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AIRFRAME AND SYSTEMS
CHAPTER 11: ICE AND RAIN PROTECTION SYSTEMS

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INTRODUCTION

Protection from the meteorological elements has been one of life's most fundamental challenges since the dawn of humanity. Aviation history is littered with all sorts of tragedies related to the weather. When the elements become nasty, the results can severely impair, if not completely negate, an aircraft's normal aerodynamic characteristics. Refer to figure 11-1.

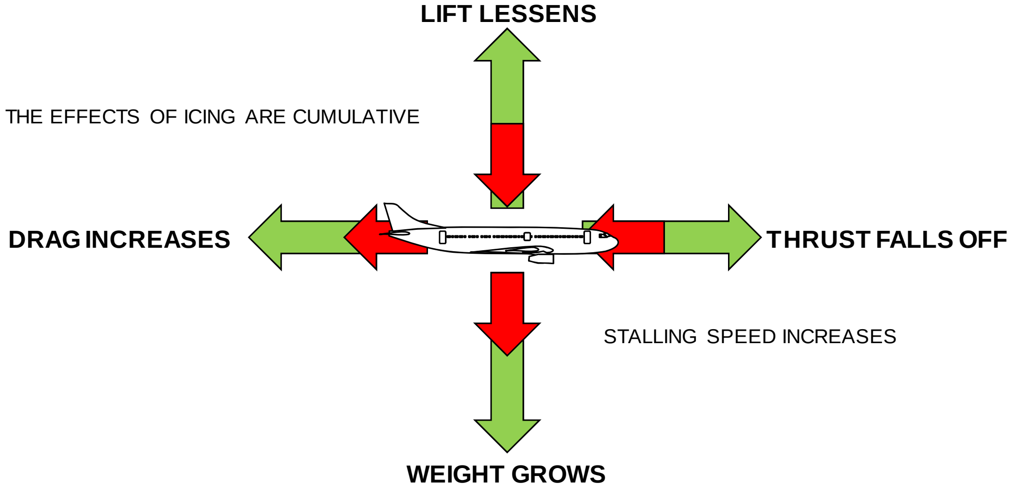


Figure 11-1 Effects of Icing

A thorough understanding of meteorological and weather phenomenon is essential for all aircrews, but even the best laid plans can go wrong and the aircraft will be exposed to the elements. How ice and rain protection systems work, and what they will and won't do for the crew is critical knowledge. This Chapter will describe the aircraft systems and ground procedures designed to protect the aircraft from;

- ice formation during flight,
- ice formation prior to take-off,
- loss of visibility due to rain, and
- loss of visibility due to internal fogging.

ICE FORMATION

Of all the elements, ice creates the greatest problems for an aircraft. It can severely effect aircraft performance as well as restrict handling characteristics. There are two main types of icing encountered during flight. They are;

- Rime ice, and
- Glaze or Clear ice.

Rime ice forms a rough surface. This is because the temperature is very cold and when tiny droplets of water contact aircraft surfaces they freeze immediately before they have a chance to spread out.

Glaze or Clear ice is formed when supercooled droplets of water come into contact with the airframe, part of the droplet freezing immediately to form ice. This formation will release latent heat and thus raise the temperature of the rest of the droplet. This can delay the freezing process until this droplet has flowed back over the wing to where it will become ice. This ice is clear like glass, very tough and it adheres strongly to the aircraft skin.

The amount of the droplet that freezes on impact is related to the temperature of the droplet and the amount of latent heat released, which is almost 80 calories per gram. Therefore the amount of the droplet that freezes on impact is about 1/80th for each 1°C below 0°C. Therefore if the droplet has a temperature of -10°C, 10/80th would freeze on impact whilst the remainder flows back to freeze over the airframe surface.

Clear ice will only form in clouds where the basic droplets are large and thus it occurs in Cumulus (Cu), Cumulonimbus (Cb) or Nimbostratus (Ns) where the temperatures are between 0°C and 20°C. It is a dangerous form of icing.

<u>Icing can be expected anywhere when there is visible moisture in the air and outside air temperatures of +10 °C or below.</u>

ICE FORMATION ON AIRCRAFT AND ENGINES

In general, ice formation occurs on the leading edges of structures that are part of the aircraft and components that protrude into the airflow. Depending on the operating speed of the aircraft and the relative airflow velocity over surfaces ice will not necessarily form at the same locations on all aircraft.

A small amount of ice can have a serious effect on aerodynamic qualities of an aerofoil, increasing drag and at the same time decreasing lift.

Icing can have a pronounced affect on aircraft antennae, ranging from mild interference with radio transmissions and navigation aids to actually breaking antennas off the airframe through vibration.

Control surfaces can freeze in one position or suffer a severe imbalance. Slots and slats can fill with ice or freeze in one position.

Engine inlets can freeze causing engine performance to deteriorate and in extreme cases to flame out, or worse still severe ice damage to the compressor making the engine useless and ensuring very costly repairs.

Ice on the windscreens can severely reduce visibility outside creating problems in all phases of flight.

The old adage "prevention is better than cure" is very relevant to icing. Prudent planning and the use of radar and weather patterns can prevent unannounced problems from the elements.

When the unavoidable happens and the aircraft must be flown in icing conditions the use of ice protection systems will enable aircraft and crew to complete its mission in relative safety.

ICE PROTECTION SYSTEMS

Aircraft ice protection systems fall into two basic groups. They are;

- Anti-icing systems, and
- De-icing systems.

Anti-icing Systems are designed to prevent the formation of ice on the surfaces that require protection. This is usually achieved by the application of heat, but can be done by other methods.

De-icing Systems are designed to allow ice to build up to a pre-determined level and then removed. This is usually achieved by the application of heat, but can be done by other methods. Refer to Figure 11-2.

Choosing the ice protection method depends on the operating speed of the aircraft and the design.

Fast jet swept wing aircraft normally use an ANTI-ICING system for wing leading edges. Because the leading edge is continuously heated, ice cannot form and the water droplets are forced off the wing surface by the high velocity airflow. Because of the relative airflow velocity most fast jet aircraft do not require ice protection for the empennage leading edges.

Some slower straight wing aircraft however, are normally fitted with a DE-ICING system to “trap the ice formation at the leading edge”. This stops further ice formation on the top and rear surfaces. When the ice has formed to a reasonable thickness it is “broken up” and pushed by the airflow off the wing. Most aircraft of this type do require ice protection for the empennage leading edges.

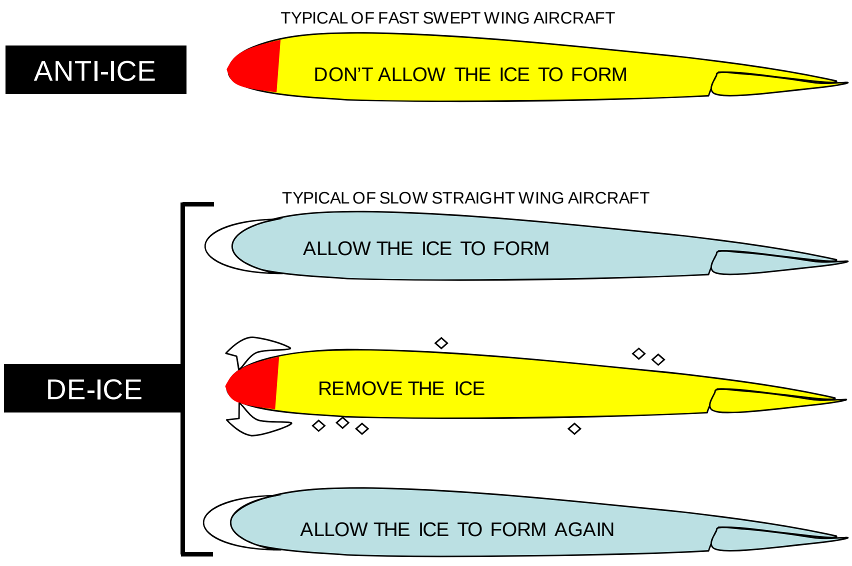


Figure 11-2 Anti-ice and De-ice Principle

The areas and components that are typically protected by an ANTI-ICE or a DE-ICE system are listed in Figures 11-4 and 11-5.

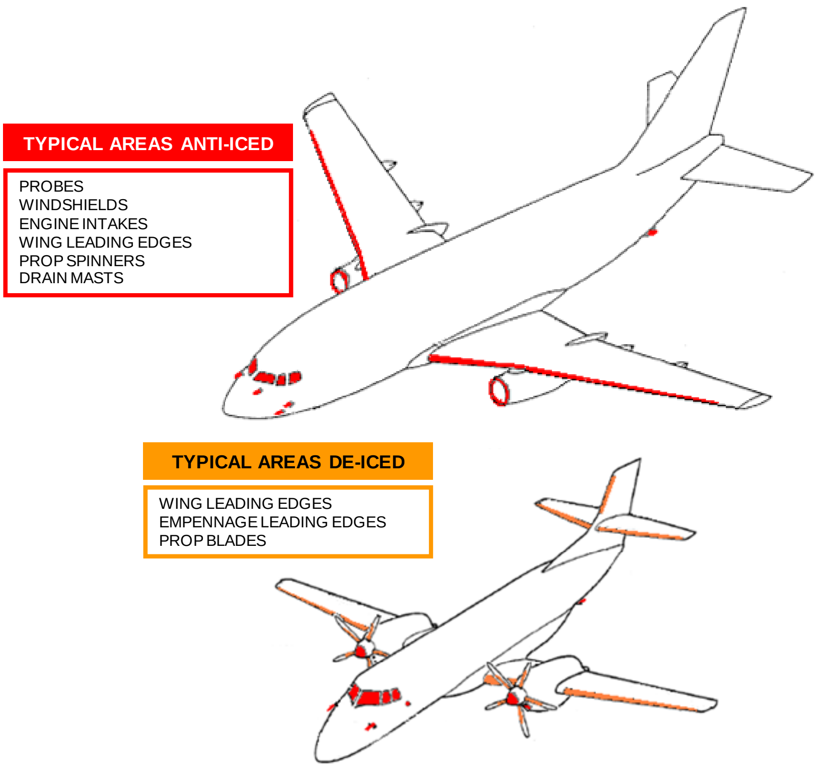


Figure 11-3 Typical Areas- Anti-iced and De-iced

STRUCTURE	LEADING EDGES	WINGS
		HORIZONTAL STABILISER
		VERTICAL STABILISER
COMPONENTS	WINDSHIELDS	FRONT
	PROBES	PITOT PROBES
		TAT PROBE
		ANGLE of ATTACK SENSOR
		STATIC PORTS
	DRAINS	WATER DRAINS
PISTON ENGINES	LEADING EDGES	SPINNER
		PROP BLADES
	COMPONENTS	CARBURETTOR
TURBOPROPS	LEADING EDGES	SPINNER
		PROP BLADES
		NACELLE INTAKES
		INLET GUIDE VANES
	COMPONENTS	PRESSURE PROBES
	STRUCTURE	INTAKE THROATS
JET ENGINES	LEADING EDGES	NACELLE INTAKES
		SPINNER
		STRUTS
		INLET GUIDE VANES
	COMPONENTS	EPR PROBE

Figure 11-4 Typical Areas that are Ice Protected

ICE DETECTION SYSTEMS

Medium to large multi-engine aircraft are fitted with some method of detecting the formation of ice and alerting the crew before it becomes a serious problem. There are many types of ice detection systems, the common types listed below. They are;

- Visual ice detectors,
- Hot rod ice detectors,
- Pressure operated ice detectors,
- Vibrating rod ice detectors, and
- Serrated rotor ice detectors.

Visual Ice Detectors are the simplest method of ice detection. There are numerous designs, ranging from a simple, strategically placed protrusion to observation of the windscreen wiper arms. Refer to Figure 11-5.

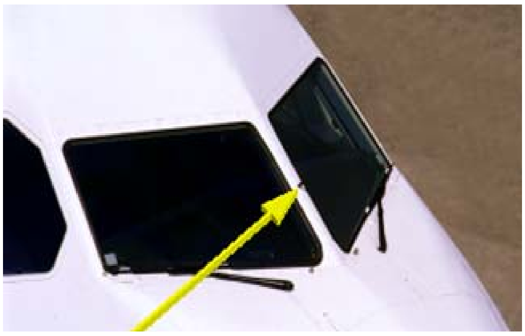


Figure 11-5 Visual Ice Detector on Airbus Aircraft

Hot Rod Ice Detectors are another form of a visual detector mounted horizontally on the side of the cockpit in easy view of the pilot. It contains an observation light for use at night and a heating element controlled from the cockpit. When icing conditions exist the pilot can observe the rate of ice formation on the detector and from experience judge the severity of icing. Switching the heater on and melting the ice allows for further observation. Refer to Figure 11-6.

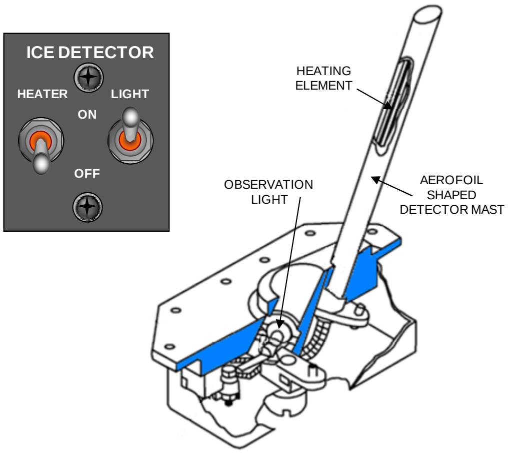


Figure 11-6 Hot Rod Ice Detector

Pressure operated Ice Detectors have a detector head mounted in the airflow, consisting of several calibrated holes through which air is allowed to pass. This air is allowed to escape through slightly smaller holes drilled in the rear of the detector head. A pressure build up occurs inside the detector, which is sensed by a pressure switch. The pressure switch is connected to the warning system on the flight deck.

The central passage of the detector contains an electrical heater coil that is also energised by the pressure switch. As ice builds up on the detector, the holes allowing air into the detector are reduced in size causing a pressure change inside the detector.

This is sensed by the pressure switch which illuminates a “ICING” light on the flight deck and switches the probe heater on.

The probe heater melts the ice in the inlet holes and the system resets itself until further icing is encountered. The frequency at which the light illuminates helps in the determination of the severity of the icing conditions. Refer to Figure 11-7.

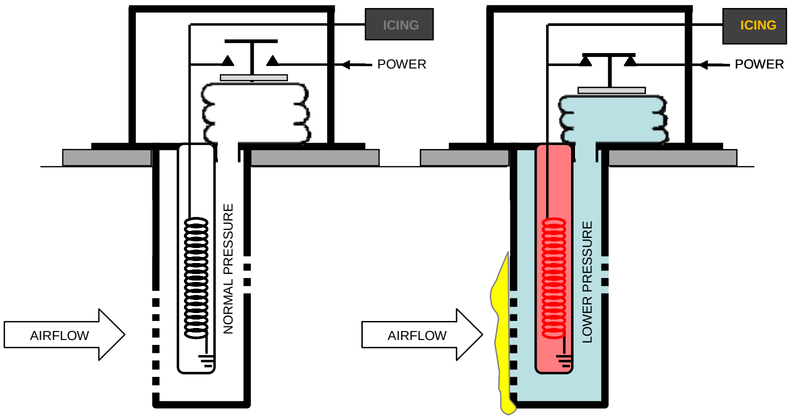


Figure 11-7 Pressure Operated Ice Detector

Vibrating Rod Ice Detectors use a probe which extends into the airstream which is mechanically vibrated at a predetermined frequency (approximately 40 Hertz). As ice builds up on the probe the vibration frequency is changed, and an electrical signal is generated to illuminate the light on the flight deck and energise the heater to melt the ice. Refer to Figure 11-8.

Figure 11-8 Vibrating Rod Ice Detector

Serrated Rotor Ice Detectors are constructed using a torque motor driving a serrated rotor which projects through the skin of the aircraft into the airflow.

A knife-edge cutter is placed next to the serrated rotor. As ice builds up on the serrated rotor the knife-edge scrapes the ice off.

The action of scaping the ice from the rotor creates an increased torque load on the motor, which causes a micro switch in the motor drive to actuate, bringing on a light on the flight deck.

The system incorporates a heater element which melts the ice on the serrated rotor and the cycle is repeated.

The frequency at which the light illuminates helps in the determination of the severity of the icing conditions. Refer to Figure 11-9.

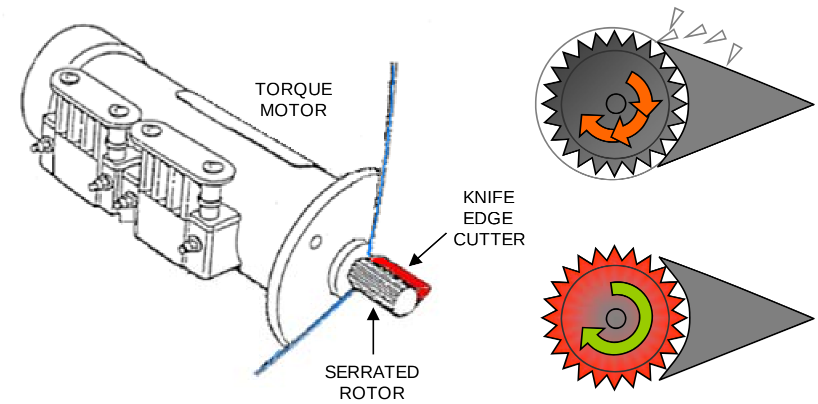


Figure 11-9 Serrated Rotor Ice Detector

Very modern aircraft will monitor the frequency of the icing cycles and alert the crew with a simple message such as; ICE DETECTED, SEVERE ICE DETECTED or ICE NOT DETECTED. Refer to Figure 11-10.

Figure 11-10 ECAM Alert for Icing

Generally speaking crews can anticipate and/or detect ice formation in the following ways;

- by observing the ambient conditions in which ice may form, (visible moisture with +10°C or less)
- by visually observing ice formation on aircraft structures (wiper blades),
- by observing changes in engine performance (erratic operation), and
- by responding to alerts provided by the aircraft's ice detecting system.

ICE PROTECTION METHODS

Depending on the design, size, engine type and availability of bleed air, aircraft may employ one or a combination of the following methods for ice protection. They are;

- mechanical,
- chemical, and
- thermal.

Mechanical systems are normally found on light to medium straight wing aircraft and are employed as DE-ICING systems. An example pneumatically operated mechanical system is described on the following page.

Chemical Systems are usually found on the same type of aircraft and are usually employed as ANTI-ICING systems. An example chemical system is described later in this Chapter.

Thermal Systems are most commonly found on medium to large aircraft and depending on the aircraft type may be employed as a DE-ICING or ANTI-ICING system. The thermal source for these systems may be from;

- bleed air,
- engine oil, or
- electrical power.

Examples of the common thermal systems will be described later in this Chapter.

MECHANICAL (PNEUMATIC BOOT) ICE PROTECTION SYSTEM

The common mechanical method of ice protection is the pneumatic boot system. De-icer boots are fitted to the leading edges and horizontal and vertical stabilisers of most small to medium sized commercial aircraft, particularly propeller driven aircraft. They are constructed of flat inflatable rubber tubes running parallel to the span of the wing, which are closed off at both ends, and then glued to the leading edge surfaces. The outer ply of some de-icer boots is made of neoprene, which provides additional protection from many chemicals and also provides protection from deterioration by the weather. It also provides a conductive coating which allows static electricity to dissipate, which if allowed to develop could discharge through the boot and cause static interference with radio equipment.

The inflatable rubber tubes lie flat against the leading edge when not in use, maintaining the aerofoil shape of the wing. When selected, the tubes inflate and break the ice away. The ice is then carried off in the airflow. Refer to Figure 11-11.

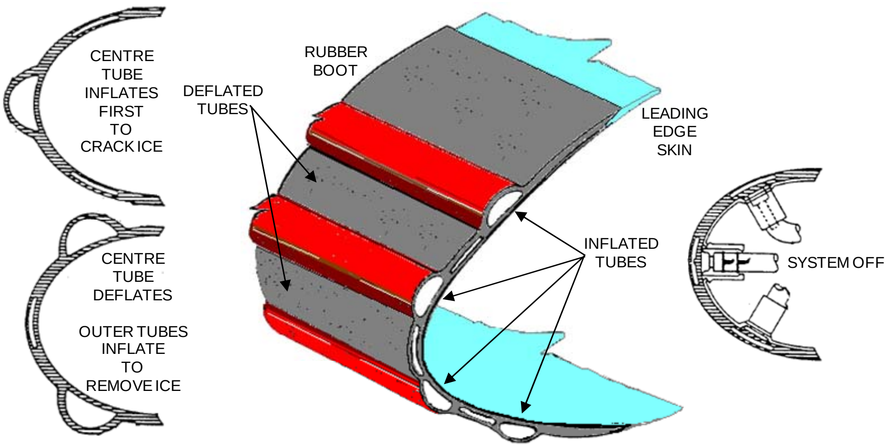


Figure 11-11 Pneumatic De-icer Boot

De-icer boots are normally made up of several individual boots rather than one long boot. As the tubes in the boots inflate they change the shape of the leading edge. If the whole leading edge were to be de-iced at once a serious loss of lift could be experienced, because of this change to the aerodynamic shape of the wing.

The compressed air to inflate the boots is usually provided by the engine compressor, and delivered to the wings through a manifold. A distribution valve is used to control the inflation sequence of the boots and a vacuum system is used to deflate the boot back to the shape of the leading edge.

The distribution valves are controlled by a cyclic timer. When the system is turned on, the de-icer port in the distributor valve is closed to vacuum. System operating pressure is then applied to the de-icers that are connected to that port. At the end of the inflation cycle, the de-icer boot pressure is shut off and the air in the de-icer boot flows overboard through the exhaust port. When the air flowing from the de-icers reaches a sufficiently low pressure, the exhaust port closes.

Vacuum is then re-applied to exhaust the remaining air from the de-icer. This cycling continues as long as the system is activated.

Flight deck controls and indications typically comprise of a control switch to select the system ON, which may have a high and low speed selection also. A gauge which indicates the relative suction and pressure values being applied to the de-icing boots is normally fitted, but may be replaced or supplemented by flashing operating lights.

Caution should be used when operating the system when close to the ground, as the actual shape of the leading edge is modified by the boots, and a serious loss of lift may be experienced. It should also be noted that due to the disturbance of the airflow over the wing, this system is not fitted to aircraft in the low relative power category. Refer to Figure 11-12.

The de-icer boots are susceptible to damage from all types of solvents, grease, knocks and abrasions and exposure to direct sunlight. The following will aid in the protection of the boots;

- do not drag fuel hoses over the de-icer boots,
- keep fuel, oil or grease away from the de-icer boots, and
- keep all tools away from the boots.

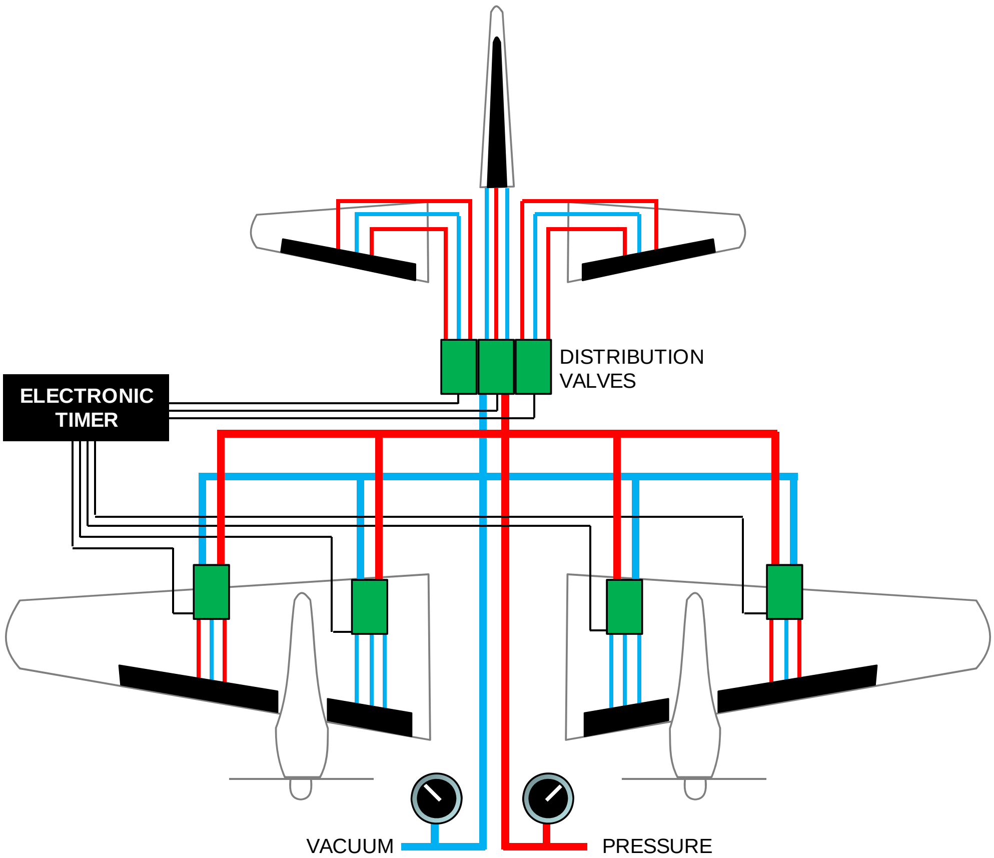


Figure 11-12 Pneumatic De-icer System Schematic

CHEMICAL (FLUID) ICE PROTECTION SYSTEMS

The common chemical method of ice protection is known as a fluid ice protection system. This method may be used for leading edges and propellers. Fluid anti-icing systems are designed to prevent ice forming. They are not capable of removing ice once it has formed. These systems must therefore be operated continuously and preferably before ice has started to form on the surfaces.

Leading Edge Systems

On some smaller aircraft, a fluid anti-ice system is used on the leading edges of the wing and empennage. With this type of system, isopropyl alcohol or ethylene glycol is stored in a tank and pumped via a filter and compensating valve to the leading edge surfaces.

Small holes along the surfaces allow the fluid to flow out and form a slick surface which prevents the bonding of ice to the airframe. Non-return valves prevent the fluid from running back from the top of the empennage. Refer to Figure 11-13.

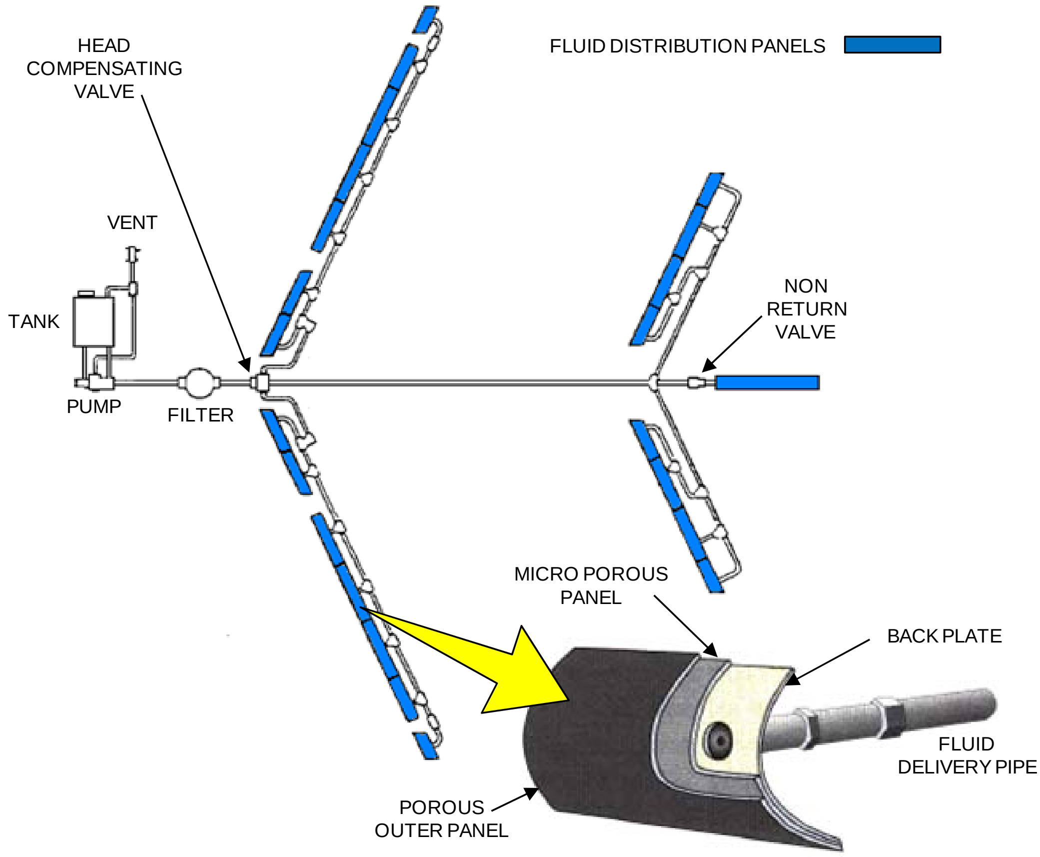


Figure 11-13 Leading Edge Fluid System

PROPELLER SYSTEMS

Anti-icing the propeller, using a fluid system is commonly used on smaller aircraft. In this system, the fluid, isopropyl alcohol or ethylene glycol is stored in a reservoir in the aircraft structure and pumped out to the propellers by a small pump. The fluid output from the pump is varied by a rheostat control located on the flight deck.

The fluid is applied to the propellers via a stationary nozzle into a rotating slinger ring attached to the rear of the propeller assembly. The slinger ring drains the fluid into fluid feed pipes positioned in front of each blade root. Centrifugal force forces the fluid outwards along the blade leading edges.

The fluid forms a very thin slick surface which the ice cannot stick to, thus stopping the ice from building up on the blades. Refer to Figure 11-14.

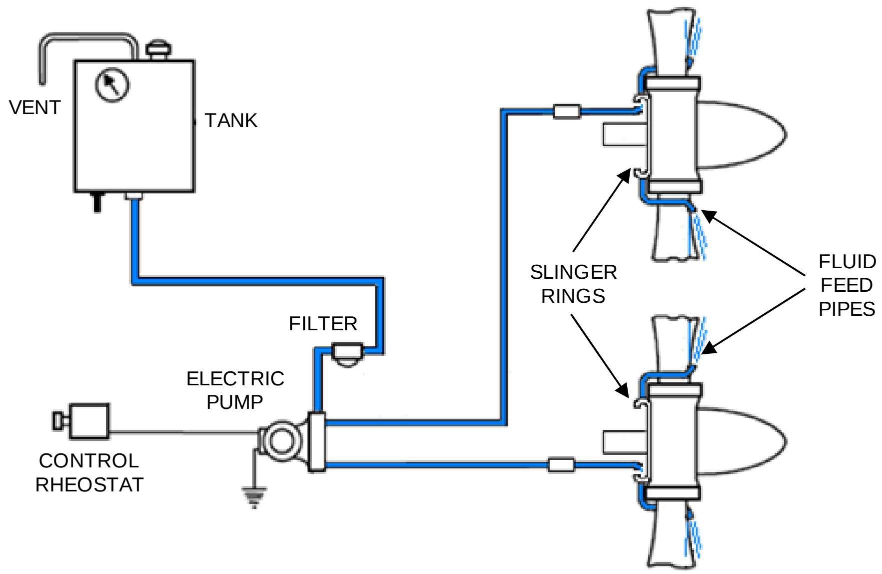


Figure 11-14 Propeller Fluid System

THERMAL ICE PROTECTION SYSTEMS

Thermal systems are used extensively on large multi-engine jet and turbo-prop aircraft for leading edges as they normally have an abundance of both bleed air and electrical power. Thermal systems are used by all aircraft types for the anti-icing of individual components such as pitot tubes, other probes, water drains and windshields.

Depending on the aircraft type thermal ice protection may be employed as DE-ICING or ANTI-ICING systems. The thermal source for these systems may be from;

- bleed air,
- engine oil, and
- electrical power

Bleed Air systems are commonly used for;

- engine anti-icing,
- wing anti-icing and de-icing, and
- empenage anti-icing and de-icing.

Engine Oil systems are rare and only used for anti-icing of some sections of the engine. This method usually heats the specific sections all of the time the engine is operating and has no ON/OFF control.

Electrical Power systems are typically used for many of the individual components that require ice protection but are occasionally used for wing and empennage systems. Typical uses are;

- pitot probes and other sensors,
- windshields,
- water drains, and
- propeller blades.

BLEED AIR SYSTEMS

Engine bleed air, already discussed in Chapter 4, Pneumatic Systems, is the most common method of protecting the engines and the wing leading edges from ice formation.

ENGINE ICE PROTECTION SYSTEMS USING BLEED AIR

Gas turbine engine intakes are always prone to icing due to the change in airflow velocities that occur in them due to shaping of the duct. The major problems associated with ice forming on engine intakes are;

- intake diameter is reduced or the airflow deformed thus causing a restriction to the mass airflow through the engine,
- as ice chunks break away they are ingested by the compressor, causing serious damage or complete failure of the engine, and
- blockage of the EPR probe can result in a dangerous false high indication.

The main areas of a jet engine that suffer from the build up of ice and are therefore protected are;

- the intake leading edge
- some parts of the inlet duct, particularly on turbo-prop aircraft,
- the engine spinner,
- the EPR probe,
- the engine struts on bypass engines, and
- the inlet guide vanes whether fixed or moveable.

Engine intakes are ANTI-ICED by taking bleed air from the engine compressor(s). The bleed air is taken forward to the intake via external ducting, where electrically controlled Anti-ice Valves distribute the air to the intake nacelle. Refer to Figure 11-15.

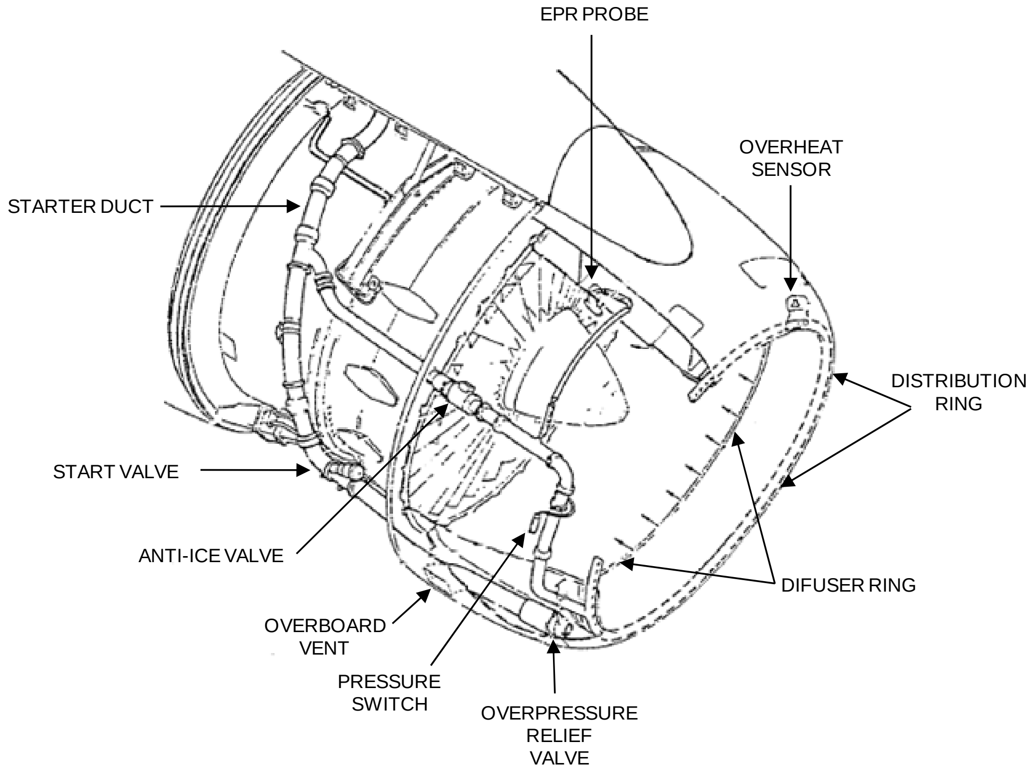


Figure 11-15 Engine Nacelle Anti-ice System

Normally the anti-ice valves are "fail safe", which means that they are electrically held closed when OFF and will open if the electrical power system fails, thus ensuring anti-icing for the engine.

The control system normally has a green indicator light to advise the crew that the system is operating.

The system is a true anti-ice system, and should normally be switched on prior to entering known icing conditions.

When the system is operated, the pilot should select one engine at a time, and monitor the engine instruments for correct indications. There should be a noticeable increase in exhaust gas temperature and a reduction in engine power and RPM.

If engine anti ice is selected ON on more than one engine at the same time, there is a possibility of a complete loss of power. As an added precaution, engine igniters should be selected ON when anti-ice is selected ON. This may be accomplished automatically by the ice detection system.

WING ICE PROTECTION SYSTEMS USING BLEED AIR

On large fast jet commercial aircraft, engine bleed air is typically used as an ANTI-ICING system unlike slower aircraft types such as turbo-props that may use bleed air as an ANTI-ICING or DE-ICING system.

Fast jet aircraft deliver bleed air to the leading edge sections by the common bleed air manifold which is a large duct that runs from one wing tip to the other and down the fuselage to the APU.

The hot air is controlled by solenoid controlled wing anti-ice valves, which, when opened, allow continuous airflow into the leading edge area ducting. The leading edge is constructed of an inner and outer skin, and the hot air is allowed to pass between the two layers and exit either into the airflow or into the leading edge cavity.

Aircraft fitted with leading edge flaps require a telescopic duct to maintain supply as the flaps extend. Refer to Figure 11-16.

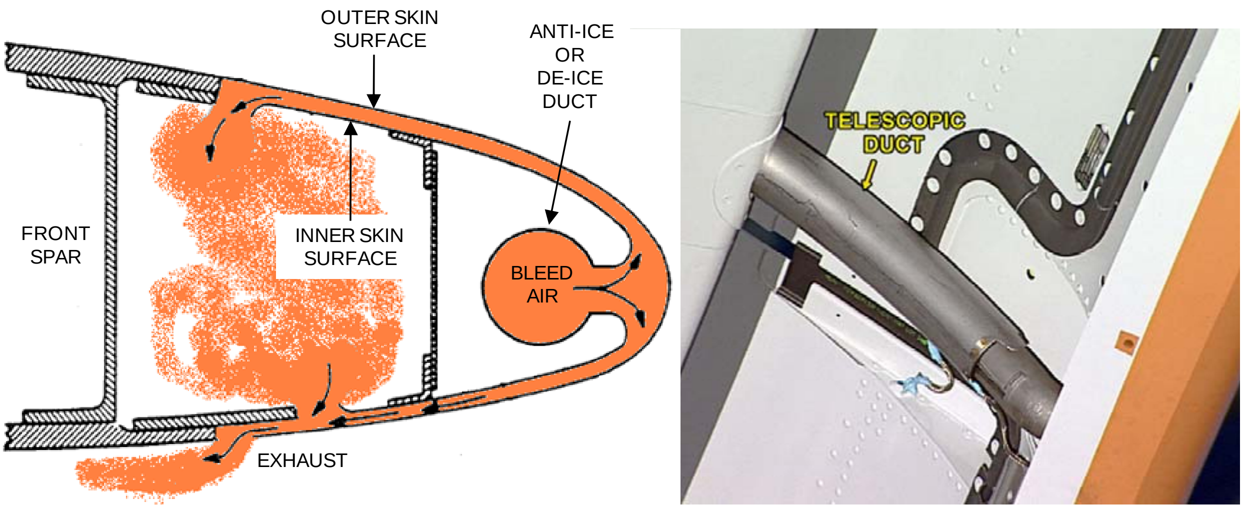
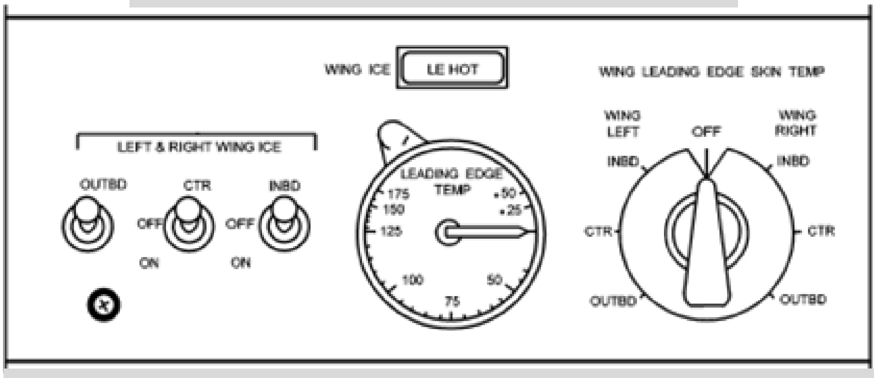


Figure 11-16 Leading Edge Anti-icing

Slower Turbo-prop aircraft also use the common bleed air manifold to deliver bleed air to the leading edge sections however each opposite pair of wing sections will have a control valve operated by the crew or a timer to produce a cycle for DE-ICING the wing leading edges.

Each section has a temperature gauge sensor to indicate to the crew the actual leading edge temperature and a caution alert if any section becomes too hot. Refer to Figure 11-17.

AFTER ICE HAS FORMED TO A REASONABLE DEPTH



THE CREW SELECTS THE OUTBOARD SECTION TO ON, AND OBSERVES THE TEMPERATURE RISING ON THE GAUGE.

AFTER ICE HAS GONE THE OUTBOARD SECTION IS SELECTED OFF AND THE CENTRE SECTION IS SELECTED ON UNTIL THE ICE IS GONE.

THE SAME PROCEDURE IS REPEATED WITH THE INBOARD SECTIONS AND THE ROTATION CONTINUES AS LONG AS ICE IS ACCUMULATING.

Figure 11-17 Leading Edge De-icing

All types of aircraft will have an over temperature monitoring system to warn of excessive heating of the leading edges during anti-icing or de-icing operations.

It should be pointed out that the common bleed air manifold runs along the forward wing beam, which on most modern commercial aircraft is the forward face of the aircraft integral wing fuel tanks. A combination of a fuel leak and a bleed air leak within the leading edge cavity could produce a potentially dangerous situation.

Full use of wing anti-ice/de-ice systems on the ground is normally restricted to testing, due to the excessive temperatures produced in the leading edge cavity, and the lack of cooling airflow over the wing. They may be inhibited against full operation by the ground/air sensing system.

The bleed air system, when operating, reduces the power output of the engine by taking air away before combustion, thus reducing aircraft performance. Normally the wing anti-ice system is not allowed to be used during the take-off as it reduces engine performance, significantly reducing take-off performance.

Whilst operating the system in flight, there is a considerable loss of engine power. For the aircraft to maintain its previous airspeed and altitude, the power on the engines must be increased back to the original settings. This naturally means an increase in fuel flow and a reduction in the available range.

COMPONENT ICE PROTECTION SYSTEMS USING BLEED AIR

It is rare to use bleed air for ice protection of individual components but some aircraft protect radio antennas and TAT probes using bleed air.

ENGINE OIL SYSTEMS

ENGINE ICE PROTECTION SYSTEMS USING ENGINE OIL

Using only hot engine oil is normally insufficient to heat all of the required surfaces and components in the engine. Hot engine oil is typically used only for specific areas and is normally used in conjunction with other methods. Refer to Figure 11-18 which depicts an engine being anti-iced by three separate methods, one of which is hot engine oil.

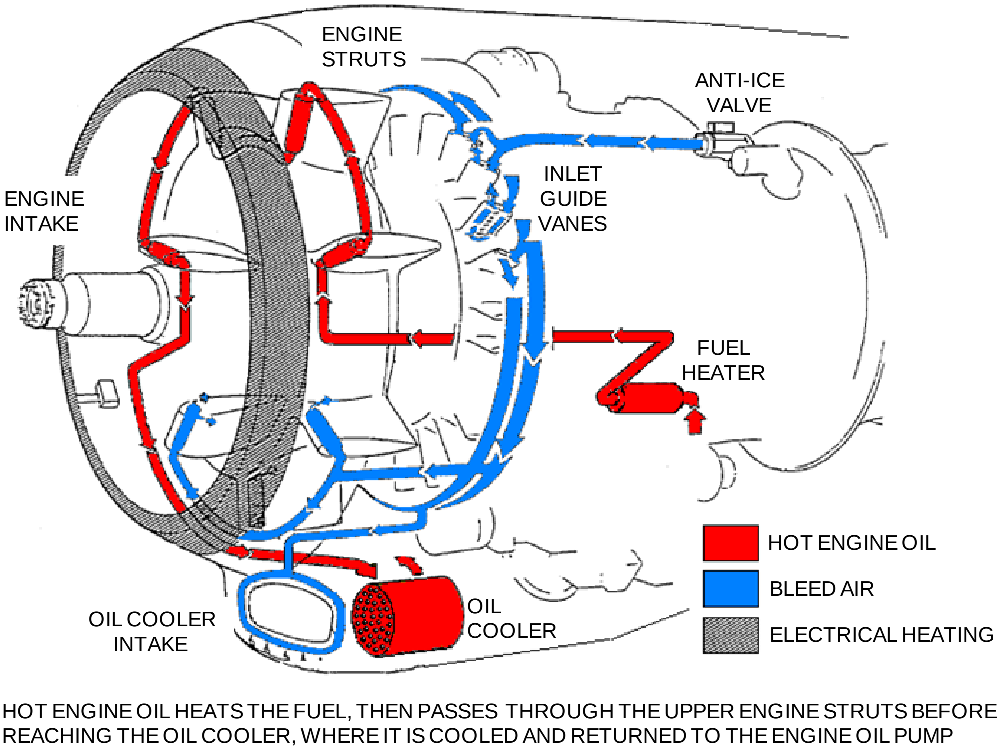


Figure 11-18 Engine Oil Anti-icing

ELECTRICAL SYSTEMS

ENGINE ICE PROTECTION SYSTEMS USING ELECTRICAL POWER

Some engines may use electrical heating elements for the intake nacelle as illustrated in Figure 11-18, but this is not a common method.

WING ICE PROTECTION SYSTEMS USING ELECTRICAL POWER

It is unusual for aircraft to heat wing leading edges with heating mats due to the very large electrical loads necessary to heat such large surfaces. Typically main plane leading edges are heated using bleed air. It is common however to heat the empennage leading edges using electrical heating mats in a de-ice type system similar to electrically heated propellers. Refer to Figure 11-19.

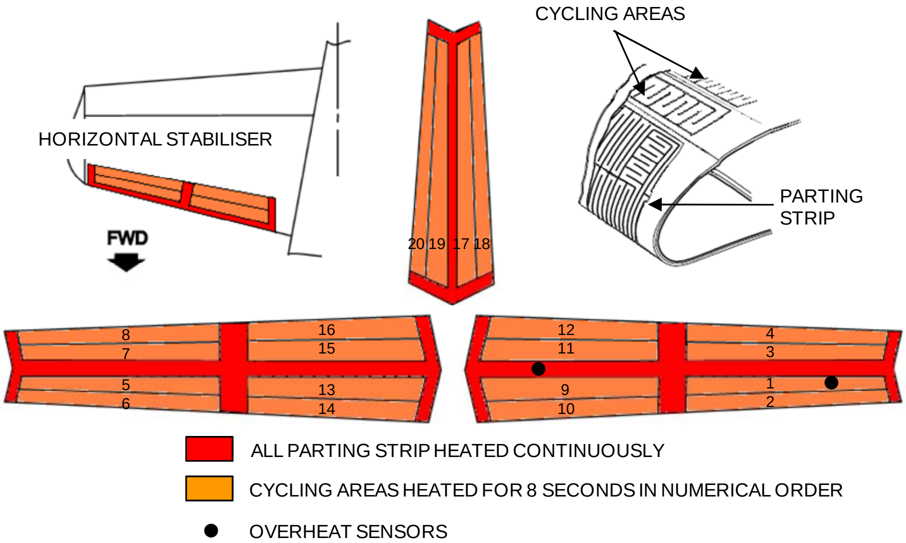


Figure 11-19 Empennage De-icing

Component Ice Protection Systems using Electrical Power

Electrical heating is used extensively to anti-ice the components of the aircraft that require ice protection. The common small components protected by heating elements are;

- pitot probes
- other sensing devices
- static ports, and
- water drains

Pitot Probes are heated at all times to prevent the possibility of blockage by ice. Even a small blockage of the inlet to the pitot head could cause severe errors in critical flight instruments.

The usual method of anti icing the pitot heads is by electrical heating elements located inside the actual head. Electrical power is applied continuously whenever the control switch on the flight deck is selected ON.

A FAILURE light is always provided to indicate when electrical power is no longer being applied to the pitot head when the control switch is in the ON position.

On aircraft where two pitot systems are fitted, each will have its own control and failure indicating system. This will normally include a change over function to allow for failures in either of the system to be transferred to the opposite set of instruments.

It is very important to check that the pitot system is operating prior to flight. However, prolonged use of the system on the ground should be avoided as overheating of the heating element will result. Refer to Figure 11-20.

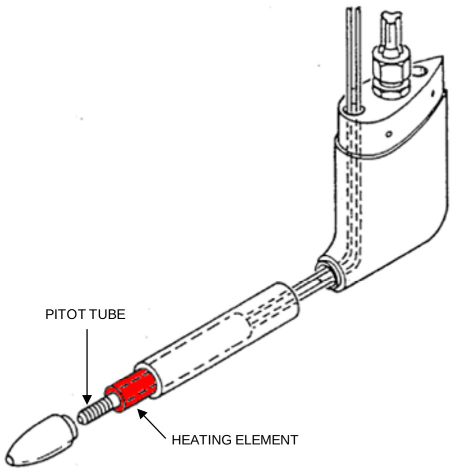


Figure 11-20 Pitot Heating

Other Sensing Devices are heated at all times to prevent the possibility of blockage by ice or restriction of movement. Commonly fitted devices are;

- Angle of Attack (AoA) sensor(s), and
- True Air Temperature (TAT) probe.

Static Ports are anti-iced on some aircraft to prevent moisture freezing and blocking the reference holes. They are normally heated by electrical heater elements surrounding the port. Electrical power is supplied from the aircraft system through a control switch, or in some installations automatically once power is turned on.

External Water Drains require some form of anti-ice system to keep the drain piping and holes free when flying in freezing conditions. Some of the more common types are:

- patch type heaters,
- ribbon heater type,
- blanket type heaters, and
- integral type heater hoses.

The systems are normally turned on automatically as power is applied to the supplying electrical bus, and are thermostatically controlled to reduce power consumption. Refer to Figure 11-21.

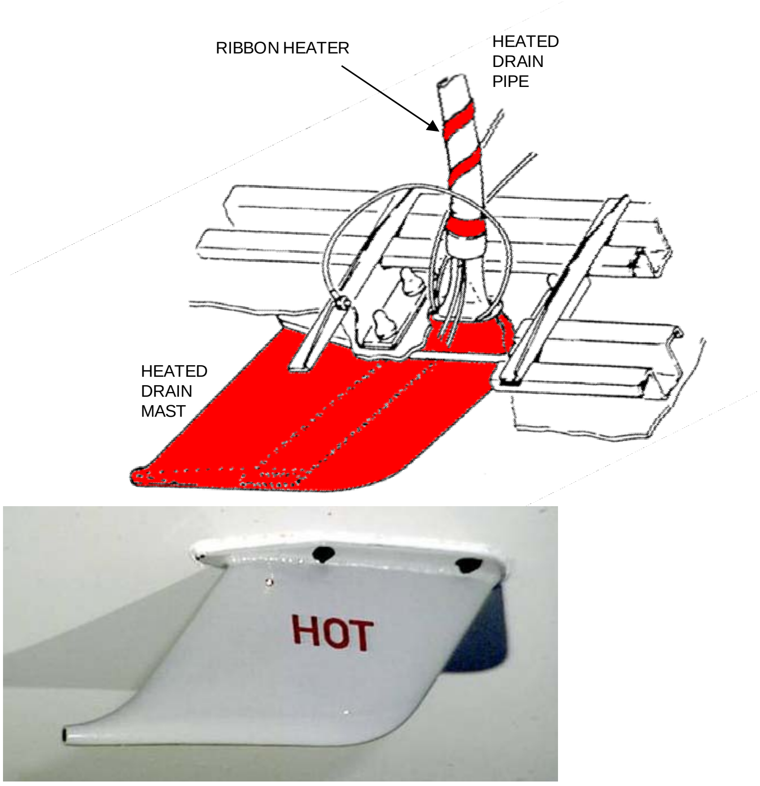


Figure 11-21 Heated Water Drain Mast (typical)

Electrical heating is used extensively to anti-ice the components of the aircraft that require ice protection. The common large components protected by heating elements are;

- propellers, and
- windshields

Propellers are commonly protected by electrical heating elements imbedded in rubber mats glued on the leading edges and the cuffs (inner sections) of the blades. Centrifugal force prevents the formation of ice on the outer sections of the blades. The propeller spinner is typically heated as well. Propeller thermal systems are usually a combination of anti-ice and de-ice principles.

PROPELLER THERMAL SYSTEM

AC electrical power, typically frequency wild, is supplied through the control switch to a timer motor. This consists of a series of switches that are actuated by movement of a rotary cam driven by an electric motor. As the contacts close, power is applied to the propeller assemblies. The power is applied to the rotating propeller parts through slip rings and brushes.

The AC current allows the use of different phases to be applied to different components through the cyclic timer motor. This allows the slower rotating areas of the propeller, such as the spinner, to have one phase of the electrical current supplied continuously, whilst still allowing other phases to be used on a cyclic basis to other areas of the propeller without overloading the generator system.

A typical electrical de-ice system will have an ammeter for reading the applied current, a method of selecting which phase the reading on the ammeter is referenced to, and a series of power relays which are energised by the cyclic timer to apply the power to the various parts of the propeller. While the system is operating, careful monitoring of the loads is essential to prevent overheating of one area which may cause holes to be burnt in the rubber heating mats. Refer to Figure 11-22.

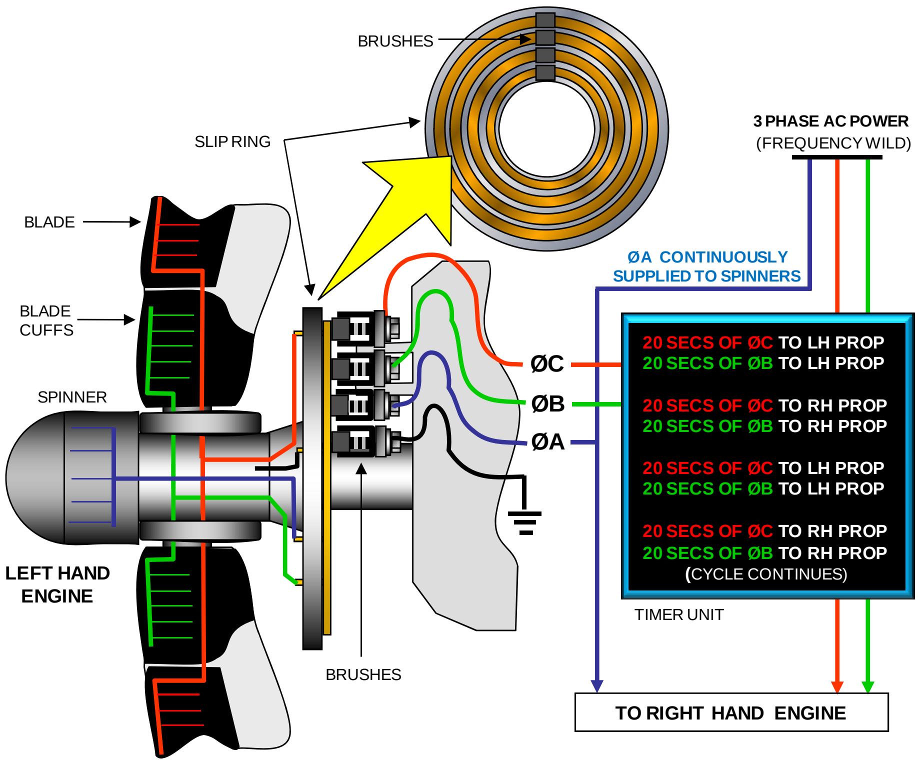


Figure 11-22 Propeller Thermal De-ice System (typical)

Windshields are very special components of the aircraft structure that many people think of as merely something to look through. On a large commercial jet, the windshield must be able to operate in a wide temperature range, through severe icing and hail and winds in excess of four hundred miles an hour.

They must also be able to withstand bird-strikes and still remain in one piece and hold a differential pressure between the inside and outside of the aircraft cabin of thousands of pounds. To do this requires very special construction techniques.

WINDSHIELD THERMAL SYSTEM

Commercial aircraft windshields are generally made of two layers of tempered high quality optical glass with a layer of vinyl between them. This gives the windshield its basic strength, but the use of heat makes the window more flexible. To heat the whole window without any impairment to visual capability, a coating of tiny conductive particles is sprayed over the vinyl layer. A series of thermistors is then fitted to control the application of electrical current. Refer to Figure 11-23.

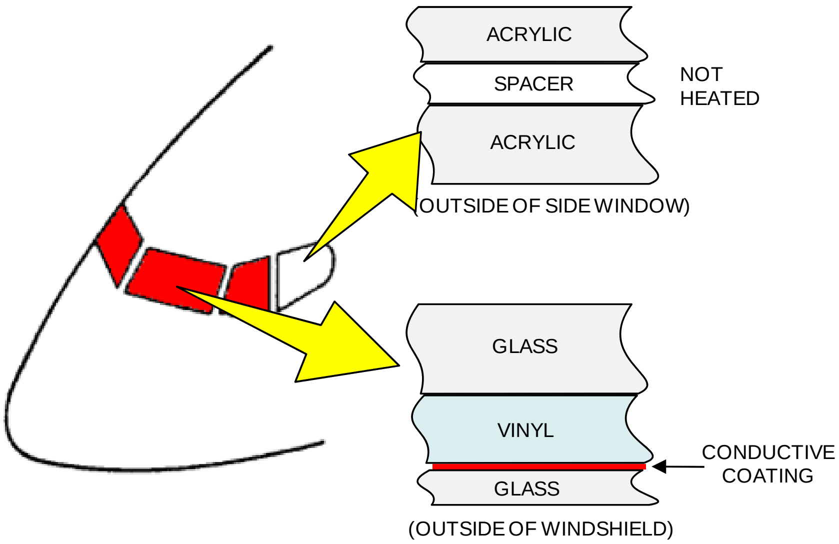


Figure 11-23 Windshield Construction (typical)

The heating of the front windows of the aircraft is not only to provide ice protection, but also makes the windows more pliable and less brittle, thereby increasing the windows ability to withstand impacts such as bird-strikes. It also allows the windows to flex outwards under the loads applied by pressurisation. On many commercial aircraft types, flight into known icing conditions without a serviceable windshield heat system is prohibited. Speed restrictions may also apply if an aircraft is to be flown with an unserviceable window heat system, or with the system turned off due to overheating or cracking

The electrical circuitry involved in heating the window is complex. The windshields are normally divide into two systems for control purposes, one for the Captain and one for the First Officer. Each system consists of the same components, those being:

- Heat control switches (Low, High, Auto),
- Indicating lights,
- Temperature sensing elements (thermistors) in the laminated panels,
- Windshield control units, and
- Heat control relays and transformers.

The system is selected on by the control switch and operation is then fully automatic.

Due to the construction and thermal operation of windshields common problems can occur. These are;

- Scratches
- Delamination
- Arcing, and
- Cracking.

Scratches are usually caused by the operation of the windshield wipers. Grit and dust trapped by the wiper blade act like a diamond cutter when the wiper is used. Prevention is the best cure for scratches, and wipers should never be used on a dry windshield.

Delamination is the separation of the windshield plies. If the pilot's view is not obstructed by the delamination and it is within the manufacturers limits then it is usually acceptable for flight.

Arcing is caused by the electrical current "jumping" across gaps in the conductive particles sprayed over the vinyl layer. This can lead to even bigger gaps or holes, and will cause control problems in the heating circuits. If arcing is observed, or a windshield panel becomes excessively hot or cold, the control switch for the window should be selected OFF to prevent possible damage. Refer to Figure 11-24 for an example of a windshield arcing procedure.

When windshield heat is selected OFF limitations will normally apply to aircraft operations due to the loss of strength caused by the lack of heating as the glass becomes more brittle. A typical limitation is a reduced airspeed when operating below 10,000 ft due to the possibility of birdstrike.

COCKPIT WINDSHIELD / WINDOW ARCING

– Affected WINDSHIELD/WINDOW WHC C/B ....PULL
In case of electrical arcing, pull the circuit breaker of the Window Heat Computer that is located on the affected side.
- *WINDSHIELD/WINDOW LEFT SIDE – WHC 1 (261 VU)*
- *WINDSHIELD/WINDOW RIGHT SIDE – WHC 2 (262 VU).*

Figure 11-24 Example Arcing Procedure

Cracking normally occurs from the edges of the windshields and may continue to crack further across the windscreen as temperature changes take place during the flight. To reduce the load on the windshield, it is normal to reduce cabin differential pressure. Refer to Figure 11-25 for an example windshield cracked procedure.

COCKPIT WINDSHIELD/WINDOW CRACKED

– MAX FL..230
– CAB PRESS MODE SEL ....MAN
– MAN V/S CTL...AS RQRD
Set the cabin altitude, according to the table below.

ΔP = 5 PSI	FL	100	150	200	230
	CABIN ALTITUDE	0	3000	6000	8000

- **When starting the final descent:**
  – CAB PRESS MODE SEL ....AUTO

Figure 11-25 Example Cracking Procedure

ICE PROTECTION METHODS PRIOR TO TAKE-OFF

For take-offs in snow and icing conditions the aircraft must be thoroughly prepared before a take-off can be attempted. This means that if required the aircraft must first be DE-ICED to remove accumulated snow or ice and then ANTI-ICED in preparation for the take-off.

The formation of ice, snow or frost on the external surfaces of an aircraft, will drastically affect its performance for take-off and initial climb. The thickness and irregularity of any build-up on the airframe will have aerodynamic consequences resulting in a loss of lift and an increase in drag. Ice formation on the control hinge points may lead to frozen controls and electrical systems may be disabled due to moisture freezing in micro-switches. Ice formation in the intake or compressor of a gas turbine engine could cause serious damage or a lower than predicted power output.

Aircraft anti-ice and de-ice systems are designed to prevent or remove ice formation from specific areas of the airframe and engines during flight. In most cases they rely on the airflow to prevent or remove the ice build up from the airframe, and as such are not efficient at removing surface icing while the aircraft is stationary on the ground. This is because the moisture will run and re-freeze in locations that are not anti-iced or de-iced, causing even more problems.

It should also be noted that apart from engines the aircraft anti-ice or de-ice systems are not used for take-off, and it will be some time in the climb-out phase before they can be used, depending on terrain clearance and engine power requirements.

The effects of snow and ice are more pronounced when the aircraft is left for prolonged periods in the open. The best method of lessening the effects of ice formation is to keep the aircraft dry and out of the elements for as long as possible. When necessary there are five common methods of removing ice from the airframe before flight. They are;

- manual brushing of surfaces,
- hot air de-icing,
- hot water de-icing,
- radiated heating, and
- spraying with de-icing fluid.

Application of Hot Air

Frost may be removed by blowing with hot air, but all moisture must be removed or it will re-freeze.

Application of Radiated Heat

Some airports have hangars designed with large radiant heaters to clear aircraft surfaces of ice or frost. Refer to figure 11-26.

Figure 11-26 Radiated Heat Hangar

Application of Fluids

There are two types of fluid available for application. They are;

- **Type 1** (unthickened) fluid has a high glycol content and a low viscosity. It is efficient at removing ice accretion, but provides only a limited anti-ice protection. This is due to the lack of adhesion to the surfaces, allowing the probability of re-freezing. This is primarily a de-icing fluid.
- **Type 11** (thickened) fluid has a lower glycol content, and contains a thickening agent which aids the fluid in staying on the sprayed surfaces until after take-off. This fluid also aids in preventing further ice build up in freezing rain. This is a de-icing and anti-icing fluid. Refer to Figure 11-27.

Figure 11-27 Type II Fluid applied

Cold spraying is the easiest method of applying the fluid, but has the disadvantage of the fluid being diluted by the melting ice and refreezing in inaccessible places.

Hot spraying is accomplished with the fluid at a temperature of between 60 - 80° C and a pressure of 100 psi. The idea is that the ice is broken away by the heat, the pressure then removes the ice and the fluid prevents the ice reforming. Overheating of the fluid will result in gelling. The gel will not be removed by the slipstream and will reduce aerodynamic efficiency resulting in loss of aircraft performance.

Frost removal fluids, such as "Kilfrost", are either isopropyl alcohol, ethylene glycol or di-ethylene glycol and are either sprayed by machine or hand. The substances are corrosive and may damage paint and acrylic panels.

After de-icing, the aircraft must now be anti-iced prior to take-off if icing conditions are still present.

ANTI-ICING

In order for the anti ice fluid to work effectively, it must be applied immediately after hot spraying or prior to the formation of ice. The fluid must be sprayed on cold for maximum viscosity. It will form a thick coating on the surfaces and prevent the formation of ice on the aircraft for up to 8 hours. Refer to Figure 11-28.

Figure 11-28 Aircraft being prepared for Take-off

TAXY THROUGH DE-ICE/ANTI-ICE FACILITIES

Many of the larger airports have a taxy through fluid de-ice/anti-ice facility. These facilities offer the advantage of being able to spray the aircraft with the engines running just prior to take-off. This allows the minimum amount of time for snow and ice build up, giving the aircraft better take-off performance capability.

The fluid sprayed is flammable and will burn if ingested by the engines or APU. This will produce toxic fumes in the cabin via the air conditioning system.

It is important that the ENGINE and APU BLEED VALVES are closed prior to entering the taxy through facility. Refer to Figure 11-30.

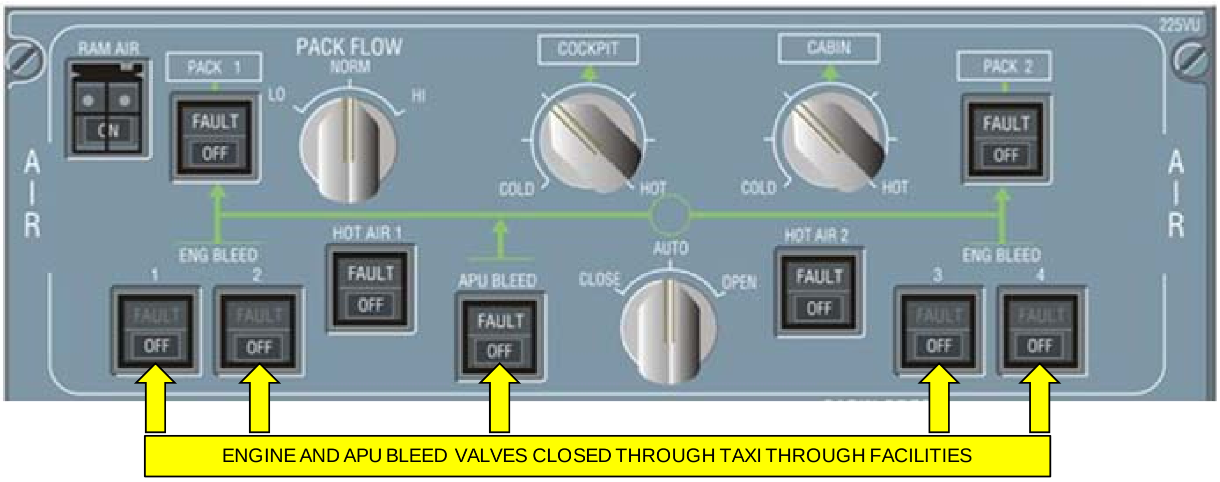


Figure 11-29 Closed Bleed Valves

HOLDOVER TIME

Holdover time is the time for which it is expected that a treatment by ground anti-icing fluid will remain valid.

Holdover time begins at the start of the anti-icing operation and ends when frozen deposits start to form on the treated surfaces.

If the aircraft does not take-off within this time it must return to the ramp or facility and be prepared again.

The following chart is reproduced from CAP 512, and gives a guide to the holdover times for the two different fluids. Refer to Figure 11-30. However, these are only guides and careful examination of the airframe is required prior to flight. It is the Captain’s responsibility to ensure the aircraft is free of ice before take-off.

GUIDE TO HOLDOVER TIMES FOR DE-ICING FLUIDS

AMBIENT TEMP	WEATHER CONDITIONS					TYPE II (AEA) FLUIDS				TYPE I (AEA) FLUIDS (SEE NOTE 2)
	FROST	FREEZING FOG	STEADY SNOW	FREEZING RAIN	RAIN ON SOAKED WING	ANTI-ICING	DE-ICING			
						100% COLD	75/25 HOT	60/40 HOT	50/50 HOT	
ABOVE 0°C	●	●	●	●	●	8 HOURS 3 HOURS 1 HOUR 20 MINS	5 HOURS 2 HOURS 45 MINS 10 MINS	4 HOURS 1¾ HOURS 35 MINS 7 MINS	3 HOURS 1½ HOURS 30 MINS 5 MINS	45 MINS 30 MINS 15 MINS 5 MINS
0°C TO -7°C	●	●	●	●		8 HOURS 1½ HOURS 45 MINS 20 MINS	5 HOURS 1 HOUR 30 MINS 10 MINS	4 HOURS 50 MINS 20 MINS 3 MINS	3 HOURS 45 MINS 15 MINS 3 MINS	30 MINS 15 MINS 15 MINS 3 MINS
-8°C to -10°C	●	●	●			8 HOURS 1½ HOURS 45 MINS	5 HOURS 50 MINS 20 MINS	4 HOURS 50 MINS 20 MINS		30 MINS 15 MINS 15 MINS
-11°C to -14°C	●	●	●			8 HOURS 1½ HOURS 45 MINS	5 HOURS 1 HOUR 30 MINS			30 MINS 15 MINS 15 MINS
-15°C to -25°C	●	●	●			8 HOURS 1½ HOURS 45 MINS				30 MINS 15 MINS 15 MINS

NOTES:

1. Under extreme cold conditions it may be necessary to heat the neat fluid (60°C MAX) to give it sprayability.
2. No significant increase in holdover time is achieved by strengthening the mix of Type I (AEA) fluids.
3. Stations using Kilfrost will normally provide a mix of 50/50 or 60/40. It may be difficult to get stronger mixes at short notice unless the temperature conditions at the stations involved are below limits for that mix.

Figure 11-30 Holdover Time Guidance Chart

In summary there are numerous methods of protecting the aircraft from ice formation during flight and prior to take-off. Refer to Figure 11-31.

AIRCRAFT SYSTEMS USED IN FLIGHT				
METHOD	**SYSTEMS**	**USED FOR**	**ANTI-ICE/DE-ICE**	**AIRCRAFT TYPE**
MECHANICAL	PNEUMATIC	WING LEADING EDGES	DE-ICE	LIGHT/MEDIUM PROP AIRCRAFT
		EMP LEADING EDGES		
CHEMICAL	ALCOHOL OR GLYCOL BASED	WING LEADING EDGES	ANTI-ICE	LIGHT/MEDIUM PROP AIRCRAFT
		EMP LEADING EDGES	ANTI-ICE	
		PROPELLOR BLADES	ANTI-ICE	LIGHT PROP
HEATING	ELECTRICAL	PROBES AND SENSORS	ANTI-ICE	ALL
		WATER DRAINS	ANTI-ICE	
		WINDSHIELDS	ANTI-ICE	
		WING LEADING EDGES	ANTI-ICE/DE-ICE	VERY MODERN
		EMP LEADING EDGES	ANTI-ICE/DE-ICE	TURBO-PROP
		PROPELLOR BLADES	DE-ICE	TURBO-PROP
	BLEED AIR	WING LEADING EDGES	ANTI-ICE/DE-ICE	LARGE AIRCRAFT
		ENGINE NACELLES	ANTI-ICE	TURBO-PROP AND MEDIUM/LARGE JET ENGINES
		ENGINE PROBES	ANTI-ICE	
		ENGINE STRUTS	ANTI-ICE	
	ENGINE OIL	ENGINE STRUTS	ANTI-ICE	
GROUND PROCEDURES PRIOR TO TAKE-OFF				
METHOD	**USED FOR**		**ANTI-ICE/DE-ICE**	**AIRCRAFT TYPE**
BRUSHING	SNOW, ICE AND FROST REMOVAL		DE-ICE	SMALLER
HOT AIR				
HOT WATER				
HEATING				LARGE
CHEMICAL				
CHEMICAL	HOLDOVER TIME PROTECTION		ANTI-ICE	ALL

Figure 11-31 Summary of Systems and Methods for Ice Protection

RAIN REMOVAL

Heavy rain, obstructing clear vision during the landing phase can be removed using three methods. They are;

- pneumatically
- mechanically, and
- chemically

Pneumatic rain removal systems are sometimes fitted to light commercial jets. Bleed air from the engine is directed across the screens blowing any rain off the glass. It is a very reliable, efficient system for small windscreens. Refer to Figure 11-32.

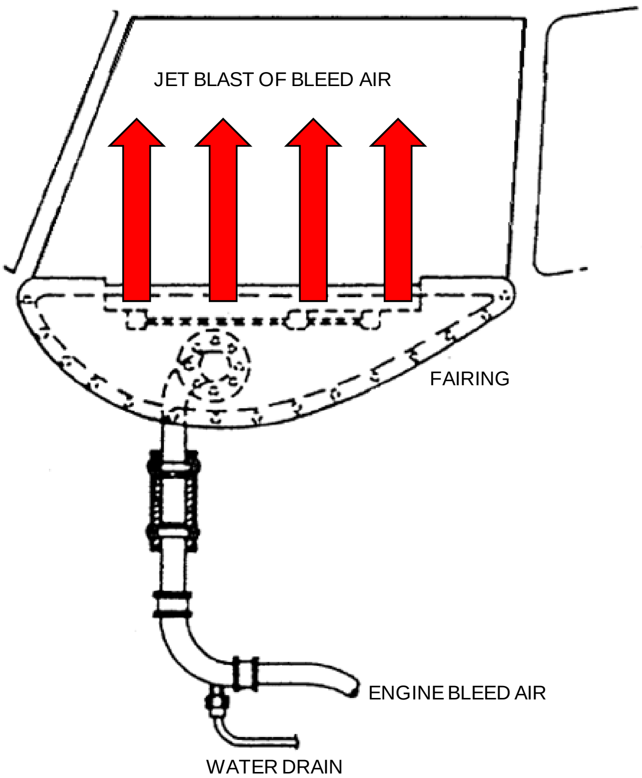


Figure 11-32 Pneumatic Rain Removal System

Mechanical rain removal using electric windshield wipers is the most common method in large commercial aircraft. These operate the same way as an automobile system.

An electric motor drives a wiper arm typically with a two-speed optional rate. Power to the wiper arm is through control switches, which will typically have OFF LOW and HIGH positions.

Each pilot will have an individual control for the wiper on their windshield panel. When the wipers are selected OFF they will "park" off the windshield and not obstruct pilot vision. Refer to Figure 11-33.

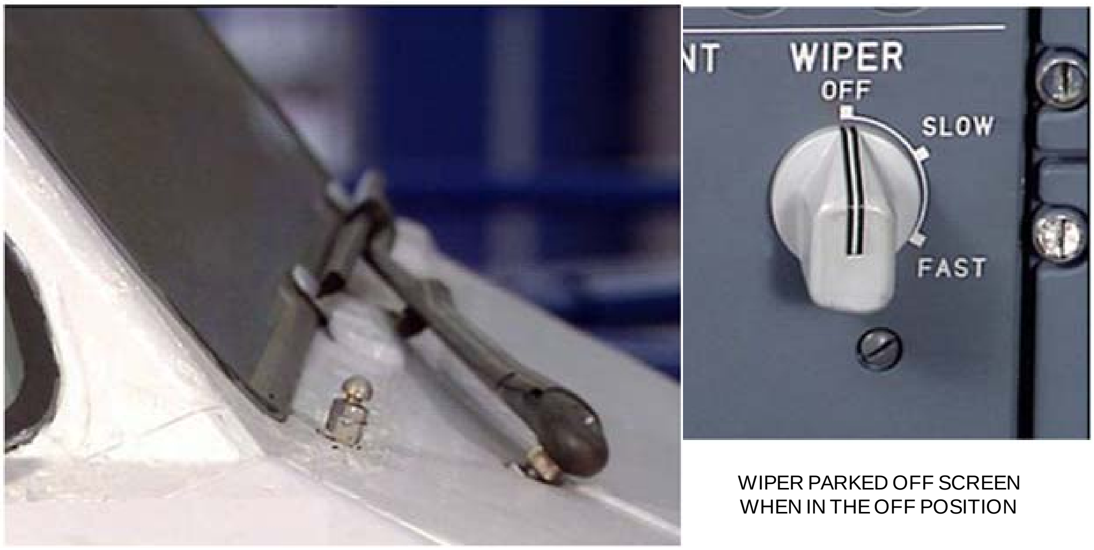


Figure 11-33 Windshield Wiper

There are two important points regarding the operation of the windshield wipers;

- never operate the wipers on dry windshields.
- keep the windshield wipers clean and free from dirt and dust.

Windshields, particularly those constructed of acrylic sheeting (side windshields), should only be cleaned with fresh, clean water and a clean soft cloth, and then wiped off with a clean chamois.

Chemical rain removal is achieved using a rain repellent. This repellent system is also normally fitted to large commercial aircraft. It applies a chemical that induces water to form large droplets which are easily blown off by the airflow. The chemical is stored in a container typically located in the cockpit and sprayed onto the windshields by a pump or pressurised container, through a nozzle assembly. Refer to Figure 11-34.

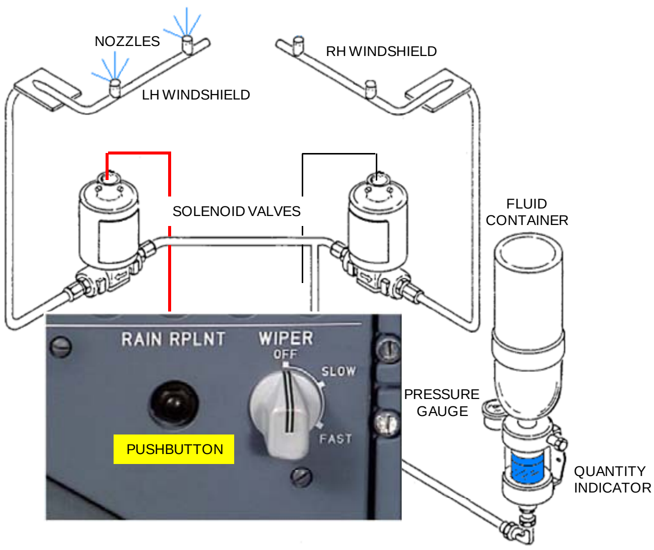


Figure 11-34 Rain Repellant System

The system is controlled by two switches, one for each of the pilots. The system must not be used on a dry windshield, as water is the carrying agent to ensure the whole screen is covered in the repellent fluid.

In most aircraft, the rain repellent should not be sprayed onto the windshield unless the windshield is wet and the wipers are operated.

DEFOGGING

Descent from high altitudes into humid ambient conditions often causes fogging to occur on the windshields, cockpit side windows and of course the windows in the cabin.

Windshield defogging is normally accomplished by high flow electrical fans blowing cockpit air across the inside of the glass.

Side Windows are sometimes heated electrically beneath the acrylic layer closest to the inside of the cockpit or have specific defogging outlets directing conditioned air onto the window.

Cabin Windows are typically vented via small holes with de-humidified cabin air passing between the two window layers.

ICE AND RAIN PROTECTION TERMINOLOGIES AND DEFINITIONS

The following defines old and/or common terms that you may encounter with reference to ice and rain protection systems. Refer to Figure 11-35.

TERM REFERRED	DEFINITION
Accretion	The formation of ice
Engine Inlet	Same as engine intake.
Teddington Ice Detector	Another name for the Hot Rod Type.
Smiths Ice Detector	Another name for the Pressure Operated Type.
Napier Ice Detector	Another name for the Serrated Rotor Type.
Rosemount Ice Detector	Another name for the Vibrating Rod Type.

Figure 11-35 Ice and Rain Protection Terms and Definitions

ICE AND RAIN PROTECTION QUESTIONS

The following questions will examine your understanding of these systems and their operation. The answers may be found in the text or diagrams of this Handbook.

1. A rotary type ice detector operates on the principle of;

a. increased torque loading on the motor as ice forms on the stationary scraper.
b. increased torque loading on the motor as ice forms on a serrated rotor.
c. decreased speed of rotation as ice forms on a visual indicator.

2. Pneumatic de-icing systems consist of;

a. a series of holes along the leading edges of flight surfaces, through which hot bleed air is expelled.
b. hot bleed air supplied to double-skinned leading edges of flight surfaces.
c. flat inflatable tubes attached to the leading edges of flight surfaces.

3. Thermal ice protection systems consist of;

a. a series of holes along the leading edges of flight surfaces, through which hot bleed air is expelled.
b. hot bleed air supplied to double-skinned leading edges of flight surfaces.
c. flat inflatable tubes attached to the leading edges of flight surfaces.

4. The main disadvantage of thermal de-icing is;

a. loss of engine power due to the use of bleed air.
b. damage to other systems due to air leakage.
c. compressor bleed air temperature is too low for most operating conditions.

5. Propeller fluid anti-icing systems usually employ;

a. isopropyl alcohol.
b. frequency wild AC.
c. a DC timer unit.

6. Propeller are de-iced in flight in icing conditions;

a. continuously for all sections.
b. one at a time.
c. one blade at a time.

7. In flight in heavy rain, excess water is removed from the windshields with the assistance of;

a. rain repellent.
b. additional wipers.

c. Kent clear view screens.

8. Aircraft anti-icing systems;

- **a.** are suitable for removal of ice accretions on the ground.
- **b.** are only suitable for removal of ice or frost when airborne.
- **c.** are designed to prevent ice formation when airborne.

9. Aircraft de-icing systems are used to;

- **a.** prevent the formation of ice in flight.
- **b.** remove ice accretions on the ground.
- **c.** remove ice accretions in flight.

10. In an aircraft fluid de-icing system, fluid is typically supplied to leading edge surfaces;

- **a.** through porous panels.
- **b.** through an external gallery.
- **c.** through spray nozzles.

11. Aircraft take-off performance may be drastically affected;

- **a.** only if ice or snow accretions are more than 6 mm in thickness.
- **b.** only by wet snow, since dry snow will be blown off during the take-off roll.
- **c.** even by a layer of frost on the wings.

12. An aircraft is to be ground de-iced, in freezing conditions, two hours before departure;

- **a.** Type II FPD fluid should be used.
- **b.** Type I FPD fluid should be used.
- **c.** either type of FPD fluid is satisfactory.

13. When an aircraft has been treated with FPD fluid, pre-flight external inspection for icing;

- **a.** is necessary.
- **b.** is unnecessary if less than 3 hours have elapsed.
- **c.** is only necessary if snow has subsequently fallen.

14. In the event of ground de-icing services being unavailable for removal of ice or snow from a parked aircraft prior to flight;

- **a.** use of the aircraft de-icing system is acceptable.
- **b.** cabin heating may be used to remove fuselage deposits.
- **c.** use of either of the above could make the situation worse.