Think Ice!
Icing Awareness for BAE Systems Regional Aircraft Operators
Welcome to this latest edition of Think Ice! This is a revised version of the 2010 issue, see preface below for more details.

It is essential for aircraft to depart snow/ice free, but an understanding of the subsequent actions required to maintain a safe aircraft is paramount. Therefore this publication includes articles and information on air and ground procedures and associated products.

Unlike the content of previous Think Ice editions, which have been limited to ice accretion on the outside of the airframe, this edition introduces the issue of ice accumulation inside fuel tanks and its potential impact on the supply of fuel to the feed tanks. In order to maintain a coherent message and because the primary aim is to indicate the most effective means for a maintenance regime to keep fuel tanks free of water, the complete Feed Low Level subject is conveyed in one section at the end of the ‘Ground Operations’ chapter.

Other topics include advice on flying control restrictions and the topic of thickened de-icing fluids, pre-season de-icing, anti-icing fluid selection plus visual and tactile checking of the aircraft.

Our understanding of aircraft operations and the effectiveness of associated controlling actions is enhanced by the reporting of incidents that affect those operations.

Therefore, in order to help further our understanding of icing issues, we would like to encourage aircraft operators and any agencies that provide supporting services to report icing related incidents to BAE Systems.

The hazards of flight in icing conditions have long been recognised, and various steps have been taken in an attempt to counter its effects ever since our developing aeronautical ability first allowed us routinely to fly in cloud. However, despite the quantum leap in standards of understanding and technology in the last decade or so, icing and the threat it poses, remains a major cause for concern among aircrews.

Why should this be? Why, after over a century of heavier than air powered flight, should we still perceive icing as posing at least as big a hazard as it has ever been? Have we made no real progress in countering its effects? Or have we, manufacturer, operator and regulator, perhaps forgotten some of the basics?

Totally effective anti-icing systems are, and will remain for the foreseeable future, impossible to achieve within the bounds of economic reality. But surely we have made progress towards lessening the dangers? Well, yes, but perhaps not to the extent of advances seen in other fields of modern aviation development.

The sophistication of modern systems tends to obscure, but not alter, the fact that it is still more or less the same wings, tails and control surfaces flying through the same moisture laden atmosphere that keeps us aloft and in business. The same restrictions, limitations and traps for the unwary therefore still largely exist.

One twist is in the leading edge profiles of modern aerofoil sections. Even modern turboprop aircraft fly considerably faster than their piston engined predecessors thanks partially to improved wing aerodynamics. The problem is that the resulting reduced leading edge radii are better ice collectors than the plumper profiles of the older designs, and the higher speeds allow better droplet penetration of leading edge pressure waves.

It may also be that the particular issues facing regional aviation recently have played a part. De-regulation leading to more direct competition; code sharing creating stiffened schedule obligations; advances in technology diluting traditional airmanship skills; much improved cockpit facilities encouraging penetration into worse weather conditions.

Perhaps these factors and more have served to distract us from the eternal truths of the causes and effects of icing.

The following pages therefore offer an opportunity to regain that focus, to refresh our memories of what the problem is all about and to revisit basic air and ground procedures.

Preface to Think Ice! 2014

BAE Systems Regional Aircraft has reviewed the use of the word ‘severe’ as used in our Manuals in reference to icing. Whilst the majority of the information printed in previous editions of Think Ice remains topical and current, the opportunity has been taken to revise and update the booklet. We have also taken the opportunity to include Supercold Large Drops and introduce the new regulatory icing appendices.

It is important to understand that the intent of this booklet is to supplement the information in the AFM, FCOM, MOM, CM and AMM and not to supersede it. If there is any conflict in information then the official publication must be taken to be correct.
Understanding Icing

Definition of Icing Conditions

The Aircraft Flight Manuals (AFMs) include a definition of icing conditions for both ground and in-flight operations. These are based on the Total Air Temperature (TAT) or Outside Air Temperature (OAT) along with the prevailing atmospheric and ground conditions.

The AFM definition of icing conditions vary for the different BAE Systems regional aircraft types and according to specific Airworthiness Authority requirements.

Whether ice accretion will actually occur or not depends upon many factors and therefore flight crews must be vigilant at all times, both on the ground and in the air.

The Icing Atmosphere

1. Cloud Forms

In-flight icing results from water droplets remaining in a liquid state even at temperatures considerably below 0 deg. C, called supercooled droplets. In discussing aircraft icing, cloud types are placed into two general classifications: stratiform (layer type clouds) and cumuliform (clouds with vertical development). Fog differs from cloud only in that the cloud base is at ground level.

- **Stratiform**
  Icing in stratiform cloud occurs normally in the middle to lower level clouds below 20,000 ft. Stratiform clouds tend to be quite stable and create extensive horizontal coverage at different levels. Flight in icing conditions can be of long duration and forms the criteria most often used for the design of de-icing protection systems for wings, empennage and propellers. Icing intensity generally ranges from light to moderate, with maximum values occurring at upper levels within these clouds.

- **Cumuliform**
  Cumuliform clouds, of which cumulonimbus (thunderstorm cloud) is the most hazardous, are important to the icing environment because of their rapid development and large liquid water content (LWC). They cover less area horizontally than stratiform clouds and icing intensities can vary from light (in small cumulus) to moderate or severe. Consequently they form the criteria often used for the design of anti-ice protection systems such as engine intakes, pitot static systems, heated leading edges and control surface horns.
“Frost can also form on windscreens and fuel tanks when descending a cold airframe into warm moist air”

2. Atmospheric Conditions

In addition to supercooled droplets, other atmospheric conditions can individually or in combination produce ice accretions.

Ice crystal clouds

These are very cold clouds, where moisture has frozen to the solid or crystal state. This includes snow, sleet, hail, graupel (pellets of soft ice) and ice crystals.

Mixed conditions

Many icing encounters consist of ice crystals and/or snow in combination with supercooled droplets. These can be critical as the mixture of ice crystals and water droplets can adhere rapidly and roughly to the airframe, or accumulate in an engine.

Freezing drizzle and rain

Freezing drizzle and rain are large, precipitating supercooled water droplets which, on impact with aircraft surfaces, may result in ice accretion which is beyond the capability of the ice protection systems. These conditions normally occur at lower altitudes and are associated with a melting layer or temperature inversion, where rain falls through a sub zero temperature layer. These are extremely hazardous conditions.

On ground

Aircraft on the ground are susceptible to additional icing conditions. They include freezing fog, frost and falling or blown snow. Frost accumulations can occur overnight and where aircraft surface temperatures remain cold following descent from high altitudes.

Frost can also form on windscreens and fuel tanks when descending a cold airframe into warm moist air.
Understanding Icing

Aircraft Ice Accretion

Ice forms in-flight on leading edges and frontal areas of the airframe, engine intakes and spinners/propellers by a complex process involving both meteorological and aerodynamic factors. Meteorological factors include the liquid water and ice crystal content of the clouds, outside air temperature, droplet and crystal size and distributions. Aerodynamic factors include aircraft speed, configuration, surface geometry and temperature, and surface adherence of droplets and crystals.

1. Ice forms

Three basic ice forms exist: Rime, Glaze (Clear) and Frost, although mixtures of Rime and Glaze ice are not unusual.

**Rime** ice is the most common form. Its rough, opaque appearance results from small supercooled droplets trapping air as they freeze on impact with the aircraft surface. It often has a spearhead or streamlined shape conforming to the shape of the surface or aerofoil and is generally encountered in stratiform clouds.

**Glaze** ice generally forms in cumuliform clouds when temperatures are close to freezing. Accretion is transparent and often produces a flat or concave ice shape with single or double ‘horns’. At the airflow stagnation point on the leading edge, freezing is delayed due to both friction and the heat released as the water begins freezing. This leads to runback ice, which initially creates a thin rough layer of ice either side of the stagnation line from which the flat fronted blunt shapes develop. Within the icing atmosphere, conditions vary continuously and often suddenly, allowing both rime and glaze ice to form on the same surface.

**Frost** is a thin layer of crystalline ice that can form on all exposed areas of the aircraft. It is generally associated with ground operations. (see page 14)

2. Accretion efficiency

Severe continuous icing conditions can be found near the freezing level in heavy stratified clouds, or in rain. Icing is rare at higher altitudes as the droplets in the clouds are already frozen. However, in cumuliform clouds with strong updrafts, large water droplets may be carried to high altitudes and structural icing is possible up to very high altitudes.

Indicated airspeed also influences the rate of ice accretion, the higher the speed (below about 250 knots IAS) the faster ice accumulates. Kinetic heating due to skin friction at speeds above 250 knots reduces risks of icing. In addition the angle of attack relative to the position of the sun also has an effect on ice accretion.

In general, ice adheres to all forward facing surfaces of the airframe. The accretion rate or catch efficiency is primarily dependent on the location and geometry. A relatively large radius aerofoil at moderate or low airspeed creates a larger pressure wave ahead of the leading edge, which forces the air around it, carrying most of the moisture with it. Only droplets sufficiently heavy to overcome this flow will impact on the leading edge. Thus, a large chord aerofoil with a blunt leading edge has low ice accretion efficiency. Conversely, a narrow radius leading edge generates a smaller pressure wave and so the accretion rate is greater. The tailplane has in general a sharper leading edge section and shorter chord than the wings and consequently can accrete ice before it is visible on the wing and at a greater rate.

3. Freezing drizzle and rain

Freezing drizzle and rain are relatively rare phenomena. However, such conditions must be treated with extreme caution as they can result in severe icing. The water droplets can be 1,000 times larger than the moisture droplets in clouds, and ice can accrete rapidly on the airframe and extend aft of the normal accretion areas around airflow stagnation points.
Aerodynamic Degradation due to Ice Accretion

1. Drag increases, Lift decreases

The effect of ice on aircraft performance and flight characteristics depends largely on the aircraft design but also on the shape, roughness and depth of the ice. It generally results in decreased lift, increased drag, increased stall speeds, trim changes and altered stall characteristics. In some circumstances there can be a change in control feel and response. The available thrust from engines can also be significantly decreased. Weight increase due to in-flight ice accretion usually has minimal effect relative to the aerodynamic degradation.

The aerodynamic penalties can be significant, not only for unprotected surfaces but also for those protected by leading edge boot de-icing systems, since they need to allow some ice build-up between shedding cycles.

Wind tunnel and flight testing conducted under research, development and certification programmes, as well as operational experience have all demonstrated the significant effect of ice on aircraft performance, flight characteristics and equipment operation. The areas normally affected include: wings, horizontal and vertical stabilisers, engine inlets and nacelles, propellers, windshields, radome, antennae, pitot static system and cooling air intakes. The degradation of aircraft performance and flight characteristics due to ice accretion on such areas is well understood.

The figure below shows the typical effect of ice accretion on the airflow and lift of unprotected aerofoils. The result is a reduction of lift at a given Angle of Attack (AOA) and a substantial degradation in maximum lift and maximum AOA. As illustrated, the degradation is generally more pronounced with glaze ice shapes.

Large amounts of ice build-up on an unprotected aerofoil may reduce the maximum lift by 30 to 40%, increasing the stall speed by 20 kts or more (for a clean aerofoil stall speed of 100 kts).

The aircraft drag polar can be significantly affected, particularly on smaller aircraft, as shown in the figure on the right. Ice will increase the drag for a given lift as well as the optimum lift-to-drag ratio occurring at a lower lift coefficient.

Even slight surface roughness, often referred to as 'sandpaper' ice, can result in large lift and drag penalties. The majority of maximum lift degradation often occurs with the first 1/4 to 1/2 inch of ice accretion (6 to 13 mm).

Further increase in ice depth and surface roughness has a less dramatic degradation of lift but will produce additional drag. Lift degradation is associated with an increase in stall speed and decrease in stall AOA. With significant ice accretion, the stall speed is increased substantially and pre-stall buffet may precede the activation of the stall warning system, particularly on aircraft with an airframe leading edge boot de-icing system.

Control and trim effectiveness may be reduced. Aileron, rudder and elevator control systems can be prone to freeze if water deposits, snow or ice are not properly drained from critical areas. Control surfaces may freeze or jam with external ice accumulation.

The power required to achieve or sustain a flight path can be increased significantly due to ice formation on the unprotected surfaces including areas of the airframe not visible from the cockpit. For turboprops, ice accretion on the propellers can significantly decrease the available thrust. Asymmetric ice shedding from propellers or jet engine fans can also give rise to vibration.

Typical effect of ice accretion on aerofoil drag polar.
2. Wing stall

The stalling of a regional transport aircraft wing normally results from flow separation from the top surface. On the BAE Systems regional aircraft types this usually starts at the inboard wing trailing edge or at the wing-to-fuselage and wing-to-nacelle junctions. The BAE 146 and Avro RJ aircraft are all fitted with stall triggers (toblerones) on the inboard wing leading edges. These simple devices ensure that the airflow separation initiates on the inboard wing. As AOA is increased, the separated flow spreads forward and outward, preventing any pitch up at the stall. Vortex generators on the wing top surface are commonly used to harness local airflow energy to delay separation at the trailing edge.

All of the BAE Systems regional aircraft types have a stick shaker installed to provide a clear indication to the pilot that the aircraft is approaching the onset of a stall. The margin above the stall at which the stick shake operates exceeds the minimum airworthiness requirements, but will vary with flap configuration, power and rate of approach to the stall.

Stall identification is defined either through the inherent aerodynamic characteristics of the aircraft (HS748 and ATP), or by a stick pusher device, incorporated in the elevator control circuit, that induces an abrupt nose down pitch change (J31/32, J41, BAE 146 and Avro RJ).

The J31/32, HS748, and ATP aircraft utilise lift transducers, located on the leading edge of each wing, to sense the airflow pattern over the wing and provide the signal for the stick shaker and, where fitted, stick pusher. On the J41 and BAE 146/Avro RJ the signals for stick shake and stick push are provided by heated angle of attack vanes mounted on each side of the forward fuselage.

With the aircraft clear of ice, the stick shaker provides a clearly distinguishable warning of approach to the stall. Where the stall identification is provided by the natural aerodynamic characteristics, acceptable indications include a nose down pitch, heavy buffeting and aircraft rolling motion. Natural stalling on aircraft with a stick pusher system installed should not usually be experienced by pilots.

With ice accretion on the wing leading edges, the mechanism of stall development remains the same but starts at a lower AOA and therefore higher speed. In addition the airflow does not have the same level of energy around vortex generators (if fitted) for them to delay progression of the stalled area as effectively as on a clean wing.

The overall effect of ice accretion on the stalling characteristics is also dependent on the type of airframe ice protection system installed. In general, the effect of ice accretion on aircraft with leading edge boot de-icing systems installed is more adverse due to the ice accretion required prior to operation of the system and inter-cycle ice build-up.

Where airframe anti-icing systems are installed as on the BAE 146 and Avro RJ, the protected areas of the airframe will in general be clear of ice and so the effect of ice on stalling characteristics can be less pronounced.

However, with some of the more adverse ice shapes the stall warning may be preceded by airframe buffet and the stick pusher (when fitted) may be preceded by some lateral instability, wing rock, pitch nodding or ‘g’ breaks. This is more probable on the aircraft types with wing mounted lift transducers, due to ice accretion around the protected area of the vanes. With ice accreted on the leading edges, high rates of descent can develop at high flap angles. It does not require an excessive level of ice accretion to generate these wing stalling characteristics, accretions of just 12.7 mm (1/2 in) can be sufficient. The Jetstream 41 stall warning and identification system was modified so that the stick shaker and stick pusher operate at a lower AOA in icing conditions. The ‘Ice Mode’ system is armed by the pilot’s selection of engine anti-icing and ensures that the stall warning and identification system operates correctly when the aircraft has accreted ice on the leading edges. The relevant speeds are increased with the ‘Ice Mode’ armed.

On the BAE 146 and Avro RJ the stall warning and identification system has been demonstrated to operate correctly at the normal AOA settings, with the airframe ice protection operating normally. As a result there is no adjustment required for flights in light or moderate icing conditions.

Recovery from a stall, with or without ice accretion on the airframe, is achieved by reducing the pitch attitude, allowing the speed to rise and the AOA to reduce after the natural stall or operation of the stick pusher, whilst applying power.
3. Tailplane stall

The phenomenon of tailplane stall is of considerable interest, particularly within the regional aircraft industry. It is one that has affected aircraft throughout the history of flight, including modern turboprop and jet aircraft. In order to increase the general awareness and understanding of its mechanism, an explanation of the causes is given below.

A tailplane stalls when the maximum angle of attack for the tailplane, either positive or negative, is exceeded. The following discussion addresses the more common negative tailplane stall and is concentrated on aircraft with un-powered mechanical elevator controls and airframe de-icing systems.

Normally, the tailplane creates a force (lift) in the downward direction to balance wing and fuselage pitching moments. Under normal conditions, without ice accreted, aerodynamic pressures above and below the elevators are roughly equal and thus create no significant control surface hinge moment (see illustration below).

With ice accreted on the tailplane, flow separation may develop on the lower surface, which will limit the maximum amount of downward lift the tailplane can generate and cause the tail to stall at a lower AOA.

The development of flow separation will also result in an adverse change in the relative pressure distribution over the upper and lower surfaces. Since the forces about the elevator hinge and the resultant stick forces sensed by the pilot are balanced by aerodynamic and mechanical system forces, any change to the airflow can affect the stick forces.

Tailplane stall may therefore be sensed by the pilot as a control anomaly (e.g. stick lightening), pitch instability or nose down trim change. For un-powered mechanical elevator controls, the magnitude and direction of stick force anomalies will depend upon the size and configuration of the elevator control system and the difference in pressure between the upper and lower surfaces.

In the worst case, the elevator would be forced to the nose down stop if unrestrained, and the aircraft would respond accordingly by pitching nose down, often rapidly. This would be in addition to the aircraft’s natural nose down pitching tendency as the tailplane loses downward lift effectiveness, and could require an extremely high pull force on the control column to recover.
4. Flap extension

Extending the flaps increases the airflow downwash angle from the wing and the tailplane negative AOA (see figure opposite). For a given flap setting, the AOA on the tailplane becomes more negative with increasing speed because of the reduced AOA of the wing (more nose down, more tail up). Therefore, at higher flap angles and airspeeds the wing stall margin is increased, but the tailplane stall margin is further reduced.

The occurrence of stall on any aerofoil contaminated by ice almost always occurs at a lower angle of attack than a clean aerofoil, hence any ice accretion reduces the tailplane stall margin further. It is worth emphasising that ice can form on the tailplane at a greater rate than the wing, primarily due to its relative small size and smaller leading edge radius. This can lead to a significant build up of ice which is not evident from observation of ice accretion on other areas of the airframe.

In general, the most adverse combination of factors for tailplane stall is ice accretion of critical shape, roughness and location, maximum flap extension, forward centre of gravity, high power and nose down elevator control inputs (which result in a tailplane camber adverse to the airflow). On the BAE Systems Regional Aircraft turboprop types, higher airspeeds close to the maximum flap extension speed are also adverse, although flight testing of the HS748 demonstrated that speeds close to the normal landing speeds can also be critical.

However, it should be understood that tailplane stall factors can be complex, and consequently symptoms for crew recognition and appropriate recovery actions are specific to the aircraft type and configuration. This is addressed further in Appendix II: Turboprops.
Icing Certification

To be approved for flight into known or forecast icing conditions, an aircraft must be equipped with ice protection systems, which are designed to provide protection for the range of conditions likely to be encountered in service. The BAE Systems Regional Aircraft range of aircraft has been certificated for flight in icing conditions in accordance with a variety of certification bases. Such certifications do not, however, allow unrestricted flight with ice on the aircraft. They also assume that flight crews follow all drills and procedures and exercise appropriate airmanship. This section provides details of the current Federal Aviation Authority (FAA), European Aviation Safety Agency (EASA) and Joint Airworthiness Authority (JAA) certification requirements for flight in icing conditions.

1. Certification requirements

The applicable icing environment within which the aircraft must be able to operate safely for FAA and EASA certification is defined by FAR/CS/JAR-25 Appendix C. Design criteria are described in terms of cloud LWC, median volume droplet diameter, ambient temperature, cloud type and horizontal extent. The cloud types are stratiform for maximum continuous intensity of icing conditions and cumuliform for intermittent maximum intensity. Small aircraft certificated under FAR Part 23 rules (such as J31/32) must meet the same icing design criteria as Part 25 large transport category aircraft.

2. Operational regulations

The operating rules and aircraft ice protection systems required for flight into known or forecast icing conditions, including ground operations, are enforced by the FAA in Parts 91, 121 and 135 of the regulations. For commercial aircraft operating under European regulations the applicable requirements are given in EU-OPS 1.

Detailed guidance material for ground operations is provided by airworthiness authorities, including FAA Advisory Circular AC20-117. In all cases the emphasis is on a ‘clean aircraft’ policy for take-off and this has always been observed for the BAE Systems range of regional aircraft.

3. Compliance demonstration

In order to demonstrate compliance with the certification regulations, extensive analysis and testing are required for the ice protection systems and the aircraft handling and performance characteristics. Analysis must be performed to establish the adequacy of the ice protection systems for the various components of the aircraft. The effectiveness of the ice protection systems and the effect of ice accretion on the aircraft handling and performance characteristics must then be demonstrated by flight tests. These normally include tests in measured natural atmospheric icing conditions, in combination with dry and icing wind tunnel tests, dry air flight tests in simulated icing condition (behind an icing tanker aircraft) and dry air flight tests with artificial simulated ice shapes. Flight tests for icing certification are generally conducted in the following stages:

- **Dry air flight tests with ice protection equipment installed.** These tests are carried out primarily to ensure all of the ice protection systems function correctly and to verify that the systems do not affect the flying qualities of the aircraft in dry air. Where ice protection is provided by heating, thermal profiles are recorded for correlation with analysis.

- **Dry air flight tests with predicted artificial ice shapes installed.** The installation of artificial ice shapes on the leading edges allows aircraft performance and handling characteristics to be evaluated for specific critical icing conditions.

These flight tests are often preceded by dry air wind tunnel tests with artificial ice shapes. The shapes can be defined from icing tunnel tests, flight tests in simulated icing conditions, or more commonly by analysis using computer simulation models.

- **Icing flight tests, including natural and simulated icing conditions.** Flight tests in measured natural icing conditions are conducted to demonstrate that the ice protection systems perform as predicted and to determine the handling and performance characteristics or validate the results of flight tests conducted with artificial ice shapes.

Additional flight tests in simulated icing conditions are generally conducted for ice protection systems. However, they may also be required for assessment of handling and performance characteristics in specific conditions within the Appendix C icing envelopes.
4. Ice accretion

During certification flight testing for assessment of the handling and performance characteristics for an aircraft with airframe de-icing systems, ice accretion on both the unprotected and protected leading edges must be considered. The ice accretion requirements for protected areas must be consistent with the procedures for operating the protection system, and should include the ice accumulation required prior to system activation and accretion during the rest period of a de-icing cycle. In addition, failure of the airframe ice protection must also be assessed and failures which require the aircraft to leave icing conditions established.

5. Handling

Detailed advisory material for the demonstration of handling and performance characteristics in icing conditions is provided by the FAA, JAA and EASA. Satisfactory stability and control must be demonstrated with the most critical ice accretion pertinent to each flight phase and related configurations (including take-off, climb, cruise, descent, holding, approach and landing). In particular, extensive flight testing is required to examine stall warning and stall characteristics, longitudinal controllability (including pushovers to zero ‘g’ for assessment of tailplane stall margin), flaps configuration changes and longitudinal, lateral and directional stability and trimmability.

6. Performance

Assessment of aircraft performance for flight in icing conditions must not only account for accumulated ice on unprotected surfaces and any residual ice on protected surfaces, but also the effects of the ice protection systems on engine power.

To ensure safe flight in icing conditions, the effect on performance must be established. Comparison of climb rates and cruise speeds of the clean aircraft and the aircraft with ice accreted should be used to determine the performance degradation. Stall speeds with ice accreted are used to establish safe flight speeds, from which scheduled performance can be derived.

The level of scheduled performance data provided in the Aircraft Flight Manual and Operating Manuals depends on aircraft type and the requirements of specific Airworthiness Authorities. It is worth noting that aircraft performance can be significantly degraded due to ice accretion on unprotected areas of the airframe not visible from the flight deck.

7. Take-off

Aircraft which are certificated for flight in icing conditions are not certificated for take-off with ice formations or any other surface contaminant. Such ice formations or contamination must be cleared from the airframe and the aircraft sustained in a clean condition prior to take-off.

Although not specifically required by Airworthiness Authorities, flight testing has been carried out to investigate the effects on performance and handling by the application of Type II and IV anti-icing fluids on the BAE Systems regional aircraft types. Their presence on wing and tailplane surfaces was demonstrated not to affect the aircraft stall characteristics, climb performance or cause a noticeable loss of lift during take-off. However, in some cases an increase in stick force was recorded during take-off rotation, but the aircraft remained fully responsive to control inputs. In general, the rotation speeds of the BAE 146/Avro RJ are sufficiently high that the majority of the fluid will be sheared off the wing and tail and stick forces remain normal.
8. Landing

Assessment of the aircraft handling characteristics during approach and landing can be conducted with either artificial ice shapes or, on an opportunity basis, during the natural icing trials if substantial ice accretions remain on the airframe. In these circumstances increased landing speed is required.

9. Freezing drizzle and rain

A Turboprop accident in 1994 drew attention to freezing drizzle and atmospheric icing conditions that were outside the existing FAR/CS/JAR Appendix C icing envelope which had been used for certification of large aircraft. Another atmospheric icing condition, also outside the Appendix C icing envelope is freezing rain. These icing conditions constitute an icing environment known as Supercooled Large Drops (SLD). Flight through such icing conditions may cause airframe ice accretion that exceeds the capabilities of the aircraft’s ice protection systems, and may seriously degrade performance and control.

BAE Systems recommend that such conditions should be avoided or left immediately.

For certification tests on new aircraft all National Aviation Authorities are introducing regulations to improve the level of safety when operating in icing conditions. In order to achieve this Appendix O is being issued to CS and FAR, and this Appendix will also address engines and pitot tubes.

10. Systems

Extensive flight testing in a broad range of natural icing conditions is required to assess the performance of all de-icing and anti-icing systems and to establish procedures for their operation. Ice protection system performance and effectiveness must be evaluated both for normal operation and following delayed activation or simulated failure of the system.

Icing wind tunnels have also been used extensively for the regional aircraft types of BAE Systems for assessment of the ice protection systems, in particular leading edge de-icing boots and electrically heated systems such as pitot probes and stall vanes. Engine ice protection systems, de-icing and anti-icing, are generally developed through many hours of ground testing in icing test cells prior to flight testing in natural icing conditions or in simulated icing conditions using a tanker spray aircraft. The icing plume created by tanker aircraft can lead to ice accretions well beyond that generally encountered in natural icing conditions. However, if the conditions are within the design icing envelopes then the protected area should remain essentially clear of ice.

11. Summary

All regional aircraft types of BAE Systems are certified for flight into known and forecast icing conditions, and are designed to meet, and usually to exceed, the criteria demanded by the Airworthiness Authorities.

However, it should be remembered that the aircraft are only certificated and approved for flight in supercooled water droplet conditions, as defined in FAR/CS/JAR-25 Appendix C.

It is important that flight crews are conscious that every atmospheric icing encounter is different and that hazardous conditions can occasionally be met which may be beyond the capabilities of the aircraft’s protection systems.
Aircraft Ice Protection Systems

1. Concept of de-icing and anti-icing

It is useful to clarify what is meant by the terms ‘Anti-icing’ and ‘De-icing’, since their sometimes random use when applied to aircraft systems suggests that some confusion may exist. In strict terms, the following definitions could be said to apply:

- **Anti-icing** is the prevention of ice formation, generally by means of heating (electrical, ducted engine bleed air, engine oil etc.).
- **De-icing** is the removal of ice that has accreted, normally by means of cyclic heating or the application of a physical impulse (commonly achieved on leading edges by pneumatic boot inflation).

However, where de-icing is provided by cyclic heating due to a restriction on the power available, and not from a requirement to allow deliberate ice accretion for the system to function effectively (as with inflatable boots), it may be argued that it is in reality an anti-icing operation. Consequently, descriptions of ice protection systems such as electrically protected propellers and engine intakes can appear in manufacturers’ manuals for example as either:

- **De-icing** - Wing and tail leading edges
- **De-icing** - Propeller leading edges
- **De-icing** - Engine intakes

- **Anti-icing** - Windshields
- **Anti-icing** - Engine intakes
- **Anti-icing** - Pitot heads and static plates
- **Anti-icing** - Temperature probes
- **Anti-icing** - Angle of attack (stall) vanes
- **Anti-icing** - Control surface balance horns

2. Ice detection methods

The certificated primary means of ice detection on all the BAE Systems regional aircraft types is by visual inspection of the airframe by the flight crew. This should include observation of the following areas:

- Windshield.
- Windshield pillars.
- Windshield wiper bosses.
- Wing leading edges (these can be illuminated at night).
- Propeller or engine fan spinners.

Ice detection systems, which provide a secondary (advisory) means of detection, are fitted to some types. These provide the flight crew with a cockpit indication when ice is accreted on the detection device.

*Ice accretion on windshield - hazardous icing conditions.*
The leading edges of the wings and stabilisers are de/anti-iced by either inflatable boots or ducted bleed air. Operation of hot air systems is prohibited during take-off and landing in order to limit the amount of bleed taken from the engines. Ground operation is also prohibited as overheating could distort the leading edges. The BAe 146/Avro RJ type has a hot air de-icing system on the inboard section of the wing, designed to remove ice prior to holding or landing, and a hot air anti-ice system on the outboard section of the wing and on the tail.

**Hot air versus inflatable boots**

The fundamental reason why turboprop aircraft are generally fitted with pneumatic boot de-icing systems, as opposed to the anti-icing heating systems found on most jet transport aircraft, is found in the power required for them to function.

Wing and empennage anti-icing systems must not only prevent ice forming on leading edges, they must also provide enough heat to evaporate the moisture to prevent it from running back and freeze on the unprotected surfaces. Therefore they need very much more bleed air to operate than pneumatic de-icing systems do, bleed air that simply is not available from the turboprop engine.

Thus while the jet engine core can absorb the loss of propulsive power incurred in driving an anti-icing system, similar extraction demands placed on the turboprop would impose proportionally much greater performance penalties. These are normally unacceptable when balanced against the performance degradation due to airframe ice accretion.

### Anti-icing Systems

1. **Turbo-fan engine**

   Engine intakes, compressor inlet ducts and fuel control sensors are all heated to prevent the formation of ice. The systems are designed for continual operation (some restrictions may apply on the ground) and should be selected ON when icing conditions exist.

2. **Turbo-propeller**

   Each blade is fitted with an electrically heated rubber mat in the root area controlled by a cyclic timer. Any ice forming on the unheated portion will shed by centrifugal force, the fuselage being protected by a Kevlar shield adjacent to the propeller disc zone (except for the HS 748 type). Propeller heating systems must only be used when the engine is running to prevent overheating of the propeller leading edges.

3. **Windshield**

   All forward facing windshields and some side screens are electrically heated. These are continuously heated to provide not only ice protection but demisting and on some types to increase the impact strength of the screen.

4. **Elevator horn**

   The unshielded elevator aerodynamic balance horns on the J31/32 and J41 are anti-iced using electrically heated mats.

5. **Pitot head, static plate, TAT probe and AOA vane**

   To prevent ice accretion on pitot heads, static plates, temperature probes and AOA vanes, independently switched and sourced electrical heating is provided. These systems are selected ON during the after start checks or the pre take-off checks.

6. **Continuous ignition**

   Although not normally associated with aircraft de-icing/anti-icing, the use of continuous and automatic ignition systems is important to prevent the flame-out of an engine due to ingestion of large amounts of precipitation or slush.
Ground Operations

The basis for safe flight operations in cold weather conditions is the ‘CLEAN AIRCRAFT CONCEPT’. This involves de-icing and if necessary anti-icing an aircraft so that the surfaces are clear of ice, snow, slush or frost at take-off.

This section provides information on ground operations in cold weather conditions, and is mostly applicable to all aircraft types. For more specific details on jet aircraft see Appendix I, and for turboprops see Appendix II.

Facts

“Taking off with frost is like walking toward the edge of a cliff blindfolded”.

Kurt Blankenship, NASA research pilot.

- Any deposit of ice, snow or frost on the external surfaces of an aircraft may drastically affect its flying qualities because of reduced aerodynamic lift, increased drag and modified stability and control characteristics.

- Freezing deposits, including anti-icing fluid residues, may cause moving parts such as elevators, ailerons, flap actuating mechanisms, etc. to jam and create a potentially hazardous condition.

- Engine operation may be seriously affected by the ingestion of snow, ice or de/anti-icing fluid into the engine, causing engine stall or compressor damage.

- Most cold weather operating difficulties are encountered on the ground, the most critical periods being immediately pre-flight and post-flight. Proper diligence on everyone’s part concerning ground operation is an important factor in successful cold weather operations.

- A thorough pre-flight inspection is extremely important when operating in winter conditions. At very low temperatures the urge to hurry is natural, particularly when the aircraft is outside, but unfortunately this is the time when the greatest care is needed.

- Due to the wide climatic variations encountered during cold weather aircraft operations, individual operators should designate a cold weather operations period (e.g. from October to April in the Northern Hemisphere) for the implementation of their cold weather operating procedures tailored to their environment and experience. Early preparation for winter season operations will always prove beneficial.

- Given good maintenance practices, including frequent inspections for and cleaning of anti-icing fluid residues, and adherence to the recommendations made in the Aircraft Maintenance Manual ATA Chapter 12, cold weather operations can be confidently performed and a high level of dispatch reliability maintained.

De-icing and Anti-icing Fluids

Operators are advised that it is their responsibility, in accordance with operating guidelines issued by their relevant airworthiness authority, that suitable de/anti-icing fluids are used. BAE Systems Regional Aircraft advise that fluids approved to the latest revisions of the Society of Automotive Engineers (SAE) AMS 1424 and AMS 1428 are suitable for use, if they are applied in accordance with the recommended de-icing and anti-icing procedures, and an appropriate inspection and cleaning programme is adopted to minimise the build-up of residues.

There are four basic types of de-icing/anti-icing fluids, as follows:

- **Type I** Fluids
  - Type I fluids are ‘unthickened’ and have a relatively low viscosity.
  - They have good de-icing properties but provide negligible protection against re-freezing.
  - They are used predominantly for removing frozen deposits from aircraft surfaces, either in the first step of a two-step operation, or where precipitation has stopped.
  - In undiluted form they are not to be used at ambient temperatures below -10 deg. C due to adverse aerodynamic effects.
Type I fluids are normally colourless in appearance.

‘Type II’ Fluids
- Type II fluids contain thickening agents which enable the fluid to be deposited as a film and to remain on the aircraft surfaces until the time of take-off.
- This film provides a longer holdover time especially in conditions of freezing precipitation, providing anti-icing protection against re-freezing or further accumulation in precipitation conditions.
- The holdover time can be extended by increasing the concentration of fluid in the fluid/water mix.
- Type II fluids are normally straw coloured in appearance.

‘Type III’ Fluids
- Type III fluids contain thickening agents which enable the fluid to be deposited as a film and to remain on the aircraft surfaces until the time of take-off.
- Type III fluids reduce in viscosity faster than type II and type IV fluids and thus provide anti-icing protection for a shorter period.
- The holdover time can be extended by increasing the concentration of fluid in the fluid/water mix.
- Type III fluids are normally bright yellow in appearance.

‘Type IV’ Fluids
- Type IV fluids have been developed in recent years to increase holdover times by the further addition of thickening agents.
- These fluids should only be used on BAE Systems aircraft subject to certain operating restrictions.
- Type IV fluids are normally coloured green.
- As with Type II, their holdover times can be extended by increasing the fluid concentration in the fluid/water mix.

All fluids must be used in accordance with the manufacturers’ recommendations. If improperly used, they can cause undesirable and potentially hazardous changes in aircraft performance, stability and control.

Fluids used during ground de/anti-icing are not intended for, and do not provide, ice protection during flight.

Pre-season Fluid selection
When developing their Winter Operations policy, in addition to the normal consideration of hold-over times and fluid concentration, operators are strongly recommended to determine the residue forming characteristics of the Type II, III and IV fluids that are available at the various stations for their operations.

It has been seen that fluids with higher residue characteristics may lead to heavier and faster residue build-up, which increases inspection and cleaning frequencies, and the potential for a frozen control incident to occur. Information on the residue characteristics for all Type II, III and IV fluids is published by the Anti-Icing Materials International Laboratory (AMIL) on their website at: http://www.uqac.ca/amil/en/, and updated regularly. Although these residue curves are not named, fluid manufacturer contact information is provided. It is recommended that each relevant fluid manufacturer is contacted to find the position of the fluids available on the graph, to determine the best fluid for use. The fluid with the lowest curve should be chosen to minimise the build-up of residues.
**De-icing Procedures**

**CAUTION:** The instructions given in the Aircraft Maintenance Manual (AMM) are overriding, therefore only carry out the procedures permitted in that manual.

De-icing is the procedure by which snow, ice, frost, and/or slush are removed from all surfaces, openings and hinge points of an aircraft to provide clean surfaces.

De-icing gives very limited to NO protection against further accumulations of ice or snow. De-icing measures can be accomplished by several means, such as:

- Mechanical means (broom, warm air)
- Heated hangar
- De-icing fluids

Mechanical means or a heated hangar should be used to de-ice the aircraft’s ‘no spray’ zones (Refer to AMM chapter 12).

Large deposits of snow and slush must first be removed by mechanical means.

1. **Mechanical means**

   Soft snow and slush should be first removed using brooms, soft hand brushes or rubber scrapers. Do not attempt to remove snow by beating it and do not use tools to scrape or scratch compacted snow from surfaces or from between fixed and movable surfaces and/or components. Using de-icing fluids initially for complete snow removal is ineffective and could result in a weak mixture re-freezing and creating an icing condition more difficult to remove. It is always good practice as a pre-step process to remove large amounts of contamination prior to the application of de-icing or anti-icing fluids, as it reduces the quantity of glycol-based fluid needed.

   Remove snow from upper fuselage areas before heating the aircraft interior, as water from melting snow might freeze over windows and lower fuselage.

   Make sure that wing and empennage control surfaces are not damaged by implements used for snow removal, and when clearing snow from upper fuselage, avoid damage to communications antennae.

   Remove all snow accumulations on fuselage nose forward of the windscreen as snow might blow back and stick to it, restricting pilot’s visibility during take-off.

   Remove snow from the top surface of the horizontal stabilisers forward to the leading edge. After being placed in the neutral position, the elevators should be cleaned from their leading edge towards their trailing edge. With the rudder in the neutral position, the vertical stabiliser and rudder should be cleaned from the top, downwards.

   Snow removal from the wings should start at the root, working towards the tip and trailing edge, avoiding the control surfaces. After being placed in the neutral position, the control surfaces should be cleaned from their leading edge towards their trailing edge.

   Thick accumulation of snow can be removed from aircraft surfaces with the use of an Ingersoll-Rand type heavy-duty air compressor, with a cold blast directed from a cherry-picker type boom at a safe distance of two to six metres depending on air pressure used.

   Lighter snow accumulations can be removed from fuselage and wing upper surfaces by working a length of cotton rope, cloth or small-diameter fabric fire hose back and forth over the surfaces.

   If using warm air to remove snow, continue heat application until the surface is completely dry. Exercise care not to overheat structure or system components (see caution; in the operating manuals). A heating source providing a large volume of warm, dry air is more effective than a small volume of hot air and can be used with less danger of overheating.

   Hot air can also be used to further clean the engine intakes where permitted by the AMM. These areas should always be inspected, even when blanks are fitted. This was once reported on an aircraft parked outside all night with blanks fitted. In the morning, the crew managed to remove two large handfuls of ice per engine, which had formed overnight as a result of water entering, pooling and freezing, despite the blanks having been fitted. If ice has accumulated on fan blades, hot air is the only method to clean this deep inside the engine area.

   For window areas, externally-applied heat should be used with care since high temperatures on cold windows will crack or craze the transparency.

   When the aircraft is clean, all openings between fixed surfaces and flight controls should be carefully checked for the presence of snow, slush or ice which could impair free movement. Bottled nitrogen or a source of dry unheated air may be used to blow snow out of these areas.
2. De-icing fluids

The de-icing fluids are:

- Heated water (recommended).
- Type I fluid.
- Heated concentrates or mixtures of water and Type I fluid (recommended).
- Heated concentrates or mixtures of water and Type II fluid.
- Heated concentrates or mixtures of water and Type III fluid.
- Heated concentrates or mixtures of water and Type IV fluid.

The use of Type II, III or IV fluids for de-icing is not recommended as it increases the build-up of residues.

For maximum efficiency, all of the above de-icing fluids should be heated (60 to 90 deg. C at the nozzle exit) and applied close to the surface of the skin to minimise heat loss. A minimum distance of 2.5 yards (2.3 metres) must be maintained though to prevent damage to the skin. The heat in the fluid effectively melts any frost, as well as light deposits of snow, slush and ice and breaks the bond between frozen deposits and the aircraft structure. The hydraulic force of the fluid spray is then used to flush off the residue.

The fluids must be used in conjunction with the manufacturer’s instructions and approved holdover guidelines.

3. De-icing fluid application

BAE Systems recommend the following methods to de-ice the aircraft:

- **Hot type I**: apply heated SAE Type I de-icing fluid (diluted in accordance with manufacturer's instructions).

- **Hot water**: apply at a temperature of 60 to 90 deg. C at the nozzle exit. This method is only permitted with OAT > -3 deg. C and in conjunction with a two-step de- and anti-icing procedure (Refer to Anti-icing Procedures chapter).

**Removal of snow**: a nozzle setting sufficient to flush off deposits should be used. For heavy deposits of wet snow a high fluid flow will be required, whereas with light deposits of dry or wet snow, similar procedures as for frost removal may be employed.

With a heavy accumulation of snow, always consider removing the worst of the snow manually before attempting a normal de-icing procedure.

**Removal of frost and light ice**: a nozzle setting giving a solid cone (fan) spray should be used. This ensures the largest droplet pattern available, thus retaining the maximum heat in the fluid.

**Removal of ice and frozen snow**: heated fluid should be used to break the bond between ice deposits and the aircraft skin. Making use of the high thermal conductivity of the metal skin, the adhesion of a large area of frozen snow or glazed ice can be broken by directing a jet of hot fluid at close range onto a number of spots.
Anti-icing Procedures

Anti-icing is a procedure which provides protection against the formation of frost or ice and accumulation of snow or slush on clean surfaces of the aircraft for a limited period of time (the holdover time).

1. Holdover time

This is the ESTIMATED time for which an anti-icing fluid will prevent the formation of frost or ice and the accumulation of snow on the protected surfaces of an aircraft.

Holdover times for specific approved fluids should be obtained from current tables published by the FAA (Federal Aviation Administration), TC (Transport Canada) or the AEA (Association of European Airlines) or the specific fluid manufacturer.

A range of holdover times is often quoted; the lower value is the estimated time for moderate precipitation rates and the upper value is the estimated time for light precipitation rates.

Heavy precipitation rates, high moisture contents, high wind velocity or jet blasts 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 the OAT. Therefore indicated times should be used only in conjunction with a pre-take-off check.

The holdover time depends on the fluid type, weather conditions and ambient temperature. After determining the holdover time applicable, the crew should ensure that it will not be exceeded due to anticipated taxi and holding times prior to take-off.

2. Anti-icing fluids

Anti-icing fluids must always be applied on a clean surface. When applicable, always carry out a complete de-icing of the aircraft before starting the anti-icing procedure.

The anti-icing fluids are:

- Heated Type I fluid.
- Heated mixtures of water and Type I fluid.
- Concentrates or mixtures of water and Type II fluid.
- Concentrates or mixtures of water and Type III fluid.
- Concentrates or mixtures of water and Type IV fluid.

The following surfaces should be protected:

- Wing upper surfaces, leading edges and ailerons.
- Horizontal stabiliser upper surfaces, including leading edges and elevator upper surfaces.
- Vertical stabiliser and rudder.
- Fuselage upper surfaces depending upon the amount and type of precipitation.
- Flaps should normally be retracted whilst the aircraft is on the ground so that they are protected from any ice formation.

Areas de-iced or anti-iced first will generally freeze first. Therefore areas which are visible from the cockpit should be anti-iced first so that during the pre-take off check the crew will have the assurance that other areas of the aircraft are clean.

CAUTION: Anti-icing fluid may not flow evenly over wing leading edges, horizontal and vertical stabilisers. These surfaces should be checked to ensure that they are properly coated with fluid.

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

On receipt of a frost, snow, freezing drizzle, freezing rain or freezing fog warning from the local meteorological service, anti-icing fluid may be applied to clean aircraft surfaces prior to the start of freezing precipitation. However predictive anti-icing is not recommended as a practise due to the possibility of leaving fluid residues on the surfaces.

The high fluid pressures and flow rates normally associated with de-icing are not appropriate for this operation, and pump speeds should be reduced accordingly. The nozzle of the spray gun should be adjusted to provide a medium spray.

The anti-icing fluid should be distributed uniformly in the form of an even thin film over the surfaces. In order to control the uniformity, all horizontal aircraft surfaces should be visually checked during application of the fluid. The correct amount is indicated by fluid just beginning to drop off the leading and trailing edges. Over application of the fluids will increase the potential for residues to form.
General Precautions

1. De-icing and anti-icing precautions

Snow or ice should be removed from the fuselage before the aircraft is heated internally to prevent melting of the snow and subsequent re-freezing, which would make the ice more difficult to remove.

Do not apply fluid in a forward direction. This is to prevent fluid entering the structure through aerodynamic fairings.

Before starting any de-icing procedure the aircraft should be parked nose into wind whenever possible.

An aircraft that has been anti-iced with undiluted Type II, III or IV fluid should not under any circumstances receive a further coating of anti-icing fluid. If it is necessary for an aircraft to be re-protected prior to 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, i.e. a two-step anti-icing process. This is to remove contamination of the previous fluid and minimise the build-up of residues.

Do not apply fluid directly to the landing gear and do not apply spray directly to windows or window seals.

Only one product can be used for each step of the de-icing and anti-icing application.

Do not spray fluid directly into the engine or APU intakes and ensure the ECS packs and APU air are left OFF for as long as practical to avoid fumes being drawn into the air conditioning system. Ingestion of combustible de-icing fluids and solutions can cause internal damage to engines and APU hot section parts and is a potential fire hazard.

Avoid applying fluid directly to exhausts, scoops, vents, drains and pitot/static heads.

Application of de/anti-icing fluids should not be indiscriminate; antifreeze solutions solidify when sufficiently cold and components that would otherwise prove trouble-free might freeze.

After de/anti-icing fluids have been used, the surfaces treated should appear glossy, smooth and wet.

De-ice the aircraft with flaps retracted to avoid exposure to precipitation and to prevent contamination of flap control mechanisms.

3. Anti-icing fluid application

The following methods can be used for anti-icing:

- **Two-step process:**
  1. De-ice with either hot water or hot diluted de-icing fluid as described in De-icing Procedures chapter.
  2. Anti-ice using SAE Type II, III or IV fluid or mixture dependent on holdover required and the local weather conditions. This step must be commenced within three minutes of starting the first step.

- **One-step process:**
  Anti-ice using heated SAE Type II, III or IV fluid OR hot diluted SAE Type II, III or IV fluid (in accordance with manufacturer’s instructions).

BAE Systems recommend using a two-step process whenever possible for anti-icing. This concurs with the latest advice given within SAE and AEA documentation as a method for reducing the potential for anti-icing fluid residues to form and build-up within aerodynamically quiet areas.
2. CAUTION: Type II, III and Type IV (Thickened) Fluids

Type II, III and IV fluids contain thickening agents which enable the fluid to be deposited as a film and to remain on the aircraft surfaces. This film provides a holdover time, especially in conditions of freezing precipitation, providing anti-icing protection against re-freezing or further accumulation.

For all types, the holdover time can also be extended by increasing the concentration of fluid in the fluid/water mix.

Gel residues

Thickened fluids have exhibited the following phenomenon, which has serious flight safety implications.

Residues are formed in aerodynamically quiet areas of the aircraft where anti-icing fluids collect, instead of being sheared off the aircraft surfaces by the airflow. These fluids dry out at low temperatures and pressures as both water and glycol are lost. Residues start to form after a 20% reduction in the weight of the fluid. If more glycol is added before this point the remaining fluid will rehydrate, delaying the formation of residues and helping the fluid to flow off the aircraft.

However, if the fluid is allowed to dry out residues form, becoming a gel and eventually a powder or thin film. This residue can subsequently absorb water, expand significantly in volume and freeze. The rehydrated residue will freeze at temperatures approaching the freezing point of water, depending on how much glycol remains in the mixture.

A long period of cold weather followed by a dry period and finally a period of heavy rainfall maximises this effect. Therefore if there has been a long period of cold weather when frequent applications of thickened fluid have been applied, additional inspection and cleaning procedures must be carried out to prevent the build-up of residues.

BAE Systems are aware of a number of incidents involving airborne handling difficulties. Subsequent inspection of the relevant control surface(s) has on several occasions revealed the presence of these rehydrated gel residues.

A recent investigation has shown that this phenomena may be made significantly worse if the anti-icing fluids come into contact with potassium and sodium formate and acetate runway de-icers. Even a small amount of the latter cause instant precipitation of the thickener in the anti-icing fluids which will increase the amount of residues left on the aircraft surfaces. It will also reduce the holdover capability of the fluid.

3. Clear ice precautions

Clear ice can form on aircraft surfaces below a layer of snow or slush. It is therefore important that surfaces are closely examined following each de-icing operation, in order to ensure that all deposits have been removed. Significant deposits of clear ice can form in the vicinity of fuel tanks, on upper wing surfaces and underwing. Aircraft are most vulnerable to this type of build-up when wing temperatures remain well below 0 deg. C during the turnaround/transit and when ambient temperatures between -2 deg. C and +15 deg. C are experienced.

Clear ice can form at other temperatures if wing temperature remains well below 0 deg. C during the turnaround/transit, precipitations occur while the aircraft is on the ground and frost or ice is present on the lower surface of either wing.

If the wing skin (fuel tank) temperature after refuelling is lower than the OAT, the tank temperature should be used instead of the OAT for determining the de/anti-icing fluid mixture and holdover times.
This type of ice formation is extremely difficult to detect. Therefore when the above conditions prevail or when there is otherwise any doubt as to whether clear ice has formed, a close examination should be made immediately prior to departure in order to ensure that all frozen deposits have in fact been removed. Clear ice normally occurs at low wing temperatures and when large quantities of cold fuel remain in the wing tanks during the turnround/transit and any subsequent refuelling is insufficient to cause a significant increase in fuel temperature. It is impossible to see clear ice on a wet wing and it is difficult to feel the difference between a wet skin plate and wet ice on the wing. The best way to check for ice is to scrape the surface with a knife - without damaging the skin!

Runway De-icers

Potassium and sodium formate and acetate runway de-icers are salts and are known to have corrosive effects on several aircraft materials.

In particular, they can cause catalytic oxidation of carbon brakes. The runway de-icer on contact, dramatically speeds up the natural carbon degradation process leading to increased overhauls and early failures. Antioxidant coatings applied by the manufacturer are the best current reduction technique combined with frequent inspection.

On cadmium-plated parts, the runway de-icers cause corrosion of the cadmium coating causing it to become brittle. Cracks and pits lead to loss of the coating as well as the wear and corrosion protection of the base metal that the cadmium plating provides. Exposure of cadmium plating to these fluids should be minimised.

**Caution:** should be exercised in the use of both aircraft and runway de-icers in and around electrical / electronic circuitry with noble metal coated wiring or terminals. Contact of these with the fluid may cause exothermic reactions, which can result in a fire.

EASA SIB 2010- 26 discusses that, even a small percentage of runway de-icer can cause instant precipitation of the thickener in an aircraft anti-icing fluid. This may significantly contribute to the build-up of residues on the surfaces, and in the aerodynamic quiet areas. On aerodynamic surfaces this may also lead to a reduction in Holdover Time if used in a one-step process, as the loss of thickener leads to a thinner film of anti-icing fluid. The preliminary testing showed that film thicknesses could be half of those of uncontaminated fluid, and Holdover Times could be up to 60% lower.

**Final Check Before Dispatch**

An aircraft should not be dispatched for departure under icing conditions or after a de/anti-icing operation until the aircraft has received a final check by a responsible authorised person.

It may be necessary to make a visual and tactile (hand on surface) check of the wing leading edge and the wing upper surface is performed when the outside air temperature is less than 42 deg. F (6 deg. C), or if it cannot be ascertained that the wing fuel temperature is above 32 deg. F (0 deg. C); and

a. There is visible moisture (rain, drizzle, sleet, snow, fog, etc.) present; or
b. Water is present on the wing; or

c. The difference between the dew point and the outside air temperature is 5 deg. F (3 deg. C) or less; or

d. The atmospheric conditions have been conducive to frost formation.

The check should visually cover all critical parts of the aircraft and be performed from points offering sufficient visibility of these parts, examples are from the de-icer itself or from another elevated piece of equipment. A checklist is useful here to make sure nothing is missed. Having ensured that the aircraft has been de-iced and anti-iced in accordance with laid down procedures, specific attention should be paid to the following areas to ensure freedom from ice:

- Engine inlets, nacelles and pylons.
- Fuselage, wing upper and lower surfaces, leading and trailing edges.
- Horizontal and vertical stabilisers.
- All control surfaces including gaps between fixed and moveable surface - Ailerons and aileron tabs
  - Rudders and rudder tabs
  - Elevators, elevator trim tabs and servo tabs.
- Drain holes in control surfaces should be checked clear of any obstruction.
- Windshields.
- Antennae.
- System inlets.
- Fuel tank vents.
- Wing lift transducers and angle-of-attack vanes.
- Pitot tubes, temperature sensors and static ports should be carefully checked for frozen contamination.
- Water drains.
- Tyres should be checked for proper inflation, and that they are not frozen to the ground or the chocks.
- The pushback or initial taxi area should be checked for ice and de-icing fluid.

Note: Pilots must have a sound knowledge of the de-icing and anti-icing procedures and limitations, both to ensure that ground crews miss nothing and most importantly, to ensure that post anti-icing holdover conditions are fully understood and met.

Both initial and recurrent training for flight crews and ground crews should be conducted to ensure that all such crews obtain and retain a thorough knowledge of aircraft de/anti-icing policies and procedures, including new procedures and lessons learned.
Ground Operations

Maintenance Recommendations

1. Detection and removal of thickened fluid residue

Type II fluids are straw coloured, Type III fluids are bright yellow and Type IV are green. The dyes are water soluble and so fade rapidly in wet conditions.

The dry residue is recognisable as a white/grey powder, film or hardened black deposit. Residues will become more visible if soaked with water and allowed to rehydrate. Typically the rehydration will take up to 15 minutes, but may require a number of repeat cleaning operations to remove completely. The residues will swell in volume and become apparent as gel. The pure gel is colourless but impurities will make it appear dark grey, green or blue.

Residues can build up in many areas of the aircraft, some of which are more critical than others, as they could cause control restrictions after a small number of thickened anti-icing fluid applications.

Critical areas:

- **Ailerons**
  - Aerodynamically quiet areas such as gaps between control surfaces and servo/trim tabs.
  - Aileron and tab bearings, hinges, gust damper, control rod areas and rod ends.
  - Aileron and tab drain holes, adjacent to the control runs.
  - Trim jacks and drive areas.

- **Elevators**
  - Aerodynamically quiet areas such as leading edge gaps between aircraft, control surfaces and servo/trim tabs.
  - Elevator and tab bearings, hinges, gust damper, control rod areas and rod ends.
  - Elevator and tab drain holes, including inside control surface adjacent to the control runs.
  - Trim jack areas.

- **Stabilisers’ drain holes**, including inside control surface adjacent to the control runs

Other areas:

- Ailerons and tab drain holes, including inside control surfaces AWAY from the control runs.
- Elevators and tab drain holes, including inside control surfaces AWAY from the control runs).
- Rudder drain holes, including inside control surface.
- Wings and horizontal stabilisers.
- Rudder aerodynamically quiet areas and cavities (gaps around control surface).
- Rudder bearings, control runs, hinges and rod ends.

2. Removal of thickened fluid residues

If control surfaces are contaminated externally with anti-icing residue build-ups, these must be washed or brushed off. It is advisable to use hot water and/or Type I de-icing fluid to wash down the residues of a Type II, Type III or Type IV fluid, but care needs to be taken that it does not freeze onto the control surfaces. Water and/or Type I fluid heated to 60 deg. C (140 deg. F) and applied at a maximum pressure of 10 psi is recommended. Higher pressures and temperatures may damage the aircraft surfaces and corrosion protection.

For residues found inside the wing and tailplane access panels, sufficient panels should be removed to enable a comprehensive cleaning process. Drain holes and vents should be cleared, making certain that no blockage exists. The above procedure should be used and repeated until the drained fluid is clear, indicating that all residues have been removed from inside the structure.

One method to thoroughly clean the control surfaces is to block up the drain holes using speed tape or another suitable product, partially fill them with hot fluid and mechanically agitate the filled structure before draining. Repeat this procedure until the drained fluid is clear, indicating that all residues have been removed from inside the structure. Ensure that the surfaces are thoroughly drained. If possible, pass copious amounts of warm, dry air through the structure to reduce the risk of corrosion.

Care also needs to be taken when working near flying controls to avoid flushing the grease out of bearings. Once the residues are rehydrated, they can then be flushed away. It may be necessary to repeat the water soak/rehydrate/clean process several times to ensure complete fluid residue removal. Fluid residues which have accumulated over several years and are completely dry will take longer to rehydrate.

It is recommended that where thickened (Type II, Type III or Type IV) anti-icing fluids are used, the aircraft should be inspected for residues daily. Operators should develop an inspection and cleaning schedule, taking into account their own operational environment and procedures, as well as the factors affecting the build-up as stated above. If any residues are found they must be removed from the aircraft before the next flight.
3. Technical log

If de-icing and anti-icing is completed away from the parking stand, it may not always be practicable to complete the Technical Log to include this activity. When de/anti-icing is carried out after the Technical Log has been completed, and the tear-out copy has been removed, there should be a procedure in place for advising the flight crew of the de/anti-icing activity and how it should be recorded.

Fuel Feed Low Level Warnings

Problem:
Whilst recent European winters have highlighted a trend of Feed Low Level warning incidents experienced by some European Avro RJ operators, the colder than average winter of 2009/2010 saw a notable increase in that trend.

Cause:
If water is present in the fuel tanks it can freeze and potentially restrict fuel transfer to the engine feed tanks. Water accumulates in fuel tanks as a result of either condensation or contaminated fuel at the point of upload.

Aviation fuels absorb moisture from the atmosphere and the resultant water can be held in solution in the fuel or be present as suspended particles or in liquid form. At low temperatures, water in the fuel comes out of solution and into liquid form. Higher fuel temperatures result in water becoming absorbed from the atmosphere to maintain a saturated solution. The cycling of temperatures results in a continuous accumulation of water which turns to ice at freezing temperatures and may affect fuel flows.

Feed Low Level warnings occur when feed tank levels decrease below full. Under normal operation, the feed tanks are maintained full by fuel feed ejector pumps in order that an adequate supply of fuel is available to each of the engines. Accumulation of ice in the fuel transfer system can result in a restriction of the fuel supply to the feed tanks. When the fuel consumption of an engine exceeds the rate of fuel transfer to the associated feed tank, its level decreases and a fall from the full level triggers a Feed Low Level annunciation on the flight deck fuel panel.

The emergency checklist procedure for ‘Fuel Tank Low Level’ describes a series of actions that aim to rectify the problem. However, if the Feed Low Level annunciation persists, the flight crew should endeavour to “Land as soon as possible”.

Icing related Feed Low Level incidents tend to occur during the latter stages of cruise or during descent and approach. This is because these flight phases follow a period of “cold soak” at high altitude where the fuel can be exposed to temperatures significantly below zero degrees, a condition that can be significantly extended during winter periods when cold temperatures persist at ground level. Under such conditions, any ice that has formed within the fuel tanks has a limited opportunity to melt.

Prevention:
Minimising water accumulation in fuel tanks is key to preventing Feed Low Level incidents. This can be achieved by continued monitoring of fuel quality and regular and effective draining of water from fuel tanks.

Monitoring of Fuel Quality

Operators should regularly review procedures for checking the water content of fuel at uplift. Though Civil Airworthiness Publication (CAP) 748, Aircraft Fuelling and Fuel Installation Management, is primarily aimed at fuel suppliers, it does contain some information pertinent to aircraft operators. Chapter 4 entitled ‘Detection and Prevention of Fuel Contamination’ provides guidance on fuel sampling, visual examination for contamination and record keeping.

Chapter 4 section 1 details advice on fuel sampling checks. It recommends fuel quality checks be made throughout the fuel handling, storage and distribution process to ensure that fuel is free of water contamination and of a fit state for use by aircraft. Where operators are not in a position to sample bulk fuel installations themselves, they should take the appropriate steps to ensure that fuel sourced from such installations is of a suitable quality before it is physically uploaded to their aircraft. Fuel quality reports may be requested or advice may be sought from the fuel supplier concerned.

CAP 748 also advises that fuel samples be taken immediately prior to fuelling an aircraft, after prolonged heavy rainfall or snow or after de-fuelling or vehicle washing. Conditions for fuel to be deemed unfit for use in aircraft are detailed in Chapter 4, section 2, entitled ‘Visual Examination and Testing for Contamination’.

Water Draining

It is recommended that the aircraft be allowed to stand for as long as possible prior to performing a water drain: for at least one hour, to ensure that the maximum amount of entrained water collects at the lower points of the tanks.

To achieve effective water draining, it is recommended that the fuel temperature be raised above -1 deg. C. To achieve this, the aircraft may need to be stored in a hangar prior to water draining or refuelled in order to raise the fuel bulk temperature above freezing. The desired result may also be achieved by applying heat to the fuel tanks in the vicinity of ribs 13, 15 and 18 using heat lamps trained on the underside of the wing.

Caution: should be exercised during heating of the fuel tanks to ensure that no fuel leaks occur and the temperature of the wing surface does not exceed 40 deg. C.

To ensure that all of the lines feeding the drain points are purged, it is recommended that a minimum of 8 litres of fuel/water be drained from each of the drain points. If water is still present having drained 8 litres, further draining should be exercised until no more water is evident.

In order to minimise the amount of water in fuel tanks during the winter months and, consequently, Fuel Feed Low Level events, it may be necessary to increase the frequency of the water draining procedure. Daily water drains using the best practice procedures described here are understood to be effective in mitigating Feed Low Level warnings.

AMM Section 12-10-28, which provides basic procedures for fuel tank water draining, is being amended to identify appropriate best practice techniques for all operators, whether or not they have experienced Feed Low Level incidents.
Flight Operations

This section looks at the phases of flight operations in cold weather from taxy-out to taxy-in, and is applicable to all aircraft types. More specific information for jet aircraft can be found in Appendix I, and for turboprop aircraft in Appendix II. For full procedures and limitations, see the relevant Aircraft Flight Manuals and Operations Manuals.

Any contamination of an aircraft’s aerofoil surfaces will adversely affect performance and handling, and even small amounts can be hazardous. Any flight in icing or potential icing conditions must be in accordance with the icing clearance of the aircraft, as detailed in the approved Aircraft Flight Manual.

Taxying

When taxyways are wet with standing water, slush or snow, the aircraft should be taxyed at lower speed than normal to avoid any slush build-up in wheel wells and to leave plenty of room to turn and stop. In order to reduce taxy speed of the Avro RJ and BAE 146 types, it is recommended to taxy on the two inner engines only, whenever it is safe and convenient to do so. However, it is not advisable to taxy-in our turbo-prop types on a single engine. Slippery taxyways in combination with strong surface winds could result in losing lateral control of the aircraft.

Minimum thrust should be used for taxy to avoid blowing snow or slush on personnel, vehicles or other aircraft. Also, the distance behind other taxying aircraft should be increased, due to reduced braking action and the negative effect of jet blast on the anti-icing fluid layer.

Nosewheel steering should be used for directional control, supported by gentle use of asymmetric braking and asymmetric thrust. If the nosewheel steering is moved rapidly or selected to large angles, nosewheel skidding can occur. Adhesion is restored by reducing the nosewheel steering demand.

Always perform a full and free check of the flying controls before departing the ramp, to ensure they are not obstructed by ice or snow.

Cold set (the condition where the tyre has a flat spot from parking for prolonged periods) may induce vibration, but it should disappear as the tyres recover their elasticity during taxy. If the vibration persists then the take-off run should not be made.

Pre Take-off Inspection

It is the captain’s responsibility to ensure that he/she does not take-off with snow or ice, or with frost other than that permitted, on the aircraft.

In conditions of freezing precipitation, flap selection should be delayed until just before take-off in order to prevent ice or snow from forming on the flaps during taxy.

Just prior to entering the runway, repeat the full-and-free control check and carry out a visual inspection of all parts of the aircraft that can be seen from suitable vantage points (but beware - a generous application of Type II/IV fluids can completely obscure the view from cabin windows).

Any evidence of re-freezing or settling snow must be treated with the utmost caution and the aircraft returned to maintenance for additional de-icing and anti-icing. Upper wing surface slush deposits should be treated with equal caution; the pressure reduction and consequent temperature drop on take-off may cause them to freeze.
Do not assume freedom from contamination by observing other aircraft - they may have been treated more recently or more effectively. The flow chart shown opposite is a tool used by one operator to ensure that pre take-off ice removal requirements are met.

Be conscious that these inspection requirements may interrupt ATC clearances and/or normal sequences of checks. If in doubt, double check before runway entry.

Do icing conditions exist?

Is aircraft contaminated?

Yes

Load the aircraft, de-ice, start timing for holdover, taxi for take off, complete pre take-off ice checks

No

Is aircraft contaminated?

Yes

Return for respray

No

Is aircraft within holdover time limit?

Yes

Is aircraft contaminated?

Yes

Return for respray

No

Is take-off within 5 minutes?

Yes

Released for take-off

No

De-ice aircraft
Flight Operations

**Take-off**

1. **Contaminated runway or low friction surface**

   A runway is considered to be contaminated when more than 25% of the required surface area is covered by standing water, slush or loose snow with a water equivalent depth exceeding 3 mm (0.125 inch), by compacted snow or by ice or wet ice. A low friction surface is considered to be a runway with ice patches such that the braking action is reduced from that experienced on a wet or dry surface.

   Major airports in cold weather climates make every effort to keep runways clear of snow, slush and its associated water, but there will be times when complete clearance cannot be sustained. At these times 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 airfield.

   **If departure cannot be delayed,** the following advice should be considered:

   - A layer of contaminant produces additional drag retardation effects on the wheels, spray impingement and increased skin friction. Consequently the distance required to accelerate is increased, and an early decision to reject the take-off is required.

   - A lower decision speed $V_1$ is also required due to reduced wheel-braking performance: reduced wheel to runway friction and aquaplaning.

   - Directional control should be maintained on a contaminated runway by small nosewheel steering inputs until rudder control becomes effective.

   - Be aware of the increased possibility of engine power loss or system malfunction due to spray ingestion or impingement.

   - After take-off, if climb-out performance is not limiting, cycle the landing gear to remove any accumulated slush deposits.

   - See AFM for limitations in depth of contaminant for take-off, as they vary with aircraft type.

   Some aircraft types have a Flight Manual Appendix containing procedures and limitations for contaminated runway operations and data for the calculation of take-off weights.

2. **Take-off in icing conditions**

   - Confirm that no frost, ice or snow is adhering to the aircraft.

   - If not already selected, engine/propeller anti-ice should be ‘ON’ if icing conditions either prevail or may be expected in the take-off or climb. Make the performance adjustments required from the appropriate AFM charts.

   - The aircraft should be rotated at the normal airspeed (VR) and pitch rate, regardless of whether or not the wings have been treated with de/anti-icing fluid.

**Good Operating Practices In-flight**

Icing can occur during flight at any time of the year.

**Know as much about your operating environment as possible.** Carefully review weather packages for pilot reports (PIREPS) of icing conditions, cloud tops reports, temperatures aloft, forecasts of icing conditions including freezing drizzle and freezing rain. Monitor indicated OAT (and Static Air Temperature if available) during climb and while on route. Use the weather radar and be aware that areas of precipitation that appear on the radar will be of sufficient size to produce freezing rain, when encountered in freezing temperatures or on a cold soaked aircraft.

**Remember to be alert for icing at all temperatures below +10 deg.C.** Marginal freezing temperatures and icing conditions should create a heightened state of awareness.

**Be alert to visual cues of unusual icing.** Remember that the unpredictable atmosphere can occasionally create conditions that no ice protection system can completely overcome and which can result in rapid and hazardous ice accretion. Should such conditions be met, the only safe course of action is to leave them as soon as possible, following the advice contained in the AFM. Since these unique conditions are usually small in area and associated with specific temperature conditions, a change in altitude of just 2,000 ft may place you in a totally different environment.

**Exercise the flying controls periodically** whilst in icing conditions to ensure that unseen ice has not filled control surface gaps or frozen hinge mechanisms.

**Thickened Fluids - a new issue**

Most of us are now familiar with the issues associated with thickened de-icing fluids, and their unwanted side-effects on flying controls. A common factor in these incidents, for the
Icing Intensity Criteria

The following intensity criteria are used for reporting icing. Be aware that they are not necessarily the same as forecasting definitions because reporting definitions are related to the aircraft type and the ice protection equipment installed, they do not involve cloud characteristics. For similar reasons, individual aircraft icing certification criteria might differ from reporting and/or forecasting criteria.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Ice accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace</td>
<td>Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though de-icing/anti-icing equipment is not utilized, unless encountered for more than one hour.</td>
</tr>
<tr>
<td>Light</td>
<td>The rate of accumulation might create a problem if flight in this environment exceeds one hour. Occasional use of de-icing/anti-icing equipment removes/prevents accumulation.</td>
</tr>
<tr>
<td>Moderate</td>
<td>The rate of accumulation is such that even short encounters become potentially hazardous and use of de-icing/anti-icing equipment, or diversion if necessary, is required.</td>
</tr>
<tr>
<td>Severe</td>
<td>The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.</td>
</tr>
</tbody>
</table>

On a contaminated or low friction runway, aim to make a positive touchdown and slow down to a low forward speed before exiting the runway. Be aware of extended stopping distances required for slippery or contaminated runways, particularly if an approach or threshold speed increment has been added.

Tyre traction is considerably reduced on low friction runways, leading to lack of directional control. If the aircraft deviates significantly from the centreline during the landing run, release the brakes and use rudder and nosewheel steering to re-align the aircraft on the runway. Re-apply brakes when directional control is regained.

After landing, flaps are retracted as part of the after landing checklist. This has the advantage of protecting them against any falling snow, sleet or freezing rain. They should be kept retracted until just prior to take-off to avoid any slush or snow, which may be thrown up by the aircraft’s wheels.

However, if it is suspected that ice, snow or slush may have accumulated on the flaps, either during flight or whilst on the landing roll, then the flaps should be left extended until they have been inspected and confirmed clear of significant ice or slush deposits. Any deposit found will need to be removed with the flaps lowered, to avoid damaging the mechanisms when they are finally retracted.

After Shutdown

Inspect the wheel wells area for snow and slush contamination and ensure that the maintenance crew understands the need for them to be thoroughly cleaned before the next operation.

Approach and Landing

Rapid descent to low altitude during approach or other deviations from prescribed operating procedures are not acceptable means of minimising exposure to icing conditions.

An icing check should be carried out during the approach. If no residual ice is present on the airframe, the approach speed can be reduced to normal.

The flare should not be prolonged and the thrust levers should be retarded quickly.

When in icing conditions, always fly at the icing speeds shown in the AFM. If severe icing is encountered, as indicated by unusual ice accretion patterns, inform the ATC and request an immediate heading and/or altitude change in order to leave these conditions as soon as possible.

Be particularly vigilant for ice when in a holding pattern. If heavy ice accretion is encountered, request a change in level or re-positioning to another hold. Do not hold with flaps or landing gear extended.

Make reports to the ATC and your Company. There is no better operational tool available today than first hand reports of unusual icing conditions. Remember that because these conditions are usually localised and can vary rapidly, another aircraft passing through the same area may experience different conditions.

If an ice detector is fitted, don’t rely on it alone. Always be on the look out for ice!
This appendix has been produced to highlight the areas where jet aircraft differ from turboprops in terms of winter operations. The content applies to the following BAE Systems jet aircraft:

- BAe 146 all series.
- Avro Regional Jet (RJ) all series.

**Ground de-icing and anti-icing**

The same principles of de-icing and anti-icing apply for both Jets and Turboprops. However, on the BAe 146 and Avro RJ, following the application of Type II or Type IV fluids, the take-off rotation speed (VR) must not be below 100 kts. If the VR is below 100 kts, fluid on the wings and tail may cause adverse aerodynamics and handling effects.

At very light take-off weights the calculated VR could be below 100 kts. In this event, a VR of 100 kts must be used and the take-off performance calculated for an aircraft weight giving a VR of 100kts. The choice of take-off flap setting maybe affected by this restriction.

The APU should be shutdown for aircraft de/anti-icing and for a minute afterwards to allow the de-ice fluids to drain. If for operational reasons the APU has to be kept running, the APU air should be selected off prior to de-icing and not re-selected during the departure section of that flight sector. All engine and APU bleeds must be switched off prior to de-icing and should also not be re-selected for as long as practical (minimum of one minute) after de-icing has finished. Flaps must be UP during de and anti-icing.

**De-icing with engines operating**

Where permitted, aircraft may be de-iced or anti-iced with the engines running although it is preferred with the engine shutdown.

Running engines must not in any way inhibit the complete de-icing of the aircraft particularly the wing and tailplane.

**Frost**

Frost is a light, powdery, crystalline ice which forms on the exposed surfaces of a parked aircraft when the temperature of the exposed surfaces is below freezing (while the free air temperature may be above freezing). Frost degrades the aerofoil aerodynamic characteristics.

It is permissible on the underside of the wings (unless the aircraft has been certificated by the FAA) over the general area of the fuel tanks, provided that the depth does not exceed 3 mm (1/8 inch). It is also permissible on the fuselage provided the layer is thin enough to distinguish surface features such as paint lines or markings underneath. However all vents, probes and ports must be clear of frost.

If frost is present on the aircraft it is recommended that a visual and tactile (hand on surface) check of the wing leading edge and upper surface is performed.

For take-off with the frost permissible, the WAT limited take-off weight must be reduced and the net flight path reference and fourth segment climb gradients must be obtained using a weight higher than the actual weight. See Limitations section of the AFM for details of this weight differential.
Taxying

If icing conditions exist on the ground, engine anti-ice should be selected ON. Wing and tail anti-ice system must not be used during ground operations or for take-off. Prolonged engine running at ground idle in icing conditions can result in ice accretion on the fan, possibly indicated by unusual airframe vibration. The ice can be shed by periodic increases of thrust which should be timed to prevent a heavy build up. An increase of N1 to 60% will usually be sufficient. Use the two inboard engines only for taxying in after landing, whenever it is convenient and safe to do so, in order to reduce taxy speed.

In cold conditions brake temperatures should be maintained above 50 deg. C to guard against the brakes freezing on. This could occur following landing gear retraction after take-off from a runway where slush or moisture could be deposited on the brakes. It is therefore recommended that brake fans should be selected as follows to minimise brake icing:

- Brake Temperature Indicator fitted:
  Select BRK FANS to either auto (if fitted) or ON for take-off and landing. After landing, select OFF when brake temperature falls below 200 deg. C.

- Brake Temperature Indicator not fitted:
  If the brakes are suspected to be below 50 deg. C prior to taxying for take-off, it is recommended that the brake fans are selected OFF. To warm the brakes use symmetric braking of approximately 500 psi, sufficient to slow the aircraft from normal taxy speed on at least three occasions, but use caution when braking on low friction surfaces. Select BRK FANS to either auto (if fitted) or ON for take-off and landing.

Take-off from contaminated runway or low friction surface

Take-off weights from contaminated runways (allowing for the failure of one engine) can be calculated using the AFM charts or operational performance software. Particular attention should be paid to the values of V1 required for contaminated surfaces and flexible thrust should never be used.

A take-off flap setting of 30 degrees must be used and a rolling take-off is recommended for low friction surfaces. Lift spoilers, airbrakes, anti-skid and all wheel brakes must be serviceable.

Continuous ignition should be selected ON for the duration of the take-off if standing water, slush, ice or snow is present on the runway, since small amounts of contaminant may be ingested by the inboard engines during cross-wind conditions.

Engine bleed air is not to be used for cabin air conditioning during take-off if slush, snow or water is present on the runway in significant quantities.

Take-off in icing conditions

If not already selected, engine anti-ice should be ON if icing conditions either prevail or may be expected before climb power selection. Make the performance adjustments required from the appropriate AFM charts. Wing and tail anti-ice systems must not be activated until climb power has been selected.
Appendix I: Jets

Maximum crosswind

The following maximum crosswind components are recommended for take-off and landing. For definition of braking action see Operations Manuals.

<table>
<thead>
<tr>
<th>Statement of braking action</th>
<th>Maximum crosswind (kts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>5</td>
</tr>
<tr>
<td>Medium poor</td>
<td>10</td>
</tr>
<tr>
<td>Medium</td>
<td>15</td>
</tr>
<tr>
<td>Medium good</td>
<td>20</td>
</tr>
<tr>
<td>Good</td>
<td>Max. demonstrated</td>
</tr>
</tbody>
</table>

The airframe ice protection must be ON in icing conditions, irrespective of whether the ICE DETECTED caption is lit or ice has formed on the airframe, in the following phases of flight:

- Below 2,500 ft AGL in the descent.
- Flight with the flaps extended.
- Prolonged holding prior to the approach.

This may reduce the period of time during the descent that the airframe ice protection system must be switched, giving potential benefits in fuel burn.

Engine ANT-ICE must be on during all phases of flight when icing conditions exist or are anticipated or if the ICE DETECTED caption is illuminated. After selection, check ENG VLV NOT SHUT indicators are illuminated and re-check periodically.

When the ICE DETECTED caption is illuminated, or ice has formed on the airframe as shown by accumulations on the windscreen wiper arm, cockpit window frame or wing leading edges, the TAIL ANT-ICE and OUTER WING ANT-ICE must be ON. Firstly select the TAIL ANT-ICE ON and check momentary lighting of NIPS annunciators and MWS WING/TAIL ANT-ICE ON. Then select OUTER WING ANT-ICE ON and check momentary lighting of NIPS. Maintain a minimum of 67% N2.

When clear of icing conditions, select INNER WING DE-ICE to ON for 1 minute and check momentary lighting of NIPS annunciators for L INNER VALVE and R INNER VALVE.

Prolonged flight in icing conditions at low engine speeds can result in ice accretion on the fan, possibly indicated by unusual engine and/or airframe vibration. The ice can be shed by periodic increases in thrust which should be timed to prevent a heavy build-up. An increase of N1 to 80% will usually be sufficient. When selecting ice protection systems OFF, always check momentary lighting of all relevant NIPS indicators.

BAe 146 only: For aircraft without engine rollback modification, flight in icing conditions above FL260 is prohibited.

Continuous ignition should be switched on before entering areas of heavy precipitation and at any other time when it is considered there is a possibility of engine flame out.

With visible ice on the aircraft or if it is suspected that ice may be accumulating on the airframe, the enroute climb speed should be increased by 7 kts.

If the aircraft has been in icing conditions and there is ice remaining on the airframe after use of the anti-ice system, the climb gradient should be reduced in accordance with the AFM.

Holding in icing conditions

Maintain flaps at 0 degrees for the hold. With visible ice on the aircraft or if it is suspected that ice may be accumulating on the airframe, all speeds including the recommended minimum manoeuvring speeds should be increased by 7 kts relative to the normal speeds.

Select INNER WING DE-ICE for 1 minute at 8 to 10 minute intervals and also when altitude is reduced for approach and landing.

Engine ANT-ICE must be ON. Maintain a minimum of 67% N2. If ice forms on the airframe, or if holding is prolonged prior to an approach, OUTER WING ANT-ICE and TAIL ANT-ICE must be ON.

Approach and landing

With visible ice on the aircraft or if it is suspected that ice may be accumulating on the airframe, target threshold speed must be VREF + 7 kts.

For landing with residual ice on the airframe, the maximum landing weight should be reduced in accordance with the AFM.

For landing on contaminated runways the field lengths required and landing weights...
achievable can be obtained for a particular type and depth of contaminant using the AFM charts or operational performance software.

Provided the APU is operating and stable and the APU generator is providing electrical power, the outboard engines can be shut down to reduce idle thrust as a last resort to slow the aircraft. This should only be done when the aircraft is under control and the speed is below 60 kts.

System failures

In the event of any loss of anti-icing or de-icing protection systems, icing conditions should be avoided or left as soon as possible.

For failures which effect the wing anti-icing or de-icing protection, wing asymmetric icing should be minimised. If asymmetric icing occurs, the wing anti-ice and de-ice switches should be selected to OFF.

Following any failure of the airframe ice protection system, if ice remains on the airframe for approach and landing, 15 kts should be added to the normal approach speeds. The landing distances will be increased by approximately 20%.

Flying Control Restrictions

The number of reports of flying control restrictions has reduced dramatically since its peak over the winter of 2004 to 2005, through a combination of maintenance, modification and service provider actions. Unusual weather conditions on one day caused a dip on the graph. Hail can readily bounce or slide into the elevator/tailplane gap, particularly when ground temperatures are relatively warm, and stay there. Due to hail having a relatively high mass and low surface area compared to snow, it takes much longer to thaw, and will remain in the gap during taxi, rotation and climb. This is why a few pilots found their elevators becoming more difficult to control as they climbed into lower temperatures, and the hail refroze, attaching itself to the control surface.

Flying Control Modification to reduce restrictions from thickened de-icing fluids

Some operators of the BAe 146 and Avro RJ who used thickened de-icing fluids had reported a series of flying control restrictions in the elevator and aileron primary and trim circuits.

This resulted in the introduction of changes to facilitate inspection and cleaning to reduce ingress of fluids to controls and to make changes less prone to restrictions. The changes are detailed in Modification Service Bulletin 27-181.

Master Minimum Equipment List (MMEL)

The CAA and FAA will permit the BAe 146 or Avro RJ aircraft to be dispatched into known or forecast icing conditions only if all the following ice protection systems are serviceable:

- Wing and tail de-ice/anti-ice valve lights.
- Wing and tail anti-icing valves.
- P1, P2 and auxiliary pitot heaters.
- Q feel pitot-static head heating system.
- One of the stall vane heater systems (FAA only).
- Static port heaters.
- Both of the 'A' Windshield heating systems.
- One of the 'B' Windshield heating systems.

Frozen power levers - ISB 71-078

Status.

There have been reports of power levers freezing in flight. Modifications to introduce a bellows on the slider and to improve pylon sealing have been effective in preventing freezing of the wire cables and the upper Teleflex cable. The majority of recent events are believed to be due to freezing of the lower Teleflex cable.

Investigations have found the following:

- On the lower cable, lubricants will dry out over time and dirt is likely to accumulate on the sliding portion.
- When the aircraft is parked, precipitation can enter engine zone 1 via gaps between the intake cowl, forward cowl doors and shoulder cowl. This water runs around the intake firewall and drips onto the exposed sliding portion of the Teleflex cable. When the power lever is advanced, the slider closes trapping water between the inner and outer parts. This water can then freeze when the slider is exposed to very low temperatures in flight.
- Drainage of water from the cowl doors could be improved. Water collecting in the doors while the aircraft is parked is likely to be blown around engine zone 1 by the very large air flow in this area during take-off and climb.

Recommended actions

Inspection Service Bulletin 71-078 addresses these problems in three ways:

- Introduce recommended maintenance for lower Teleflex cable (via Morse Controls Service Bulletin 188949-76-61):
  - Clean and relubricate slider at 600 hours.
  - Clean and relubricate inner cable at 3,000 hours.

- Introduce drain holes through cowl door skins to prevent water pooling in the bottom of the doors.

Fan blades cleaning

Operators should develop their own fan blade cleaning programme, so as to reduce the risk of induced vibrations in icing conditions. The cleaner the blades are, the less likely ice will accumulate.

Ref. eSiLs 12-146-RJ-616-1, 12-146-RJ-615-2 and AMM 71-00-00 B. Clean engine fan and compressor.

BAE Systems strongly recommends that operators accomplish all parts of this Service Bulletin at the earliest opportunity.
This appendix has been produced to highlight the areas where turboprops differ from jets in terms of Winter Operations. The content applies to the following BAE Systems turboprop aircraft:

- Jetstream 3100 & 3200
- Jetstream 4100
- ATP
- HS 748

The main differences are:

- Turboprops are flown at lower cruise altitudes and at significantly lower speeds than jets.
- Turboprop aircraft employ pneumatic airframe de-icing systems, involving leading-edge inflatable boots, plus propeller de-icing systems.

It is generally considered that turboprop and other propeller driven aircraft are more prone to icing induced wing stall than are large turbo-jets, due to the lower altitudes and speeds of operation and the relative aerodynamic degradation due to ice accretion.

**ATP engine intakes**

To avoid torque interrupts due to intake icing, it is essential to ensure that the engine intake is free from into wind steps, and that the flexible duct is in a satisfactory condition.

**Ground de-icing and anti-icing**

The same principles of de-icing and anti-icing apply for both jet and turboprop aircraft.

- Increased stick forces have been experienced at rotation by turboprops after application of Type II or Type IV fluids. This is due to the lower rotation speed of turboprops, at which not all the fluid has sheared off the wings and elevators, together with collection of fluids in the control surface ‘gaps’. These characteristics were confirmed by BAE Systems during flight tests and assessed as being within acceptable limits.

**Airframe de-icing boots**

The location of airframe de-icing boots on leading edges makes them particularly susceptible to damage by erosion, impact, or contact with ground equipment. Winter conditions increase the risk of such damage and the importance of regular inspections and functional testing cannot be over-emphasised.

Pilots flying aircraft with de-icing boots are generally aware that stalling speeds increase until the ice is shed by operation of the de-icing boots. However, they should also be aware that residual pieces of ice remaining on the boots after inflation together with ice accumulation on other parts of the aircraft can significantly affect lift and hence stall speed, and also drag.
Pre-flight

If icing conditions exist on the ground, engine and propeller anti-icing should be selected ON. It is sometimes necessary to taxi to a de-icing area or facility. The engines are usually stopped during de-icing and the crew should confirm complete de-icing of visible parts of the aircraft before starting the engines and continuing taxiing.

When taxiways are slippery, be prepared to use reverse if the brakes have no effect. The serviceability of all ice protection systems should be checked prior to departure.

Ensure full and free movement of flying controls when the gust locks are removed immediately before take-off. Every time the gust locks are engaged, a full and free check MUST be made when the locks are disengaged.

In fog or rain at temperatures below +1 deg. C, ice may form on the propellers during prolonged taxiing or long periods at idle. This ice build up can affect the airflow into the engines and reduce propeller efficiency. Ensure that correct torque and ITT/EGT readings are obtained prior to releasing the brakes for take-off.

Take-off in icing conditions

If not already selected, engine and propeller anti-ice should be ON if icing conditions either prevail or may be expected in the take-off or climb. Make the performance adjustments required from the appropriate Flight Manual charts. Wing and tail de-icing systems must not be activated until safely airborne.

ATP take-off following application of thickened de/anti-icing fluid

Following the application of a thickened fluid the ATP is subject to limitations that are given in the AFM (Section 2.10.13). These limitations require the take-off to be performed by the IHS pilot, only 7 flap is approved, the crosswind must not exceed 10 kts, maximum pressure altitude is limited to 2,000 ft and the temperature must be between +10°C and -40°C. Additionally there are performances penalties.

In-flight

Significant ice accretion during climb can seriously degrade aircraft performance due to increased drag, loss of lift, and reduction of propeller efficiency. The minimum en-route climb speed should be increased in icing conditions: see the AFM for details of this increase.

Both the icing speed increments and ice accretiation on the airframe have an effect on the aircraft performance. The aircraft should be operated in accordance with the associated performance information given in the AFM or the operations manual.

Rate of climb can be dramatically reduced such that achieving the desired altitude may not be possible. In such circumstances, the autopilot should be disengaged and the aircraft flown manually.

If airframe vibration (not propeller) is experienced, this may be pre-buffet stall, in which case the aircraft should be levelled, the speed increased and icing conditions left as soon as possible.

In-flight systems operation

Before entering icing conditions select and confirm operation of:
- Continuous/automatic ignition.
- Engine anti-icing system.
- Propeller de-icing system.
- Elevator horn anti-icing.
- Windshield anti-icing.
- Pitot/static, stall vane and temperature probe anti-icing.

When in icing conditions, monitor ice build-up and operate the airframe de-icing system in accordance with the AFM and Operations Manuals procedures.

Airframe Continuous De-icing

For all of the turboprop types it is recommended that approximately 13 mm (0.5 in) of ice is allowed to build up prior to activation of the system. After one or two cycles of the system it should then be switched off to allow a further build up of 13 mm (0.5 in).

BAE Systems are aware of proposed changes to the FAA Part 121 operating regulations, which require airframe de-icing boot systems to be activated at the first indication of ice formation and continuously cycled until after leaving icing conditions.

The company is supportive of the intent to improve the level of safety of flight in icing conditions. BAE Systems is supportive of the intent to improve the level of safety of flight in icing conditions. The current procedures, for non FAA established during extensive icing certification flight testing, are considered to be safe.

The use of flaps is prohibited in icing conditions when en-route or holding.

During approach, an airframe check should be carried out for accreted ice at approximately 1,000 ft AGL. If ice is seen or suspected on the airframe, the de-icing system should be operated irrespective of the thickness of ice.

The airframe de-icing system should be switched off passing 500 ft AGL, but no later than 200 ft AGL on the approach to landing.
Appendix II: Turboprops

Encounter with unusual icing conditions

Some icing conditions outside FAR/CS/JAR-25 Appendix C may result in ice forming beyond the protected surfaces, which cannot be shed by the airframe de-icing system. The effect of such ice accretion, following flight in freezing drizzle conditions, was the subject of an FAA investigation. An article about freezing drizzle issued by the FAA stated that as a result of this type of ice accretion, ‘Roll upset may be caused by the airflow separation (aerodynamic stall) inducing self deflection of the ailerons, loss or degradation of roll handling characteristics.’ BAE Systems successfully completed the test programme defined by the FAA to investigate these phenomena and showed that Jetstream 31/32/41, ATP and HS 748 aircraft are not susceptible to roll anomalies in these conditions.

The AFMs were updated to clarify the position and to contain the following advice:

- Freezing rain, freezing drizzle and unusual icing conditions may cause heavy accretion which could exceed the capabilities of the ice protection systems. Such ice can also accrete on the unprotected surfaces. This ice cannot be shed and may seriously degrade the performance and control of the aircraft.

- If the aircraft exhibits airframe buffet onset, unexpected loss of speed, uncommanded roll or unusual roll control-wheel forces, immediately reduce the angle of attack (AOA) and avoid excessive manoeuvring until the airframe is clear of ice.

- If ice is seen forming behind the protected surfaces or there are unusual roll-trim requirements or autopilot trim warnings then the following actions should be taken:
  1. If flaps are extended, do not retract flaps until the airframe is clear of ice.

  2. Leave icing conditions as soon as possible.

  3. Hold the control wheel firmly and disengage the autopilot.

  4. Increase the airspeed as much as configuration will allow, but not above rough air speed ($V_{RA}$).

  5. Do not engage the autopilot until the airframe is clear of ice.

Prolonged operations in altitude bands where temperatures are near freezing and heavy moisture is visible on the windshield should be avoided.

Restricted flight control movements in conditions of sleet, snow and hail

It is recommended that the following precautions be observed in order to minimise the risk of any unseen contamination affecting the flying controls:

- Prior to take-off, carry out the normal control check but take care not to operate the elevators or ailerons towards the up stop too vigorously, this might dislodge any precipitation causing it to fall into the control surface gap.

- During the climb, make regular small deflections of the ailerons and elevators to ensure they are behaving normally.

- On the HS748, use of the autopilot is not recommended until established in the cruise with the controls behaving normally.

- If the controls become stiff, consider a descent or diversion.

- If the elevator becomes stiff, apply an increasing but controlled manual force to the control column in an attempt to maintain some freedom of movement. Do not under these circumstances apply increasing amounts of elevator trim because if the elevator suddenly becomes free, the aircraft could pitch rapidly.

  - In the extremely unlikely event of the elevator becoming immovable, attempt to control pitch by:
    - Making power changes. To lower the nose, power would be gradually reduced and vice versa.
    - Using the elevator trim in the reverse sense. To pitch the aircraft down, the trimmer would be adjusted nose up (see caution below).

  CAUTION:
  When using the elevator trim tab as an elevator, its effect will be small. However, if the ice should clear, the reaction of the freed elevator to the elevator trim tab may be very powerful. Therefore it is most important that the pilot should continue to hold the control column firmly, use only small amounts of trim, and be ready to combat any violent aircraft response in pitch,
Advice to pilots on icing-induced stall recognition and recovery

There have been incidents with turboprop aircraft involving loss of control in icing conditions, due to undetected stalling at speeds significantly above the normal stall speed, accompanied by violent roll oscillations. In the light of these events the UK CAA issued an Aeronautical Information Circular (AIC 98/1999) providing the following advice on the recognition and recovery from such insidious icing-induced wing stalls:

- Loss of performance in icing conditions may indicate a serious build-up of airframe icing (even if this cannot be seen), which causes a gradual loss of lift and a significant increase in drag. This build-up of ice can cause the aircraft to stall at speeds significantly above its normal stall speed.
- The longitudinal characteristics of an icing-induced wing stall can be so benign that the crew may not be aware that it has occurred.
- The stall warning system may not alert the crew to the insidious icing-induced wing stall, so it should not be relied upon to give a warning of this condition. However, airframe buffet may assist in identification of the onset of wing stall.
- The first clue may be a roll control problem; this can appear as a gradually increasing roll oscillation or a violent wing drop.
- A combination of rolling oscillation and onset of high drag can cause the aircraft to enter a high rate of descent unless prompt recovery action is taken.
- If a roll control problem develops in icing conditions, the crew should suspect that the aircraft has entered an icing-induced wing stall and should take immediate recovery action. The de-icing system should be activated if not already on and consideration should be given to leaving icing conditions by adjusting track and/or altitude.

Holdings

To ensure a safe margin above increased stall speeds with ice accreted, the speed in the hold should be increased - see Operating Manuals for details. When holding in icing conditions, aircrew should be extra vigilant for unusual/heavy ice accretion. If such conditions are encountered, the aircraft should be flown manually and the conditions should be exited as soon as possible.

Approach

Rapid descent to low altitude during approach or other deviations from prescribed operating procedures are not acceptable means of minimising exposure to icing conditions.

Stall margin: Lift increases with the square of speed ($V^2$), thus even small increases in airspeed are useful if the stall margin is in doubt.

Tailplane icing

The tailplane is naturally more susceptible to ice accretion than the wings and the effect of excessive ice accretion on the tailplane can be sudden and most unwelcome.

Tailplane stall is a critical condition, which may occur without warning. Since the AOA of the tailplane becomes more negative with extension of flaps, tailplane stall is most likely encountered when the flaps are fully extended. It is critical that its symptoms are not confused with those of the more familiar wing stall, since the corrective recovery procedure for wing stall will aggravate a tail stall and vice-versa. A tabulated guide is shown opposite.

The tailplane stall symptoms may occur immediately after flap extension and subsequent pilot nose down pitch inputs.

<table>
<thead>
<tr>
<th>Wing stall</th>
<th>Tail stall</th>
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</thead>
<tbody>
<tr>
<td>characteristics</td>
<td></td>
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<tr>
<td>Low speed</td>
<td>Higher speed</td>
</tr>
<tr>
<td>Airframe buffet</td>
<td>Landing flap selection</td>
</tr>
<tr>
<td>Lateral instability</td>
<td>Elevator control gain, oscillations, or vibrations</td>
</tr>
<tr>
<td>Stick shaker</td>
<td>Abnormal nose down trim change or other unusual pitch anomalies</td>
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<tr>
<td>Nose drop tendency</td>
<td>Reduced or loss of elevator effectiveness</td>
</tr>
<tr>
<td>Stick push (if fitted)</td>
<td>Sudden elevator force changes</td>
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<tr>
<td>Tailplane icing tendency</td>
<td>Rapid recommended pitch down</td>
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</table>

Recovery actions

<table>
<thead>
<tr>
<th>Characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Full power</td>
<td>Immediate hard pullback</td>
</tr>
<tr>
<td>Lower nose</td>
<td>Retract flap to previous setting</td>
</tr>
<tr>
<td>Actions-Low AFM</td>
<td>Apply power and maintain precise control</td>
</tr>
</tbody>
</table>

Note: Some of these symptoms may not be detected by the pilot if the autopilot is engaged.

From the pilot’s point of view, the most important characteristic of a tailplane stall is usually the suddenness and magnitude of the nose down pitch change most often accompanied by unusual stick forces, with the control column moving towards the forward limit.

It makes sense to select flaps early to allow adequate height for recovery from any undemanded manoeuvre that might possibly occur.

Comprehensive wind tunnel and flight testing, including zero ‘g’ pushovers, with real and simulated tailplane ice accreted showed the J32, J41 and ATP to be free from tailplane stall tendency at all flap settings. However, later flight testing on the HS 748 resulted in the prohibition of selection of the 27½ deg. flap landing configuration when ice is visible on the airframe.
Tailplane icing - continued

The J31 and J32 have been shown to be free from tailplane stall tendency at flap settings of 35 deg. or less.

Tailplane icing summary

In the event of encountering tailplane stall, it is therefore critical that the symptoms are recognised and not confused with those of the more familiar wing stall. The main symptoms of a tail stall are nose down trim changes (often strong and rapid), with pitch control force anomalies. This may be briefly preceded by buffet through the control yoke. The quickest and most effective recovery is by pulling the control yoke back and reducing flap to prevent a recurrence.

System failures

In the event of any failure of the de-icing or anti-icing systems flight in icing conditions must be avoided.

- **Wing de-ice failure.** Following any failure of the airframe de-icing system on the Jetstream 31/32 or Jetstream 41, it is recommended that the flaps are not extended beyond the approach setting. If airframe buffet occurs, the airspeed must be increased until the buffet ceases. The landing distance required should be increased in accordance with AFM procedures.

- **Tailplane de-ice failure.** The most effective means of increasing the tailplane stall margin during or following flight in icing conditions is achieved by limiting the maximum flaps extension angle. Consequently, in the event of failure of the tailplane de-icing system on the J31/32, J41, HS748 and ATP whilst flying in actual or potential icing conditions, it is recommended that the flaps are not extended beyond the approach setting. Tailplane icing may cause a strong trim change when flaps are lowered. Allow adequate height for all flap operations to permit a stabilised approach. On the Jetstream 41, large rudder and sideslip angles should be avoided with ice accreted on the fin as pedal forces may reduce and, in extreme conditions, rudder overbalance may occur.

Landing

For flight in icing conditions or with accreted ice on the airframe, the approach and landing speeds should be increased and the appropriate performance penalties applied in accordance with the AFM of the operations manual.

On contaminated runways, greater use of reverse thrust than normal may be necessary to achieve satisfactory braking. However if possible, it should not be used at low speed to avoid ingestion of contaminants.

As a result of a review of the Jetstream 31 and 32 information for landing on a slippery runway, the factor to be applied to the landing distances is now standardised at 33%. When landing on a slippery runway, only the fully factored destination distance must be used.

All selections of steering/braking and power adjustments should be made with care.

Taxy-in

Do not taxy-in on one engine. Slippery taxyways in combination with strong surface winds could result in losing lateral control of the aircraft.
References

- Frost, ice and snow removal (All types)
  - BAe 146 / Avro RJ AMM 12-30-31
  - J31 & J32 AMM 12-31-05
  - J41 AMM 12-31-00, 12-31-05
  - ATP AMM 12-31-00, 12-31-05
  - HS 748 AMM 12-14-00


- Fan blades cleaning (BAe 146 and Avro RJ)
  - eSIL 12-146-RJ-616-1 and 12-146-RJ-616-2
  - AMM 71-00-00

- ISB 71-078 - Changes to reduce freezing of the throttle control lower Teleflex cable
  - Morse Controls SB 188949-76-61

- UK CAA Aeronautical Information Circulars

- UK CAA Flight Operations Department Communications
  - http://www.caa.co.uk

- FAA web site
  - http://www.faa.gov

- Association of European Airlines
  - 'Recommendations for De-icing/Anti-icing of Aircraft on the Ground'
  - 'Training Recommendations and background information for De-icing/Anti-icing of Aeroplane on the Ground'
  - http://www.kea.be

- NASA's pilot's guide to ground and in-flight icing courses (All types)
  - http://aircrafticing.grc.nasa.gov/courses.html