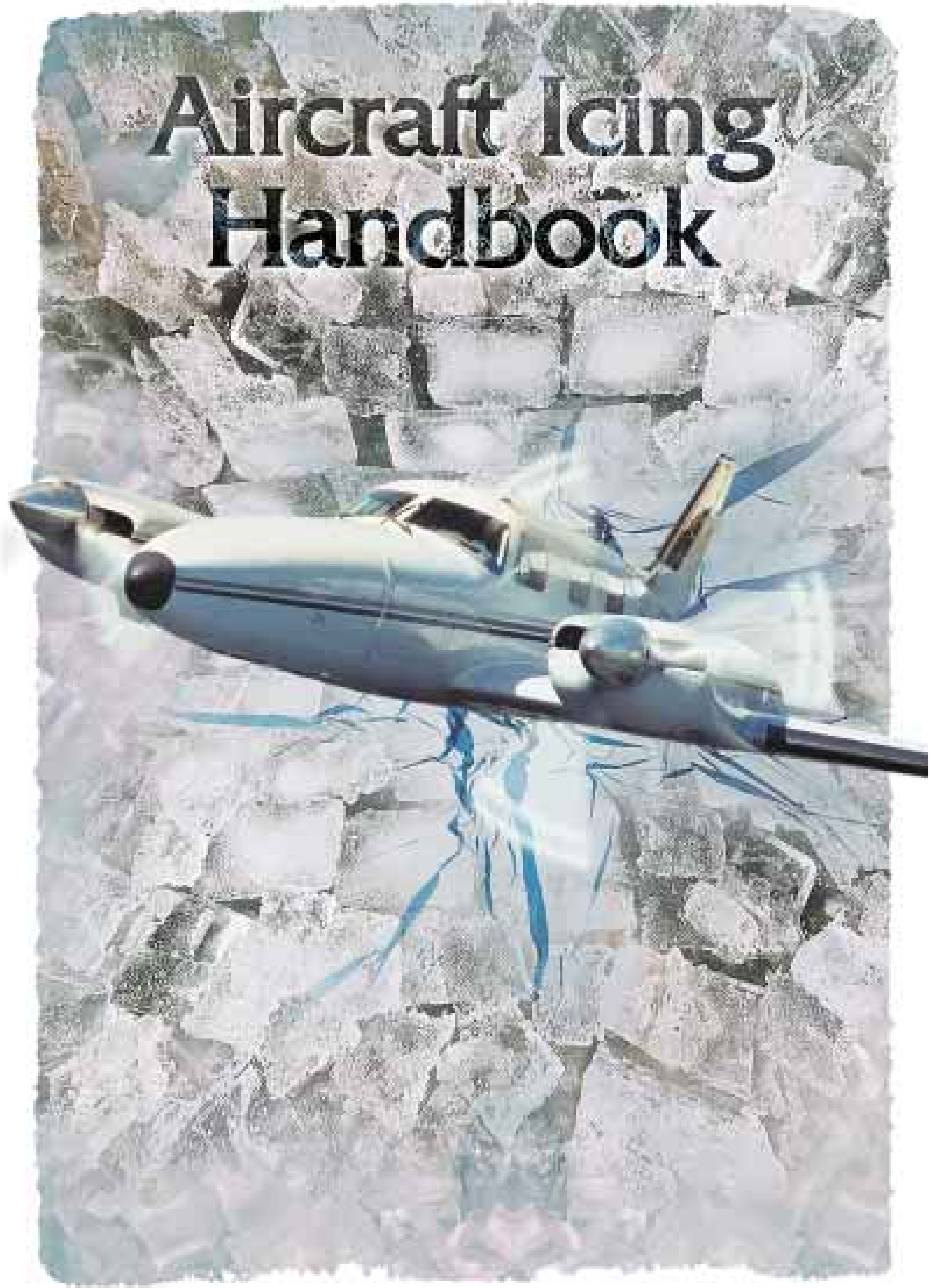
Aircraft Icing Handbook



Aircraft Icing Handbook

Civil Aviation Authority

This GAP handbook was published by the Civil Aviation Authority in 2000.

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FOREWORD

“Strange as it may seem, a very light coating of snow or ice, light enough to be hardly visible, will have a tremendous effect on reducing the performance of a modem aeroplane.” These words are as true today as they were 58 years ago when Flight Safety Foundation (FSF) founder Jerome “Jerry” F. Lederer said them during a lecture on aviation safety. And despite new technology, training and procedures developed since then to address the problem, accidents related to icing conditions continue to occur. This Handbook brings together a variety of major informational and regulatory documents issued by international authorities on the subject of icing-related accident prevention.

In the past 50 years, ice has played a role in numerous accidents that have killed crews and passengers and destroyed aircraft. No phase of operations is immune to the threat. Recent U.S. and New Zealand examples of icing encounters with fatal consequences include the following:

(a) New Zealand Cessna Caravan crashed off the coast of the New Zealand South Island in November 1987 killing both occupants. The pilot had reported icing.

(b) A commuter flight impacted terrain during landing in December 1989, in Pasco, Washington, U.S., killing both crewmembers and all four passengers. The aircraft had been in icing conditions for about 10 minutes on approach.

(c) An air transport stalled on takeoff in March 1992, in Flushing, New York, U.S., killing two crew members and 25 passengers; 24 persons survived. The aircraft had been de-iced twice before leaving the gate.

(d) A commuter flight went out of control in icing conditions and dived into a soybean field en route to Chicago, Illinois, U.S., in October 1994. killing all 68 aboard.

(e) June 1997 Beechcraft BE 58 Baron crashed in the North Island of New Zealand killing the sole occupant – the pilot. The aircraft was operating in a forecast icing environment.

Icing-related accidents have captured the aviation industry’s attention, and it is now widely understood that the problem is international, not just regional. Even the national air carriers of countries with balmy tropical climates are likely to fly to and from latitudes that can be gripped by icy conditions.

This CAA Icing Handbook – published at the onset of the icing season in New Zealand – displays the international scope of efforts to guard against icing-related accidents. The book would not have been possible without the labours of the organisations whose work is included here. And they are by no means the only contributors to progress in de-icing and anti-icing. Numerous other organisations and individuals – too many to recognise here without unfairly omitting some names – have played their valuable part. As several documents adapted in this Handbook attest, the U.S. Federal Aviation Administration (FAA) has undertaken major efforts in icing-related research and regulatory updates. The lengthy list of regulatory and advisory documents beginning on page 201 of the Flight Safety Foundation, Safety Digest "Protection Against Icing: A Comprehensive Overview" dated June-September 1997 most of which were published by the FAA, shows the breadth of icing-accident preventive measures.

The contents of this Handbook speak compellingly of the need for continuing research and development of technological safeguards for ground operations and flight in icing conditions. But improved equipment, and even improved operating procedures, do not in themselves guarantee safety. They must be applied with understanding. Pilots, air traffic controllers, ground crews and dispatchers must be fully knowledgeable about the effects of icing.

This Handbook, developed mainly from the Flight Safety Digest is dedicated to helping educate all personnel associated with flight operations in icing conditions. This is not the last word on the subject; nothing could be, because research and experience create new issues and insights. As a whole, this Handbook offers a sobering reminder that in this aspect of aviation, there can be no such thing as too much vigilance.

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CHAPTER ONE — AIRFRAME ICING

1.1 Icing Hazards

In-flight icing is a serious hazard. It destroys the smooth flow of air, increasing drag, degrading control authority and decreasing the ability of an airfoil to lift. The actual weight of the ice on the aeroplane is secondary to the airflow disruption it causes. As power is added to compensate for the additional drag and the nose is lifted to maintain altitude, the angle of attack increases, allowing the underside of the wings and fuselage to accumulate additional ice. Ice accumulates on every exposed frontal surface of the aeroplane – not just on the wings, propeller, and windshield, but also on the antennas, vents, intakes, and cowlings. It builds in flight where no heat or boots can reach it. It can cause antennas to vibrate so severely that they break. In moderate to severe conditions, a light aircraft can become so iced up that continued flight is impossible. The aeroplane may stall at much higher speeds and lower angles of attack than normal. It can roll or pitch uncontrollably, and recovery may be impossible.

1.2 Kinds of Ice and Its Effect on Flight

Structural ice adheres to the external surfaces of the aeroplane. It is described as rime, clear or glaze, or mixed:

(a) Rime ice has a rough, milky white appearance. Much of it can be removed by de-ice systems or prevented by anti-ice.

(b) Clear or glaze ice is smooth and generally follows the contours of the surface closely, however after further accumulation, it can form ridges. It is hard to remove.

(c) Mixed ice is a combination of rime and clear ice.

Ice distorts the flow of air over the wing, diminishing the wing's maximum lift, reducing the angle of attack for maximum lift, adversely affecting aeroplane handling qualities, and significantly increasing drag. Wind tunnel and flight tests have shown that frost, snow, and ice accumulations (on the leading edge or upper surface of the wing) no thicker or rougher than a piece of coarse sandpaper can reduce lift by 30 percent and increase drag up to 40 percent. Larger accretions can reduce lift even further and increase drag by 80 percent or more. Even aircraft equipped for flight into icing conditions are significantly affected by ice accumulation on the unprotected areas. A NASA study (NASA TM83564) revealed close to 50 percent of the total drag associated with an ice encounter remained after all the protected surfaces were cleared. Unprotected surfaces include antennas, flap hinges, control horns, fuselage frontal area, windshields, windshield wipers, wing struts, fixed landing gear, etc. If pilots can learn to understand where ice will probably occur, they can then formulate an ice-avoidance flight plan before leaving the ground.

Ice forms on aircraft surfaces at 0 degrees Celsius (0° C)or colder when liquid water is present. However even the best plans have some variables. The following table illustrates the icing risk in terms of cloud type and ambient temperature:

1.2.1 Icing Risk

Cumulus Clouds	***Stratiform Clouds***	***Rain and drizzle***
0° to -20°C	**High** 0° to –15°C	0°C and below
-20° to –40°C	**Medium** -15° to –30°C	
< than –4 0°C	**Low** < than – 30°C	

Generally, the worst continuous icing conditions are found near the freezing level in heavy stratified clouds, or in rain, with icing possible up to 8,000 ft higher. Icing is rare above this higher altitude as the droplets in the clouds are already frozen. In cumuliform clouds with strong updrafts, however large water droplets may be carried to high altitudes and structural icing is possible up to very high altitudes. Further, in cumuliform cloud the freezing level may distorted upwards in updrafts and downwards in downdrafts, often by many thousands of feet. This leads to the potential for severe icing to occur at almost any level.

1.2.2 Clear Ice

Clear ice is most likely to form in freezing rain, a phenomena comprising raindrops that spread out and freeze on contact with the cold airframe.

It is possible for liquid water drops to exist in the atmosphere at temperatures well below the normal freezing point of water. These are known as super-cooled drops. This situation can occur below a warm front. Super-cooled drops are unstable, and will freeze on contact with a surface that is below zero degrees — the skin of an aeroplane, or the propeller blades, for example. Freezing of each drop will be relatively gradual, due to the latent heat released in the freezing process, allowing part of the water drop to flow rearwards before it solidifies. The slower the freezing process, the greater the flow-back of the water before it freezes. The flow-back is greatest at temperatures just at O° C. The result is a sheet of solid, clear, glazed ice with very little air enclosed.

The surface of clear ice is smooth, usually with undulations and lumps. Clear ice can alter the aerodynamic shape of airfoils quite dramatically and reduce or destroy their effectiveness Clear ice is tenacious and, if it does break off, large chunks may damage the airframe. Freezing rain may exist at higher altitudes in the presence of ice pellets, formed by rain falling from warmer air and freezing during descent through colder air. That is, the presence of ice pellets usually indicates cold air below freezing with a layer of warmer air above. Wet snow, however, indicates sub zero temperatures at some higher altitude. The snow, which formed in the sub-zero temperatures of air above, melts to form wet snow as it passes through the warmer air at lower levels.

1.2.3 Rime Ice

Rime ice occurs when tiny, super-cooled liquid water droplets freeze on contact with a surface whose temperature is below freezing. Because the droplets are small, the amount of water remaining after the initial freezing is insufficient to coalesce into a continuous sheet before freezing. The result is a mixture of tiny ice particles and trapped air, giving a rough, opaque, crystalline deposit that is fairly brittle. Rime ice often forms on leading edges and can affect the aerodynamic qualities of an airfoil or the airflow into the engine intake. Due entrapped air, and slow accumulation rate, rime usually does not cause a significant increase in weight.

The temperature range for the formation of rime ice can be between O° C and –40° C, but is most commonly encountered in the range from –10° to –20° degrees C.

1.2.4 Mixed Ice

Different moisture droplet sizes are commonly encountered in cloud, this variation produces a mixture of clear ice (from large drops) and rime (from small droplets.) Known as mixed ice, or in some countries as cloudy ice, most ice encounters take this form. Pure rime ice is usually confined to high altostratus or altocumulus, while pure clear ice is confined to freezing rain (below nimbostratus.)

1.2.5 Hoar Frost

Frost occurs when moist air comes in contact with a surface at sub zero temperatures. The water vapour, rather than condensing to form liquid water, changes directly to ice and deposits in the form of frost. This is a white crystalline coating that can usually be brushed off. Typical conditions for frost to deposit on a surface require a clear night (i.e. cool), calm wind, and high humidity. Frost can form on an aeroplane when it is parked in temperatures less than O°C, with a dew deposit. Frost can also occur in flight when the aircraft flies from below freezing temperatures into warmer moist air – for example, on descent, or when climbing through a temperature inversion.

Although frost can obscure vision through a cockpit window and degrade a wing’s lift. Frost does not alter the basic aerodynamic shape of the wing (unlike clear ice) however it can disrupt the smooth airflow over the wing, inducing early separation of the airflow over the upper surface. Frost is particularly dangerous during take-off when the flow disturbance may be sufficient to prevent the aeroplane becoming airborne.

1.3 Airframe Icing and Cloud Type

1.3.1 Cumulus Type

Cumulus-type clouds consist predominantly of liquid water droplets at temperatures down to about –20° C. Below this temperature either liquid drops or ice crystals may predominate. Newly formed cloud segments will tend to contain more liquid drops than mature parts. The risk of airframe icing is severe in cumuliform clouds in the range O° C to –20° C. Airframe ice is unlikely below –40°C. The vertical motion in a convective cloud varies its composition and corresponding ice risk throughout a wide altitude band. Updrafts will tend to carry the water droplets higher and increase their size. If significant structural icing does occur, it may be necessary to descend into warmer air.

1.3.2 Stratiform

Liquid water drops down to about –15°C, with a corresponding risk of structural icing, usually predominates in stratiform clouds. If significant icing is a possibility, it may be advisable to fly at a lower level where the temperature is above 0°C, or at a higher level where the temperature is colder than –15°C. Stratiform clouds associated with an active front or with orographic lifting of a moist maritime stream, increase the icing probability at temperatures lower than usual; continuous upward motion of air generally means a greater retention of liquid water in the clouds.

1.3.3 Precipitation

Raindrops and drizzle from any sort of clouds will freeze on contact with a surface whose temperature is below O° C. The risk of severe clear ice increases with the size of the water drops. Vigilance is essential when flying in rain at freezing temperatures.

1.3.4 High-Level Clouds

High-level clouds, such as cirrus clouds, with their bases above 20,000 ft, are usually composed of ice crystals that will not freeze onto the aeroplane, and so the risk of structural icing is slight when flying at very high levels.

1.3.5 Water Content in Cloud

The greater the water content the greater the rate of ice accretion. High water content is often found in clouds caused by orographic and frontal lifting. An added and important factor that determines the water content is temperature at the cloud base. Recalling that warm air requires greater water content at saturation than cold air it follows that a warm cloud base implies high water content. Thus, curiously, ice accretion due to water content is more severe in summer (when clouds can be expected to be warmer) than in winter. Similarly, water content in tropical cloud is greater than in polar cloud and therefore the rate at which ice builds up is greater in the tropics (above the freezing level) than in Polar Regions.

1.4 Icing Characteristics

Sharp components such as thin leading edges, fins, aerials, propeller and helicopter blades gather ice more readily than blunt components. The main reason is that air tends to stagnate at blunt objects increasing the ambient pressure that, in turn, increases the temperature. Similarly, sharp items have thin boundary layers giving little insulation between skin and ice. This principle is also relevant when considering thrust produced by a propeller. When ice builds up, the additional thrust requirement may not be available if propeller blade efficiency has been degraded. Indicated airspeed also influences the rate of ice accretion, the higher the speed (below some 250 knots) the faster ice accumulates. Kinetic heating due to skin friction at speeds above 250 knots reduces risks of icing significantly.

1.4.1 Aircraft Handling

Another hazard of structural icing is the possible uncommanded and uncontrolled roll phenomenon referred to as roll upset that is associated with severe in-flight icing. Pilots flying aeroplanes certificated for flight in known icing conditions should be aware that severe icing is a condition that is outside of the aeroplane's certification icing envelope. Roll upset may be caused by airflow separation inducing self-deflection of the ailerons and loss of or degraded roll handling characteristics. This phenomenon can result from severe icing conditions without the usual symptoms of ice accumulation or a perceived aerodynamic stall.

The term "severe icing" is associated with the rapid growth rate of visible ice shapes most often produced in conditions of high liquid water content and combinations of other environmental and flight conditions. Severe icing is often accompanied by aerodynamic performance degradation such as high drag, aerodynamic buffet, and premature stall.

In addition, ice associated with freezing rain or freezing drizzle can accumulate on and beyond the limits of an ice protection system. This kind of ice may not produce the familiar performance degradation; however, it may be potentially hazardous. Freezing rain and freezing drizzle contain droplets larger than the criteria specified by certification requirements.

Another hazard of structural icing is the tailplane (empennage) stall. Sharp-edged surfaces are more susceptible to collecting ice than large blunt surfaces. For this reason, the tailplane may begin accumulating ice before the wings. The tailplane will also accumulate ice faster. Because the pilot cannot readily see the tailplane, the pilot may be unaware of the situation until the stall occurs.

A tailplane stall occurs when the critical angle of attack is exceeded. Since the horizontal stabilizer counters the natural nose down tendency caused by the centre of lift of the main wing, the airplane will react by pitching nose down, sometimes uncontrollably, when the tailplane is stalled. Application of flaps can aggravate or initiate the stall. The pilot should use caution when applying flaps during an approach if there is the possibility of icing on the tailplane.

Perhaps the most important characteristic of a tailplane stall is the relatively high airspeed at the onset and, if it occurs, the suddenness and magnitude of the nose down pitch. A stall is more likely to occur when the flaps are approaching the fully extended position or during flight through wind gusts.

Ice detection is very important in dealing with icing in a timely manner. A careful preflight of the aircraft should be conducted to ensure that all ice or frost is removed before takeoff. Pilots operating in icing conditions must check for ice formation. At night, aircraft can be equipped with ice detection lights to assist in detecting ice. Being familiar with the aeroplane's performance and flight characteristics will also help in recognising the possibility of ice. Ice build-up will require more power to maintain cruise airspeed. Ice on the tailplane can cause diminished nose up pitch control and heavy elevator forces, and the aircraft may buffet if flaps are extended. Ice on the rudder or ailerons can cause control oscillations or vibrations.

De-icing is a procedure in which frost, ice, or snow is removed from the aircraft in order to provide clean surfaces. Anti-icing is a process that provides some protection against the formation of frost or ice for a limited period of time. There are various methods and systems that are used for de-icing and anti-icing. Pneumatic boots are commonly used on smaller aircraft and usually provide ice removal for the wing and tail section by inflating a rubber boot. Ice can also be removed by a heat system or by a chemical fluid. De-icing the propeller is usually done by electrical heat, however it can also be done with a chemical fluid.

Anti-icing can be accomplished by using chemical fluid or a heat source. Anti-ice systems are activated before entering icing conditions to help prevent the ice from adhering to the surface. These methods provide protection for the wings, tail, propeller, windshield, and other sections of the aircraft that need protection.

For an aeroplane to be approved for flight Into icing conditions, the aeroplane must be equipped with systems that will adequately protect various components. There are two regulatory references to ice protection: The Application to Aeroplane Type Certification in FAR Parts 23 and 25.

1.5 Roll Upsets

The following paragraphs contain a summary of the cues leading up to an uncommanded or uncontrolled roll upset due to severe in-flight icing. It is based on the FAA's investigation of aeroplane accidents and incidents during or after flight in freezing rain or freezing drizzle conditions. The term "supercooled large droplets" (SLD) includes freezing rain or freezing drizzle. The general information in this section is intended to assist pilots in identifying inadvertent encounters with SLD conditions. The following suggestions are not intended for use in prolonged flight in conditions that may be hazardous. Because of the broad range of environmental conditions, limited data available, and various aeroplane configurations, pilots must use the manufacturer's airplane flight manual (AFM) for specific guidance on individual types of aircraft.

Roll upset can occur without the usual symptoms of ice or perceived aerodynamic stall. Roll upset can be caused by airflow separation inducing self-deflection of the ailerons and/or degradation of roll-handling characteristics. It is a little known and infrequently occurring flight hazard that can affect aeroplanes of all sizes. Recent accidents, however, have focused attention on such hazards in relation to turboprop aircraft. Despite the U.S. Federal Aviation Regulations (FARs) and the most current aircraft certification requirements, there is evidence that icing conditions and their effects on aeroplanes are not completely understood. Simply put, pilots must not be over reliant on de-icing/anti-icing equipment fitted aboard aeroplanes that have been certified for flight into icing conditions. Severe icing conditions can be outside the airplane certification-icing envelope, and each pilot must be vigilant to avoid conditions beyond an aeroplane's capabilities.

The U.S. Aeronautical Information Manual (AIM) defines severe icing as, "the rate of accumulation is such that the de-icing/anti-icing equipment fails to control the hazard. Immediate flight diversion is necessary." Severity in the context of the AIM is associated with rapid growth of visible ice shapes, most often produced in conditions of high liquid water content (LWC) and other combinations of environmental and flight conditions. This kind of severe ice is often accompanied by aerodynamic degradation such as high drag, aerodynamic buffeting and premature stall. Ice associated with freezing rain or freezing drizzle accreting beyond the limit of the ice-protection system is also described as severe. This kind of ice may not develop large shapes, and may not produce familiar aerodynamic degradation such as high drag, but nonetheless, may be hazardous. Freezing rain and freezing drizzle contain droplets larger than those considered in meeting certification requirements, and temperatures near freezing can produce this kind of severe icing. As prescribed by FAA policy, a 40-micron (one micron is one thousandth of a millimetre) sized droplet diameter is normally used to determine the aft limit of ice-protection system coverage. Drizzle-size drops may be 10 times that diameter (400 microns), with 1,000 times the inertia, and approximately 100 times the drag, of the smaller droplets. Drizzle drops not only impinge on the protected area of the airplane, but may impinge aft of the ice-protection system and accumulate as ice where it cannot be shed. Freezing raindrops can be as large as 4,000 microns (four millimetres). Freezing rain, however, tends to form in a layer sometimes coating an entire airplane.

Freezing drizzle tends to form with less extensive coverage than freezing rain, but with higher ridges. It also forms ice fingers or feathers, ice shapes perpendicular to the surface of the airfoil. For some airfoils, freezing drizzle appears to be far more adverse to stall angle, maximum lift, drag and pitching moment. A little known form of freezing drizzle aloft – also described as supercooled drizzle drops (SCDD) – appears to have been a factor in the American Eagle ATR-72's roll upset.

1.5.1 SCDD

SCDD is a new challenge. The physics of ice formation and altitude vs. temperature profiles differ between freezing drizzle and SCDD, but for the discussion of ice accretion only, freezing drizzle and SCDD may be considered synonymous. Droplets of supercooled liquid water at temperatures below 0 degrees C (32 degrees F) having diameters of 40 microns to 400 microns are found in both freezing drizzle and SCDD. Like freezing rain and freezing drizzle, SCDD conditions tend to be limited in horizontal and/or vertical extent. These conditions are reported in AIRMETs but are not usually reported in SIGMETs, which report on conditions in areas of less than 3,000 square miles (7,770 square kilometres). No aircraft is certificated for flight in supercooled large droplet (SLD) conditions.

Surface temperature varies with air pressure along the airfoil. At the leading edge, where pressure is the highest, the surface temperature will also be higher than farther aft. If the local surface temperature on the airfoil is warmer than freezing, no ice will form. Infrared measurements of a typical airfoil in the icing tunnel at a true air speed of 150 knots show that there can be a decrease in temperature of more than 1.9 degrees C (3.5 degrees F) along the airfoil. At temperatures close to freezing, there may be no ice on the leading edge, but ice can form further aft because of the lower temperatures. Because there is liquid runback, any ice formation aft of the leading edge tends to act like a dam, making ice growth more rapid.

1.5.2 Airfoil Sensitivity

Although ice can accrete on many airplane surfaces, concern is focused on wing-airfoil icing. Some airfoil designs tend to be less sensitive to lift loss with contamination than other, more efficient, airfoils. Traditionally, the industry has relied on the infrequency of occurrence, limited extent of coverage, forecasting and reporting to avoid freezing rain and freezing drizzle, and recognition to exit the conditions. An infinite variety of shapes, thickness and textures of ice can accrete at various locations on the airfoil. Each ice shape essentially produces a new airfoil with unique lift, drag, stall angle and pitching moment characteristics that are different from the wing's own airfoil, and from other ice shapes. These shapes create a range of effects. Some effects are relatively benign and are almost indistinguishable from the wing's airfoil. Others may alter the aerodynamic characteristics so drastically that all or part of the airfoil stalls suddenly and without warning. Sometimes the difference in ice accretion between a benign shape and a more hazardous shape appears insignificant. The effects of severe icing are often exclusively associated with ice thickness. For example, it is reasonable, in a given set of conditions, to believe that a specific three-inch (7.6-centimeter) shape would be more adverse than a similar 1.5 inch (3.8-centimeter) shape in the same place. Contrary to that one criterion, however, a five-inch (12.7 centimetre) ice shape on one specific airfoil is not as adverse as a one-inch (2.54 centimetre) ice ridge located farther aft on the chord. In another example, a layer of ice having substantial chord wise extent is more adverse than a three-inch ice accretion having upper and lower horn-shaped ridges (double horn). Ice can contribute to partial or total wing stall followed by roll, aileron snatch or reduced aileron effectiveness.

Wing stall is a common consequence of ice accretion. Ice from freezing drizzle can form sharp-edged roughness elements approximately 0.5 centimetre to one centimetre (0.2-inch to 0.4-inch) high over a large chord wise expanse of the wing's lower surfaces (perhaps covering 30 percent to 50 percent) and fuselage, increasing drag dramatically, thereby reducing speed. Correcting for this demands increased power, increased angle-of-attack (AOA) or both to maintain altitude. Ultimately, such unmitigated adjustments lead to exceedance of the stall angle and a conventional stall, likely followed by a roll.

Aileron snatch is a condition that results from an imbalance in the sum of the product of aerodynamic forces at an AOA that may be less than wing stall, and that tends to deflect the aileron from the neutral position. On unpowered controls, it is felt as a change in control-wheel force. Instead of requiring force to deflect the aileron, force is required to return the aileron to the neutral position. With all else equal, smaller ailerons would have smaller snatch forces. Aileron instability sensed as an oscillation, vibration or buffeting in the control wheel is another tactile cue that the flow field over the ailerons is disturbed. Although flight testing using simulated ice shapes on an ATR-72 demonstrated that these forces were less than the 60 pound certification limit for temporary application in the roll axis, the force's sudden onset and potential to cause a rapid and steep roll attitude excursion were unacceptable. FAA investigation has revealed similar roll attitude excursions affecting other aircraft types that are equally unacceptable. Ailerons that exhibit the snatch phenomenon have control-wheel forces that deviate from their normal relationship with aileron position. Nevertheless, the ailerons may be substantially effective when they are deflected.

Degradation of roll control effectiveness results from flow disruption over the wing ahead of the ailerons, and the controls do not produce the rolling moments associated with a given deflection and airspeed. Degradation of aileron control caused by ice may or may not be accompanied by abnormal control forces. If, for example, the airplane is displaced in roll attitude, through partial stall caused by ice, the pilot's efforts to correct the attitude by aileron deflection are defeated by the aileron's lack of effectiveness.

Ice tends to accrete on airfoils in different ways, depending on the airfoil, the AOA and other aircraft variables. Ice accretion at the wing tip may be thicker, extend farther aft and have a greater adverse effect than ice at the root. The airfoil at the tip is in all probability a different airfoil than at the root. It is probably thinner, may have a different camber, be of shorter chord, and probably two or three degrees of washout relative to the root section.

1.5.3 Wing Tip Stalling

Normally, washout helps to ensure that the symmetric stall starts inboard, and spreads progressively, so that roll control is not lost. Greater ice accretion has probably occurred at the tip, leaving it more impaired aerodynamically than the inboard wing section. Stall, instead of starting inboard, may start at the tip. Because the tip section may have a sharper nose radius and probably has a shorter chord, it is a more efficient ice collector. As a result, ice accretion at the wing tip may be thicker, extend farther aft and have a greater adverse effect than ice at the root. Even if the ice does build up at the root to nearly the same thickness as that at the tip, ice still tends to affect the smaller chord section, such as the wing tip, more adversely.

Power effects can aggravate tip-stall. The effect of the propeller is to reduce the AOA of the section of the wing behind it. At high power settings, stall on the inner wing tends to be delayed by propeller wash. But the outer wing does not benefit from the same flow field, so the outer wing tends to stall sooner. Finally, because of its greater distance from the flight deck to the outer wings, the crew may have difficulty in assessing ice there. This means that at some AOAs, the outer wings maybe undergoing partial aerodynamic stall, while normal flow conditions still prevail over the inner parts of the wing. If such a stall occurs, there may be no pronounced break and the pilot may not sense the stall, so the stall is insidious. This partial stall condition also accounts for a degree of degradation of aileron effectiveness. Where ice builds up on a given airfoil depends on the AOA, airspeed and icing variables. For example, the ATR accident flight testing included flying in drizzle-size drops. At the test airspeed, ice would predominantly build on the upper surfaces of the wings with the flaps extended to 15 degrees (resulting in a smaller AOA) and predominantly on the lower surfaces of the wings with the flaps retracted (resulting in a larger AOA).

On the upper surfaces, there was little drag increase until separation. On the lower surfaces, the expanse of rough ice was accompanied by a substantial drag increase. In an icing environment, the propeller wash also tends to influence icing impingement on the airfoil. Unless the propellers are counter-rotating, the flow field is asymmetric over the wings, and ice impingement tends to be slightly asymmetric as well. After aerodynamic stall occurs, reattaching flow generally requires a marked reduction of AOA and then refraining from increasing the AOA to the stall angle for that part of the wing. This characteristic is configuration dependent, and is not limited to just one airplane type. For example, in two different airplane types studied in detail, the stall angle for the outer wings was about five degrees with ice accretion forward of the ailerons on the upper wing surface aft of the de-icing boots. The normal stall angle was near 20 degrees with no ice accretion. In both aircraft, reattachment of flow occurred when the AOA was reduced to substantially less than the stall angle. Applying power and maintaining attitude may not be most effective in recovering from an outer wing stall, because the reduction in AOA does not occur as rapidly.

In recent years, reports of roll excursions associated with icing appear to have increased in frequency, especially among turboprop aeroplanes used in regional airline commuter operations. One possible reason for this increase is that exposure to icing conditions in general has dramatically increased. In 1975, the number of annual departures for all U.S. major airlines was 4.74 million. In 1994, almost two decades later, the regional segment alone has grown to 4.60 million annual departures.

Annual regional airline exposure to icing may be double that of jet aircraft, which service the longer routes and tend to operate above most icing conditions at higher altitudes for a greater percentage of their flight time. The increase in operations suggests increased exposure to all icing conditions, so a commensurate increase in the number of flights involving SLD could be expected. For whatever reasons, exposure to these hazardous conditions appears to be more frequent than was previously believed. Substantial effort is being placed into improving forecasts for all SLD. Since fall 1995, there have been preliminary changes to mathematical models used to forecast these conditions. The models will be reviewed and updated periodically, based on correlation with observations and pilot reports (PIREPs).

Pilots are best situated to submit a real-time report of actual icing conditions. But there is no assurance that another airplane will transit that small volume of the sky containing SLD. If it does, there must be some way for the pilot to identify that the icing is caused by SLD and then submit the PIREP. Not all pilots may be sensitive to what SLD icing looks like on their airplane, and PIREPs are a low priority during periods of high cockpit workload.

In-flight meteorological conditions reported by the crew of one airplane might not reflect the hazards of that same airspace for other aeroplanes, because of the many variables involved. The variables include the size and type of the aeroplane's airfoil, configuration, speed, AOA, etc. If the reporting airplane was a large transport, the effect of icing may have been unnoticed and unreported, but the conditions could be a problem for a smaller aeroplane. PIREPs from an identical-model aeroplane are most likely to be more useful, but even the identical-model aeroplane climbing through an icing layer would likely result in a different ice accretion than one descending.

Ice accreted beyond ice-protection system coverage will not be shed and will continue to accrete until the airplane exits the icing conditions. Remaining in such icing conditions cannot improve the situation. Severity indices of trace, light, moderate and severe vary among aeroplanes for the same cloud and tend to be subjective. Not too far from the American Eagle ATR accident site at about the same time, a jet airplane experienced a rapid ice accretion. The jet aeroplane's captain said that he had never experienced such a fast ice build-up. One inch (2.54 centimetres) of milky ice accumulated on a thin rod-shaped projection from the centre windshield post in one to two minutes. The captain reported the build-up as light rime. In these extraordinary conditions, does "light" icing convey a message to others suggesting vigilance or complacency?

1.6 Upsets

Extent of accretion, shape, roughness and height of ice are the most important factors affecting an airfoil. Unfortunately, operational descriptors of rime. clear or mixed ice are not adequate to convey nuances of the icing environment and the hazards of SLD. Ice forming aft of the boots may be white, milky or clear. Non-hazardous ice may also be described using the same terms. In the same cloud, one airplane may accrete rime ice, while another aeroplane, at a higher speed, accretes mixed ice. To avoid ambiguity, meaningful terminology must be well defined. PIREPs are very useful in establishing a heightened sense of awareness to a possible icing condition and to aid forecasters in correlating forecast meteorological data with actual ice. Although a forecast projects what may be, and a PIREP chronicles what was, the most important issue is: What is the icing condition right now? Cues that can be seen, felt or heard signal the potential for ice to form and the presence of ice accretion or icing severity.

Cues may vary somewhat among airplane types but typically cues include:

(a) temperature below freezing combined with visible moisture;

(b) ice on the windshield-wiper arm or other projections, such as engine-drain tubes;

(c) ice on engine-inlet lips or propeller spinners;

(d) decreasing airspeed at constant power and altitude; or

(e) ice-detector annunciation.

1.6.1 Identifying SLD Conditions

Experience suggests that it has been impractical to protect aeroplanes for prolonged exposure to SLD icing because, at its extreme, it tends to cover large areas of the airplane. A conventional pneumatic ice-protection system able to deal with such extensive ice accretion would likely affect airfoil performance as much as the ice, would be expensive and would be heavy. Conventional electrothermal systems would require extraordinary amounts of power. Because of the broad range of environmental conditions, limited data available and various airplane configurations, the manufacturer's pilots operating manual should be consulted for guidance on a specific airplane type. The suggestions below are not intended to prolong exposure to icing conditions, but are a warning to exit the conditions immediately:

(a) Ice visible on the upper or lower surface of the wing aft of the active part of the de-icing boots. It may be helpful to look for irregular or jagged lines or pieces of ice that are self-shedding. For contrast, a portion of the wing may be painted a dark colour with a matte finish, different than the colour of the boots. The matte finish can help identify initial formation of SLD ice, which may be shiny. All areas to be observed need adequate illumination for night operation.

(b) Ice accretion on the propeller spinner. Unheated propeller spinners are useful devices for sorting droplets by size. Like a white wing, a polished spinner may not provide adequate visual contrast to detect SLD ice. If necessary, a dark matte circumferential band may be painted around the spinner as a guide.

(c) Granular dispersed ice crystals, or total translucent or opaque coverage of the unheated portions of the front or side windows. These may be accompanied by other ice patterns, such as ridges on the windows. Upon exposure to SLD conditions, these patterns may occur within a few seconds to approximately one minute.

(d) Unusually extensive coverage of ice, visible ice fingers or ice feathers. Such ice can occur on parts of the airframe not normally covered by ice.

At temperatures near freezing, other details take on new significance:

(a) Visible rain (which consists of very large water droplets). In reduced visibility, occasionally select taxi/ aircraft landing lights ON. Rain may also be detected by the sound of impact.

(b) Droplets splashing or splattering on impact with the windshield. Droplets covered by the icing certification envelopes are so small that they are usually below the threshold of detectability.

Ice tends to accrete more on the upper surface at low angles of attack associated with higher speeds or flap extension.

(a) Water droplets or rivulets streaming on the heated or unheated windows. These may be an indication of high LWC of any size droplet.

(b) Weather radar returns showing precipitation. These suggest that increased vigilance is warranted for all of the severe icing cues. Evaluation of the radar display may provide alternative routing possibilities.

1.6.2 Ice Secretion

The shape of the ice that forms and the amount of ice that accumulates primarily influence aerodynamic performance degradation while the amount of liquid water in the cloud and the duration of the exposure to icing primarily determine the quantity of ice collected. Cloud droplet size is generally a secondary consideration. Temperature can determine the amount of accretion; if it is close to freezing, some of the intercepted water droplets blow off before they can freeze.

Ice accretion shape is a result of the rate of freezing on the surface. Low temperatures and droplet impingement rates (water concentration X velocity), along with small droplets, promote rapid freezing on the surface. Such conditions produce the rather smooth ice surface and pointed accretion shape of rime ice. However, temperatures near freezing, higher rates of accretion and larger droplet sizes result in delays in freezing when the droplets strike the surface. These conditions create irregular ice formations with flat or concave surfaces sometimes having protuberances ("double-horn" ice formation) facing the airstream either side of the airflow centre or stagnation line. This type of ice formation is usually described as glaze ice. Ice shapes are of extreme importance because the contour, roughness and location of the ice formation on the various aircraft components can significantly degrade aerodynamic performance. Glaze ice shapes, runback ice and ice can produce significant aerodynamic penalties by decreasing lift and stall angle and increasing drag and stall speed.

In addition to the distance flown in icing clouds, the amount of ice collected depends upon the concentration of liquid water in the clouds and a factor called the collection efficiency (the higher the efficiency the greater the amount of ice collected). Values of collection efficiency depend upon airspeed, size of the cloud droplets and size and shape of the moving surface.

In general, the collection efficiency is greatest for high airspeeds, large droplets and small objects (windshield wiper posts, outside temperature probes, airfoils). For aircraft wings, the collection efficiency can vary from near zero for very small droplets to nearly 100 percent for large droplets in freezing rain. Because of their smaller leading edge radius and chord length, tail surfaces have higher collection efficiencies than wings and can collect two to three times greater ice thickness. Two significant parameters of icing intensity for a given aircraft component are the amount of liquid water and distribution of droplet sizes in the clouds. For a given airspeed, these factors determine the rate of ice accretion and the total amount of ice accumulated in a given encounter.

Ice can form on tailplanes and antennas faster than on wings, while the overall rate of accrual may depend on whether the aircraft is in a layer type (stratiform) cloud or a cumulus type cloud with large vertical development. Ice can generally build up twice as fast in cumulus clouds because of their high water content; but the extent of the icing exposure in cumulus clouds is not nearly as great as that of stratus clouds, and the total accumulation could be small. Data acquired in past research studies have indicated the very limited vertical extent of icing clouds (90 percent within less than 3,000 feet vertically) so that during climb and descent, icing will continue for only a short time, depending upon airspeed and rate of climb. A survey has disclosed that, at constant attitude, 90 percent of the icing encounters are less than 50 miles in horizontal extent and none measured longer than 180 miles.

The greatest amount of liquid water, and therefore the highest rate of ice accretion, occurs generally near the tops of clouds. This condition is to be expected from the physics of cloud formation, i.e. the cooling of ascending air and increase in condensation with height above the cloud base. An aircraft flying in clouds with the outside air temperature sufficiently below freezing to form ice will not necessarily collect ice. On the average, this aircraft has only approximately a 40 percent chance of icing, and that occurs near freezing temperatures. As the temperature gets further from the freezing point (colder) there is less chance of picking up ice. If the temperature is below –20° C, the chance for accumulating ice is 14 percent. Most clouds below freezing start to glaciate (change over to ice crystals), and the colder the temperature the more rapidly this process occurs. Also, the droplets may be too small to strike the wing in any significant amount. If one were free to choose a flight level under 20,000 feet and vary it as required to avoid icing, the frequency and intensity of icing would be cut to a minimum, except for encounters during climb and descent. In these cases, the amount of ice formed would be a function of the thickness of the icing cloud layer and the rate of climb through it. Only about one in 10 single icing cloud layers exceed a thickness of 3,000 feet. No icing cloud thickness that was measured totalled more than 6,000 feet in thickness. These data were acquired from instrumented fighter-interceptor aircraft operating from air bases in the northern United States.

Maximum icing conditions are treated separately for cumulus clouds and for stratiform clouds. Icing cloud parameters are called “maximum intermittent” for cumulus clouds and “maximum continuous” for stratiform clouds. Separate parameters were required because of the differences in vertical and horizontal extents of the two cloud types. Cumulus clouds are limited in horizontal extent but extend through a wide range of altitudes; stratiform clouds can extend long horizontal distances but are limited in vertical thickness.

Icing cloud meteorological parameters for FAR Part 25 were based on historical data obtained more than 40 years ago by the U.S. National Advisory Committee for Aeronautics (NACA). Their use in establishing ice protection design standards has proved successful for many different types of aircraft. These design standards were determined on the basis of an ice protection system providing nearly complete protection in 99 percent of the icing encounters, and that some degradation of aircraft performance would be allowed. A statistical study determined that in the 99 percent of the icing encounters, the probability of exceeding the maximum values of all three icing parameters simultaneously (liquid water, temperature and droplet size) would be equivalent to one in 1,000 icing encounters. In severe icing conditions, evasive action would be required. In previous recommendations for in-flight reporting of icing intensity, the definition of heavy or severe icing was stated as that situation where the rate of ice accumulation is such that the ice protection system fails to reduce or control the hazard and immediate diversion of the flight becomes necessary. Not knowing the quantitative value of an existing icing condition, the point to emphasise is that a pilot cannot become complacent by assuming that the aircraft’s certified ice protection system will provide complete protection under all conditions. For example, it is not possible for designers to provide complete protection against ice accretions caused by freezing rain. In severe icing conditions, evasive action would be required.

1.6.3 Tailplane Ice Studies

Ice is not accreted if a cloud is composed only of ice crystals. If some liquid water is present (mixed clouds), ice does form, but the condition does not last long. In the presence of ice crystals, liquid drops evaporate because of the difference in saturation vapour pressure between ice crystals and liquid droplets. Usually, little, if any, icing is found in areas of snow. However, when flying below the snow level, aircraft icing can occur if a temperature inversion exists to melt the snow and the resulting rain falls to a below-freezing level – the conditions for freezing rain. These conditions are characterised by very large drops and low values of liquid water. Despite the low concentration of liquid water, a considerable amount of ice can accumulate because of the high collection efficiency of the large drops. In freezing rain, ice can form on many different surfaces of the aircraft. Freezing drizzle can occur under different conditions than freezing rain. The joining process of coalescence and collisions of small droplets produce drops smaller than freezing rain, an above-freezing level is not necessary. Both freezing rain and drizzle can exist down to ground level below a cloud deck and thereby cause ice to form on aircraft surfaces during landing, takeoff and ground operations if the aircraft surface temperature is below freezing.

Tailplane stall is certainly not a new phenomenon. However, it has recently been thrust into the spotlight by a series of accidents involving turboprop aircraft. Several FAA airworthiness directives (ADs) have been issued that affect several different turboprop aircraft. The common element leading to these ADs appears to be sensitivity to ice build-up on the horizontal stabiliser resulting in control problems that can involve an uncontrollable pitch-down during flap extension. The specifics of ice formation on the tailplane and the penalties associated with it may not be fully understood by many aircraft crewmembers.

A joint NASA/FAA International Tailplane Icing Workshop to address this problem was held in November 1991.The workshop provided the most complete information to date on the tailplane icing problem. Among numerous recommendations resulting from it were the need for a survey of the current fleet to determine whether unsafe conditions exist on various aircraft and the need for ice detection capability on the horizontal tail. The FAA is planning such a survey with upcoming ice-detection studies.

1.6.4 Landing Approach After or During an Icing Encounter

In addition to the fact that the horizontal stabiliser is a more efficient collector, the aerodynamic effect of a given thickness of ice on the tail will generally be more adverse than the same thickness of ice on the wing. This is due to the ratio of thickness to chord length and leading edge radius. Tailplane stall due to ice contamination is seldom a problem in cruise flight. However, when trailing edge flaps are extended, some new considerations enter the picture. On conventional aircraft, the horizontal tail provides longitudinal stability by creating downward lift (in most cases) to balance the wing and fuselage pitching moments. With flaps extended, the wing centre of lift moves aft, downwash is increased and the horizontal tail, as a result, must provide greater downward lift. In some aircraft, depending on forward centre of gravity (CG), the tail may be near its maximum lift coefficient and a small amount of contamination could cause it to stall. As the aircraft slows after flap extension, the requirement for downward lift by the horizontal tail increases to increase the angle of attack of the wing and produce a given amount of lift at a slower speed. With flaps full down and the aircraft at approach speeds, the angle of attack of the horizontal stabiliser is very high. It is high also because of the downwash over the tail created by the extended flaps. This will increase the angle of attack of the stabiliser even more. This situation is where tailplane ice can cause trouble. A small amount of ice contamination on the leading edge of the horizontal stabiliser can interfere with the airflow on the underside of the stabiliser.

Current aviation wisdom advises the pilots of boot-equipped aircraft to wait until one-quarter inch to one-half inch of ice has collected on the wing before activating the de-icing system. On some horizontal stabilisers one-half inch of a ice shape may cause unacceptable aerodynamic penalties. In addition, since the horizontal stabiliser is normally a more efficient collector of ice, it is very possible that it has collected much more than the half inch of ice. Remember, it is possible to have very little or no accumulation of ice on the wings and yet have significant accumulation on the tail. It also seems to be an accepted practice to increase the landing airspeed some amount if the wings are contaminated. It also may be that the pilot has opted not to de-ice because there is only a minor accumulation of ice on the wing. Trouble may now be twofold. There may be much more ice on the horizontal stabiliser than on the wing, and the increased speed will create a much greater wing downwash and therefore higher angle of attack for the stabilizer. This may lead to separation of the flow on the lower surface of the stabilizer, a sudden change in elevator hinge moment and forward stick force that may overpower the pilot. In aircraft without boosted controls, the pilot may notice lightening stick forces, although the above sequence has happened suddenly and without a recognisable warning when flaps are extended. The answer is to reduce flap angle immediately, if altitude and airspeed permit.

In most instances, this problem manifests itself when the final segment of flaps is extended (creating the greatest amount of downwash) at very low altitude during the landing phase. The odds of recovery from uncontrollable nose pitch-down at low altitude are poor. Adding airspeed in this case may actually reduce the margin of safety. The remedy is to land at a reduced flap angle or get rid of all of the ice. Generally, the tailplane stall problem that has been presented here seems to be associated with aircraft that have the following characteristics. They:

(a) do not have powered control surfaces, and rely on aerodynamic balance to keep stick forces low;

(b) have high efficiency flaps that produce relatively high downwash which results in high angle of attack on the tailplane;

(c) have non-trimmable stabilisers:

(d) have efficient stabilisers with short chord length and small leading edge radii; and,

(e) mostly have inflatable boots for ice protection.

The characteristics listed above fit most of the turboprop aircraft used in the regional airline fleet today. The six ADs regarding the effects of tailplane ice on turboprop commuter aircraft plus several recent accidents have prompted a closer look at the problem.

One of the highlights of the NASA/FAA workshop was the recognition of the need for more education and training for pilots. This workshop recognised that while much training has been provided for recognition and proper actions related to wind shear, training for operations in icing conditions has received less attention. Some of the current recommended procedures suggested during crew training (e.g., increased airspeed) may actually exacerbate an already adverse situation at the horizontal tail.

1.6.5 Tailplane Stall Symptoms

Warning: Once a tailplane stall is encountered, the stall condition tends to worsen with increased airspeed and possibly may worsen with increased power settings at the same flap setting. Airspeed, at any flap setting, in excess of the aeroplane manufacturer's recommendations for the flight and environmental conditions, accompanied by uncleared ice contaminating the tailplane, may result in a tailplane stall and uncommanded pitch down from which recovery may not be possible. Tailplane stall symptoms include:

(a) Elevator control pulsing, oscillations, or vibrations.

(b) Abnormal nose down trim change.

(c) Any other unusual or abnormal pitch anomalies (possibly resulting in pilot induced oscillations).

(d) Reduction or loss of elevator effectiveness.

(e) Sudden change in elevator force (control would move nose down if unrestrained).

(f) Sudden uncommanded nose down pitch.

Ice can form on the aircraft's tail at a greater rate than on the wing and can exist on the tail when no ice is visible on the wing. When ice is visible, do not allow ice thickness to exceed the operating limits for de-icing system operation or the system may not shed the tail ice. If the control symptoms listed above are detected or ice accumulations on the tail are suspected, land with a lesser flap extension setting and increase airspeed commensurate with the lesser flap setting.

This discussion of tailplane icing only applies to aeroplanes having tailplane pitch control. It is not applicable to aircraft with foreplane (canard) pitch control. Generally, a tailplane stall would be encountered immediately after extension of the trailing edge flaps to an intermediate position or, more commonly, after extension from an intermediate position to the full down position. Usually, tailplane stall (or impending stall) can be identified by one or more of the symptoms listed above occurring during or after flap extension. The symptom(s) may occur immediately or after nose down pitch, airspeed changes, or power increases following flap extension.

1.7 Other Adverse Affects of Ice

1.7.1 Performance

Ice accretions can degrade the performance of aircraft by:

(a) causing loss of control, particularly during a critical manoeuvre such as landing;

(b) increasing total drag substantially;

(c) reducing lift and climb capability;

(d) losing the capability to maintain altitude with one engine out on a twin-engine aircraft; and

(e) Causing the loss of artificial stall warning.

1.7.2 Increase in Total Drag

Research measurements taken on an aircraft with a glaze ice accretion disclosed a substantial increase of more than 60 percent in total drag compared to an clean condition. These data were from a typical twin engine commuter type aircraft operating at a normal lift coefficient.

1.7.3 Loss of Lift

Accompanying the above increase in drag was a 17 percent loss of lift.

1.7.4 Loss of Engine-Out Capability

Analysis of the power required versus power available curves for the above situation with the aircraft at 6,000 feet, indicated that without de-icing, the aircraft would descend if one of the two engines failed. On many routes, a 6,000-foot minimum en route altitude (MEA) could spell disaster.

1.7.5 Loss of Artificial Stall Warning

Activation of an artificial stall warning device, such as a stick shaker, is based on a pre-set angle-of-attack several knots above stall speed. This setting allows warning prior to stall onset characteristics where buffeting or shaking of the aircraft occurs. Thus, for an clean aircraft, the pilot has adequate warning of impending stall. However, an iced aircraft may exhibit stall onset characteristics before stick shaker activation because of the affect of ice formations on reducing the stall angle-of-attack. In this case, the pilot does not have the benefit of an artificial warning of stall.

1.7.6 Normal Symptoms May Be Absent

SLD conditions may challenge contemporary understanding of the hazards of icing. Moreover, an airplane may not exhibit the usual symptoms (warnings) associated with severe icing prior to loss or degradation of performance, stability or control characteristics. No aircraft is certificated for flight in SLD conditions.

The American Eagle accident airplane was operating in a complex icing environment that likely contained supercooled droplets having an LWC estimated to be as high as 0.7 grams per cubic meter and a temperature near freezing. Estimates of the droplet diameter vary significantly depending on the estimating methodology, but the droplets with the most severe adverse consequences appear to be in the range of 100 microns to 400 microns, or up to 10 times larger than the droplets upon which normal certification requirements are based.

1.7.7 Ice Intensity/Pilot Action

(a) Trace: Ice becomes perceptible. Rate of accumulation of ice is slightly greater than the rate of loss due to sublimation.

(b) Light: The rate of accumulation may create a problem for flight in this environment for one hour. Unless encountered for one hour or more, de-icing/anti-icing equipment and/or heading or altitude change not required.

(c) Moderate: The rate of accumulation is such that even short encounters become potentially hazardous. De-icing/anti-icing required to remove/ prevent accumulation or heading or attitude change required.

(d) Severe: The rate of accumulation is such that de-icing/ anti-icing equipment fails to reduce or control the hazard. De-icing/anti-icing required, immediate heading or altitude change required.

1.7.8 Icing Certification

With regard to ice protection, airplane type certification is currently accomplished by meeting either the requirement of FAR 23.1419 or FAR 25.1419. These rules require an analysis to establish the adequacy of the ice protection system for the various components of the airplane based on the operational needs of that particular aircraft. In addition, tests of the ice protection system must be conducted to demonstrate that the airplane is capable of operating safely in the continuous maximum and intermittent maximum icing conditions. These conditions are described in Part 25, Appendix C. The type certificate data sheet (TCDS) gives the certification basis for the airplane and lists the regulations with which the airplane has demonstrated compliance. Therefore, when an aeroplane complies with one of the regulations which refers to Part 25, appendix C, the icing certification is indicated on the TCDS and in the AFM. The AFM lists the equipment required to be installed and operable. The AFM or other approved material will also show recommended procedures for the use of the equipment.

The FAA operating rules also permit flight into specified icing conditions provided that the aircraft has functioning de-ice and/or anti-ice equipment protecting specified areas of the aircraft. There are aircraft with partial installations of de-icing and/or anti-icing equipment that do not meet the certification or the operating regulatory requirements for flight into icing conditions. Those installations are approved because it has been demonstrated that the equipment does not adversely affect the aircraft’s structure, systems, flight characteristics, or performance. In such cases, the AFM or other approved material must explain the appropriate operating procedures for the partial de-icing and/or anti-icing equipment and contain a clear statement that the aircraft is not approved for flight into known icing condition.

It is important for pilots to understand that an airplane equipped with some types of de-ice and/ or anti-ice systems may not be approved for flight into known icing conditions. To be approved for such flight, the airplane must be specifically certificated to operate in known icing conditions.

Also, it is important to remember that the certification standards provide protection for the majority of atmospheric conditions encountered, but not for freezing rain or freezing drizzle or for conditions with a mixture of supercooled droplets and snow or ice particles. Some airfoils are degraded by even a thin accumulation of ice aft of the de-icing boots that can occur in freezing rain or freezing drizzle.

More information on icing certification is available in Chapter Seven.

1.8 Summary

It is extremely important that pilots understand the dangers of aircraft icing. Even if an airplane is equipped and certificated to operate in known icing conditions, there are limitations. Flight into known or potential icing situations without thorough knowledge of icing and its effects and appropriate training and experience in use of de-ice and anti-ice systems should be avoided. It is important to know both the pilot's and the aeroplane's limitations. Pilots should become familiar with the types of weather associated with and conducive to icing and understand how to detect ice forming on the airplane. Pilots should know the adverse effects of icing on aircraft systems, control, and procedures to be adopted during icing encounters.

CHAPTER TWO — INDUCTION SYSTEM ICING

Based on the UNITED KINGDOM AERONAUTICAL INFORMATION CIRCULAR AIC 145/1997 (Pink 161) 30 December

2.1 Introduction

Piston engine induction system icing, commonly, but not completely accurately, referred to as ‘carburettor icing’ may occur even on warm days, particularly if they are humid, IT CAN BE SO SEVERE THAT, UNLESS CORRECT ACTION IS TAKEN, THE ENGINE MAY STOP. Induction system icing is more likely at low power setting such as those used during descent, holding, on the approach to a landing or during auto-rotation on a helicopter.

Statistics continue to show an average of 10 occurrences, including 7 accidents, per year, which were probably caused by engine induction icing. After a Forced landing or accident the ice may well have disappeared before an opportunity occurs to examine the engine, so that the cause cannot be identified positively.

Some aircraft and engine combinations are more prone to icing than others and this should be borne in mind when flying various aircraft types.

2.2 Induction System Icing

There are three main types of induction system icing:

(a) Carburettor Icing:

The most common type of induction system icing is carburettor icing which is caused by the sudden temperature drop due to fuel vaporisation and reduction in pressure at the carburettor venturi. The temperature reduction may be as much as 20°- 30°C and results in moisture in the induction air forming ice. The ice gradually builds up, constricting the venturi and, by upsetting the fuel/air ratio, causes a progressive decrease in engine power. Engines which have a conventional float type carburettor are more prone to this type of icing than are those which have a pressure jet carburettor, i.e. the Stromberg type of carburettor. Engines with a fuel injection system are not, of course, subject to carburettor icing.

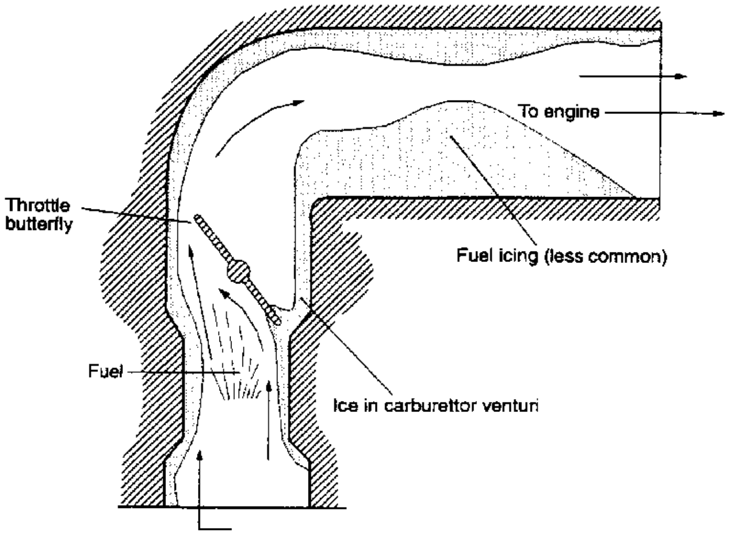
(b) Fuel Icing:

Fuel Icing is the result of water, held in suspension in the fuel, precipitating and freezing in the induction piping, especially in the elbows formed by bends.

(c) Intake or Impact Ice:

Ice which builds up on air intakes, fitters and on carburettor heat or alternate air valves etc is known as Intake or Impact ice (for consistency the term Impact ice is used throughout this chapter). Impact ice can accumulate in snow, sleet, sub-zero temperature cloud or in rain when the temperature of the rain or the aircraft is below 0°C. This type of icing affects fuel injection systems as well as carburettor systems.

BUILD-UP OF ICING IN INDUCTION SYSTEM



Testing has shown that, because of the greater volatility and possible greater water content, carburettor and fuel icing is more likely to occur with MOGAS than with AVGAS.

Reduced power settings are more conducive to icing in the throttle area because there is a greater temperature drop at the carburettor venturi and the partially closed butterfly can more easily be restricted by the ice build-up,

2.3 Atmospheric Conditions

Carburettor icing is not confined to cold weather and will occur in warm weather if the humidity is high enough, especially when the throttle butterfly is only partially open as it is at low power settings. Flight tests have produced serious icing at descent power with the ambient (not surface) temperature above 30C, even with a relative humidity as low as 30%. At cruise power, icing can occur at 20°C with a relative humidity of 60% or more. Ice accretion is less on cold, dry, winter days than on warm, humid, summer days because the water vapour content of the air is lower. Thus, where high relative humidity and ambient temperatures of between -10C and +25°C are common, pilots must be constantly alert to the possibility of icing and should take the necessary steps to prevent it. If the appropriate preventive action has not been taken in time it is vital to be able to recognise the symptoms. Corrective action must be taken before an irretrievable situation develops. Should the engine stop due to icing it may not re-start or, even if it does, the delay may result in a critical situation.

Carburettor or fuel icing may occur even in clear air and these are, therefore, the most insidious of the various types of icing because of the lack of visual clues. The risk of all forms of induction system icing is higher in cloud than in clear air but because of the visual clues the pilot is less likely to be taken unawares.

Specific warnings of induction system icing are not included in standard weather forecasts for aviation. Pilots must use knowledge and experience to estimate the likelihood of its occurrence from the weather information available. When information on the dewpoint is not available, New Zealand pilots should assume a high relative humidity, particularly when:

(a) the surface and low level visibility is poor, especially in the early morning and later evening and particularly when near a large area of water;

(b) the ground is wet (even with dew) and the wind is light;

(c) just below the cloud base or between cloud banks or layers;

(d) in precipitation, especially if it is persistent;

(e) in cloud or fog – these consist of water droplets and therefore the relative humidity should be assumed to be 100%;

(f) in clear air where cloud or fog has just dispersed.

The chart on the following page shows the wide range of ambient conditions conducive to the formation of induction system icing for a typical light aircraft piston engine. Particular note should be taken of the much greater risk or serious icing with descent power. The closer the temperature and dewpoint readings the greater the relative humidity.

Impact icing occurs when flying through snow or sleet, or in cloud in which super-cooled water droplets are present. It can occur, but is less frequent, when flying through super-cooled rain or to an aircraft which has a surface temperature below 0C when flying through rain which is above freezing temperature. The ambient temperature at which impact ice may be expected to build up most rapidly is about -4 degrees C in conditions in which visible ice is forming on other parts of the aircraft.

2.4 Prevention, Recognition and Remedial Practices

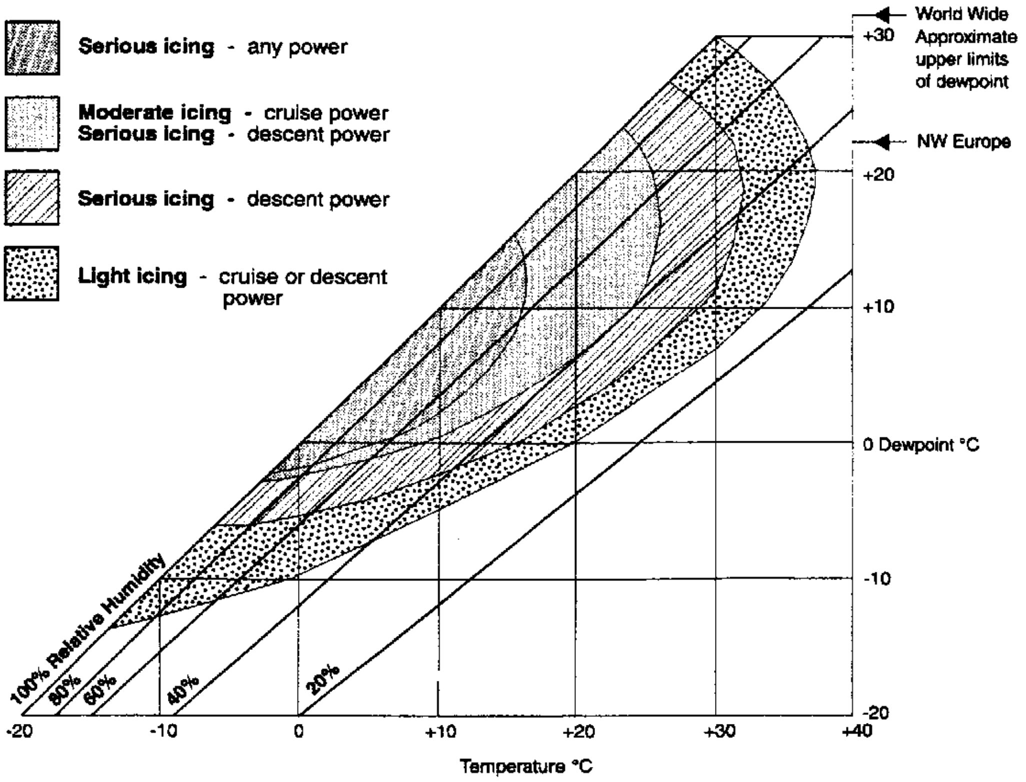
2.4.1 Prevention

Whilst the following provides a general guide to assist pilots to avoid induction system icing, the Pilot's Operating Handbook or Flight Manual must be consulted for specific procedures applicable to a particular airframe and engine combination. The procedures are likely to vary between different models of the same aircraft type:

(a) heating the intake air in an exhaust heat exchanger before it reaches the carburettor prevents carburettor icing, (Design Requirements typically demand a temperature rise of 50 °C at 75% power). This is usually achieved by use of a manually operated carburettor heat control, marked HOT or COLD and which, in the HOT position, by-passes the normal intake filter and derives the induction air from a heated source. The HOT position should be selected in time to prevent the formation of ice, because if the selection is delayed the use of hot air might be too late to melt the ice before the engine stops;

CARBURETTOR ICING IN AIR FREE OF CLOUD, FOG OR PRECIPITATION

(risk and rate of icing will be greater when operating in cloud, fog and precipitation)



(b) engines with fuel injection normally have an alternate air intake, marked ON or OFF, located within the engine cowling and operated by a valve downstream of the normal intake. Although the air does not pass through a heat exchanger it derives some heat from the engine. Some engine installations have automatic alternate air selection activated by pressure sensitive valves;

(c) other than on take-off, the HOT position should be selected periodically when icing conditions are suspected or when flying in conditions of high humidity with the outside air temperature within the high probability ranges indicated on the chart. Unless expressly permitted the continuous use of the HOT position should be avoided, especially during hovering flight in a helicopter. It should be selected intermittently for long enough to pre-empt the loss of engine power; this time period will vary dependent on the prevailing conditions;

(d) as a consequence of the increased susceptibility to carburettor icing at reduced power settings, the HOT position should be selected prior to descent, approach and landing.

2.4.2 Recognition

Should no preventative action have been taken, or was taken too late, or was insufficient, the onset of induction icing may be recognised in the following ways:

(a) with a fixed pitch propeller, a slight drop in RPM is the first sign which may indicate the onset of icing in the induction system. If not rectified there will be a loss of airspeed and possibly height. The loss of RPM may be gradual with no associated rough running. The usual reaction is to open the throttle slightly to restore the RPM and this action masks the early symptoms. As the icing increases there will be rough running, vibration and further RPM reduction; a loss of airspeed or height will result and ultimately, THE ENGINE MAY STOP. Thus the main detection instrument is the RPM gauge used in conjunction with the Air Speed Indicator;

(b) where a constant speed propeller is fitted and in a helicopter the loss of power would have to be large before the RPM reduced, hence the onset of induction system icing could be even more insidious. However, the effect of icing will be shown by a drop in manifold pressure and then by a reduction of airspeed or height. The primary detection instrument is, therefore, the manifold pressure gauge. Engine rough running may provide an additional indication;

(c) an exhaust gas temperature indicator will show a decrease in Exhaust Gas Temperature (EGT) with the onset of icing but engine rough running would, probably, have already been detected.

2.4.3 Remedial Action

When the presence of induction system icing is suspected the HOT or alternate air ON position must be selected immediately:

(a) the recommended practice with most engines is to use full heat whenever carburettor heat is applied. The control should be selected fully to the HOT position. Partial heating can induce induction system icing because it may melt ice particles, which would otherwise pass into the engine without causing trouble, but not prevent the resultant mixture from freezing as it passes through the induction system. Alternatively partial heat may raise the temperature of the air into the critical range.

(b) with some engine installations the use of partial carburettor heat may be considered, particularly where an intake temperature gauge is fitted, An intermediate position between HOT and COLD should only be used if an intake temperature gauge is fitted and appropriate guidance is given in the Flight Manual.

Note: *Remembered that the selection of the HOT position, after ice has already formed may, at first appears to make the situation worse. This is due to the reduction in power because of the hot air, and to an increase in rough running as the ice melts and passes through the engine. If this happens the temptation to return to the COLD position must be resisted in order that the hot air may have time to clear the ice. This may take 15 seconds or more and may seem a very long time in difficult circumstances.*

2.5 Maintenance and Handling Procedures

2.5.1 Maintenance

Periodically check the induction heating system and controls for proper condition and operation. Pay particular attention to the condition of seals which may have deteriorated and are allowing the hot air to become mixed with cold air and thus reducing the effectiveness of the system.

2.5.2 Start Up

Start up with the carburettor heat control in the COLD position or with the alternate air selector in the OFF position, as applicable.

2.5.3 Ground Taxiing

The use of hot or alternate air while taxiing is not normally recommended because in most engine installations this air is unfiltered, hence there is a risk of dust and foreign matter being ingested. However, if engine run down occurs this may indicate that induction system icing is present and the use of hot air will be the only way of preventing further problems.

2.5.4 Pre Take-off Engine Run Up

Check that there is the appropriate decrease in RPM and/or manifold pressure when the HOT position is selected (about 75-100 RPM and 3-5” manifold) and that power is regained when the COLD position is re-selected. If it is suspected that induction system icing is present the HOT position should be selected and maintained until the ice has cleared and full power is restored.

2.5.5 Immediately before Take-off

Induction icing can occur when taxiing at low power or when the engine is idling. If the weather conditions appear to be conducive to the formation of induction icing then the HOT position should be selected before take-off for sufficiently long enough to remove any accumulation which may have occurred. If the aircraft is kept at the holding point in conditions of high humidity it may be necessary to run up the engine to the take-off power setting more than once to dear any ice which may have formed. The take-off must not be commenced if the pilot has any suspicion that carburettor icing is present.

2.5.6 Take-off

When the throttle is fully open for take-off the pilot should check that the manifold pressure and/or RPM are correct for the aircraft type. The static RPM with a fixed pitch propeller will be less than the maximum RPM approved for the engine but the relevant value should be known for each aircraft. Carburettor heat must not be selected to HOT nor alternate heat to ON during take-off unless specifically authorised in the Flight Manual or Pilot’s Operating Handbook.

2.5.7 Climb (including hovering flight in a helicopter)

Be alert for symptoms of induction icing, especially when visible moisture is present or when the dew point and ambient temperatures are close, indicating high relative humidity.

2.5.8 Cruise

Monitor the RPM, manifold pressure, induction or carburettor air temperature gauge, or EGT for a slow decline which would indicate the onset of induction system icing, Periodically select the HOT position to check for the presence of induction icing. Maintain the HOT selection and remember that it may take 15 seconds or more to clear the ice and the engine may run roughly as the ice melts. If the icing is so severe that the engine stops maintain the HOT selection as the residual heat may still be sufficient to melt the ice and enable power to be restored. If impact icing is encountered select HOT or alternate air ON in case the selector valve becomes immovable due to packed ice. Avoid clouds as much as possible.

2.5.9 Descent and Auto-Rotation Flight in a Helicopter

As reduced throttle openings are much more conducive to the formation of carburettor icing, the HOT position should be selected before the throttle is closed for the descent or an auto-rotation, ie. before the exhaust temperature starts to fall. Maintain the HOT selection during prolonged periods of flight at reduced throttle settings, eg during long descents at low power, and increase engine power to cruise settings at intervals of approximately 500 ft so as to increase exhaust temperatures in order to melt any ice which has formed.

2.5.10 Downwind

Include a check of the carburettor heat in the pre-landing checks and observe the reduction and subsequent increase in manifold pressure and/or RPM.

2.5.11 Base Leg and Finals

Unless stated to the contrary in the Pilot's Operating Handbook or Flight Manual the HOT position should be selected on base leg as the power is reduced for the approach. On some engine installations, to ensure better engine response and to permit a go-around to be initiated without delay, carburettor heat should be selected to COLD at about 200/300 ft on finals.

2.5.12 Go-Around or Touch and Go

If the carburettor heat has not been selected to COLD on finals this should be done concurrently with the application of go-around power, or as shortly thereafter as is possible.

2.5.13 After Landing

Ensure that the carburettor heat has been selected to COLD or the alternate air to OFF before taxiing.

2.6 Summary

(a) It is better to prevent ice building up than to attempt to melt it.

(b) Induction system icing forms insidiously.

(c) Icing can occur in warm and humid conditions, and is a possibility at any time of the year in New Zealand.

(d) Be aware of the possibility of the formation of induction system icing and be prepared to take appropriate preventive measures in time.

(e) Carburettor icing is more likely to occur at low power settings.

(f) When flying in conditions conducive to the formation of carburettor icing the HOT position should be selected periodically and certainly at the first indication of a reduction in RPM/manifold pressure/airspeed or height.

(g) Some aircraft/engine combinations are more susceptible than others.

(h) Use of MOGAS increases the possibility of carburettor icing.

(i) Unless the Flight Manual or Pilot's Operating Handbook authorises a different procedure the HOT/ALTERNATE air control should be selected fully ON or OFF.

(j) If ice has been allowed to form it will take some time to melt and the engine may run roughly while this is happening – PERSIST!

CHAPTER THREE — HELICOPTER ICING

3.1 Introduction

3.1.1 Through practical experience, a wealth of knowledge has been accumulated operating fixed-wing aircraft in icing conditions; there are some other considerations, however, with rotary-wing aircraft.

3.1.2 Conditions for Ice Formation

The conditions in which ice formation is possible are given below:

(a) Icing may occur in conditions of high humidity when the ambient air temperature is at or below 0°C.

(b) Due to local reduction pressure, icing may occur in conditions of high humidity when the ambient air temperature is above zero degrees centigrade. High humidity occurs in all forms of precipitation, cloud and fog, or in air close to these conditions.

3.1.3 Categories

For convenience, helicopter icing is considered under three general headings, in the following order of priority:

(a) Rotor system icing.

(b) Engine icing.

(c) Airframe icing.

3.2 Rotor System Icing

3.2.1 Icing Effects on Main Rotor System

The primary effect of ice on the rotor system is drag; the secondary effect is loss of lift due to the change in aerodynamic efficiency of the blade. The way in which ice forms on the blade is affected by five main factors:

(a) Temperature.

(b) Liquid content and droplet size.

(c) Kinetic energy.

(d) Blade section.

(e) Mechanical flexion and vibration.

Some blade forms produce more kinetic heating than others and this can be related to the design of the blade and its speed of rotation.

Continuous operation in rain ice/freezing rain is impossible; this is because the water content is so high that ice will form all over the blade surface giving maximum drag and change of aerodynamic shape at the same time. Ice shedding will tend to worsen this condition.

3.2.2 Blade Icing Characteristics

Each time a blade rotates in continuous icing conditions, a thin layer of ice is deposited on 20% of the leading edge, span wise from the tip. If a section of this ice, which has been formed in temperatures below -10 degrees C, is examined, it will be seen to have bands of slightly differing colour tone that can be seen by the naked eye. These bands are, in fact, growth bands and the greater the number of rotations, the greater the growth of ice.

3.2.3 Ice Formation on Different Blade Types

High Performance Blade

On a blade with a characteristically high rotational speed, ice forms readily on the leading edge because the radius is small and the boundary layer shallow (see Figure 1); super cooled droplets can easily penetrate this layer allowing the formation of ice.

High Lift Blade

A blade having typical high lift characteristics, is deep in section, has a large tip radius and a slow rotational speed. Because the tip radius is greater than that of the high performance blade, the boundary layer that surrounds it is deeper and most of the super-cooled droplets that penetrate this layer are centrifuged off again and only a small proportion form ice on the leading edge (see Figure 2). This is a better blade configuration in icing conditions than the high performance blade.

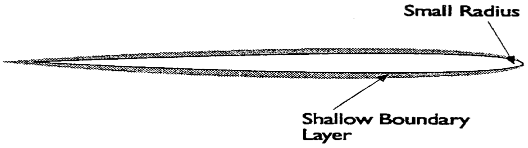


Figure 1 – High Performance Blade

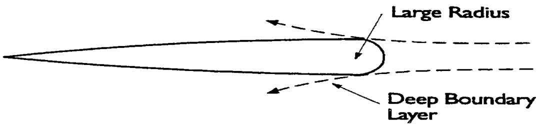


Figure 2 – High Lift Blade

Tail Rotor Blades

So few problems have been encountered with icing of the tail rotor blades that it is unnecessary to go into great detail; ice is picked up on only 20% of the blade from the root ends towards the tip. Although ice does build on the pitch change mechanism, this can be kept clear by regularly cycling the controls.

3.2.4 Ice Formation at Different Temperatures

Ice Formation at, or Just Below, Freezing Point

Between 0°C and -3°C ice will form in natural icing conditions on the leading edge of the blades from the blade root towards the tip covering about 70% of the span and 20% of the chord from the tip of the leading edge, the remaining 30% of the span at the tip being free of ice due to kinetic heating. If the blade ice is allowed to build up, the maximum accretion point will be the mid-point of this area, with another area of high accretion around the blade root caused by turbulence (see Figure 3). The ice formed on the leading edge at these relatively high temperatures will have the classical mushroom shape. At the blade root there may also be a degree of run-back which, in itself, is not important as little lift is produced in this area.

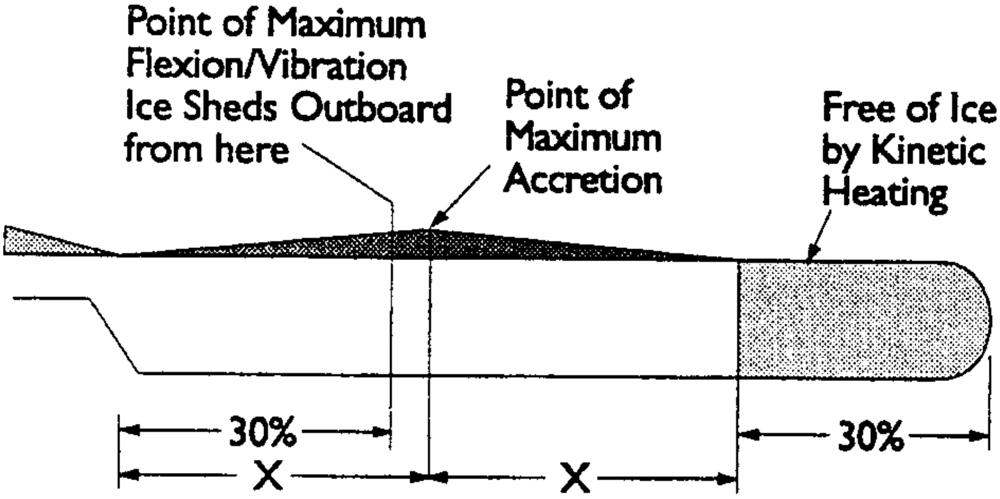


Figure 3 – Blade Ice Coverage at Temperatures Just Below Freezing Point

Ice Formation at Temperatures Between -3°C and -15°C

It has been shown that at -3°C about 70% of the leading edge span will be covered by ice. As the temperature decreases, ice is deposited farther along the blade until 100% coverage from root to tip takes place (see Figure 4) the lower temperature having overcome the kinetic heating. With 100% coverage of the leading edge, drag becomes very high and, if this ice cannot be shed, the drag will increase to a point where power is limited.

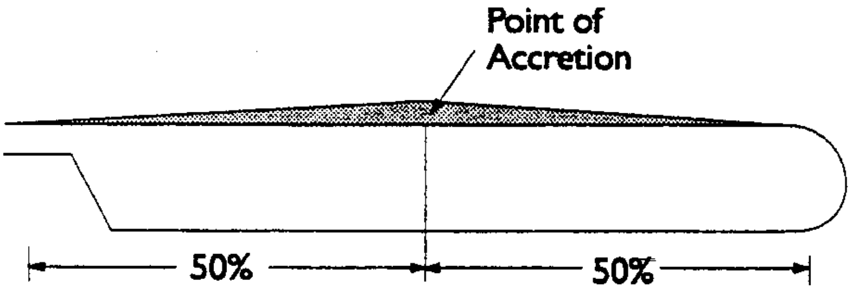


*Figure 4 – Blade Ice Coverage at Temperatures Between -3*C and –15*C*

Leading Edge Ice Formation at Temperatures Above -l0C

Figure 5 shows the ice formation on the leading edge at a temperature above -10°C with a definite depression at the stagnation point (point A). The ice build-up at point B is heavier than at A because only the freezing fraction, which is the smallest part of the super cooled droplet, freezes on impact, the remainder runs back towards point B and freezes between B and C. The drag factor produced by this type of ice accretion is high.

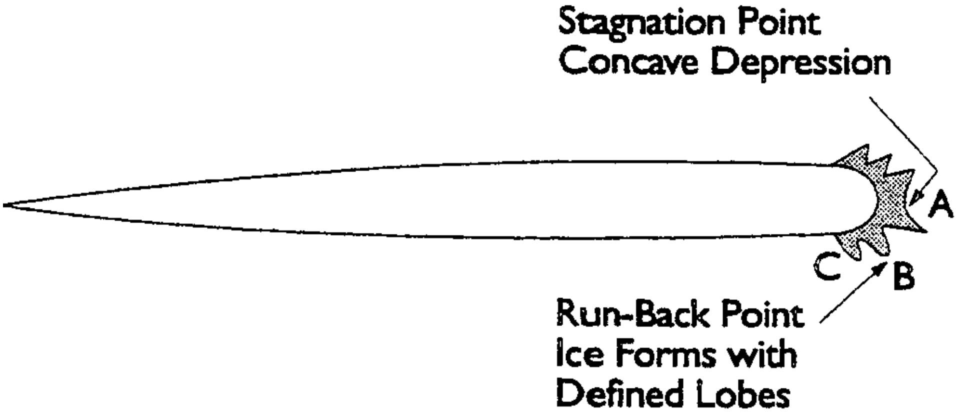


*Figure 5 – Leading Edge Ice Formation at Temperatures Above –10*C*

Leading Edge Ice Formation at Temperatures Below –l0 C

At temperatures below -10°C, ice forms on the leading edge in a different way; there is no longer a concave depression at the stagnation point and the formation is more symmetrical (see Figure 6). This is because the freezing fraction of the super cooled droplet is much larger with very little run-back; consequently, the drag factor is not so high but the problem of asymmetric shedding is now posed. The rate of accretion is much slower because the air is drier.

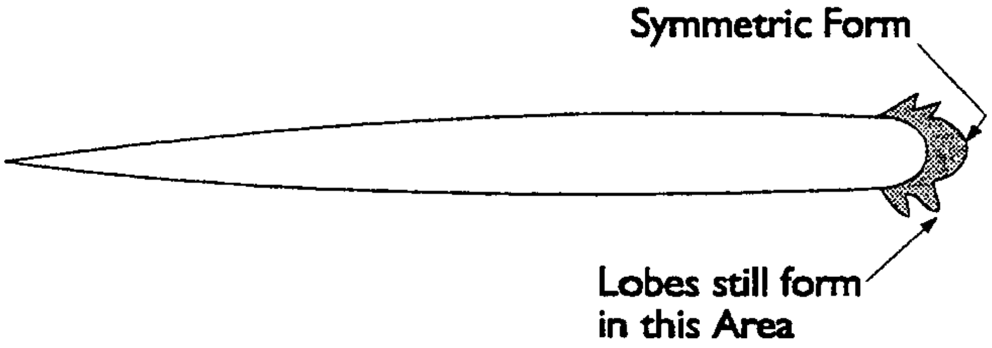


*Figure 6 – Leading Edge Ice Formation at Temperatures Below –10*C*

3.2.5 Icing Effects on Rotor Head Control Rods

Although icing of the rotor head control rods will occur in flight, the control rod ends are always in a condition of movement and this keeps the vital area clear and does not normally restrict control movement. However, it is highly desirable to keep these areas as clear as possible from ice accretion and this is done by fitting an airflow deflector plate forward of the control rod area; a secondary reason for keeping the control rods free of ice is that in some designs they are adjacent to the engine intake and any shedding can result in engine ice ingestion.

3.2.6 Natural Ice Shedding

All main rotor blades have some degree of self-shedding and this always starts at a point 30% outboard from the blade root and continues to the tip. The reason for this is that, at this point, the blade is subject to mechanical forces and flexion and vibration are at their maximum here. The characteristics of the high lift blade are much better for natural shedding than those of the stiffer, high performance blade with its weak boundary layer.

Before any shedding can take place in the natural shedding range, sufficient ice must have been built up; this varies with different types of helicopters and blade design.

Flight in continuous icing conditions is not dangerous provided that the helicopter is not flown in temperatures at which natural shedding cannot be guaranteed; this temperature limit is known as the critical shedding temperature.

Determination of Critical Shedding Temperature

The critical shedding temperature is determined by test flying, at the hover, in an icing rig over a wide range of temperatures, water content and droplet size. The temperatures at which shedding is no longer reliable are carefully bracketed, but have to be exceeded under carefully controlled test conditions. These temperature limits are clear-cut and the icing rig test flying is followed by free flight over a wide time and condition range in icing cloud, freezing fog and wet and dry snow. There is a need to repeat many of these conditions in free flight with varying quantities of ice on the blades. This is because, whilst it may appear that conditions are satisfactory in the hover and low speed manoeuvres where the ice has been retained, in forward flight (eg. climbing, descending, steep turns and autorotation), asymmetrical shedding may take place.

Asymmetric Shedding

Below critical shedding temperature, ice may be retained on all blades for some time; however, one or more blades can suddenly shed its ice, giving an asymmetric condition. If asymmetric shedding occurs in flight it can cause violent vibration, possibly leading to destruction. In such a condition, the only course is to land immediately and shut down as soon as possible, even if this means using the rotor brake harshly.

Damage to the Tail Rotor by Shed Ice

The incident rate of damage to the tail rotor from ice shed from the main rotors is very low and may amount only to slight denting of the leading edge, not sufficient in itself to cause vibration or balance problems.

3.2.7 Blade Anti-icing

The equipment for blade anti-icing consists of an electrical matrix that covers 20% of the leading edge chord wise from the tip along the length of the blade. Heat is phased into this matrix in different sectors, timed to coincide with the natural shedding cycle, ie. when sufficient ice has built up.

This works well until the heat application and the natural shedding cycle get out of phase; heat may then be applied at the wrong time. This causes run-back, the ice reforming further back along the chord line, causing the blade CG to move backwards which, in turn, causes imbalance and flutter, it can also cause a residual build-up of ice. The extreme case is the failure of heating to one blade causing asymmetric problem.

The power supply for the matrix equipment is a drain on the electrical resources and, since the only satisfactory solution would be to heat the whole blade, a generator large enough to do this would impose weight installation problems.

Much research is going into solving this problem, but no clear solution is imminent. The only free, untapped source of heat that exists is from the engine efflux, but, until this can be harnessed to provide an efficient de-icing system, natural shedding and its restrictions must be accepted.

3.3 Engine Icing

3.3.1 Turbine Engine Icing

The only ice produced on a turbine engine is at the throat near the first compressor stage. This is not an insurmountable problem as there is sufficient heat available from hot air bleeds and hot oil, to heat this area, and the inlet guide vanes (where fitted).

Because of their delicate construction however, there is a problem of ice ingestion by high performance turbines. A sudden slug of slush, even as low as 350cc water equivalent, can put out the engine flame. Momentum separators are effective in preventing the ingestion of ice and slush and the multi-purpose air intake system, when in the anti-icing mode, separates out any ice particles that may be present and deposits them in an evacuation compartment.

3.4 Airframe Icing

3.4.1 Problem Areas

The main airframe icing problems are:

(a) *Intakes:* It has been found that some intakes, although heated, allow ice to form. Generally, engine intakes must be very clean in design, avoiding any projections; even rivet heads will cause sufficient turbulence to form an accretion point If the intakes are hinged to give engine access, the sealing at the hinge point must not offer any leakage.

(b) *Windscreen Anti-Icing:* Electrically-heated windscreens are completely satisfactory and also reliable, even in the most severe conditions.

(c) *Outside Air Temperature (OAT) Gauge:* Once in the icing range, temperatures are critical and an OAT gauge that is accurate to one degree is essential.

(d) *Pitot/Static Systems:* Most pitot heads are heated and operate satisfactorily in icing conditions. The combined pitot/static probe is excellent because both its sources are combined and the whole heated.

(e) *Grilles:* Most helicopters are fitted with a grille that may cover a fire-lighting access point or serve to ventilate a small gearbox. These grilles are usually made of expanded metal or wire mesh and are natural catchments and ice traps.

3.4.2 Appearance of Airframe Ice

At temperatures between -5°C and -10°C, ice usually appears clear; between 0°C and -5°C it may appear granulated because it will have been formed from fairly large droplets. At lower temperatures, ie. at -15°C and below, ice appears whitish and opaque. At the higher temperatures (0°C to +3°C) the ice, because of its appearance, may appear much more dangerous than it is.

It is certain that at these temperatures the weight of fuel being burnt will be greater than the weight of ice deposited. This is not the case with rain ice/frozen rain which will deposit clear ice faster than fuel is being used and will not shed naturally at temperatures normally safe to fly in.

3.5 Operating Considerations

3.5.1 Indications of Main Rotor Blade Icing and Natural Shedding by Instrument Interpretation

Before a pilot contemplates flying in cloud in natural icing conditions it is essential that he can interpret these conditions by reference to his instruments; it is equally important that he is aware of the aircraft temperature limits in these conditions and at no time is it wise that he should attempt to exceed them - except in an emergency and then he must be aware of the consequences.

Depending on the temperature and water liquid content of the cloud, ice will start to form on the main rotor blades. This ice will produce increased drag which, in turn, will demand more power from the engine to maintain the rotor rpm. When this extra power is demanded, it is shown by an increase in torque for a set collective angle, ie. the torque will be seen to increase although no alteration has been made to the position of the collective lever. Furthermore, a stage in the deterioration in the aerodynamic section may be reached such that maintaining Rrpm in autorotation is not possible; this being at a time when the engine(s) are susceptible to damage from ice ingestion.

As the ice builds up on the leading edge of the blades, the torque will show a steady rise up to 20% of its original value and at the same time a slight increase in the general vibration level will be apparent. At the point where sufficient ice has been built up to shed, natural shedding takes place and the engine torque returns to its original value, as will the vibration level. A steady cycling of this nature will continue as long as the helicopter remains in icing conditions.

3.5.2 Aircraft Limitations

Limitations on flying in icing conditions are defined in the relevant Aircrew Manual and are mandatory; flight in icing conditions is only permitted if the aircraft is suitably equipped or is modified to the necessary standard (eg. intake door configuration, OAT gauge, lighting etc).

The Aircrew Manual or Release to Service for the particular helicopter may also need to state the following:

(a) The accuracy of the OAT gauge and, therefore, the maximum indicated temperature at which 0°C ambient air temperature can be expected.

(b) The maximum temperature at which engine icing could be expected.

(c) The minimum gas generator rpm, with time limits, for effective engine anti-icing.

(d) The areas where icing may be expected at temperatures above 0°C.

CHAPTER FOUR — PRE-FLIGHT PREPARATION

4.1 The Basic Requirements

4.1.1 Responsibility

The person technically releasing the aircraft is responsible for the performance and verification of the results of ground de-icing/anti-icing treatment. The responsibility of accepting the performed treatment lies, however, with the pilot-in-command. The transfer of responsibility takes place at the moment the aircraft starts moving under its own power.

4.1.2 Necessity

Icing conditions on the ground can be expected when air temperatures approach or fall below freezing and visible moisture is present in the form of either precipitation or condensation.

Aircraft related circumstances could also result in ice accretion when humid air at temperatures above freezing comes in contact with cold structure.

4.1.3 Clean Aircraft Concept

Any contamination of aircraft surfaces can lead to handling and control difficulties, performance losses and/or mechanical damage.

4.1.4 De-icing

De-icing is a procedure by which frost, ice, snow or slush is removed from the aircraft in order to provide clean surfaces.

4.1.5 Anti-icing

Anti-icing is a precautionary procedure that provides protection against the formation of frost, ice or snow accumulation on treated surfaces of the aircraft for a limited period of time.

4.2 Awareness

4.2.1 Communication

To get the highest possible awareness concerning de–icing /anti-icing, a good level of communication between ground and flight crews is necessary. Any observations or points significant to the flight or ground crew should be discussed. These observations may concern the weather or aircraft related circumstances or other factors significant to the dispatch of the aircraft.

Several incidents have shown that increased awareness of one part of the flight/ground crew team could have avoided a critical situation. Both parties should know the details of when the aircraft was de-iced and the type of fluid involved. Remember, uncertainty should not be resolved by transferring responsibility, the only satisfactory answer is clear communication.

4.3 Icing conditions

4.3.1 Weather

Icing conditions on the ground can be expected when air temperatures fall to or below freezing and moisture exists in the form of humidity, precipitation or condensation. Precipitation may be rain, sleet or snow. Frost can occur in humid clear air, while condensation can produce fog or mist.

4.3.2 Aircraft Related Conditions

The concept of icing is usually confined to weather exposure. However, even if the OAT is above freezing point, ice or frost can form if the aircraft structure is below 0°C and moisture or relatively high humidity is present.

With rain or drizzle falling on a sub-zero structure, a clear ice layer can form on the upper wing when the aircraft is on the ground. In most cases this is accompanied by frost on the underwing surface.

4.4 De-ice /anti-ice checks

4.4.1 Clean Wing Concept

The certified aircraft performance is based upon an uncontaminated or clean structure. Ice, snow or frost accumulations will disturb the airflow, affecting lift and drag and also increasing weight. The result on performance can be dramatic. Aircraft preparation for service begins with a thorough inspection of the aircraft exterior to ensure all lifting and control surfaces are aerodynamically clean. There must be no ice, snow, slush or frost adhering to critical surfaces. Exceptions are sometimes allowed in the aircraft flight manual, however the flying surfaces must definitely be free of any contamination.

The inspection of the aircraft must cover the following components and be performed from points offering a clear view of each item:

(a) Wing surfaces including leading edges.

(b) Horizontal stabiliser upper and lower surface.

(c) Vertical stabiliser and rudder.

(d) Fuselage.

(e) Air data probes.

(f) Static vents.

(g) Angle-of-attack sensors.

(h) Control surface cavities.

(i) Engines.

(j) Intakes and outlets.

(k) Landing gear and wheel bays.

4.5 Clear Ice Phenomenon

A clear ice layer is usually accompanied by frost on the underwing. Severe conditions occur during precipitation when sub-zero fuel is in contact with the wing panels. Clear ice accumulations are very difficult to detect from ahead of the wing or behind during walk-around, especially in poor lighting and when the wing is wet. The leading edge may not feel particularly cold. The clear ice may not be detected from the cabin if wing surface detail shows through the ice.

Upper wing surface ice is especially hazardous to jet aircraft with aft-mounted engines. The ice may separate from the wing during take-off roll and rotation, when lift forces flex the wings and destroy ice adhesion. Dependent on the layout of the aircraft and its aerodynamics, ice plates can be ingested by the engines and cause significant damage, compressor surge or stall. In the more serious cases, more than one engine may be damaged.

The following factors contribute to the formation and final thickness of the clear ice layer:

(a) Fuel at low temperature added during the previous technical stop and/or wing fuel cooling to below 0°C during flight.

(b) Freezing fuel in contact with upper and lower wing panels.

(c) Adding relatively warm fuel may melt dry falling snow with the possibility of re-freezing. Drizzle/rain and an ambient temperature around 0°C on the ground is very critical. Heavy freezing has been reported during drizzle/rain even at temperatures of 8 to 14°C (46 to 57° F). The use of thermal leading edge anti-icing may melt falling dry snow which re-freezes later

(d) The areas most vulnerable to freezing are:

  (i) The wing root area between the front and rear spars.

  (ii) Any part of the wing that will contain unused fuel after flight.

  (iii) The areas where different structures of the wing are concentrated (a lot of cold metal) such as areas above the spars and the main landing gear doubler plate.

4.6 General Checks

High steps should be placed close the wing upper surface and fuselage so a wide area of tank panel may be checked by hand. If clear ice is detected, the wing upper surface should be de-iced and then re-checked to ensure that all ice deposits have been removed.

During ground checks, electrical or mechanical ice-detectors should only be used as a back-up advisory. They are not a primary system and are not intended to replace physical checks.

Ice can build up on aircraft surfaces when descending through dense clouds or precipitation during an approach.

When ground temperatures at the destination are low it is possible that flaps retraction will result in undetected accumulations of ice between stationary and moveable surfaces. These areas must be checked before departure.

In freezing fog conditions the rear side of the fan blades should be checked for ice build-up before start. Any deposits should be removed with a low flow hot air source, such as a cabin heater.

Inspect the aircraft for contamination after operation on slushy manoeuvring areas. If the aircraft arrives at the gate with flaps extended, they should be inspected and, if necessary, de-iced before retraction.

The operating manual for certain aircraft types may allow take-off with frost on certain parts of the aircraft. It is important to note that the rate of ice formation is considerably increased by the presence of an initial deposit of ice. If icing conditions are expected to occur along the taxi and take-off path, ensure that all ice and frost is removed before departure. Pilots should remember that surface contamination and blown snow are also potential triggers for ice accretion.

4.7 Responsibility: The De-Icing/Anti-Icing Decision

4.7.1 Maintenance Responsibility

The person releasing the aircraft is responsible for the performance and verification of the results of the de/anti-icing treatment. The responsibility of accepting the performed treatment lies, however, with the pilot-in-command (PIC).

4.7.2 Operational Responsibility

The general transfer of operational responsibility takes place at the moment the aircraft starts moving under its own power:

(a) Maintenance/ground crew decision:

The responsible ground crew member should be clearly nominated. He/she should check the aircraft for the need to de-ice. He/she will, based on personal judgement, initiate de-/anti-icing and will remain responsible for the correct and complete de-icing and/or anti-icing of the aircraft.

(b) Pilots decision:

(i) As the final decision rests with the PIC, the pilot’s requirement will override any ground crew decision not to de-ice.

(ii) As the PIC is responsible for the anti-icing condition of the aircraft during ground manoeuvring before take-off, he/she can request additional anti-icing application with a different mixture ratio for aircraft protection over a longer period. Similarly the pilot may simply request a repeat application.

(iii) Captains should take account of forecast or expected weather conditions, taxi conditions, taxi times, hold-over time and other relevant factors. The PIC must, when in doubt about the aerodynamic cleanliness of the aircraft, ensure an inspection or a further de-/anti-icing is performed.

(iv) Even when responsibilities are clearly defined and understood, continued communication between flight and ground crews is essential. All relevant observations should be mentioned to the other party with the aim of achieving redundancy in the decision making process.

4.8 Application – The procedure to De-Ice and Anti-Ice an Aircraft

Note: *For definitions of the terminology used in this section, refer to Glossary.*

When aircraft surfaces are contaminated by ice, they must be de-iced before dispatch. When freezing precipitation exists and there is a risk of ice adhering to the surface during dispatch, aircraft surfaces must be anti-iced. If both anti-icing and de-icing are required, the procedure may be performed in one or two steps. The selection of a one or two step process depends upon weather conditions, available equipment, available fluids and the hold-over time required.

When a long hold-over time is anticipated, a two-step procedure using undiluted fluid should always be considered for the second step.

4.8.1 De-Icing

Ice, snow, slush or frost may be removed from aircraft surfaces with heated fluids or mechanical methods. For maximum effect, fluids shall be applied close to the aircraft surfaces to minimise heat loss.

4.8.2 General De-Icing Fluid Application Strategy

The following guidelines describe effective ways to remove snow and ice, however, certain aircraft may require unique procedures to accommodate specific design features. The relevant aircraft maintenance or servicing manuals should be consulted:

Wings/Horizontal Stabilisers:	Spray from the tip towards the root, from the highest point of the surface camber to the lowest.
Vertical Surfaces:	Start at the top and work down
Fuselage:	Spray along the top centreline and then outboard; avoid spraying directly onto windows.

Landing Gear and Wheel Bays:	Keep application of de-icing fluid in this area to a minimum. It may be possible to mechanically remove accumulations such as blown snow. However, where deposits have bonded to surfaces they can be removed using hot air or by careful spraying with hot de-icing fluids. A high-pressure spray is not recommended.
Engines:	Deposits of snow should be mechanically removed (using a broom or brush) from engine intakes before departure. Any frozen deposits that may have bonded to either the lower surface of the intake or the fan blades may be removed by hot air or methods recommended by the engine manufacturer.

4.8.3 Anti-Icing

Applying anti-icing protection means that ice, snow or frost will, for a period of time, be prevented from adhering to and accumulating on aircraft surfaces. This is done by the application of anti-icing fluids.

Anti-icing fluid should be applied to the aircraft surfaces when freezing rain, snow or other freezing precipitation is falling and adhering at the time of aircraft dispatch.

For an effective anti-icing protection, an even film of undiluted fluid is applied over clean or de-iced aircraft surfaces. For maximum anti-icing protection, undiluted, unheated Type II or IV fluid should be used. The high fluid pressures and flow rates normally associated with de-icing are not required for this operation and pump speeds should be reduced accordingly. The nozzle of the spray gun should be adjusted to give a medium spray.

The anti-icing fluid application process should be continuous and as brief as possible. Anti-icing should be carried out as near to the departure time as is operationally possible to ensure maximum hold-over time. To check uniform coverage, all horizontal surfaces must be visually inspected during fluid application. Fluid should be starting to drip from the leading and trailing edges.

4.8.4 Surfaces to be Protected During Anti-Icing

(a) Wing upper surface.

(b) Horizontal stabiliser upper surface.

(c) Vertical stabiliser and rudder.

(d) Fuselage upper surface depending upon amount and type of precipitation (especially important on centre engine aircraft).

Type I fluids have limited effectiveness when used for anti-icing purposes. Little benefit is gained from the minimal hold-over time generated.

4.8.5 Limits and Precautions

Aeroplane related limits:	The use of Type II and IV fluids in 100% concentration or 75/25 mixture is limited to aircraft with a rotation speed (VR) higher than 85kts. This is to assure sufficient fluid flow-off during take-off.
Temperature limits:	When performing two-step de-icing/anti-icing, the freezing point of the heated fluid used for the first step must not be more than 3°C above ambient temperature.

The freezing point of the Type I fluid mixture used for either one-step de-icing/anti-icing or as the second step in a two-step operation shall be at least 10°C below the ambient temperature.

Type II and IV fluids used as de-icing/anti-icing agents have a lower temperature application limit of -25°C.

The application limit may be lower, provided that a 7°C buffer is maintained between the freezing point of the undiluted fluid and the outside air temperature. Freezing points are provided in the fluid manufacturers documentation.

Application Limits:	Under no circumstances can an aircraft that has been anti-iced receive a further coating of anti-icing fluid directly on top of the existing film. In continuing precipitation, the original anti-icing coating will be diluted at the end of the hold-over time and re-freezing could start. Also a double anti-ice coating should not be applied as the flow-off characteristics during take-off may be compromised.

Should it be necessary for an aircraft to be re-protected before the next flight, the external surfaces must first be de-iced with a hot fluid mix before a further application of anti-icing fluid is made.

The aircraft must always be treated symmetrically, the left hand and right hand sides (e.g. left wing/right wing) must receive the same, complete treatment.

Engines are usually not running or are at idle during treatment Air conditioning should be selected OFF. The APU may be run for electrical supply but the bleed air valve should be closed.

All reasonable precautions must be taken to minimise fluid entry into engines, other intakes/outlets and control surface cavities.

Do not spray de-icing/anti-icing fluids directly onto hot brakes, wheels, exhausts or thrust reversers.

De-icing/anti-icing fluid should not be directed into the orifices of pilot heads, static vents or directly onto angle-of-attack sensors.

Do not direct fluids onto flight deck or cabin windows due to the risk of cracking acrylics or penetrating the window sealing. All doors and windows must be closed to prevent:

(a) Galley floor areas being contaminated with slippery de-icing/anti-icing fluids.

(b) Upholstery becoming soiled.

Forward areas should be free of fluid residues to avoid blowback onto cockpit windscreens during departure. If Type II fluids are used, all traces of the fluid on cockpit windows should be removed prior to departure. Particular attention being paid to windows fitted with wipers.

De-icing/anti-icing fluid can be removed by rinsing with clear water and wiping with a soft cloth. Do not use the windscreen wipers for this purpose. This will cause smearing and loss of transparency.

Landing gear and wheel bays must be free from build-up of slush, ice or accumulations of blown snow.

Do not spray de-icing fluid directly onto hot wheels or brakes.

When removing ice, snow or slush from aircraft surfaces, care must be taken to prevent it entering and accumulating in auxiliary intakes or control surface hinge areas. Remove snow from wings and stabiliser surfaces forward over the leading edge and remove from ailerons and elevators back over the trailing edge.

Do not close any door until all ice has been removed from the surrounding area.

Depending upon AFM requirements, a functional flight control check with an external observer may be required after de-icing/anti-icing. This is particularly important if an aircraft that has been subjected to an extreme ice or snow covering.

4.8.6 Checks

(a) Final check before aircraft despatch:

A responsible authorised person should only dispatch an aircraft after the aircraft has received a final check.

The inspection must include all critical parts of the aircraft, and must be performed with a clear view of the relevant areas. It may be necessary to touch the structure to ensure that there is no clear ice on suspect areas.

(b) Pre take-off check:

A Pre Take-Off Check of the first surface to be de-iced/anti-iced, will be carried out within five minutes of takeoff.

When freezing precipitation exists, it may be appropriate to check aerodynamic surfaces just prior to the aircraft entering the active runway or starting the take-off roll in order to confirm that they are free of all forms of frost, ice and snow. This is particularly important when severe conditions are experienced, or when the published hold-over times have either been exceeded or are about to run out, or when particular AFM demands this specific consideration.

When contamination exists it will be necessary for the de-icing operation to be repeated.

If the take-off location cannot be reached within a reasonable time and/or a reliable check of the wing upper surface cannot be made from inside the aircraft, consider a repeat aircraft treatment.

In freezing precipitation, and when the airport layout allows, de-icing/anti-icing and inspection of aircraft should be conducted near the threshold of the departure runway to reduce the time between aircraft de-icing/anti-icing and take-off.

(c) Contamination check:

If the hold-over time has been exceeded, or if the Pre Take-Off Check has been inconclusive a Contamination Check must be carried out to determine the condition of the aircraft. The check must be performed outside the aircraft by an authorised person, include all critical surfaces and be completed within five minutes of takeoff.

4.9 Flight Crew Information – Communication

No aircraft should be dispatched after a de-icing/anti-icing operation unless the flight crew has been notified of the type of de-icing /anti-icing operation performed. The ground crew must make sure that the flight crew has been informed. The flight crew should make sure that they have the information.

This information includes the final inspection confirmation that critical parts are free of ice, frost and snow.

This information also includes the necessary anti-icing codes to allow the flight crew to estimate the hold-over time to be expected under the prevailing weather conditions:

(a) Anti-icing codes:

It is essential that flight crew receive clear information from ground personnel as to the treatment applied to the aircraft.

The AEA recommendations and the SAE and ISO specifications promote the standardised use of a four-element code. This gives flight crew the minimum details to assess hold-over times. The use of local time is preferred but, in any case, statement of the reference is essential. This information must be recorded and communicated to the flight crew by referring to the last step of the procedure.

(b) Hold over time tables:

The tables on page s14/15 provide an indication of the time frame of protection that could reasonably be expected under conditions of precipitation. However, due to the many variables that can influence hold-over times, these times should not be considered as finite. The actual time of protection may be extended or reduced, depending upon the particular conditions existing at the time.

4.10 Flight Crew Techniques

The purpose of this section is to deal with the issue of ground de-icing/anti-icing from the Flight crew's perspective. The topic is covered in the order it appears on the cockpit checklists and is followed through, step by step from flight preparation to take-off. The focus is on the main points of decision making, flight procedures and flight crew techniques.

4.10.1 Receiving Aircraft

If the prevailing weather conditions call for protection during taxi, flight crews should try to determine "Off block time" to ensure adequate anti-icing protection regarding hold-over time.

Communication: *This information should be passed to the de-icing/anti-icing units, the ground maintenance, the traffic staff, dispatch office and all other units involved.*

4.10.2 Cockpit Preparation

Before treatment, avoid pressurising or testing flight control systems and ensure that all flight support services are completed prior to treatment to avoid delays between treatment and start of taxiing.

During treatment ensure that:

(a) Engines are shut down or at idle.

(b) APU may be used for electrical supply, bleed air OFF.

(c) Air conditioning OFF,

(d) All external lights in treated areas must be OFF.

Consider whether communication and information with the ground staff is/has been adequate.

The minimum requirement is to receive the anti-icing code in order to calculate the available protection time from the hold-over timetable.

Do not accept the information given in the hold-over timetables as precise. There are several parameters influencing hold-over time.

The time frames given in the hold-over timetables consider the very different weather situations worldwide. The view of the weather is rather subjective; experience has shown that different people can judge a certain snowfall as light, medium or heavy. If in doubt, a pre-take-off check should be considered.

As soon as the treatment of the aircraft is completed, proceed to engine starting.

4.10.3 Taxiing

During taxiing, the flight crew should observe the precipitation intensity and monitor the aircraft surfaces visible from the cockpit. The ice warning systems of engines and wings or other additional ice warning systems must be considered.

Sufficient distance from the preceding aircraft must be maintained as blowing snow or jetblasts can degrade the anti-icing protection of the aircraft.

The extension of slats and flaps should be delayed, especially when operating on slushy areas. Slat/flap extension should be verified prior to take-off.

Refer to individual manufacturer recommendations.

4.10.4 Take-Off

All manufacturers' recommendations regarding procedures and performance corrections when operating in icing conditions must be considered.

4.10.5 General Remarks

Flight crews should not allow commercial pressures to influence operational decisions. General precautions and minimum requirements have been presented here: these considerations must be observed.

If there is any doubt as to whether the wing is contaminated – ***DO NOT PROCEED.***

As in any other business, the key factors to keep procedures efficient and safe are awareness, understanding and communication.

4.11 Fluid Characteristics and Handling

4.11.1 De-icing/Anti-icing Fluids – Characteristics

Although numerous fluids are offered by several manufacturers world-wide, fluids can be principally divided into, Type I, Type II and Type IV fluids.

Type 1 fluid characteristics:

(a) No thickener system.

(b) Minimum 80 percent glycol content.

(c) Viscosity depends on temperature

(d) Newtonian fluid.

(e) Relatively short hold-over time.

Depending on the respective specification, they contain at least 80 percent per volume of either monoethylene, diethylene, or monopropyteneglycoi or a mixture of these glycols. The rest comprises water, inhibitors and wetting agents. The inhibitors act to restrict corrosion, to increase the flash point or to comply with other requirements regarding material compatibility and handling. The wetting agents allow the fluid to form a uniform film over the aircraft's surfaces.

Type I fluids show a relatively low viscosity which only changes depending on temperature.

Giycols can be well diluted with water.

The freezing point of a water/glycol mixture varies with the content of water, whereas the concentrated glycol does not show the lowest freezing point; this is achieved with a mixture of approximately 60 percent glycol and 40 percent water (freezing point below -50°C).

Therefore Type I fluids are normally diluted with water of the same volume. This 50/50 mixture has a lower freezing point than the concentrated fluid and, due to the lower viscosity, it flows off the wing much better.

Type II and Type IV fluid characteristics

(a) With thickener system.

(b) Minimum 50 percent glycol.

(c) Viscosity depends on temperature and shear rates to which the fluid is exposed.

(d) Pseudo-plastic or non-Newtonian fluid.

(e) Relatively long hold-over time.

These fluids contain at least 50 percent per volume monoethylene, diethylene, or propyleneglycoi, different inhibitors, wetting agents and a thickener system giving the fluid a high viscosity. The rest is water.

Although the thickener content is less than one percent, it gives the fluid particular properties. The viscosity of the fluid and the wetting agents causes the fluid to disperse onto the sprayed aircraft surface, and acts like a protective cover.

The fundamental idea is a lowering of the freezing point. Due to precipitation such as snow, freezing rain or any other moisture, there is a dilution effect on the applied fluid. This leads to a gradual increase of the freezing point until the diluted fluid layer is frozen due to the low ambient temperature. By increasing the viscosity a higher film thickness exists having a higher volume which can therefore absorb more water before freezing point is reached. In this way the hold-over time is increased. The following summarises the properties of particular constituents of Type II fluids:

(a) The glycol in the fluid reduces the freezing point to negative ambient temperatures,

(b) The wetting agent allows the fluid to form a uniform film over the aircraft's surfaces.

(c) The thickening agents in Type II fluid enables the film to remain on the aircraft's surfaces for longer periods.

Type II fluids can be diluted with water. Because of the lower glycol content, compared to the Type I fluids, the freezing point rises all the time as water is added.

The viscosity of Type II and IV fluids is a function of the existing shear forces. Fluids showing decreasing viscosity at increasing shear forces have pseudo-plastic or non-Newtonian flow properties.

During take-off, shear forces emerge parallel to the airflow at the fluid and aircraft surface. With increasing speed the viscosity decreases drastically and the fluid flows off the wing.

The protective effect of the Type II and IV fluids is much better when compared to the Type I fluids. Therefore they are most efficient when applied during snowfall, freezing rain and/or with long taxiways before take-off.

ISO Type II and Type IV Fluids

(a) Approved concentrations of ISO Type II and Type IV fluids, used either for one-step de-icing/anti-icing or as the second step in a two-step operation, are listed below, together with details of the lowest temperatures at which the various concentrations may be applied to aircraft surfaces:

Mixture Strength (fluid/water)	Lower Temperature Limit for Application (OAT)
50/50	-3°C
75/25	-14°C
100/0	-25°C

(b) Approved concentrations of ISO Type II and Type IV fluids, used for the first step in a two-step operation, are listed below, together with details of the lowest temperatures at which the various concentrations may be applied to aircraft surfaces:

Mixture Strength (fluid/water)	Lower Temperature Limit for Application (OAT)
0/100 (hot water no glycol)	-3°C
25/75	-6°C
50/50	-13°C
75/25	-23°C

Upper wing skin temperatures may, under certain circumstances, be lower than the OAT. When this is suspected, eg. when large quantities of 'cold' fuel remain from the previous sector, consideration should be given to selecting a stronger mix than would be required by the existing OAT. This will ensure that an adequate buffer is maintained between the freezing point of the fluid used and the temperature of the upper wing surface.

CAUTION

THE TIMES OF PROTECTION REPRESENTED IN THE FOLLOWING TABLES ARE FOR GENERAL INFORMATION PURPOSES ONLY. THEY ARE TAKEN FROM THE UNITED KINGDOM AIC 32/1998. THE TIME OF PROTECTION WILL BE SHORTENED IN SEVERE WEATHER CONDITIONS. HIGH WIND VELOCITY AND JET BLAST MAY CAUSE A DEGRADATION OF THE PROTECTIVE FILM. IF THESE CONDITIONS OCCUR, THE TIME OF PROTECTION MAY BE SHORTENED CONSIDERABLY. THIS IS ALSO THE CASE WHEN THE AIRCRAFT SKIN TEMPERATURE IS SIGNIFICANTLY LOWER THAN THE OUTSIDE AIR TEMPERATURE.

TABLE 1

Guideline for Holdover Times for ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT

OAT		***APPROXIMATE HOLDOVER TIMES UNDER VARIOUS WEATHER CONDITIONS (hours : minutes)***					
°C	°F	*Frost	Freezing Fog	Snow	**Freezing Drizzle	Light Freezing Rain	Rain or Cold Soaked Wing
above 0	above 32	0:45	0:12-0:30	0:06-0:15	0:05-0:08	0:02-0:05	0:02-0:05
0 to –10	32 to 14	0:45	0:06-0:15	0:06-0:15	0:05-0:08	0:02-0:05	
below –10	below 14	0:45	0:06-0:15	0:06-0:15			

°C	Degrees Celsius	OAT	Outside Air Temperature
°F	Degrees Fahrenheit		

* During conditions that apply to aircraft protection for active frost.

** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

ISO Type I Fluid/Water Mixture is selected so that the Freezing Point of the mixture is at least 10°C (18°F) below actual OAT.

Caution: *The time of protection will be shortened in heavy weather conditions. Heavy precipitation rates or high moisture content, high wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when the aircraft skin temperature is lower than OAT. Therefore, the indicated times should be used only in conjunction with a pre-takeoff check.*

ISO Type I fluids used during ground de-icing/anti-icing are not intended for and do not provide ice protection during flight.

TABLE 2

Guideline for Holdover Times for ISO Type II Fluid Mixtures as a Function of Weather Conditions and OAT

OAT		***ISO Type II Fluid Concentration Neat-Fluid/ Water (Vol%/Vol%)***	***APPROXIMATE HOLDOVER TIMES UNDER VARIOUS WEATHER CONDITIONS (hours : minutes)***					
°C	°F		*Frost	Freezing Fog	Snow	***Freezing Drizzle	Light Freezing Rain	Rain or Cold Soaked Wing
above 0	above 32	100/0	12:00	1:15-3:00	0:20-1:00	0:30-1:00	0:15-0:30	0:10-0:40
		75/25	6:00	0:50-2:00	0:15-0:40	0:20-0:45	0:10-0:25	0:05-0:25
		50/50	4:00	0:20-0:45	0:05-0:15	0:10-0:20	0:05-0:10	
0 to –3	32 to 27	100/0	8:00	0:35-1:30	0:20-0:45	0:30-1:00	0:15-0:30	
		75/25	5:00	0:25-1:00	0:15-0:30	0:20-0:45	0:10-0:25	
		50/50	3:00	0:15-0:45	0:05-0:15	0:10-0:20	0:05-0:10	
below –3 to –14	below 27 to 7	100/0	8:00	0:35-1:30	0:15-0:40	**0:30-1:00	**0:10-0:30	
		75/25	5:00	0:25-1:00	0:15-0:30	**0:20-0:45	**0:10-0:25	
below –14 to –25	below 7 to –13	100/0	8:00	0:20-1:30	0:15-0:30			
below –25	below –13	100/0	ISO Type II Fluid may be used below –25°C (–13°F) provided that the freezing point of the fluid is at least 7°C (13°F) below the actual OAT and the aerodynamic acceptance criteria are met. Consider use of ISO Type I when ISO Type II fluid cannot be used. (See Table 1).					

°C	Degrees Celsius	OAT	Outside Air Temperature
°F	Degrees Fahrenheit	Vol	Volume

* During conditions that apply to aircraft protection for active frost.

** The lowest use temperature is limited to –10°C (14°F).

*** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

Caution: *The time of protection will be shortened in heavy weather conditions. Heavy precipitation rates or high moisture content, high wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when the aircraft skin temperature is lower than OAT. Therefore, the indicated times should be used only in conjunction with a pre-takeoff check.*

ISO Type II fluids used during ground de-icing/anti-icing are not intended for and do not provide ice protection during flight.

TABLE 3

Guideline for Holdover Times for Type IV Fluid Mixtures as a Function of Weather Conditions and OAT

OAT		***ISO Type IV Fluid Concentration Neat-Fluid/ Water (Vol%/Vol%)***	***APPROXIMATE HOLDOVER TIMES UNDER VARIOUS WEATHER CONDITIONS (hours : minutes)***					
°C	°F		*Frost	Freezing Fog	Snow	***Freezing Drizzle	Light Freezing Rain	Rain or Cold Soaked Wing
above 0	above 32	100/0	18:00	2:20-3:00	0:45-1:25	0:40-1:00	0:35-0:55	0:10-0:50
		75/25	6:00	1:05-2:00	0:20-0:40	0:30-1:00	0:15-0:30	0:05-0:35
		50/50	4:00	0:20-0:45	0:05-0:20	0:10-0:20	0:05-0:10	
0 to –3	32 to 27	100/0	12:00	2:20-3:00	0:35-1:00	0:40-1:00	0:35-0:55	
		75/25	5:00	1:05-2:00	0:20-0:35	0:30-1:00	0:15-0:30	
		50/50	3:00	0:20-0:45	0:05-0:15	0:10-0:20	0:05-0:10	
below –3 to –14	below 27 to 7	100/0	12:00	0:40-3:00	0:20-0:40	**0:30-1:00	**0:30-0:45	
		75/25	5:00	0:35-2:00	0:15-0:30	**0:30-1:00	**0:15-0:30	
below –14 to –25	below 7 to –13	100/0	12:00	0:20-2:00	0:15-0:30			
below –25	below –13	100/0	ISO Type IV Fluid may be used below –25°C (–13°F) provided that the freezing point of the fluid is at least 7°C (13°F) below the actual OAT and the aerodynamic acceptance criteria are met. Consider use of ISO Type I when ISO Type IV fluid cannot be used. (See Table 1).					

°C	Degrees Celsius	OAT	Outside Air Temperature
°F	Degrees Fahrenheit	Vol	Volume

* During conditions that apply to aircraft protection for active frost.

** The lowest use temperature is limited to –10°C (14°F).

*** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

Caution: *The time of protection will be shortened in heavy weather conditions. Heavy precipitation rates or high moisture content, high wind velocity or jet blast may reduce holdover time below the lowest time stated in the range. Holdover time may also be reduced when the aircraft skin temperature is lower than OAT. Therefore, the indicated times should be used only in conjunction with a pre-takeoff check.*

ISO Type IV fluids used during ground de-icing/anti-icing are not intended for and do not provide ice protection during flight.

4.12 Fluid Handling

4.12.1 General

De-icing/anti-icing fluids are chemical products with an environmental impact. During fluid handling, avoid any unnecessary spillage, comply with local environmental and health laws and the manufacturer's safety data sheet.

Mixing of products from different suppliers is generally not allowed and needs extra qualification testing.

Slippery conditions due to the presence of fluid may exist on the ground or on equipment following the de-icing/anti-icing procedure. Caution should be exercised due to increased slipperiness, particularly under low humidity or non-precipitating weather conditions.

4.12.2 Fluid Handling Equipment

The following information is generally valid for both types of fluid, but especially for Type II and IV fluids.

As the structure of Type II and IV fluids is relatively complicated to comply with several requirements, they are rather sensitive with regard to handling.

The hold-over time, as one of the most important criteria, is gained essentially by viscosity. Overheating, mechanical shearing and contamination by corroded tanks in such a manner that the expected and required hold-over times cannot be achieved can adversely affect the visco-elastic property of the fluid.

Therefore trucks, storage tanks and dressing plants have to be adequately conceived and maintained to comply with these requirements.

Fluid shearing occurs when adjacent layers of fluid are caused to move relative to one another, whether in opposite directions or in the same direction at different speeds. This condition is unavoidable when pumping a fluid. For example, when merely moving a fluid through a pipe, fluid velocity ranges from zero at the pipe wall to a maximum at the centre. Type II fluids are damaged when the magnitude of shear is sufficient to break the long-polymer chains that make up the thickener. Therefore specific equipment must be used.

4.12.3 Storage

Tanks dedicated to storage of the de-icing/anti-icing fluid are required. The tanks should be of a construction material compatible with the de-icing/anti-icing fluid. They should be conspicuously labelled to avoid contamination.

Tanks should be inspected annually for corrosion and/or contamination. If corrosion or contamination is evident, tanks should be maintained to standard or replaced. To prevent corrosion at the liquid/vapour interface and in the vapour space, a high liquid level in the tanks is recommended.

The storage temperature limits must comply with the manufacturer’s guidelines. The stored fluid shall be checked routinely to ensure that no degradation or contamination has taken place.

4.12.4 Pumping

De-icing/ant-icing fluids may show degradation caused by excessive mechanical shearing. Therefore only compatible pumps as well as compatible spraying nozzles should be used. The design of the pumping systems must be in accordance with the fluid manufacturer’s recommendations.

4.12.5 Transfer Lines

Dedicated transfer lines must be conspicuously labelled to prevent contamination and must be compatible with the de-icing/anti-icing fluids. An in-line filter, constructed according to the fluid manufacturer’s recommendations, is recommended to remove any solid contaminant.

4.12.6 Heating

De-icing/anti-icing fluids must be heated according to the fluid manufacturer’s guidelines. The integrity of the fluid following heating in storage should be checked periodically, by again referring to the fluid manufacturer’s guidelines. Such checks should involve at least checking the refractive index and viscosity.

4.12.7 Application

Application equipment shall be cleaned thoroughly before the first fill in order to prevent fluid contamination. Fluid in trucks should not be heated in confined or poorly ventilated areas such as hangars. The integrity (viscosity) of the Type II and IV fluids at the spray nozzle should be checked annually, preferably at the beginning of the winter season.

4.13 Environment and Health

Besides water, de-icing/anti-icing fluids contain glycols and different additives as main ingredients. Type II and IV also contain a thickener system.

The glycols used are bivalent alcohols. Glycols are colourless fluids with a sweet taste (not recommended to try).

Regarding environmental compatibility, the most important criteria are biodegradability and toxicity.

4.13.1 Biological Degradation

The single glycols, like monoethylene, diethylene and propyleneglykol, are entirely biodegradable. Biodegradable means that aerobe bacteria changing glycol to water and carbon dioxide by the aid of oxygen achieve a conversion.

For the different glycols there are minor differences with regard to the rapidity of biodegradation and the oxygen used. Also the temperature is an important parameter. Biodegradation results faster at higher temperatures and slower at lower temperatures.

The best way to handle waste fluids is to drain them into local wastewater treatment plants.

Fluids can be drained into surface waters during winter as the oxygen content will be higher than summer. The colder the water, the more oxygen is available.

Substantial drainage into surface waters during summer is not ideal as the biodegradation occurs faster and, moreover, less oxygen is available. The overall effect on surface waters can be adverse in such a case.

The glycols mentioned are practically non-toxic versus bacteria. Exceptionally high amounts (10 to 20 grams per litre water) would be necessary to adversely affect the biodegradation. These concentrations are effectively never reached, therefore biodegradation generally does occur.

Nevertheless, caution in this matter should be exercised.

The thickener system of Type II and IV fluids, approximately one percent of volume of the fluid, is totally neutral to the environment. It will not be degraded but has no negative effects to the environment; it may be compared to a pebble.

The additives and inhibitors can have an effect on the overall biodegradability.

In any case, the fluids have to meet local regulations concerning biodegradability and toxicity.

4.13.2 Toxicity

Although biodegradable, monoethyle-negtycol should be considered harmful if swallowed. The principal toxic effects of ethylene glycol is kidney damage, in most cases with fatal results.

Several reports concerning the toxicity of diethylenegtycol showed that it may be compared to glycerine in this matter; glycerine is considered to be non-toxic.

Propyleneglycol is classified as non-toxic. A special pure quality is used in the pharmaceutical, cosmetic, tobacco and beverages industry. Propyleneglycol is not irritating and the conversion in the human body occurs via intermediate products of the natural metabolism.

However, precautions generally usual in relation with chemicals should be considered also when handling glycols.

4.13.3 Protective Clothes

Precautions include preventive skin protection by use of suitable skin ointment and thick protective clothes as well as waterproof gloves.

Because of the possibility of atomisation, protective glasses should be worn. Soaked clothes should be changed and, after each de-icing/anti icing activity, the face and hands should be washed with water,

Further details are available from the fluid manufacturers and the material data sheets for their products.

4.14 De-icing/Anti-icing Equipment

4.14.1 De-icing/Anti-icing Trucks

Most of the equipment used today is trucks comprising a chassis on which the fluid tanks pumps, heating and lifting components are installed.

Although in older equipment centrifugal pumps are installed, more modern equipment is fitted with cavity pumps or diaphragm pumps showing very low degradation of Type 11 fluids.

Most of the trucks have an open basket from which the operator de-ices /anti-ices the aircraft. Closed cabins are also available, offering more comfort to the operator in a severe environment.

4.14.2 Stationary Equipment

Stationary de-icing/anti-icing facilities, currently available at a limited number of overseas airports, consist of a gantry with spraying nozzles moving over the aircraft, similar in concept to a carwash.

The advantage of such a system is a fast and thorough treatment of the surface of the aircraft. As computers can operate these systems, working errors are practically excluded and consistent quality can be ensured.

The disadvantage, however, is the operational bottleneck. If only one system is available and de/anti-icing is necessary, the take-off capacity of the respective runway will be limited by the productivity of the gantry.

4.15 Glossary and References

4.15.1 Glossary

The following definitions are related to aircraft ground de-icing/anti-icing with fluids:

ANTI-ICING is a precautionary procedure, which provides protection against the formation of frost or ice and snow accumulation on treated surfaces of the aircraft for a limited period of time (hold-over time).

DE-ICING is a procedure by which frost, ice, slush or snow is removed from the aircraft in order to provide clean surfaces.

DE/ANTI-ICING is a combination of the two procedures, de-icing and anti-icing, performed in one or two steps.

A de-/anti-icing fluid, applied prior to the onset of freezing conditions, will give a protection against the build up of frozen deposits for a certain period of time, depending on the fluid used and the intensity of precipitation. With continuing precipitation hold-over time will eventually run out and deposits will start to build up on exposed surfaces. However, the fluid film present will minimise the likelihood of these frozen deposits bonding to the structure, making subsequent de-icing much easier.

4.15.2 Fluids

De-icing fluids are:

(a) Heated water.

(b) Newtonian fluid (ISO or SAE or AEA Type I).

(c) Mixtures of water and Type I fluid.

(d) Non-Newtonian fluid (ISO or SAE or AEA Type II and IV).

(e) Mixtures of water and Type II and IV fluid.

De-icing fluid is normally applied heated to ensure maximum efficiency.

Anti-icing fluids are:

(a) Newtonian fluid (ISO or SAE or AEA Type 1).

(b) Mixtures of water and Type 1 fluid.

(c) Non-Newtonian fluid (ISO or SAE or AEA Type II and IV).

(d) Mixtures of water and Type II and IV fluid.

Anti-icing fluid is normally applied cold on clean aircraft surfaces.

HOLD-OVER TIME is the estimated time anti-icing fluid will prevent the formation of frost or ice and the accumulation of snow on the protected surfaces of an aircraft, under (average) weather conditions mentioned in the guidelines for hold-over time.

The ISO/SAE specification states that the start of the hold-over time is from the beginning of the anti-icing treatment

NON-NEWTONIAN fluids have characteristics that are dependent upon an applied force. In this instance it is the viscosity of Type II and IV fluids which reduces with increasing shear force. The viscosity of Newtonian fluids depends on temperature only.

ONE STEP DE-/ANTI-IC1NG is carried out with an anti-icing fluid, typically heated. The fluid used to de-ice the aircraft remains on aircraft surfaces to provide limited anti-ice capability.

TWO STEP DE-1C1NG/ANTI-1CING consists of two distinct steps. The first step, de-icing, is followed by the second step, anti-icing, as a separate fluid application. After de-icing a separate over-spray of anti-icing fluid is applied to protect the relevant surfaces thus providing maximum possible anti-ice capability.

4.16 Postscript

This document is the product of an industry working group whose aim is to promote awareness of aircraft ground de-icing/anti-icing procedures.

The project was initiated by a group of airlines that requested the assistance of aircraft manufacturers. Later the Association of European Airlines (AEA) adopted the project. Working group members came from Lufthansa, Finnair, Airbus Industrie, Boeing and McDonnell Douglas.

The AEA has been instrumental in developing improved techniques and materials for aircraft protection in icing conditions. This development has seen progress from simple glycol based de-icing fluids to sophisticated materials that provide anti-icing protection. Understanding the difference between “de-icing” and “anti-icing” is critical, the anti-ice protection given by longer hold-over times is vital to prevent disruption of air services while maintaining full airworthiness safety levels.

The rate of progress in the development of fluids, definition of procedures and specifications of the de/anti-icing equipment, resulted in the need for widespread information to all involved in their use: ground crews, flight crews, airport authorities, air traffic control, etc.

This document is intended to provide information in an easily digestible form. It may be used directly as training material or it may be adapted to suit the requirements of individual operators.

The contents of this document have been taken from various sources. The document has not been submitted for formal approval by any regulatory authority. The above mentioned working group, the publishers or the distributors do not accept any liability for the contents which are intended only as a guide.

CHAPTER FIVE -– THE NEW ZEALAND ENVIRONMENT

5.1 Statistical Comparison

In 1999 CAA commissioned a study into the aircraft icing hazard in New Zealand. The resultant paper included a comparison of the US accident rate due to icing with the New Zealand experience. The local rate proved to be significantly lower.

In fact the New Zealand rate was so low, it was difficult to reconcile it with statements by SAAB and ATR pilots. The commuter crews were adamant that icing in New Zealand was as severe, if not worse, than the encounters they experienced in Europe and the U.S.

5.2 Meteorological Study

In attempting to determine the facts, a questionnaire was addressed to MetService. Questions on air mass and forecasting have been extracted from the questionnaire and presented below. The MetService responded with the answers in italics:

5.2.1 Air Mass

(a) In New Zealand, which air masses/streams are conducive to icing?

The simple answer is conveyor belts. These may be associated with surface cold, warm, occluded or even stationary fronts. Sometimes, however, there is no related surface front though there may be an upper front. It should also be mentioned that deep convection, which can occur in air masses which themselves are not conducive to icing, is also a major icing risk.

(b) Which air masses/streams become hazardous after modification?

Not sure if there's an exact answer to this question. What can be said is that flows of the conveyor belt type, when subjected to suitable lifting and cooling, can be greater areas of icing risk than before (for example, a broad and deep northwest flow which has been lifted over the Southern Alps and hence which contains lenticular type waves).

(c) Does a simple relationship of air mass source, topography and stream modification exist to guide pilots?

The answer to the question "Does a simple relationship of air mass source, topography and stream modification exist?" is no. The relationships between these variables and aircraft icing are complex. The answer to the question "Does a simple relationship of air mass source, topography and stream modification exist to guide pilots?" is: MetService promotes no such relationship for the guidance of pilots. We have no idea, however, what may be in pilot licensing syllabi or taught at aviation colleges.

5.2.2 Icing Forecasts

(a) Is adequate icing information issued or included in aviation forecasts?

MetService Standards Manual Chapter 4 Section 2.1: states: "The Meteorological Service of Zealand provides aviation meteorological services in accordance with Civil Aviation Rules Part 174 Meteorological Service Organisations – Certification. These rules are issued as a requirement of the Civil Aviation Act 1990"

It is the responsibility of organisations other than MetService (namely, the Designated Meteorological Authority, ICAO and WMO) to specify what icing information shall he issued and/or included in aviation forecasts.

(b) What impediments limit the accuracy of icing forecasts?

The primary impediments are the very nature of icing itself: it is a mesoscale phenomenon, and the lack of observational data on aircraft icing,

However, the issues surrounding the forecasting of icing – or any other meteorological phenomenon, for that matter, are complex. The question could be answered more completely by undertaking a review of the meteorological literature.

5.3 New Zealand Environment

The clue to the national icing hazard lies in the earlier MetService reply. "What can be said is that flows of the conveyor belt type, when subjected to suitable lifting and cooling, can be greater areas of icing risk than before…" New Zealand's alpine spine straddles a latitude comparable that of Mediterranean countries, California or Japan. The islands are exposed to a relatively warm maritime airflow (conveyor belt) that is lifted and cooled by their mountainous interiors.

Surface temperatures are warmer than those of higher latitudes. The moisture content of the maritime air is higher and the conveyor belt meets the MetService definition of broad and deep. Finally the stream encounters orographic lifting when it meets the land. The potential exists for icing at altitude.

Weather patterns, specifically surface weather, is more extreme in Europe and North America – a simple product of colder latitude and continental modification. Without the benefit of research or a historical comparison one can only speculate that New Zealand weather is comparatively benign while the propensity to icing at altitude is equal to, if not greater than, that in colder, continental environments. In this context, the FAA Flight Safety Research Section has recorded most U.S. icing accidents during the approach and landing phase of flight (AOPA Online – Aircraft Icing 06/03/2000). As discussed in Chapter One, icing at low level, particularly tailplane icing, is a grave situation. A greater potential for this to occur at higher latitudes could explain the statistical disparity between North America and New Zealand ice related occurrences.

While the incidence of low altitude icing may not be very high in New Zealand, the risk of severe icing at altitude exists – a risk as great, if not greater, than elsewhere in the world. The Cessna Caravan that crashed in 1987 was flying at 11,000 ft. In July 1994 a SAAB commuter experienced loss of airspeed and a series of roll upsets at 11,000 ft in the Tory hold. In 1997 the Baron climbed to 10,000 before the pilot lost control. By comparison, in 1987 an F27 crashed during a single engine approach to East Midland after encountering ice between 900 and 1700 ft. An Embraer 120 stalled at 4,500 ft during approach to Clermont-Aulnat, France, and in 1991 the fatal ATR upset at Mosinee occurred at 8,000 ft after a longish hold at 10,000. None of which means that icing does not occur at higher levels overseas – it does.

Accordingly the main icing risk in New Zealand is not seen as a low altitude problem. Rather, the risk of severe icing at altitude, icing beyond the certification criteria, is the challenge. Severe icing can occur when any onshore conveyor is lifted. While it would be convenient to define specific locations and altitudes, it is nevertheless impractical: the variables defy simplification. Of course there are known ice areas, the 'Otaki Iceberg,' the Nelson – Christchurch route, Timaru – Alexandra, the Southern Alps. These hazard regions are best left to individual operator training programs and their briefing procedures.

5.4 New Zealand Statistics

During the five years from January 1995, New Zealand CAA recorded 487 aircraft accidents and 1940 incidents, a total of 2427 occurrences. 13 of these were attributable to in-flight icing – a rate of .53%. This analysis has been treated with caution due to the absence of a dedicated icing database and reluctance of some pilots to report icing occurrences. Nevertheless the rate is significantly lower than the FAA, so low in fact that Authority research led to the conclusion that a warmer environment and benign climate meant less ice in critical low altitudes.

Not that New Zealand is entirely without this risk as the following summary illustrates:

5.4.1 Incident Summary

The following incidents were extracted from the CAA files:

(a) Power interruption with immediate re-light during climb out of Hamilton. Moderate icing was present at the time.

(b) Cessna 172 unable to maintain MSA of 9000 feet. Descends under radar and starts shedding ice at 6,000 feet.

(c) IFR Air transport category lost MAP on one engine from 23" to 17". Received vectors and radar descent with alternate air selected. Icing had not been forecast at the cruise level.

(d) Moderate ice and high AUW limited climb to FL140 rather than the planned FL 180.

(e) Domestic jet requested local standby due ice ingestion and reduced power on one engine.

(f) Moderate ice encountered crossing the South Taranaki coast at FL200. One engine shutdown at top of descent to avoid engine damage due faulty anti-ice system and the presence of cowl ice.

(g) Wide body jet ice encounter at FL370 resulted in speed decay from .84M to .81.

(h) Ice encountered at 5,000 feet, power increased at 7,000, max continuous at 9,000. Max altitude achieved was FL 130 (ROC 200FPM). Ice conformed to a forecast for moderate icing. The aircraft would not have maintained a safe altitude if an engine had failed.

(i) Aircraft crashed after failing to climb out of ground effect during take-off. Clear ice found on the wings after the accident.

(j) Repeated power loss due to induction icing led to a diversion and successful landing.

(k) Freezing fog and ice covered runway at Dunedin.

(l) Ice covered runway at Queenstown.

(m) Ice damage to cabin window from ice shed by a propeller at FL140.

(n) 2-3 second flame out with all anti-icing on at 5,000 feet during a DME arc approach. The aircraft had been holding in significant ice for 20 minutes before the approach.

(o) VFR aircraft flown by non-instrument rated pilot encountered ice when forced to descend in IMC.

(p) Marked nose down pitch requiring considerable back pressure on the controls was experienced when the tailplane de-ice boots inflated during a clear ice encounter.

Neither the Cessna Caravan nor the Baron accidents have been included in this list. Both accidents were characterised by pilot inexperience, and single pilot night freight operations in aircraft lacking airframe anti-ice/de-ice equipment. Forecast or actual icing was a factor in both accidents.

5.5 Summary

To summarise the situation:

(a) New Zealand's middle latitude location, surrounded by a relatively warm ocean is conducive to atmospheric moisture and corresponding cloud formation.

(b) The countries maritime climate and mild temperatures do not produce the icing extremes encountered at low altitude in colder high latitude countries.

(c) This does not mean that runway contamination or aircraft icing on the ground does not occur, it does. However the problem is neither as frequent nor as severe as in the Northern Hemisphere. Nevertheless operators should be prepared to occasionally de-ice aircraft before flight.

(d) The mountainous terrain combined with strong prevailing winds induces significant lifting to a very moist maritime air mass.

(e) Resultant cloud formations comprise a mix of stratiform, cumuloform and wave cloud. Both the wave and the cumulus clouds can generate ice to very high altitudes, while erratic temperature gridlines in lee waves make this icing difficulty to forecast.

(f) Specific locations are more prone to icing. Localised uplifting and convergence lead to correspondingly localised phenomena. It is difficult to account for these local influences in forecasts especially when situations can change quickly.

(g) Pilots should look for onshore conveyors when evaluating synoptic situations. Developing/large systems over the Tasman Sea with their depressions, fronts and warm conveyors should be related to topography. Significant uplifting will produce Cb and high stratiform with varied freezing levels and significant ice formation.

(h) Occasional outbreaks bring very cold streams across the South Island. These streams often contain cold, warm and occluded fronts. Convair pilots have reported severe icing, described as freezing rain, over the Southern Ocean – however the phenomenon was reported during cruise rather than during an instrument approach or landing phase.

CHAPTER SIX – IN-FLIGHT MANAGEMENT

6.1 Frost, Ice and Snow Accumulation

The following sample of incidents and accidents involving frost or ice or snow as a causative factor is included to illustrate the type of problems that may be encountered. Although the data was derived from UK CAA sources, it is equally relevant to ice encounters in New Zealand:

(a) Ice build-up on engine inlet pressure probes causing erroneous indications of engine power;

(b) a thin layer of ice on control surfaces inducing flutter and consequent structural damage;

(c) severe tailplane icing leading to a loss of control on selection of landing flap;

(d) very small deposits of ice on wing leading edges dangerously eroding performance;

(e) windscreens being obscured by snow when operating with an unserviceable heater, leading to a loss of directional control on take-off;

(f) attempting a take-off with wet snow on the wings and tail-plane surfaces after earlier de-icing with diluted fluid;

(g) snow/slush on helicopter upper fuselage surfaces entering engine intakes after engine start causing flameout and engine damage;

(h) engine breather pipes freezing;

(i) inability to open doors after a successful landing. (Although to date such occurrences have not resulted in serious consequences, these conditions could be extremely hazardous in an emergency situation). This problem has been caused by external coverings of ice; ice in locking mechanisms, hinges and seals; and freezing moisture in pressure locking systems;

(j) non-use of engine igniters in potential icing conditions which, in conjunction with other factors, contributed to a double engine failure and consequent forced landing;

(k) very low ambient temperatures at high altitude resulting in apparent fuel freezing leading to subsequent multiple engine rundown, in spite of application of fuel heating systems. (Given a sufficiently long exposure time to low ambient air temperatures, fuel will eventually cool to a temperature that can be well below the freezing point of the fuel). Pilots should therefore be aware of the freezing points of their specified fuels and/or the operational limitations of these fuels and plan accordingly. There are aircraft types, including those with piston engines, where the use of special fuel anti-freeze additives are specified as being mandatory in certain conditions;

(l) contamination of retractable landing gear, doors, bays and micro-switches by snow, wet mud or slush. Any contamination should be removed before flight;

(m) carburettor icing. (However, it should be emphasised that this particular problem is not confined to winter operations);

(n) wing upper surface icing due to very low fuel temperature. Such ice is usually clear and very difficult to detect visually. In addition to any aerodynamic effects caused by this contamination, there is a serious hazard to rear engine aircraft if this ice breaks off. This often occurs during take-off and in such cases ice ingestion and turbine damage has occurred. Typical factors favouring the formation of such ice include:

   (i) Low temperature of up-lift fuel;

   (ii) protracted flight in low temperatures resulting in fuel cold-soak to 0°C or below. This is followed by fuel cooling the wing surfaces through direct contact, or conduction through the structure in contact with the fuel. Coupled with an environment comprising high humidity, drizzle, rain or fog and temperatures ranging from of 0°C to +10°C, ice will form. It should be noted, however that ice has formed in drizzle and rain in temperatures between +8 C and +14°C. When carrying out a check of the wing surface in these circumstances, it must be remembered this ice may have formed below a layer of slush or snow.

(o) a twin-engine aeroplane landing in winter conditions experienced a significant wing drop accompanied by a nose-up pitch. Despite application of power and full opposite aileron and rudder the aircraft was slow to recover and the wing tip struck the ground. Control was regained and a safe landing made. Although no ice was seen during a visual check of the wing surfaces prior to landing, the aircraft had been operating all day in icing conditions and prior to this flight had been delayed on the ground in rain conditions for 40 minutes;

(p) a twin-engine aeroplane stalled at an IAS considerably above the basic stall speed and at a much lower than normal angle of attack; the approach to the stall was so insidious that the pilot was unaware that the aircraft had stalled. The pilot did not have the expected visual cues on the rapid accretion of ice and the action of the autopilot in correcting for the aerodynamic effects of the accretion was to actually drive the aircraft further into the stall configuration. Heavy stall buffeting, which was mistaken for propeller icing caused the pilots difficulty in reading instruments. The temperature was much warmer than usual and large water droplets were present;

(q) a twin-engine aeroplane stalled on the approach to an airport, probably after becoming uncontrollable at a speed well above its stalling and minimum control speeds. It was deduced that its handling and flying characteristics had been degraded by ice accumulation;

(r) another twin-engine aeroplane suffered a double engine failure, possibly as a result of ice ingestion. There have been a number of reported flameouts from this cause, most of which have been suspected as being due to either late or non-selection of engine icing protection systems.

6.1.1 Avoidance

Without labouring the obvious, the first component of an effective icing strategy is recognition of potential hazard(s) during flight planning. In this regard:

(a) Check route and terminal forecasts;

(b) Examine synoptic situations for fronts, conveyor belts and warm onshore situations;

(c) assess route segments for orographic lifting;

(d) assess escape routes to facilitate descent into warmer air, and

(e) check METARS and PIREPS for indications of icing.

If in doubt contact the nearest MetService office. Often, slight diversions on North/South routes will clear areas of icing probability with very small distance penalties. Coast to coast flight over the mountain ranges require more care, even accepting significant diversion to avoid known or suspected icing areas.

6.1.2 Situation Awareness

In-flight, the key is situation awareness. The crew must be aware of the aircraft's anti-ice/de-ice capability, its performance and ability to climb out of trouble, alternatively their escape route for descent. They must watch for any ice build up. They must be conscious of the environment, the cloud type, and its propensity for ice. The vagaries of stratiform versus cumuloform cloud, their relative vertical and horizontal extent the option to climb or descend in stratiform, the need to divert from cumuliform.

The crew must monitor any ice build up once IMC is encountered. They must consider the possibility of a significant ice encounter, watch for the development of moderate to severe conditions, review their escape strategy, and advise ATC of the situation. Prolonged flight in icing should be avoided; the escape strategy should be adopted during an enroute segment, a clearance to descend or divert obtained if holding in icing conditions. Anti-icing/de-icing systems should be activated immediately the ice is encountered (or in accordance with AFM requirements).

6.2 Handling in SLD Conditions

Warning: This document describes two types of upset: roll upset and tailplane stall (pitch upset). The procedures for recovery from one are nearly opposite those for recovery from the other. Application of the incorrect procedure during an event can seriously compound the event. Correct identification and application of the proper procedure is imperative.

6.2.1 Preventive and Remedial Measures

Before takeoff:

Know the PIREP and the forecast — where potential icing conditions are located in relation to the planned route, and which altitudes and directions are likely to be warmer and colder. About 25 percent of SLD icing conditions arc found in stratiform clouds colder than 0 degrees C (32 degrees F) at all levels, with a layer of wind shear at the cloud top. There need not be a warm melting layer above the cloud top.

When exposed to severe icing conditions:

Pilots should rely on visual and tactile cues to determine the presence of SLD. After confirming SLD, they must divert immediately. Because SLD conditions tend to be localised, the procedure has proved to be practical and safe. Using cues requires alertness to existing conditions and a very clear understanding of the aeroplane and its systems. Pilots should have an equally clear understanding of aviation weather and know the temperatures and conditions likely to the left, right, ahead, behind, above and below the flight. Tactile cues such as vibration, buffeting or changes in handling characteristics normally trigger a mental warning that ice has already accreted to a perceptible, and perhaps detrimental, level. Typically, as ice increases in thickness, cues become more prominent. These cues alert pilots to activate the various ice-protection systems, and when necessary, to exit the conditions. In this context:

(a) Disengage the autopilot and hand-fly the aeroplane. The autopilot may mask important handling cues, or may self-disconnect and present unusual attitudes or control conditions.

(b) Advise air traffic control, and promptly exit the icing conditions. Use control inputs as smooth and as small as possible.

(c) Change heading, altitude or both. Find an area that is warmer than freezing, or substantially colder than the current ambient temperature, or clear of clouds. In colder temperatures, ice adhering to the airfoil may not be completely shed. It may be hazardous to make a rapid descent close to the ground to avoid severe icing conditions.

(d) Reporting severe icing conditions may assist other crews in maintaining vigilance. Submit a PIREP of the observed icing conditions. It is important not to understate the conditions or effects.

Although there is ongoing atmospheric research, the SLD environment has not been extensively measured or statistically characterised. There are no regulatory standards for SLD conditions, and only limited means to analyse, test or otherwise confidently assess the effects of portions of the SLD environment. Ice shape-prediction computer codes currently do not reliably predict larger ice shapes at temperatures near freezing because of complex thermodynamics.

Near freezing seems to be where SLD conditions are most often – but not exclusively – reported. Further research using specially instrumented aeroplanes will be necessary to accurately characterise the SLD environment. In addition to energy balance problems, there are other challenges not addressed by computer codes, such as the shape (and therefore drag) of large droplets as they are influenced by the local flow field; fragmentation of drops; and the effect of drops splashing as they collide with the airfoil. Ice shedding and residual ice are not currently accounted for, either. The U.S. National Aeronautics and Space Administration (NASA) and others are working on these computational tasks and simultaneously pursuing validation of icing tunnels to simulate SLD conditions. Those efforts will require comparison against measured natural conditions, but there is no universally accepted standard on how to process or accurately characterise data collected in the natural icing environment. Clearly, until these tasks are complete, more specific certification issues cannot be resolved.

If roll control anomaly occurs:

(a) Reduce AOA by increasing airspeed or extending wing flaps to the first setting if at or below the flaps-extend speed.

(b) If in a turn, roll wings level.

(c) Set appropriate power and monitor airspeed/AOA. A controlled descent is vastly better than an uncontrolled descent.

(d) If flaps are extended, do not retract them unless it can be determined that the upper surface of the airfoil is dear of ice. Retracting the flaps will increase the AOA at a given airspeed.

(e) Verify that wing ice protection is functioning normally and symmetrically. Verify by visual observation of the left and right wings. If the ice-protection system is dysfunctional, follow the manufacturer's instructions.

If pitch upset symptoms occur:

(a) Immediately retract the flaps to the previous setting and apply appropriate nose up elevator pressure.

(b) Increase airspeed appropriately for the reduced flap extension setting.

(c) Apply sufficient power for aircraft configuration and conditions. (High engine power settings may adversely impact response to tailplane stall conditions at high airspeed in some aircraft designs. Observe the manufacturer's recommendations regarding power settings.)

(d) Make nose down pitch changes slowly, even in gusting conditions, if circumstances allow.

(e) If a pneumatic de-icing system is used, operate the system several times in an attempt to clear the tailplane of ice.

6.3 System Operation

6.3.1 Carburettor Heat

When the presence of induction system icing is suspected the HOT or alternate air ON position must be selected immediately:

(a) The recommended practice with most engines is to use full heat whenever carburettor heat is applied. The control should be selected fully to the HOT position;

(b) With some engine installations the use of partial carburettor heat may be considered, particularly where an intake temperature gauge is fitted. An intermediate position between HOT and COLD should only be used if an intake temperature gauge is fitted and appropriate guidance is given in the Flight Manual.

6.3.2 Pneumatic De-ice Boots (Piston Engines)

Piston engine pneumatic systems employ mechanical pumps to supply air pressure to the e-ice boots. These systems usually employ longer dwell time, lower pressure and less efficient boot shapes. These systems may be prone to ice bridging, and pilots should refer to the Aircraft Flight Manual concerning operating technique. In particular, they should refer to the Flight Manual before adopting the following techniques that are applicable to high-pressure boots on turboprop aircraft.

6.3.3 Pneumatic De-ice Boots (Turboprop Aircraft)

The following discussion is based on comments by Eugene G. Hill the FAA's chief scientific advisor for environmental icing. Eugene Hill had 36 years experience with Boeing, including extensive work on icing certification. He had a significant role in developing the FAA's current icing strategy.

Manufacturers of most turboprops and some small jets are reviewing their recommended de-ice boot operating procedures and, in some cases, rewriting them.

The activity stems from the FAA's July 1999 proposed AD directly affecting 17 models of turboprops and light jets including the Saab 340 series, and de Havilland's Dash 7 and Dash 8 amongst others. The proposal would have manufacturers change the procedures in aeroplane Flight Manuals (AFMs) to require flight crews to activate pneumatic de-ice boots at the first indication of ice accumulation and to keep the boots cycling until the aircraft exits icing conditions.

The proposed ADs, will be relatively inexpensive in that they involve only paperwork changes to AFMs and airline operating manuals, however they are not without controversy. De-icer operating instructions in the AFMs were developed through flight test during each aeroplane's original certification trials. Typically these certification tests involved flight in actual icing conditions or behind ice-making tankers.

The majority of U.S operators of modern, high performance turboprops believe that ice bridging should not occur with modern pneumatic systems, however they also think 'the FAA needs to clarify some important issues.' The NPRMs refer to 'modern' de-ice systems however the operators are unsure exactly which systems are considered modern and which are not. The FAA should identify the specific equipment it is talking about.

There is continuing concern regarding a paperwork change lacking flight validation. A lot of regional carriers have been flying these aeroplanes safely on the understanding that de-ice equipment was to be cycled only after a build up interval to maximise its effectiveness. These operators want aeroplane by aeroplane verification that the new procedure will work. They also point out that some of the manufacturers listed in me NPRM did not participate in technical discussions.

Engineers agree that pneumatic boots are most effective at shedding ice cleanly if the crew waits for a build-up. Cycling the boots continuously usually leaves a messy leading edge with some residual 'inter-cycle' ice. On the other hand, ice that accumulates while the crew waits for the AFM recommended thickness can involve its own hazards, and the feeling now is that this ice can be far more dangerous than the inter-cycle residue.

Accident investigators and ice experts believe that autopilot use and pilot training also contribute to icing upsets and accidents, and must be addressed along with boot operating procedures.

The first challenge is to get flight crews to activate de-ice systems early. A lot of the in-flight, ice-related accidents and incidents are so vicious, it has become fairly apparent that they occur when de-icing systems are not used. In most of these incidents, the FAA suspect the flight crews were comfortable with some level of accretion and intended to delay the activation of their de-icing systems until they gauged that the ice had reached [the AFM] recommend thickness.

The authority believes there is generally great danger in waiting. That pilots do not seem to appreciate the significantly increased drag and loss of stall speed and manoeuvre margins that develop from a seemingly innocuous frosting of ice. FAA research, and that of others, demonstrates that even minor airfoil icing can increase stall speeds from 15 to 20 percent and can reduce the stall angle by four to five degrees. Thus, during time the crew waits for ice to build up to AFM recommended thickness, the stall occurs earlier than expected, and the accompanying drag can prevent normal acceleration when the crew applies throttle.

Even stall warning cues can change dramatically during initial ice build-up. In the past, the FAA has approved aeroplanes allowing multiple, configuration based stall warning cues — stick shaker for a clean aeroplane, for example, and aerodynamic buffeting for one with ice accretion. While some argue that the aerodynamic buffeting is sufficiently significant and that it will warn the flight crew that the aeroplane is stalling, many pilots will wait for stick shaker — and that's where they've been caught. If they mistake aerodynamic buffeting for the vibration felt when ice is being shed from the propellers, they may find themselves in a full stall.

Part of the FAA push for the proposed ADs grows out of the loss of an EMB-I20 near Monroe, Mich., on January 9,1997. The aeroplane was being vectored to the final approach in icing conditions when it rolled and stalled. The NTSB found that the crew failed to activate the de-icing boots as the aircraft entered icing conditions, and that the aeroplane accumulated a thin, rough layer of ice on its lifting surfaces. This happened very quickly — in just a few minutes. The accumulation of ice, in combination with the slowing of the aeroplane to an airspeed "inappropriate for the icing conditions in which the aeroplane was flying," resulted in the upset. Following that investigation, the NTSB requested that the FAA mandate (at least for EMB-120s) that flight crews activate pneumatic de-icing boots as soon as the aeroplane enters icing conditions. This was done.

Obviously, a thin, frost-like coating of ice on the leading edge can create problems. Things can be worse in supercooled large droplets (SLD) conditions where ice can accrete behind the boots. This situation can increase stall speed by 70 percent, and the angle at stall may be only a few degrees above the cruise angle-of-attack. An ice ridge aft of the boots at about 10-percent chord is in a very critical area. That is where pressure recovery begins, disturbing airflow in this area can destroy the boundary layer.

Flight crews are accustomed to flying in icing conditions at normal operating attitudes and have not been exposed to the surprises that occur when an iced aeroplane achieves an unusual attitude. Pilots operating in ice can become very comfortable because they've 'been there before and the aeroplane can handle it.' With ice contamination you are really flying a different aeroplane — different performance capabilities and different handling qualities. As long as they keep the attitude low, they may not appreciate that fact. It is only when pilots enter the lift divergence regime that disturbances occur. The only change in performance an alert crew will detect is the increased throttle required to maintain normal cruise speed. If the crew has auto-throttle, they might nor even notice that.

Crews need to understand that ice protection systems have been put on their aircraft to enable them to penetrate and exit known icing conditions — not to hold in those conditions. Flight crews need to avoid icing conditions if possible and when they have to penetrate icing, they should have a plan for escaping.

FAA experts believe activation of the de-icing system is the first thing to do upon entering icing conditions. (Of course crews ultimately have to follow AFM instructions). Then, in severe icing conditions, crews should exit immediately. If they have planned appropriately, they will be able to follow the exit strategy developed before entering the icing conditions.

6.3.4 Beware of Automation

Flight crews must be especially wary of automation during icing encounters. Autopilots and auto-throttles can mask the effects of airframe icing and even contribute to ultimate loss of control. There have been several accidents in which the autopilot trimmed the aeroplane to stall upset by masking heavy control forces. Then pilots have been surprised when the autopilot automatically disconnected with the aeroplane on the brink of stall. Autopilot control laws are at the heart of the problem. Wing ice accretion sometimes causes the wing to stall before stick shaker activation. Some autopilots are designed with control laws that enable them to continue to operate until they get to stick shaker. Alternatively, the autopilot may disconnect early because of excessive roll rates, roll angles, control surface deflection rates, or forces that are not normal. These autopilots are not malfunctioning; they are conforming to design parameters. When they were approved, the rules assumed they were non-mandatory equipment. The assumption was that the crew would remain continuously aware of what the autopilot was doing and how it is flying the aeroplane. That, of course, is not always a valid assumption.

When workload allows, crews should manually fly their aeroplane in icing conditions so they can monitor control forces and feel trim changes. It is most important that the proper ice penetration speed is observed. The idea is to keep an adequate margin above stall, remembering that stall speed is increasing and stall alpha is lowering. Unfortunately, there are no reliable rules of thumb for icing speeds. The manufacturers have to provide them based on wind tunnel and flight tests.

The FAA also intends reviewing autopilot certification process with focus on the warning support system as flight crews are placing increased reliance on the autopilots, especially during the approach phase when the workload is high and the icing encounters are frequent.

6.3.5 Thermal Anti-icing

FAA recommendations regarding early use of de-icing/anti-icing, and the need to reference aircraft flight manuals, apply equally to turbo jet aircraft using thermal engine and airframe anti icing.

6.4 Contaminated Runway Operations

6.4.1 Introduction

Operations from contaminated runways, by all classes of aeroplane, should be avoided whenever possible.

Major airport authorities make every effort, within the limits of manpower and equipment available, to keep runways clear of snow, slush and its associated water, but circumstances arise when complete clearance cannot be sustained. In such circumstances, continued operation involves a significant element of risk and the wisest course of action Is to delay the departure until conditions improve or, if airborne, divert to another aerodrome.

6.4.2 Operational Factors

At major aerodromes, when clearing has not been accomplished, the runway surface condition is reported as follows:

(a) Dry Snow.

(b) Wet Snow.

(c) Compacted Snow.

(d) Slush.

(e) Standing Water.

The presence of water on a runway will be reported to the pilot using the standard descriptors. For performance purposes, runways reported as DRY, DAMP or WET should be considered as NOT CONTAMINATED.

Depths greater than 3 mm of water, slush or wet snow, or 10 mm of dry snow, are likely to have a significant effect on the performance of aeroplanes. The main effects are:

(a) additional drag – retardation effects on the wheels, spray impingement and increased skin friction;

(b) possibility of power loss or system malfunction due to spray ingestion or impingement;

(c) reduced wheel-braking performance – reduced wheel to runway friction and aquaplaning;

(d) directional control problems;

(e) possibility of structural damage.

A water depth of less than 3 mm is normal during and after heavy rain and in such conditions, no corrections to take-off performance are necessary other than the allowance, where applicable, for the effect of a wet surface. However, on such a runway where the water depth is less than 3 mm and where the performance effect is insignificant, isolated patches of standing water or slush of depth in excess of 15 mm run may lead to ingestion and transient power fluctuations which could impair safety. Some aircraft types are susceptible to power fluctuations at depths greater than 9 mm and AFM limitations should be checked.

In assessing the performance effect of increased drag the condition of the up-wind two thirds of the take-off runway is most important, i.e. the area where the aeroplane is travelling at high speed. Small isolated patches of standing water will have a negligible effect on performance, but if extensive areas of standing water, slush or wet snow are present and there is doubt about the depth, take-off should not be attempted.

It is difficult to measure, or predict, the actual coefficient of friction or value of displacement and impingement drag associated with a contaminated runway. Therefore, it follows that aeroplane performance relative to a particular contaminated runway cannot be scheduled with a high degree of accuracy and hence any ‘contaminated runway’ data contained in the Flight Manual should be regarded as the best data available.

The provision of performance information for contaminated runways should not be taken as implying that ground handling characteristics on these surfaces will be as good as can be achieved on dry or wet runways, in particular, in crosswinds and when using reverse thrust. Remember that the use of a contaminated runway should be avoided if at all possible. A short delay in take-off or a short hold before landing can sometimes be sufficient to remove the contaminated runway risk. If necessary a longer delay or diversion to an airport with a more suitable runway should be considered.

6.4.3 General Limitations for Take-off

When operations from contaminated runways are unavoidable the following procedures may assist:

(a) take-off should not be attempted in depths of dry snow greater than 60 mm or depths of water, slush or wet snow greater than 15 mm. If the snow is very dry, the depth limit may be increased to 80 mm. In all cases the AFM limits, if more severe should be observed;

(b) ensure that all retardation and anti-skid devices are fully serviceable and check that tyres are in good condition;

(c) consider all aspects when selecting the flap/slat configuration from the range permitted in the Flight Manual. Generally greater increments of flaps/slats will reduce the unstick speed but could, for example, increase the effect of impingement drag for a low wing aircraft. Appropriate field length performance corrections should be made;

(d) fuel planning should include a review all aspects of the operation; including whether the carriage of excess fuel is justified;

(e) ensure that de-icing of the airframe and engine intakes, if appropriate, has been properly carried out and that the aircraft is aerodynamically clean at the time of take-off. Necessary de-icing fluids on the aerodynamic surfaces are permitted;

(f) pay meticulous attention to engine and airframe anti-ice drills;

(g) do not attempt a take-off with a tail wind or, if there is any doubt about runway conditions, with a crosswind in excess of the slippery runway crosswind limit. In the absence of a specified limit take-off should not be attempted in crosswinds exceeding 10 kt;

(h) taxi slowly and adopt other taxiing techniques which wilt avoid snow/slush adherence to the airframe or accumulation around the flap/slat or landing gear areas. Particularly avoid the use of reverse thrust, other than necessary serviceability checks which should be carried out away from contaminated runway areas. Be cautious of making sharp turns on a slippery surface;

(i) use the maximum runway distance available and keep to a minimum the amount of runway used to line up. Any loss should be deducted from the declared distances for the purpose of calculating the RTOW;

(j) power setting procedures appropriate to the runway condition as specified In the AFM should be used. Rapid throttle movements should be avoided and allowances made for take-off distance increases;

(k) normal rotation and take-off safety speeds should be used, (e.g. where the Flight Manual permits the use of data for overspeed procedures to give improved climb performance, these procedures should not be used). Rotation should be made at the correct speed using normal rate to the normal attitude;

(l) maximum take-off power should be used.

Aircraft Commanders should also take the following factors into account when deciding whether to attempt a take-off:

(a) the nature of the overrun area and the consequences of an overrun off that particular runway;

(b) weather changes since the last runway surface condition report, particularly precipitation and temperature, the possible effect on stopping or acceleration performance and whether subsequent contaminant depths exceed Flight Manual limits.

6.4.4 Landing

Attempts to land on heavily contaminated runways involve considerable risk and should be avoided whenever possible. If the destination aerodrome is subject to such conditions, departure should be delayed until conditions improve or an alternate used. It follows that advice in the Flight Manual or Operations Manual concerning landing weights and techniques on very slippery or heavily contaminated runways is there to enable the Commander to make a decision at despatch and, when airborne, as to his best course of action.

Depths of water or slush, exceeding approximately 3 mm, over a considerable proportion of the length of the runway, can have an adverse effect on landing performance. Under such conditions aquaplaning is likely to occur with its attendant problems of negligible wheel-braking and loss of directional control. Moreover, once aquaplaning is established it may, in certain circumstances, be maintained in much lower depths of water or slush. A landing should only be attempted in these conditions if there is an adequate distance margin over and above the normal Landing Distance Required and when the crosswind component is small, The effect of aquaplaning on the landing roll is comparable with that of landing on an icy surface and guidance is contained in some Flight Manuals on the effect on the basic landing distance of such very slippery conditions.

CHAPTER SEVEN – PILOT TRAINING SYLLABI

7.1 Theoretical Syllabus

7.1.1 Introduction

The theoretical syllabus for instrument rating training is based on the information presented in Chapters One through Five. Certain commercial texts have been used over the years and these have not been excluded as reference sources, however students should check these publications for inclusion of contemporary information on supercooled droplets, icing certification, airfoil characteristics, stalling, roll upsets and tailplane stalling.

7.1.2 Syllabus Content

The icing syllabus encompasses the following headings:

- Icing hazards
- Formation of Airframe icing
- Clear ice
- Rime ice
- Mixed Ice
- Hoar frost
- Airframe icing and cloud types
    - Cumulus type
    - Stratiform
    - Precipitation
    - High Level clouds
- Freezing rain
- Freezing drizzle
- Supercooled Drizzle Droplets SDD
- Supercooled Large Droplets SLD
- Recognition of SLD conditions
- Airfoil characteristics
- Performance and handling degradation
- Stall characteristics
- Roll upsets
- Tailplane stalling
- Anti-icing and de-icing systems
    - Turbine/Pneumatic
    - Piston/pneumatic
    - Electrical propeller
    - Thermal
    - Pitot heat/stall warning
    - Windscreen

- Engine icing
  - Atmospheric conditions
  - Induction icing
  - Intake icing
  - Fuel icing
  - Carburettor heat
- Operation from contaminated runways
  - General limitations for take-off
- Icing certification requirements
  - FAR Part 23
  - FAR Part 25

7.1.3 Syllabus Amplification

These headings are amplified down as follows:

- Icing Hazards
  - Ice formation
  - Types of icing
  - Importance of ice detection
  - Operations into icing conditions
  - Icing certification
  - Ice Intensity and Pilot Action
- Super Cooled Large Droplets
  - Definition of Icing Conditions
  - Recognition of SLD Conditions
- FAA Certification Requirements
- Roll upsets
  - Detecting SLD
  - Actions when exposed to SLD conditions
  - Roll Upset Recovery
- Tailplane Stall
  - Cause
  - Symptoms
  - Corrective actions
- Anti-icing and de-icing systems
  - Anti-icing
  - De-icing
  - Propeller anti-icing
  - Heated Wings thermal systems
  - Inflatable Boots
  - Weeping wing de-icing
  - Windshield anti-icing
  - Carburettor Heat

- Engine Icing
    - Induction system icing
        - Carburettor icing
        - Fuel icing
        - Intake icing
    - Atmospheric conditions
    - Prevention, Recognition and Remedial Practices
        - Prevention
        - Recognition
        - Remedial Action
    - Maintenance and Handling Procedures
- Operation from Contaminated Runways
    - Operational Factors
    - Take-off Performance
    - Icing Certification
    - General Limitations for Take-off
    - Landing

7.2 Practical Syllabus

7.2.1 Training Discussion

Transport crews do not receive very much unusual attitude training and they rarely experience full stalls and recovery in the aircraft they are flying. Without this training, they may think that the aerodynamic buffeting they experience when their aeroplane ices up is the result of ice on propeller blade(s). A similar misconception was the case in the Melbourne SF-340A stall/roll upset (November 1998) when the crew didn't recognise the situation.

Typically, transport crews are trained down to stick shaker and taught to power out of the stall warning with minimal altitude loss. Pilots thus trained may not recognise an ice-induced stall that occurs before stick shaker activation, and they might not be aggressive enough in recovery action even if they do recognise the situation. In this regard most air carrier and general aviation simulators aren't programmed to provide realistic motion beyond the shaker threshold, however airframe manufacturers have the data, and it should be possible to provide exposure to a full stall. Weather this can be continued into a full roll upset, and weather this is wise or practical during actual air training in light twin and turboprop commuter aircraft is another matter.

On a similar theme, making wholesale changes to flight training syllabi is not particularly easy. For commuters and air carriers alike, training is expensive and the time the trainers have with flight crews is limited. Course designers have to balance the training exercises with the probability that the flight crew will need to employ them. For example, the probability of a flight crew ever experiencing a full stall is much lower than the probability of a stick shaker encounter.

Arguments that operational changes can mitigate the problem are valid. Changes such as activating boots early, flying the aeroplane manually, maintaining speeds at or above ice penetration speed and, most important, avoiding or exiting ice as quickly as possible are alternatives to the ambulance down in the valley. Here the real issue is situation awareness, airmanship and compliance with AFM procedures.

7.2.2 Stall/Unusual Attitude Recovery Training

Instrument flying training accounts for unusual attitude recovery however carrying this on to ‘upset’ training, involving the variables of an iced up aeroplane, is hardly practical. Moderate to severe ice accrual creates entirely new, unpredictable aerodynamic flow over the wings and tail. Airfoil shape, aerodynamic flow, the relationship of forces and design logic are all subject to random changes unique to the specific ice encounter. The pilots of the Comair EMB-120 that crashed after a roll upset in Michigan responded to the situation with control wheel inputs within one second of autopilot disengagement. They continued to apply inputs in an apparent attempt to regain control until the FDR recording ceased. The pilots in the Roselawn ATR upset continued their uncoordinated corrections all the way to ground impact, and an MU2 crew transmitted details of their predicament and their efforts to recover from a fatal spin in Western Australia.

These accidents indicate that once an upset has developed, the pilots face a grave situation – that attempts to recover in an aeroplane that has ceased to conform to control logic may be impossible. There is no guarantee they will be able to recover from the resultant unusual attitude. *Clearly, the only options are avoidance or immediate diversion while the aircraft is still under control.*

7.2.3 Simulator Training

Originally some US operators had embarked on a syllabus of upset/unusual attitude training. One example, the Comair training, included the following practical simulator exercises:

(a) Control wheel displacement.

(b) Stall series to stick pusher and stick shaker.

(c) Unusual attitudes.

(d) Slow/fast indicator demonstration.

(e) Yaw demonstration with rapid power lever advancement.

During simulator sessions pilots rolled the simulator to an unusual attitude presentation. The demonstration was repeated, with the instructor stopping (“freezing”) the simulator at various points to discuss the visual cues and attitude indications that occur during the roll. The EADI always contained information regarding both the sky and the ground, even in the most extreme attitudes. During the “stop and go” roll demonstration, instructors pointed out the blue/brown (sky/ground) picture and the indications, which indicate the “up” direction during unusual attitudes, including inverted flight. Instructors emphasised that, when the aeroplane was upside down, the pilots must push forward, not pull back on the control yoke.

A number of US operators found that students had an aversion to an inverted aeroplane. Pilots usually tried to right the aeroplane by rolling against the turn, although in some cases it would be easier to continue through the roll. One chief pilot stated that “the people who do the best are the ones who add power.” Another instructor reported that pilots with previous acrobatic experience usually did better with the upset training. If a pilot did not satisfactorily complete the upset manoeuvre, the demonstration was continued until a successful outcome was achieved.

Obviously the intent was to prepare pilots for recovery from a roll upset; an unrealistic gaol in view of the control degradation experienced in a number of ice encounters. A secondary consideration is the simulator itself; the absence of tactile cues (sustained ‘G’ force for one) and program limitations.

7.2.4 An Alternative Program

Alternatively, training should focus on classroom education supplemented with practical training in either a simulator or an aircraft, the goal of the training being enhanced pilots knowledge and awareness. This awareness should include icing considerations, recognition of icing situations, escape strategy, recognition of potential upset situations and escape from these situations.

This training needs to be formally incorporated during every phase of an operator’s pilot training program (initial, upgrade, transition, and recurrent).

7.2.5 Classroom Training

The classroom discussion should encompass the following:

(a) Icing certification.

(b) Autopilot limitations.

(c) SCDD/SLD formation.

(d) New Zealand icing environment.

(e) Recognition of SLD.

(f) De-ice/anti-ice system management.

(g) Aircraft handling in icing conditions.

(h) Recovery from roll upsets.

(i) Recovery from tailplane stall.

(j) Ground de-icing.

(k) Contaminated runway operations.

7.2.6 In-flight Training – Simulation

Most simulator programs include icing logic, however they lack data beyond a fully developed stall and/or extreme unusual attitudes. Similarly, if ice accrual reaches this stage, continued control of the aeroplane is very doubtful. This does not exclude U/A training however, due to simulator variables, it does exclude inverted attitudes and full stalls as a result of ice upsets.

Accordingly an icing syllabus should include the following simulator exercises:

(a) Pre-flight briefing:

Normal pre-flight briefing, icing discussion, de/anti-ice systems and operation, AFM handling requirements, recognition of SLD, SLD strategy, stall symptoms without stick shaker, stall recovery, roll upset recovery, tailplane stall symptoms, tailplane stall recovery.

(b) Air exercise:

(i) Onset of light to moderate icing.

(ii) Initial performance degradation.

(iii) Use of de-ice systems.

(iv) Onset of SLD.

(v) Escape strategy.

(vi) Handling in SLD.

(vii) De-activate stall warning, then

(viii) Approach to the stall.

(ix) Aerodynamic buffet.

(x) Stall recovery at the buffet, aggressive use of attitude and power.

(xi) Unusual attitude recovery, ADI/EADI presentation and interpretation, recovery technique.

7.2.7 In-Flight Training – Aircraft

(a) Pre-flight briefing:

Per-flight briefing similar to that for the simulator program.

(b) Air exercise:

- Operation of de-ice systems.
- Approach to the stall.
- Aerodynamic buffet.
- Stall recovery at the buffet, aggressive use of attitude and power.
- Unusual attitude recovery, ADI/EADI presentation and interpretation, recovery technique.

(c) ADI interpretation

A key feature of unusual attitude recoveries is the ability to interpret the ADI/EADI. Familiarisation with these presentations does not necessarily involve elaborate simulation; rather it may be accomplished using simple models made from cardboard or ply. Where an operator lacks simulation, efforts should be made to improvise training aids in order to prepare for actual air lessons.

CHAPTER EIGHT – OPERATIONS MANUAL CONTENT/ OPERATOR CERTIFICATION

8.1 Operations Manual Inclusions

The following guidelines for the icing content of operations manuals was derived from FAA AC 23.1419-2A, Appendix 2, titled AFM Limitations and Normal Procedures Sections, dated 8/19/98.

These guidelines should be incorporated in operations manuals where an AFM has not been amended to include the information.

8.2 Limitations and Normal Procedures Sections

8.2.1 Limitations Section

In the case of severe icing, the following text and warning information should be used:

Flight in meteorological conditions described as freezing rain or freezing drizzle, as determined by the following visual cues, is prohibited:

(a) Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.

(b) Accumulation of ice on the upper surface (for low-wing aeroplanes) or lower surface (for high-wing aeroplanes) of the wing aft of the protected area.

(c) Accumulation of ice on the propeller spinner farther back than normally observed.

If the aeroplane encounters conditions that are determined to contain freezing rain or freezing drizzle, the pilot must immediately exit the freezing rain or freezing drizzle conditions by changing altitude or course.

Note: *The prohibition on flight in freezing rain or freezing drizzle is not intended to prohibit purely inadvertent encounters with the specified meteorological conditions; however, pilots should make all reasonable efforts to avoid such encounters and must immediately exit the conditions if they are encountered.*

Use of the autopilot is prohibited when any ice is observed forming aft of the protected surfaces of the wing, or when unusual lateral trim requirements or autopilot trim warnings are encountered.

Note: *The autopilot may mask tactile cues that indicate adverse changes in handling characteristics; therefore, the pilot should consider not using the autopilot when any ice is visible on the aeroplane.*

8.2.2 Normal Procedures Section

In the case of severe icing, the following text and warning information should be used in the Normal Procedures Section of the AFM:

Warning: If ice is observed forming aft of the protected surfaces of the wing or if unusual lateral trim requirements or autopilot trim warnings are encountered, accomplish the following:

(a) if the flaps are extended, do not retract them until the airframe is clear of ice;

(b) the flight crew should reduce the angle-of-attack by increasing speed as much as the aeroplane configuration and weather allow, without exceeding design manoeuvring speed;

(c) if the autopilot is engaged, hold the control wheel firmly and disengage the autopilot. Do not re-engage the autopilot until the airframe is clear of ice;

(d) exit the icing area immediately by changing altitude or course; and

(e) report these weather conditions to Air Traffic Control.

Caution: Severe icing comprises environmental conditions outside of those for which the aeroplane is certificated. Flight in freezing rain, freezing drizzle, or mixed icing conditions (supercooled liquid water and ice crystals) may result in hazardous ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and it may seriously degrade the performance and controllability of the aeroplane.

The following shall be used to identify freezing rain/freezing drizzle icing conditions:

(a) Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.

(b) Accumulation of ice on the upper surface (for low-wing aeroplanes) or lower surface (for high-wing aeroplanes) of the wing aft of the protected area.

(c) Accumulation of ice on the propeller spinner farther back than normally observed.

The following may be used to identify possible freezing rain/freezing drizzle conditions:

(a) Visible rain at temperatures below +5° Celsius [outside air temperature (OAT)].

(b) Droplets that splash or splatter on impact at temperatures below +5 degrees Celsius OAT.

8.2.3 Procedures for Exiting the Freezing Rain/Freezing Drizzle Environment

These procedures are applicable to all flight phases from takeoff to landing. Monitor the outside air temperature. While severe icing may form at temperatures as cold as -18 degrees Celsius, increased vigilance is warranted at temperatures around freezing with visible moisture present. If the visual cues for identifying possible freezing rain or freezing drizzle conditions are observed, accomplish the following:

(a) Exit the freezing rain or freezing drizzle severe icing conditions immediately to avoid extended exposure to flight conditions outside of those for which the aeroplane has been certificated for operation. Asking for priority to leave the area is fully justified under these conditions.

(b) Avoid abrupt and excessive manoeuvring that may exacerbate control difficulties.

(c) Do not engage the autopilot. The autopilot may mask unusual control system forces.

(d) If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.

(e) If an unusual roll response or uncommanded control movement is observed, reduce the angle-of-attack by increasing airspeed or rolling wings level (if in a turn), and apply additional power, if needed.

(f) Avoid extending flaps during extended operation in icing conditions. Operation with flaps extended can result in a reduced wing angle-of-attack, with ice forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.

(g) Report these weather conditions to Air Traffic Control.

Note: *Alternate means of providing this information may be approved by CAA.*

8.2.4 Additional Information on Tailplane Stalling

In addition to AC 23.1419-2A contents, the following information should be included on tailplane stalling.

Warning: This document describes two types of upset: roll upset and tailplane stall (pitch upset). The procedures for recovery from one are nearly opposite those for recovery from the other. Application of the incorrect procedure during an event can seriously compound the event. Correct identification and application of the proper procedure is imperative.

8.3 Tailplane Stall Symptoms

Elevator control pulsing, oscillations, or vibrations*

Abnormal nose down trim change*

Any other unusual or abnormal pitch anomalies (possibly resulting in pilot induced oscillations)*

Reduction or loss of elevator effectiveness*

Sudden change in elevator force (control would move nose down if unrestrained).

Sudden uncommanded nose down pitch.

** May not be detected by the pilot if the autopilot is engaged.*

8.4 Corrective Actions

If any of the above symptoms occur, the pilot should:

(a) Immediately retract the flaps to the previous setting and apply appropriate nose up elevator pressure.

(b) Increase airspeed appropriately for the reduced flap extension setting.

(c) Apply sufficient power for aircraft configuration and conditions. (High engine power settings may adversely impact response to tailplane stall conditions at high airspeed in some aircraft designs. Observe the manufacturer's recommendations regarding power settings.)

(d) Make nose down pitch changes slowly, even in gusting conditions, if circumstances allow.

(e) If a pneumatic de-icing system is used, operate the system several times in an attempt to clear the tailplane of ice.

Warning: Once a tailplane stall is encountered, the stall condition tends to worsen with increased airspeed and possibly may worsen with increased power settings at the same flap setting. Airspeed, at any flap setting, in excess of the aeroplane manufacturer recommendations for the flight and environmental conditions, accompanied by uncleared ice contaminating the tailplane, may result in a tailplane stall and uncommanded pitch down from which recovery may not be possible.

8.5 Summary

Ice can form on the aircraft's tail at a greater rate than on the wing and can exist on the tail when no ice is visible on the wing. When ice is visible, do not allow ice thickness to exceed the operating limits for de-icing system operation or the system may not shed the tail ice. If the control symptoms listed above are detected or ice accumulations on the tail are suspected, land with a lesser flap extension setting and increase airspeed commensurate with the lesser flap setting. Avoid uncoordinated flight (side or forward slips) and, to the extent possible, restrict crosswind landings because of the possible adverse effect on pitch control and the possibility of reduced directional control. Avoid landing with a tailwind component because of the possibility of more abrupt nose down control inputs. Increased landing distances must also be considered because of increased airspeed at reduced flap settings.

8.6 Operator Certification

Icing was suspected in the recent Cessna Caravan and Beech Baron accidents in New Zealand. While a number of other factors were revealed during the subsequent investigation, significantly both aircraft were operating IFR in forecast icing, while neither was certified or equipped for flight in icing conditions.

An operational policy or philosophy allowing commercial IFR operations in New Zealand without ice protection is flawed. In this regard:

(a) the New Zealand environment is conducive to heavy icing at altitude, and SLD encounters are a known occurrence;

(b) operator certification for IFR/IMC operations must be predicated on adequate fleet anti-ice and/or de-ice equipment;

(c) this pre-supposes the certifying authority is aware of the fleet composition, including its icing status, and

(d) that training and line pilots are familiar with the equipment, operation of the equipment, recognition and nuances of an icing environment and strategies in the event of an encounter with moderate/ severe conditions.

In short, aircraft required to operate IMC on commercial services must be certified for flight in icing conditions, and operating crews must receive training appropriate to the role.

8.7 Basic Aircraft Certification

The following extract, based on the FAA AC 23. 1419-2A, is a guide to basic icing certification requirements. This extract has been edited in the interests of brevity, readers requiring complete details should refer to the original Advisory Circular.

In 1987, with the creation of the commuter category, aeroplanes that had weight, altitude, and temperature limitations for takeoff, en route, climb, and landing distance were being certificated. Since the operational rules preclude takeoff with ice on the aeroplane, the FAA determined that ice accretion on unprotected surfaces should not be a consideration until the aeroplane climbs through 400 feet above ground level (AGL). The FAA does not believe any significant ice will accumulate prior to 400 feet if there is no ice on the aeroplane at takeoff.

8.7.1 Design Objectives

The applicant should demonstrate by analyses, tests, or a combination of analyses and tests that the aeroplane is capable of safely operating throughout the icing envelope of Part 25, Appendix C.

8.7.2 Analyses

The applicant normally prepares analyses to substantiate decisions involving application of selected ice protection equipment and to substantiate decisions to leave normally protected areas and components unprotected. Such analyses should clearly state the basic protection required, the assumptions made, and delineate the methods of analysis used. All analyses should be validated either by tests or by previously FAA approved methods. This substantiation should include a discussion of the assumptions made in the analyses and the design provisions included to compensate for these assumptions. Analyses are normally used for the following:

(a) Areas and Components to be protected:

The applicant should examine those areas listed below to determine the degree of protection required:

- (i) Leading edges of wings, winglets, and wing struts; horizontal and vertical stabilisers; and other lifting surfaces.
- (ii) Leading edges of control surface balance areas if not shielded.
- (iii) Accessory cooling air intakes that face the airstream and/or could otherwise become restricted due to ice accretion.
- (iv) Antennas and masts.
- (v) Fuel tank vents.
- (vi) External tanks.
- (vii) Propellers.
- (viii) External hinges, tracks, door handles, and entry steps.
- (ix) Instrument transducers including pilot tube (and mast), static ports, angle-of-attack sensors, and stall warning transducers.
- (x) Forward fuselage nose cone and radome.
- (xi) Windshields.
- (xii) Landing gear.
- (xiii) Retractable forward landing lights.
- (xiv) Ram air turbines.
- (xv) Ice detection lights if required.

An applicant may find that protection is not required for one or more of these areas and components. If so, the applicant should include supporting data and rationale in the analysis for allowing them to go unprotected. The applicant should demonstrate that allowing them to go unprotected does not adversely affect the handling or performance of the aeroplane.

(b) The 45-minute Hold Condition:

The 45-minule-hold criterion should be used in developing critical ice shapes for which the operational characteristics of the overall aeroplane are to be analysed. The aeroplane's tolerance to continuous ice accumulation on the unprotected surfaces should be evaluated. The applicant should determine the effect-of the 45-minute hold in continuous maximum icing conditions. A median droplet diameter of 22 microns and a liquid water content of 0.5 gm/m1 with no horizontal extent correction is normally used for this analysis.

(c) Flutter Analysis:

A flutter investigation should be made to show that flutter characteristics are not adversely affected, taking into account the effects of mass distribution of ice accumulations. This investigation relates to unprotected surfaces and to protected surfaces where residual accumulations are allowed throughout the normal airspeed and altitude envelope: however, the effect of ice shapes on aerodynamic properties need not be considered for flutter analysis.

(d) Power Sources:

The applicants should evaluate the power sources in their ice protection system design. Electrical, bleed air, and pneumatic sources are normally used. A load analysis or test should be conducted on each power source to determine that the power source is adequate to supply the ice protection system, plus all other essential loads throughout the aeroplane flight envelope under conditions requiring operation of the ice protection system.

(e) Failure Analysis:

Substantiation of the hazard classification of ice protection failure is typically accomplished through analyses and/or testing.

A failure modes and effects analysis (FMEA) is the bottom-up method used for identifying hazards that may result from failures. During the analysis, each identifiable failure within the system should be examined for its effect on the aeroplane and its occupants. Examples of failures that are hazardous include:

(i) those that allow ice to accumulate beyond design levels; or

(ii) those that allow asymmetric ice accumulation to the extent that it results in loss of control.

A probable malfunction or failure is any single malfunction or failure that is expected to occur during the life of any single aeroplane of a specific type. This definition should be extended to multiple malfunctions or failure when:

(i) The first malfunction or failure would not be detected during normal operation of the system, including periodic checks established at intervals that are consistent with the degree of hazard involved; or

(ii) The first malfunction would inevitably lead to other malfunctions or failures. A procedure requiring a pilot to exit icing conditions would not be acceptable after any failure condition that would become catastrophic within the average exposure time probability it takes to exit icing conditions.

(f) Similarity Analyses:

Specific similarities should be shown for physical, functional, thermodynamic, pneumatic, aerodynamic, and environmental areas. Analyses should be conducted to show that the component installation and operation is equivalent to the previously approved installation.

Similarity requires an evaluation of both the system and installation differences that may adversely affect the system performance Similarity may be used as the basis for certification without the need for additional tests provided:

(i) only minimal differences exist between the previously certificated system and installation, and the system and installation to be certificated; and

(ii) the previously certificated system and installation have no unresolved icing related service history problems.

If there is uncertainty about the effects of the differences, additional tests and/or analyses should be conducted as necessary and appropriate to resolve the open issues.

(g) Impingement Limit Analyses:

The applicant should prepare a droplet trajectory and impingement analysis of the wing, horizontal and vertical stabilisers, propellers, and any other leading edges that may require protection. This analysis should examine all critical conditions within the aeroplane's operating envelope, as well as those in the icing envelope of Part 25, Appendix C. This analysis is needed to establish the upper and lower aft droplet impingement limits that can then be used to establish the aft ice formation limit and the protective coverage needed. Typically, 40 micron droplets are used to establish the aft impingement limits, while 20 micron droplets are used to establish the water collection rate.

(h) Induction Air System Protection:

The induction air system for turbine engine airplanes is certificated for icing encounters in accordance with 23.1093(b). These requirements are for all airplanes even those not certificated for flight into known icing conditions. Thus ice protection systems installed on previously type certificated airplanes to protect the engine induction air system should be adequate and need not be re-examined.

8.8 EROPS

EROPS certification is both the subject of a separate NZCAA study and a topic that justifies a paper in itself. Anything beyond a cursory examination is inappropriate in this handbook. Nevertheless the following information has been extracted from FAA bulletin # HBAT 98-21, titled Relief of Icing Fuel Penalties Associated With critical Fuel Calculations for ETOPS, and included to illustrate aspects of fuel planning and icing during EROPS.

8.8.1 Icing Studies

Boeing and Airbus have jointly participated in several icing studies in order to pursue a better understanding of icing and its effect on aircraft. Topics include:

(a) Better definition of the icing threat.

(b) Meteorological approach.

(c) Study of ice accretion at high speeds.

A pilot study conducted by Dr. Judith Currey on "Assessment of Aircraft Icing Potential Using Satellite Data," established the possibility of developing a climatology that would enable probability forecasts by data fusion between satellite microwave imaging and computer meteorological models. Some side results mentioned in the report support the idea that icing patches should be very limited in size. The study covered a one-month period, January 1979.

The Canadian Government, with assistance from Boeing and Airbus, funded an icing research exercise called Canadian Atlantic Storms Program (CASP) II. This followed an earlier CASP I campaign, which was research initiated by the need to protect the Canadian cod fleet from the hazards associated with winter storms. Severe weather poses a significant problem for small ships operating off the coast of Newfoundland in mixed hot/cold waters due to the gulfstream. In winter months fishing vessels can encounter extreme icing conditions. The most severe icing may result in the ship capsizing due to heavy ice accumulation on the superstructure in a short period of time.

CASP II was run by the Atmospheric Environment Service (AES) and the National Research Council of Canada (NRC), and was conducted in St. John's, Newfoundland from January through March 1992. The program had high level scientific support, two research aircraft fully equipped for icing measurements and significant support by Canadian Weather Services (particularly in the field of satellite coverage). The research aircraft accumulated 185 flight hours, and 242 icing encounters were recorded.

The results of CASP II are of extreme interest to aeroplane operations in icing conditions. The data provides valuable information that enhances the current knowledge of icing. No catastrophic icing was encountered during the flight study, and severe icing was limited to altitudes below 10,000 feet. A preliminary conclusion of CASP II is that extreme icing at altitudes would probably be associated with orographic effects, or from freezing drizzle.

8.8.2 Definitions

Airframe Icing

Two basic conditions are required for ice to form on an airframe in significant amounts. First, the aircraft surface temperature must be colder than 0°C. Second, supercooled water droplets, e.g., liquid water droplets at subfreezing temperatures, must be present. Water droplets in the free air, unlike bulk water, do not freeze at °C.

Engine Icing

In reference to engine icing, the B-767 Airplane Flight Manual (AFM) states "icing conditions exist when the OAT on the ground and for takeoff, or TAT in-flight is 10°C or below, and visible moisture in any form is present (such as clouds, fog with visibility of one mile or less, rain, snow, sleet and ice crystals)." Due to the engine inlet temperature drop effect, the FAA has established the outside air temperature at which the engine can experience icing is 10°C higher than the temperature at which the airframe will start collecting ice.

Icing Atmosphere

Icing necessarily occurs at sub-zero (°C) temperatures where droplets of liquid water are present. This limits it to flight levels where there is cloudiness or precipitation. The presence of liquid water droplets at subfreezing temperatures is called supercooled liquid water (SLW) and its spatial concentration (SLWC) is measured in grams of water per cubic meter of air.

Ice Accretion Mechanism

The leading edge of a wing flying into icing air is supposed to be exactly at air temperature (negative °C). That air is loaded with water droplets, but air particles do pass around the leading edge without touching it (continuity of airflow). Since water droplets are much heavier than air particles, they do not pass around as easily, and some of them impact the leading edge. Supercooled water freezes on impact. Ice accretion results from the continuation of this process.

Double Horn Shape

The above process leads to an uneven distribution of water droplet impacting the leading edge. The supercooled liquid about to impact the middle of the leading edge is slightly deflected because of a slighter curved path than the airflow due inertia, and therefore freezes on the upper and lower portion of the leading edge. This process starts the double horn shape on the leading edge, and is a divergent process that is further enhanced by ram effect.

Ram Effect

It is a basic aerodynamic principle that due to the Bernoulli principle, the temperature at stagnation points on the airplane's outer surfaces will be greater than the static air temperature. The ram rise is directly proportional to the square of the aeroplane speed, i.e., the faster the aeroplane, the greater the ram rise. Hence it is possible for the aeroplane not to collect any ice even though it is flying in icing conditions, i.e., atmosphere concentrated with super cooled liquid water droplets at subfreezing temperatures. For example, the air temperature rise at 150 knots and 10,000 feet is +4°C, whereas the temperature rise at 300 knots at the same altitude is +16°C. It is important to take this temperature rise into account for the assessment of ice accretion.

Run Back Ice and Shear Forces

An aircraft flying in icing conditions when the leading edge temperature is positive can experience run back icing. Due to ram energy, water droplets do not ice at impact, but explode into numerous small particles that migrate by the airflow along the wing surfaces. When the wing surface is at a negative °C temperature, it will cool the water. If the cooling effect is quicker than the blowing off, the water will ice on the spot. This process is called run back ice. Efficiency of the blowing off process depends on the shear forces present in the boundary layer. Higher airspeed will increase shear force.

Sublimation

Ice accrued on surfaces can be dissipated through sublimation. Sublimation is the direct change of water from a solid to vapour. Once out of cloud and icing conditions, the accrued ice thickness on the airframe will decrease. The rate of sublimation is dependent on the relative humidity of the air, and the effect of sublimation on long flights is worth considering.

8.8.3 Importance of Airspeed

Table 3-1 shows the required airspeed and static air temperature (SAT) that will result in total air temperature (TAT) of O°C and +10°C at the wing leading edge of the aeroplane in level flight at 10,000 feet. (Note; Static Air Temperature (SAT) is the same as the Outside Air Temperature (OAT).

Table 3-1 : Resulting SAT and TAT Due to Airspeed

Airspeed at 10,000 feet	**Static Air Temperature (SAT) Equivalent to**	
Airspeed (KCAS)	0°C TAT	+10°C TAT
250	-10.7°C	-1.1°C
290	-14.2°C	-4.7°C
330	-18.0°C	-8.7°C

As an example, if the airline's approved ETOPS single engine speed is 330 KCAS, the wing and empennage leading edge will not collect any ice in an atmosphere with super cooled water droplets at subfreezing temperatures unless the temperature is -18°C or colder. Based on AFM data, the engine anti-ice should not be turned ON until a temperature of -8.7°C SAT or colder is encountered.

Planning ETOPS operations requires consideration of continued flight following cabin depressurisation. The depressurisation could be a result of structural failure that may restrict the operating speed envelope. The nature of the structural failure will determine the limiting speed. Typically the flight crew will attempt to fly at the turbulent penetration speed. For the B-767, the turbulent penetration speed is 290/.78. At this speed, a SAT of -14.2°C will result in 0°C TAT at the wing leading edge. If the flight crew elects to slow to 250 KCAS, a SAT of -10.7°C will result in 0°C TAT.

The TATs shown in the table are at the stagnation points on the wing and empennage leading edges. Consideration must also be given to the temperature behind the leading edges and other surfaces on the aeroplane where the surface temperature may be lower than at the stagnation points. If the leading edge is at 0°C TAT, the wing surface behind the leading edge will be at a negative temperature and, depending on the aeroplane speed, there is a possibility of run-back ice formation behind the leading edge. Speeds that result in higher than 0°C TAT at the leading edge will minimise any significant formation of run-back ice. It should also be remembered that any ice that is formed would slowly dissipate through normal physical process of sublimation once the aeroplane is out of the icing conditions.

Questions and issues have been raised regarding the flight operating at single engine altitude versus 10,000 feet altitude. Most of today's twins are capable of maintaining 16,000 feet to 25,000 feet at single engine Maximum Continuous Thrust levels. Studies shown that icing areas rarely extend thousands of feet vertically or hundreds of miles horizontally. If the aeroplane encounters icing at the single engine altitude during a diversion, it is logical to expect the flight crew to descend to a lower altitude, as low as 10,000 feet, to avoid icing. The critical fuel scenario accounts for icing conditions to be encountered at 10,000 feet.

8.8.4 Program for Relief of Ice Drag Fuel Penalty in Critical Fuel Scenario

This program for ice drag fuel relief applies to the mid-Pacific routes between the U.S. mainland and Hawaii. This area is relatively free of icing. Data from the U.S. Marine Climatic Atlas indicates percentage frequency of icing in winter ranges from a high of 30% in Seattle, to 12% in Oakland, to 0% in Hawaii.

The program has certain constraints. There is no relief granted in this program for the anti-ice penalty (use of) which is provided in the manufacturer's data (e.g., 6% fuel penalty for use of anti-ice systems on B-757). Other requirements to be applied to the critical fuel calculation in addition to the 6% anti-ice requirement are the 5% addition for errors in wind forecasts, and the 5% (required for 180-minute ETOPS) addition for weather diversions.

Table 3-2 is an example of anti-ice/icing fuel penalty applicable to the B757-200 equipped with PW2037 engines. Air carriers are required to use actual data relevant to specific airframe/engine combination operated ETOPS.

Table 3-2 : Anti-Ice Penalty and Ice Drag of B757-200 with PW2037 Engines

Speed	Anti-Ice Penalty	Ice Drag
ALL ENGINE LRC	5%	12%
1 ENGINE LRC	6%	12%
1 ENGINE 290 KIAS	6%	12%
1 ENGINE 310 KIAS	6%	13%
1 ENGINE 330 KIAS	6%	14%
1 ENGINE 340 KIAS	6%	14%

The program consists of two different methods that may be used to determine the amount of ice drag penalty that has to be applied to the critical fuel calculations. The air carrier may select either method, or develop a system that uses both.

The simplest method is the TAT method. The TAT method is based on aerodynamic heating (ram rise), and is calculated based on the air carrier's approved single engine speed. This method does not consider the icing scenario when the TAT is at or above +10°C. If meteorological forecast for the time and intended route of flight indicates a 10,000 feet OAT corresponding to a +10°C TAT or warmer, no ice drag penalty fuel is applied to the critical fuel calculation. For temperatures colder than a corresponding TAT of +10°C at 10, 000 feet for any portion of the intended route of flight, full ice drag fuel penalty must be applied to the critical fuel calculation. TAT is calculated by adding the aerodynamic ram rise (airspeed) to the OAT.

Note: *The additive fuel value for use of anti-ice systems is always applied.)*

The second method uses Temperature/Relative Humidity (TRH) forecast data for 10,000 feet, and may be applied when the TAT method indicates possible icing (TAT colder than +10°C). This method can better define the areas of forecast icing by determining the relative humidity content of the air. This method considers icing likely only within the temperature range of O°C to -20°C, with a relative humidity (RH) of 55% or greater.

A RH of 55% is chosen as a conservative value that allows for a margin, of error in the RH meteorological forecast data for 10,000 feet (700 millibar forecast chart). The National Centre for Environmental Predictions (NCEP), the National Climatic Data Centre, and the FAA Technical Centre, Flight Safety Research Branch, have conducted an evaluation to determine the accuracy of the temperature and RH forecast data for 700 Mb over the oceans.

The ability to determine icing areas with the TRH method allows the flight diversion profile to be planned into thirds. The ice drag penalty fuel is calculated in full for icing forecasts in the first third, down to one third of the requirement if icing is only forecast in the last third of diversion. The basis for computation for both methods is further explained below.

Method 1: Total Air Temperature (TAT) Method

(a) Total Air Temperature (TAT) method is based on aerodynamic heating (ram rise). Using this method, icing is not considered if the TAT is +10°C or higher. TAT is calculated by adding the aerodynamic ram rise temperature to the Outside Air Temperature (OAT) for the approved single engine speed.

(b) Using the 700 Mb forecast chart, delineate the appropriate ° C isotherm. If the temperatures along all ETOPS routes are at that temperature or warmer, forecast no icing. Indicate "NO ICING EXPECTED" on the forecast charts. The critical fuel calculation is therefore computed without the penalty for ice drag. No further action is required other than to monitor the forecast area.

(c) Fuel for ice drag is required in full to be included in the ETOPS critical fuel calculation when the OAT (SAT) at 10,000 feet is forecast to be below the OAT values shown in the Table 3-3.

Table 3-3 : OAT °C Values at 10,000 feet

Airspeed (KIAS)	**OAT°C (equivalent to +10°C TAT**
250	-1.1
260	-2.0
270	-2.9
280	-3.8
290	-4.7
300	-5.7
310	-6.6
320	-7.6
330	-8.7

Method 2: Temperature AND Relative Humidity (TRH) Method

(a) Using the 700 Mb forecast chart, delineate the 0°C and -20°C isotherm and the 55% relative humidity isoline. Areas with relative humidity 55% or greater and bounded by the 0°C and -20°C isotherms should be considered icing areas and shaded. Transfer the potential icing areas to the route of flight overlay. If any further information from other available forecast data such as frontal analysis and satellite analysis indicate convective areas along the planned route, it must be included in the forecast process. If there is no icing potential within any area covered by the planned route, indicate "NO ICING EXPECTED" on the forecast chart

(b) If potential icing areas overlay the planned route, determine the critical fuel calculation based on segments of the possible diversions divided into thirds. This is illustrated in Table 3-4.

Table 3-4 : Method of Applying ETOPS Icing Penalty

Icing Forecast	Icing Penalty Applied
Within First 1/3 of the planned ETOPS Diversion	Full Icing Penalty
Within Second 1/3 of the planned ETOPS Diversion	2/3 of Full Accumulated Icing Penalty
Within Last 1/3 of the planned ETOPS Diversion	1/3 of Full Accumulated Icing Penalty
No Icing Forecast during planned ETOPS	Anti-Ice Bleed System Penalty Only

The following Table 3-5 for a B757-200 aeroplane shows the application of ice drag fuel penalty for different forecast ice scenarios. The example does not address other factors that are required to complete the critical fuel requirements.

Table 3-5 : Ice Drag Fuel Penalty for Ice Scenarios

Icing Forecast In			**No Forecast Icing**	
1st 1/3 of division	2nd 1/3 of division	Last 1/3		
13%	9%	5%	0%	Penalty for accumulated ice
6%	6%	6%	6%	Anti-ice bleed penalty
19%	15%	11%	6%	Total fuel penalty for diversion segment

REFERENCES

Flight Safety Foundation, Flight Safety Digest Special Issue ‘Protection Against Icing: A Comprehensive Overview’ – the following articles:

- ✈ Foreword. Flight Safety Foundation.
- ✈ Pilots Can Minimise the Likelihood of Aircraft Roll Upset in Severe Icing – John P Dow Sr.
- ✈ Tailplane Icing and Aircraft Performance Degradation - Porter J. Perkins and William J. Reike.
- ✈ Recommendations for De-Icing/Anti-Icing of Aircraft on the Ground. Association of European Airlines (AEA).

FAA Advisory Circulars:

- ✈ 91-51A, July 17,1996 Effect of Ice on Aircraft Control and Airplane Deice and Anti-ice Systems.
- ✈ 23.1419-2A. Certification Of Part 23 Airplanes for Flight in Icing Conditions.
- ✈ 23.1419-2A. Appendix 2. AFM Limitations and Normal Procedures Section

FAA Flight Standards Handbook, Bulletin Number HBAT 98-21. Relief of Icing Fuel Penalties Associated with Critical Fuel Calculations for ETOPS.

Aviation Theory Centre, Chapter 4, Icing.

AOPA Online – Aircraft Icing.

American Meteorological Society, Remote Sensing of Aircraft Icing Regions Using GOES Multi-spectral Imager Data – Gary P. Ellrod and James P. Nelson.

Meteorological Service of New Zealand.

SAAB SF340A Standard Operating Procedures.

SAAB SF340A Aircraft Operations Manual

ATR Icing Conditions Procedures

United Kingdom Aeronautical Information Circulars:

- ✈ AIC 126/1996. 13 December. Risks and Factors associated with Operations on Runways Contaminated with Snow, Slush or Water.
- ✈ AIC 145/1997. 30 December. Induction System Icing on Piston Engines as Fitted to Aeroplanes, Helicopters and Airships.
- ✈ AIC 32/1998. 24 March. Ground De-Icing of Aircraft: Recommendations for Holdover Times.
- ✈ AIC 104/1998. 8 September. Frost, Ice and Snow on Aircraft.

Business and Commercial Aviation, October 1999. New Approaches to Flight in Icing Conditions – Richard N. Aarons.

CAA Vector, 1997 Issue 3. New Problems with Ice – Dan Manningham.

Air Safety Week, Vol13, No.31. In-flight Icing Hazard Under Sweeping Review.

FAA Office of Systems Safety, Safety Reports. Weather Study: Summary of Findings.

NTSB Recommendations to FAA and FAA Responses Report.

Various New Zealand Operator Operations Manuals

BASI Interim Factual Report 9805068 (SAAB roll upset at Eildon Weir, VOR)

TAIC Aviation Occurrence Report 97-012 Beechcraft BE58 Baron, ZK-KVL.

Skyferry Public Inquiry – ZK-SFB off KAIKOURA.

NTSB Aircraft Accident Report, American Eagle ATR Flt 4184, Roselawn, Indiana.

NTSB Aircraft Accident Report, COMAIR EMB-120 Flt 3272, Monroe, Michigan.