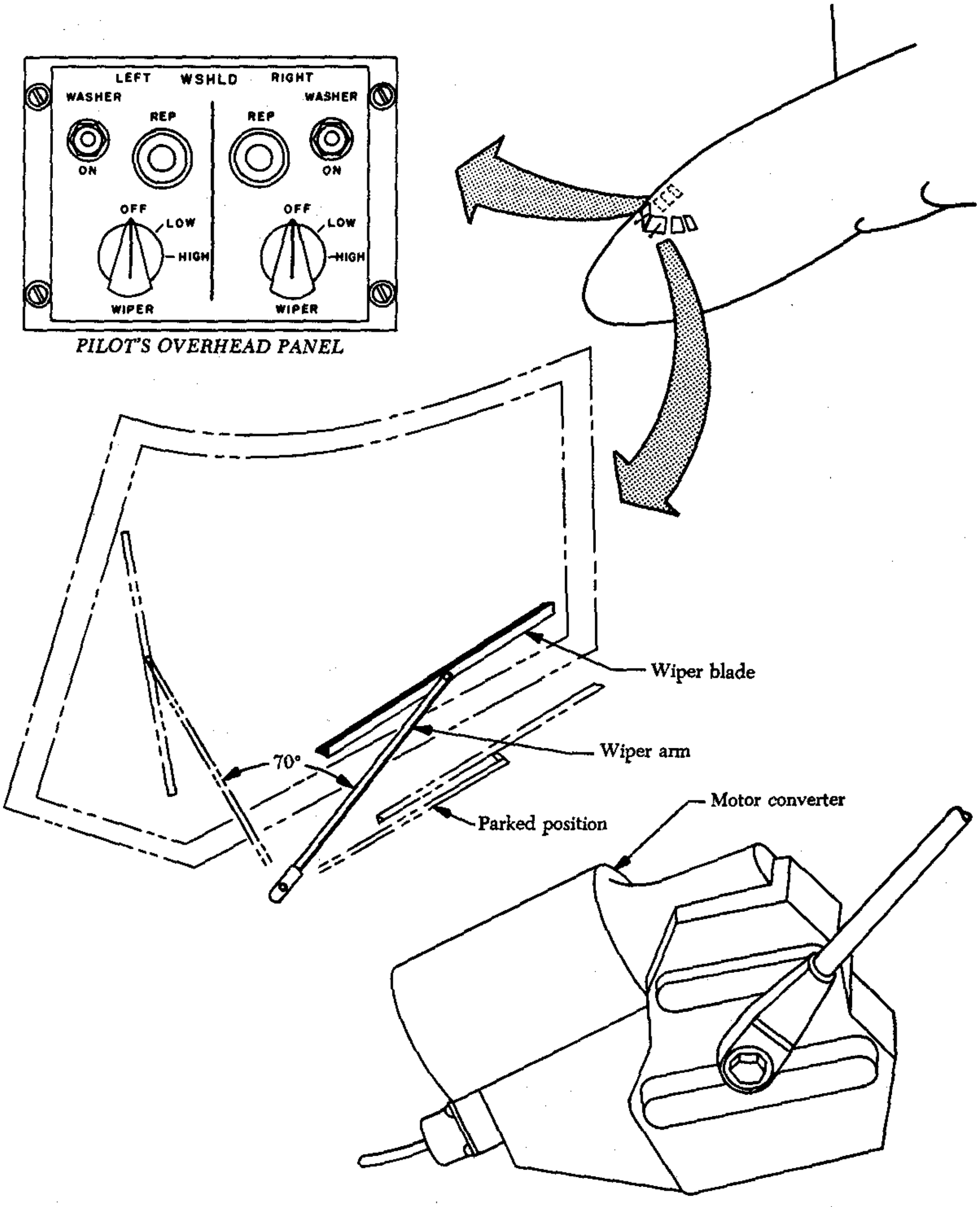

FIGURE 7–17. Electrical windshield wiper system.

The speed control valve is used to start, stop, and control the operating speed of the windshield wipers. The speed control valve is a type of variable restrictor. Turning the handle of this valve counterclockwise increases the size of the fluid opening, the flow of fluid to the control unit, and therefore the speed of the windshield wipers.

The control unit directs the flow of hydraulic fluid to the wiper actuators and returns fluid discharged from the actuators to the main hydraulic

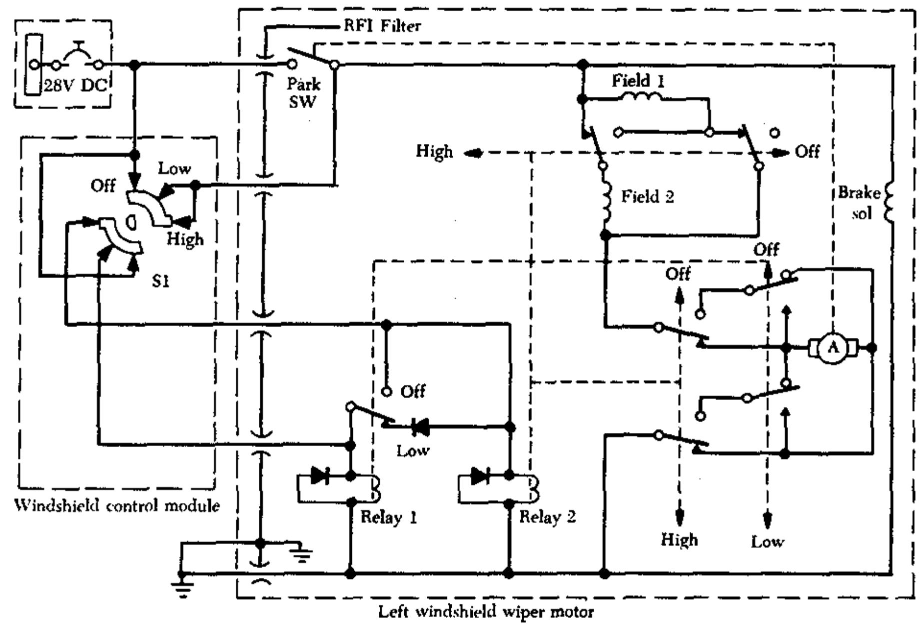

FIGURE 7–18. Windshield wiper circuit diagram.

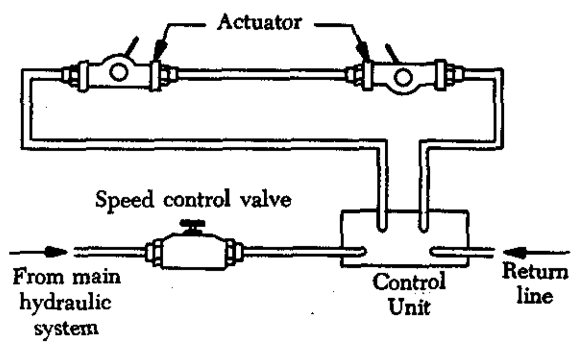

FIGURE 7–19. Hydraulic windshield wiper schematic.

system. The control unit also alternates the direction of hydraulic fluid flow to each of the two wiper actuators. The wiper actuators convert hydraulic energy into reciprocating motion to drive the wiper arms back and forth.

Figure 7–20 shows the construction and the plumbing of the actuators. Notice that each actuator consists of a two-port housing, a piston rack, and a pinion gear. The teeth of the pinion gear mesh with those on the piston rack. Thus, whenever pressurized fluid enters the actuator and moves the piston rack, the pinion gear is rotated a fraction of a turn. Since the pinion gear connects through a shaft to the wiper blade, the blade rotates through an arc. Notice that one line from the control unit connects to port No. 1 of actuator A, while the other line connects to port No. 4 of actuator B. Notice, toc that a line connects ports No. 2 and No. 3 of th actuators.

Turning on the speed control valve allows fluid to flow from the main hydraulic system into the control unit, which directs pressure first into one line and then into the other. When line No. 1 is placed under pressure, fluid flows into port No. 1 and into the chamber at the left of actuator A. This drives the piston rack to the right, causing the pinion and wiper blade to rotate through a counterclockwise arc. As the piston rack moves to the right, it forces fluid in the right chamber of actuator A to move out port No. 2, through the connecting line to port No. 3 and into actuator B. This causes the piston rack in actuator B to move to the right, causing its pinion and wiper blade to rotate counterclockwise. As the piston rack moves to the right, it forces fluid in the right chamber of actuator B to move out of

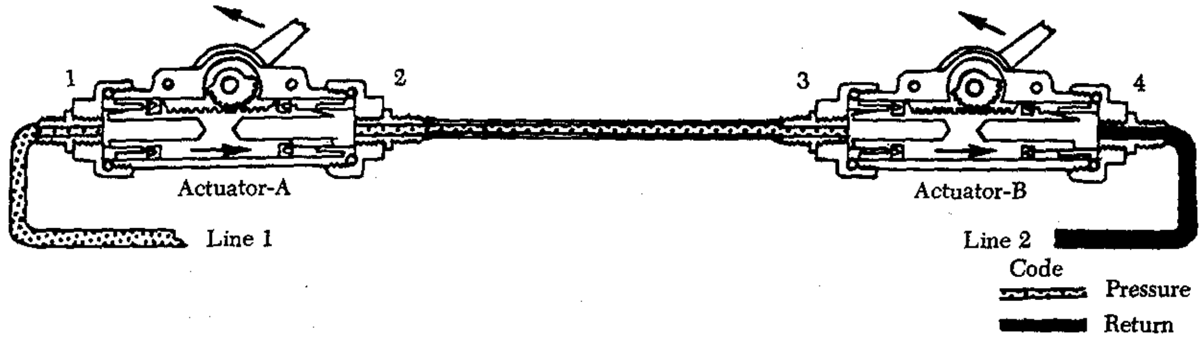

FIGURE 7–20. Windshield wiper actuators.

port No. 4, into line No. 2, through the control unit, and into the hydraulic system return line. When line No. 2 is pressurized by fluid from the control unit, the flow of fluid and the action of the actuators are reversed.

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.

With the advent of turbine-powered aircraft, the pneumatic rain removal system became feasible. This method uses high pressure, high temperature engine compressor bleed air which is blown across the windshields (figure 7–21). The air blast forms a barrier that prevents raindrops from striking the windshield surface.

Windshield Rain Repellant

When water is poured onto clean glass, it 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 which causes the water to behave very much like mercury on glass. The water draws up into beads which 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.

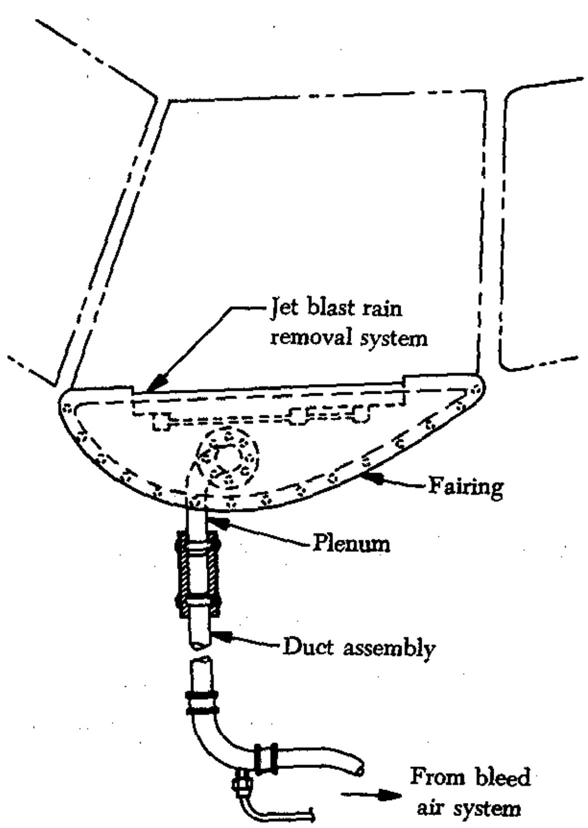

FIGURE 7–21. Typical pneumatic rain removal system.

A rain repellant system permits application of the chemical repellant by a switch or push button in the cockpit. The proper amount of repellant is applied regardless of how long the switch is held. The repellant is marketed in pressurized disposable cans which screw into the aircraft system and provide the propelling force for application. Actuating the control switch opens an electrically-operated solenoid valve which allows repellant to flow to the discharge nozzles. The liquid repellant is squirted onto the exterior of the windshield and uses the rain itself as the carrying agent to distribute the chemicals over the windshield surface.

The rain repellant system should not be operated on dry windows because heavy undiluted repellant will restrict window visibility. Should the system be operated inadvertently, do not operate the windshield wipers or rain clearing system as this tends to increase smearing. Also the rain repellant residues caused by application in dry weather or very light rain can cause staining or minor corrosion of the aircraft skin. To prevent this, any concentrated repellant or residue should be removed by a thorough fresh-water rinse at the earliest opportunity.

After application, the repellant film slowly deteriorates with continuing rain impingement. This makes periodic re-application necessary. The length of time between applications depends upon rain intensity, the type of repellant used, and whether windshield wipers are in use.

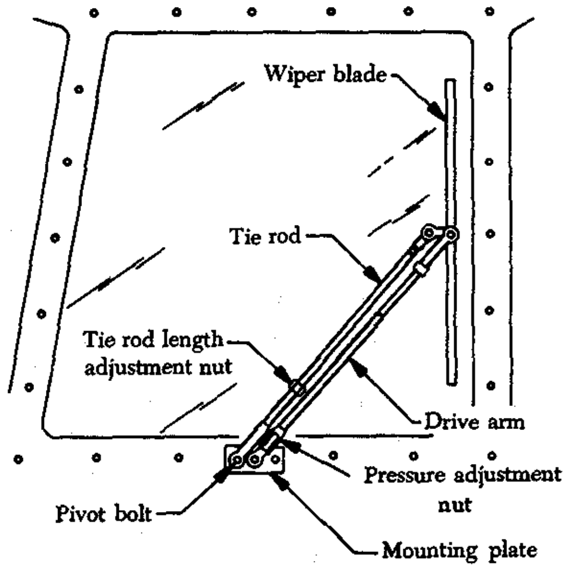

FIGURE 7–22. Adjustment of windshield wiper components.

MAINTENANCE OF RAIN ELIMINATING SYSTEMS

Windshield Wiper Systems

Maintenance performed on windshield wiper systems consists of operational checks, adjustments, and troubleshooting.

An operational check should be performed whenever a system component is replaced or whenever the system is suspected of not working properly. During the check, make sure that the windshield area covered by the wipers is free of foreign matter and is kept wet with water.

Adjustment of a windshield wiper system consists of adjusting the wiper blade tension, the angle at which the blade sweeps across the windshield, and proper parking of the wiper blades. Figure 7–22 illustrates the adjustment points on a typical wiper blade installation.

One adjustment is that of the tie rod length. The tie rod length adjustment nut is shown in figure 7–22. The tie rod connects the wiper blade holder to a pivot bolt next to the drive shaft. With the drive arm and the tie rod connected to the wiper blade holder, a parallelogram linkage is formed between the wiper blade holder and the wiper converter. This linkage permits the wiper blade to remain parallel to the windshield posts during its travel from one side of the windshield to the other. The length of the tie rod may be adjusted to vary the angle at which the wiper blade sweeps across the windshield.

Another adjustment is that which is required for proper parking of the windshield wiper blades. When they are not operating, the wiper blades should move to a position where they will not interfere with vision. If the wipers do not park as they should, the cam which actuates the microswitch on the converter can be adjusted.

The other adjustment to be made is that of the windshield wiper spring tension. To make the adjustment, place a lightweight spring scale under the drive arm at its point of attachment to the wiper blade, and lift the scale up at a 90° angle to the drive, to a point at which the blade is just ready to leave the glass. (If tension is properly adjusted, the spring scale should indicate between 5 and 6 lbs.) If the scale reading does not fall within this limit, adjust the pressure adjustment nut shown in figure 7–22 until the proper tension is indicated on the scale.

Pneumatic (Jet Blast) Systems

Maintenance of a jet blast system includes the replacement of defective components, the checking (by hand) of duct-to-valve connections for leakage, and an operational checkout.