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ADVISORY MATERIAL FOR HELICOPTER LIMITED ICING CLEARANCES

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Abstract

For a helicopter without a rotor ice protection system the level of icing clearance available must be constrained to ensure continued safe flight at all times. The envelope available for flight into known icing conditions is therefore 'limited' to operation within a number of important restrictions. This is likely to be framed in terms of the allowable rotorcraft mass, airspeed, temperature, altitude limits, required equipment fit (e.g. FOD screens) and, most importantly, the need for an escape route to be available at all times. In addition, if systems or components are found to be vulnerable to ice, accretion or time, limits may need to be imposed if protective methods are inappropriate. This document provides guidance to manufacturers and operators seeking a limited clearance for operation in icing conditions. It is intended to form the basis of future advisory material to be provided on helicopter limited icing clearances. An introduction is provided into the basic physics of ice accretion in order to establish the relative importance to the icing severity of, for example, air temperature and liquid water concentration. In recognition of the fact that it is extremely difficult to test an aircraft over the full icing envelope within a practicable time frame allowed for trials, guidelines are provided as to the likely minimum test data that should be obtained in order to support a clearance. Advice is provided on the type of data likely to be required and, more specifically, the role of evidence obtained from simulation, ground and flight based tests. The document also provides a record of some of the more important aspects of helicopter icing trials which have been gained from practical experience on UK military helicopters.

Contents

1 INTRODUCTION

1.1 In order to obtain full UK certification for flight into icing conditions, the applicant must demonstrate that the rotorcraft can be safely operated in the range of icing conditions defined in JAR-29 Appendix C or BCAR Working Draft Paper G 610 'Flight in precipitation and ice-forming conditions'. JAR-29 requires safe operation in Continuous Maximum and Intermittent Maximum icing conditions as defined in its Appendix C, within the altitude envelope appropriate to rotorcraft. Paper G 610 similarly provides design requirements for continuous and intermittent icing and extends the requirements to include falling and recirculating snow. However, it is noted that neither document appears to address other forms of precipitation such as mixed icing conditions and freezing rain that are likely to be encountered in practice.

1.2 Few civil helicopters have the necessary rotor ice protection systems to enable a full icing clearance to be granted. This document provides guidance to the applicant (normally expected to be the manufacturer and/or the operator) seeking a limited clearance for operation in icing conditions.

1.3 The term 'limited clearance' is explained and the range and extent of data likely to be required to support a clearance are discussed. A description of the various icing parameters, such as temperature, droplet diameter and liquid water concentration, is provided and ranked according to their likely significance in terms of icing severity and hence the potential hazard they may represent to the rotorcraft. The different forms of precipitation (snow, freezing fog, freezing drizzle and rain) are discussed in relation to a practical limited icing clearance. The type of evidence (rig, analysis, and flight test) that is considered acceptable for certification is discussed, with particular emphasis on the data that should be provided.

2 LIMITED ICING CLEARANCES

2.1 Definition of a limited icing clearance

2.1.1 A limited icing clearance is a prescribed envelope in which the rotorcraft may be safely operated in icing conditions, either for continuous periods or for a sufficient time to allow safe exit from the conditions, should this prove necessary. This envelope must be specified in terms of parameters readily available to, and observable by, the pilot. In practice, the clearance is likely to be framed in terms of the allowable rotorcraft mass, airspeed, temperature and altitude limits, the required equipment fit (e.g. Foreign Object Damage (FOD) screens) and, most importantly, the need for an escape route to be available at all times. Accretion limits may also be imposed if the aircraft or specific systems are identified as vulnerable to damage or adverse effects from ice accretion or shed ice. It should be noted that a clearance is likely to be granted in the knowledge that under certain icing conditions, within the specified release envelope, the aircraft will be forced to vacate the icing condition. Hence the requirement for an escape route is paramount. In practice, the escape route is likely to take the form of a requirement for a non-icing layer of air to exist above the surface or minimum operating altitude. The extent of this band of non-icing air is likely to be between 500 ft and 1000 ft, dependent on the nature of the operations. All limited clearances, irrespective of operating altitude, are therefore likely to have associated with them a number of important restrictions, relating to torque increase, vibration, the extent of airframe accretion that is allowed and the need for an escape route to be available at all times.

2.1.2 While a limited clearance will be based on the available flight test evidence, it must be recognised that it is unlikely that this will permit flight at ambient air temperatures below about –10°C, due to known rotor problems at low temperature. For colder temperatures, a rotor protection system will be required.

2.2 Ice protection considerations

2.2.1 While it is acknowledged that a rotor protection system will not normally be fitted to an aircraft for which a limited icing clearance is sought, the rotorcraft is nevertheless unlikely to be allowed to operate in snow and icing conditions unless certain features of the aircraft are adequately protected either by direct or indirect means. A direct means of protection represents an equipment actively protected against ice accretion such as heated engine intakes. The indirect method is protection by, for instance, a requirement to exit the conditions after an appropriate exposure of the airframe in order to avoid large ice accretions which may pose a hazard to the aircraft, or people and property in the vicinity of the aircraft, if the ice were to be shed.

2.2.2 A list of components that are likely to require protection along with suggestions of the means of providing protection are presented in Appendix 1 for information. The list is intended to be illustrative only, and it is the responsibility of the applicant to ensure that the complete rotorcraft comprising all systems and sub-systems have been adequately protected.

2.2.3 The list in Appendix 1 shows that, for a limited clearance, active ice protection will be required for the engines, intakes, pitots and cockpit windscreens.

2.3 Overview of test evidence required

2.3.1 As a result of the simulation techniques presently available, a limited icing clearance is unlikely to be granted without flight test evidence in natural icing conditions. The extent of the clearance available will in general be limited to that proven by successful safe experience gathered during test flights in natural icing conditions. Due to the unpredictable nature of natural icing conditions, the flight test data will in turn be limited by the choice of geographic location for the trials and the length of time that the aircraft is deployed. A guide to the minimum level of evidence necessary to support a limited icing clearance is given in section 5. In practice, any clearance must be based on the evidence available, and may fall well below that for which the aircraft is potentially capable of operating.

2.3.2 Whilst certain systems and sub-systems (e.g. windscreen, pitot and engines) could be cleared by analytical, ground and tunnel tests for operation to the full icing envelope, in practice a safe clearance can only be granted on the test evidence gathered on the whole aircraft. Testing of the whole system is necessary in order to investigate the interaction of icing on sub-systems and on components. For example, an aerial positioned ahead of the engine intakes may shed ice and hence produce a potential FOD hazard to the engine. Tests of the maximum ice ingestion capability of engines are not required for certification at present. Hence, the clearance of an engine by rig testing is unlikely to have investigated the capability of the engines to ingest snow and ice shed from forward areas of the fuselage.

2.3.3 However, the use of rig and analytical methods for icing simulation should be explored to the full, since these techniques can be used to reduce the technical programme, and hence the cost risks, by the potential early identification of problems. While the use of such data to *extend* the clearance would need to be carefully scrutinised, the simulation data may be of more benefit by providing supporting evidence to fill gaps within the range of flight test conditions evaluated.

2.3.4 Note that flight test results obtained from artificial icing conditions, using spray tanker aircraft, are unlikely to be accepted as a substitute for testing in natural icing conditions. The available experience to date with artificial icing conditions suggests that they do not yet adequately simulate natural icing conditions. The reasons for this are unclear, although limitations on the size of the icing cloud and consequent coverage[1] of the aircraft, the ambient humidity and hence temperature of the water droplets, and the diameter of the water droplets are important features which are not thought to be fully representative of natural icing. The use of a spray tanker to gather early test data during development of protection systems or for analysis of susceptibility may be useful.

2.3.5 Overall, the limited clearance is likely to be based on a combination of simulation and flight test data in natural icing. With the present simulation capabilities it is likely to rely heavily on the latter.

3 ICING PARAMETERS

3.1 General

3.1.1 This section discusses the various parameters which influence the severity of the icing condition. The parameters discussed include both the icing conditions (outside air temperature, OAT, volume median diameter, VMD, and the liquid water concentration, LWC) as well as certain other flight and atmospheric conditions (airspeed and altitude) which can contribute to the severity of the condition as experienced by the rotorcraft.

3.1.2 The term 'icing severity' requires qualification since, in a given set of icing conditions, the effect of the icing environment on the handling and performance of one type of aircraft may be benign while to another aircraft it may be extremely hazardous. The term 'severity' should not therefore be confused with the effect of the icing on a particular aircraft. In the following text, severity is intended to imply the degree or rate of ice accretion. In practice, a large ice accretion may well have a significant impact on the handling and performance of the aircraft and hence there is a tendency for confusion between the severity in relation to the effect on the aircraft and the severity in relation to the rate and, in consequence, size of the ice accumulation.

3.1.3 Ice accretion from super-cooled water droplet cloud represents only one form of a number of natural hazards to the aircraft. Though the classical super-cooled cloud may exist by itself, it is also likely that the aircraft will encounter other forms of ice producing precipitation. A limited clearance will need to address the hazards posed by snow, ice crystals and super-cooled water both in isolation and in appropriate combinations. In practice, these forms of natural hazard are closely related. While the physics of ice nucleation are somewhat complex and outside the scope of the present document, a brief description is considered useful. Readers are referred to Reference 1 for a more in depth explanation.

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[1] Experience during trials of military rotorcraft in simulated icing suggest that intermittent or poor cloud coverage, particularly whilst flying in a tanker or rig generated cloud on an otherwise cloudless day, fails to produce representative rotor accretions and the normally associated performance degradation. This is considered to be in part due to a well established tendency for the rotor ice to shed immediately on exiting the cloud, coupled with ice sublimation effects.

3.1.4 In practice, water droplets will condense on soluble nuclei to form a cloud. Due to their relatively small size, cloud droplets may frequently exist in the super-cooled state down to –20°C and, less frequently, down to as low as –30°C to –35°C. For very small droplets of a few microns diameter, water droplets have been observed in the laboratory (Reference 1) to remain super-cooled down to –40°C. However, at temperatures below this, the droplet will freeze spontaneously. The degree of super-cooling at temperatures above –40°C depends on the purity of the water, the size of the droplets and whether ice particles are already present in the cloud parcel. If ice particles are present then they will grow at the expense of the water droplets which will rapidly evaporate. Also, if super-cooled water droplets collide with ice particles or other ice nuclei, the water droplets will freeze. It is important therefore to note that as the ambient temperature reduces, the likelihood of large super-cooled water droplets will reduce. In consequence, therefore, freezing rain, which is effectively super-cooled cloud with very large droplets, (up to around 5 mm diameter) is unlikely to exist at cold temperatures. This feature is supported by the observation that this is a relatively warm temperature phenomenon. Since the droplets are associated with precipitation, it is possible to encounter freezing rain at temperatures above 0°C[2]. A typical guideline for the temperature band appropriate to freezing rain is commensurate with the likely extent of a limited icing clearance and therefore of relevance to this document.

3.1.5 Freezing rain differs from freezing drizzle in terms of the diameter of the droplets and the processes by which the droplets form. Most precipitation in mid-latitudes is initiated with glaciation of clouds. Snow which forms within these clouds falls through the warmer, lower layers of the atmosphere and melts to form large rain droplets ($> 400\ \mu m$ in size). If these droplets once more fall through a sub-freezing layer, which can be associated with an inversion layer, they can become super-cooled and freeze on contact with a surface. This is generally referred to as freezing rain. Freezing drizzle is expected to consist of droplets with diameters typically in the range $50\ \mu m$ to $400\ \mu m$ and is associated with stratoform cloud of relatively small vertical extent which forms in sub-freezing temperatures. The drizzle size droplets are produced by coalescence, which can be enhanced by turbulence induced collisions near cloud top, but because of the small cloud depth they fall out of the cloud before they can grow to larger raindrop sizes. The maximum water concentration is expected to be relatively low, in the range $0.3\ g/m^3$ to $0.4\ g/m^3$.

3.1.6 Ice crystals may grow in an ice supersaturated environment by diffusion of water vapour to their growing surface. As the equilibrium saturated vapour pressure over ice is lower than over water, once glaciation is initiated in a super-cooled water droplet cloud, the cloud will quickly transform into an ice crystal cloud. The ice crystals may aggregate to form a snowflake and the snowflakes may themselves collect super-cooled water. Depending on the conditions, therefore, the crystalline particles may range from pure, 'dry', ice crystals through to large melting, 'wet' snowflakes. The hazard that the ice crystals represent to the aircraft will be different, as will the hazard to individual components. For instance, pure ice crystals are unlikely to accrete on the rotor, having a tendency to bounce off the surface, whereas in sufficient quantities, the ice crystals may collect in an intake plenum chamber and hence represent a hazard to the engines. Furthermore, such crystals may produce a hazardous accretion, slush

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[2] Freezing rain is normally associated with frontal conditions where temperature inversions exist. Ice accretion on an airframe exposed to freezing rain or drizzle may be produced by one of two mechanisms. The first, and most likely, is precipitation (such as snow) that has fallen through or from a positive temperature layer into a subzero level where the resulting large droplets have been cooled and then impinged and accreted upon a cold surface. The second is a transient condition associated with an aircraft that has climbed or descended into positive air where rain of positive or negative temperature accretes for a period upon a cold soaked airframe; this latter condition is unlikely to produce any rotor blade icing.

or ice, if captured by a wet surface, produced possibly by a heated or fluid anti-iced surface. Water running from such melted crystals or snowflakes may run to colder unprotected areas of the airframe and form hazardous ice accretions.

3.1.7 A review of icing hazards can only be relatively brief and superficial in this document and an attempt has been made only to convey the more significant aspects as perceived by the authors. Further information is provided on each of the parameters affecting ice accretion in the following paragraphs. Examples of the ranges and typical values found in nature are also provided where appropriate for information.

3.2 Fundamentals of ice accretion

3.2.1 In order for the reader to become better able to understand the relevance and significance of the various icing and geometrical parameters, a basic introduction into the physics of ice accretion is described below. This is primarily intended for readers new to the field of icing.

3.2.2 Icing is defined as flight in cloud at temperatures at or below freezing when supercooled water droplets impinge and freeze on the unprotected areas on which they impact (hence the term 'impact icing' used in the BS 3G100 icing requirements). The rate and amount of ice accretion on an unheated surface depends on the shape including surface finish[3], the size, the speed at which the body is travelling, and the temperature, liquid water concentration and the size of the droplets in the cloud.

3.2.3 It is convenient to consider accretion in two distinct parts. The first part is the rate at which the water droplets are intercepted by the body. This is the product of the efficiency that the body collects the water (usually referred to as the water droplet collection or catch efficiency) and the amount of water contained in the cloud, the LWC. The water droplet collection efficiency of the body is controlled mainly by the size (e.g. rotor blade chord length) and the shape of the body, including the incidence, and in particular the diameter of the cloud droplets. While airspeed is important also, the ambient pressure (altitude) and temperature have only a limited effect on the collection efficiency over the range of values appropriate to rotorcraft.

3.2.4 The second aspect to ice accretion is the rate at which the impacted water will freeze to form an ice accretion. This is primarily governed by the heat transfer from the surface of the body. This heat transfer includes kinetic heating, convective cooling, evaporative cooling, latent heat of freezing and a number of smaller contributions from the sensible heat gained or lost arising from the change in the temperature of the water droplets and of any ice that might form. For the impacting water droplets to freeze, their latent heat of fusion must be dissipated. The primary mechanisms of heat loss are normally convection and evaporation. The convective heat transfer is in practice largely controlled by the geometry and speed of the body in the airflow, the roughness of the iced surface, and the ambient temperature difference that exists between the surface and the freestream (edge of boundary layer under compressible flow conditions). The evaporative cooling is a function of the vapour pressure of the water, which is itself a function of the temperature and the pressure at the surface. The pressure effect is through the enhanced concentration gradient which exists if the air is expanded and cooled, as in the upper surface suction region of an aerofoil or within an engine inlet.

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[3] Very small discontinuities on a smooth surface, such as dents, rivet heads and poorly aligned panel edges, can promote considerable ice growth on surfaces and in areas that would otherwise remain significantly ice free.

3.2.5 At combinations of low airspeed, low ambient temperature or low LWC the super-cooled water droplets will freeze on impact, tending to form a streamlined accretion which is white and opaque due to the presence of minute trapped air bubbles. The accretion may become less streamlined as the size of the accretion increases. The accretion is termed ***rime*** ice.

3.2.6 At certain combinations of speed, ambient air temperature and LWC, not all of the surface water freezes on impact, some running back along the surface which can freeze at aft positions on the body. On an aerofoil, the tendency is for this accretion to exhibit a horn growth on each of the upper and lower surfaces, i.e. either side of the stagnation region. This type of accretion is termed ***glaze*** ice (sometimes referred to as clear or horned ice). The central region where runback water is present tends to be translucent in appearance, although the accretion further aft may again become white and opaque like rime ice, the water droplets in this region freezing on impact. This is the more common form of glaze ice. If the accretion surface is particularly wet, then the whole accretion may be translucent and it will have an extremely rough surface. Such accretions may be difficult to see at night.

3.2.7 Specific to rotor blades, at combinations of high speed (rotor tip) and warm ambient temperatures, the only place where ice can form is in the region of low pressure on the upper surface of the rotor close to the leading edge. Under these circumstances, a 'slushy' ridge of ice forms, termed ***beak*** ice. These accretions have been observed in rig tests and on rotors in flight. The 'slushy' ridge of ice has been observed to grow and shed at regular intervals. The accretion extends typically 2% chord in both the chordwise extent and in height. The potential for performance degradation from this form of accretion is significant and should not be over-looked.

3.2.8 A pictorial representation of the main ice types that may occur on a rotor is shown in Appendix 2.

3.2.9 Due to the variation in the local velocity with span along a helicopter rotor, it is possible for all three types of accretion to be present at the same time. Rime ice can form on inboard stations, glaze ice further outboard, and beak ice on the outboard span of the rotor. However, on other components such as the fuselage or stabiliser, the accretion will in general be of either rime or glaze ice type or a combination of both, sometimes referred to as ***glime*** ice.

3.2.10 One final point to note is the change in the temperature of a surface during the initial period of icing, the direction of which varies depending on the total air temperature. If the total air temperature is below zero then the convective and evaporative cooling mechanisms combine to dissipate the latent heat of the super-cooled droplets and this maximises the rate of accretion. The temperature of the accreting surface in this icing condition will tend to *rise* due to the release of latent heat and will be at the freezing point if the accretion is particularly wet. On the other hand, if the total temperature is positive due to kinetic heating (i.e. in the region of a rotor tip), the only 'cooling' mechanism is likely to be evaporation. Under these conditions, the surface temperature will *fall* to zero and hence ice may accrete.

3.3 Ambient air temperature

3.3.1 By far the most critical parameter influencing the accretion of ice from super-cooled cloud is the ambient air temperature. While the static temperature of the air is important to ice accretion, and is relatively easily measured and therefore available to the pilot, it represents only one part of the accretion physics. In practice, it is the surface temperature of the body which dictates whether accretion is possible and the rate at which this accretion proceeds. Clearly, with a thermal protection system fitted, the aim is to raise the temperature of the surface above zero, either on a temporary basis (de-icing) or on a permanent basis (anti-icing). For an unheated and thermally isolated surface, the total temperature is the more relevant parameter to the rate of ice accretion. For instance, the tips of a rotor blade experience considerable kinetic heating. Simple analysis suggests that the tip of a rotor on a typical conventional helicopter, near the stagnation airflow position, will be around 20°C to 25°C warmer than the root of the blade. Heat conduction within the blade will reduce the temperature rise that is achieved in practice. It is the kinetic heating in the outboard section of the rotor which makes a limited icing clearance (without rotor protection) feasible. In practice, kinetic heating will prevent or reduce the susceptibility of the rotor to icing, and consequent performance degradation, when operating at ambient static air temperatures in the region between 0°C and –10°C. As the ambient air temperature reduces, the potential and the extent of the ice along the span of the rotor will increase. As ice forms further outboard on a rotor as the ambient temperature is reduced, so the performance degradation caused by the ice accretion will increase.

3.3.2 It is important to note that the occurrence of a total temperature greater than 0°C alone at the surface of a body (fuselage, and in particular the rotor) in clear air is not a valid criterion for the prevention of ice accretion on a body in super-cooled cloud. Evaporative cooling will drive the surface temperature of the body to the freezing point and, under appropriate conditions, will lead to ice formation. The rotor is again a prime example. The degree of evaporative cooling is affected by the surface pressure of the body. While the outboard region of a rotor in clear air may be at a temperature above the freezing point, the presence of impacting cloud water droplets will drive the surface temperature to zero due to evaporative cooling. This is particularly true in the low pressure region on the upper surface of a rotor. This evaporative cooling due to low pressure at high speeds can lead to the formation of a 'beak' ice accretion, as defined above.

3.3.3 In contrast, however, the kinetic heating on the fuselage is small (less than 2.5°C maximum at 140 knots). Hence the static air temperature provides a reasonable guide to the likelihood that ice will accrete on the fuselage and other components mounted on the fuselage. In the absence of external heat sources, therefore, the colder the air temperature the greater the ability for the impinging water to freeze on the airframe and other non-rotating components.

3.4 Cloud water droplet size

3.4.1 The mass of a water droplet is directly proportional to the cube of its diameter. As a consequence, droplets with large diameter (large mass and hence large inertia) will be affected less by the local aerodynamic forces and will tend to follow a straighter trajectory due to the dominant effect of the inertia forces. In contrast, droplets with small diameter and hence low mass will tend to follow the air streamlines and may not impact the surface. Hence, whether a droplet impacts the surface or is swept past the body in the airflow, depends on the ratio of the inertia to the aerodynamic forces. Put more simply, for a given droplet diameter, large bluff bodies (e.g. a fuselage) at low speed will collect less water than small streamlined bodies travelling at high speed (e.g. a rotor blade).

3.4.2 The diameter of the droplets within any single cloud will usually vary. The spectrum of droplets that exists in practice is frequently characterised by the VMD of the cloud (sometimes referred to as median volumetric diameter, (MVD)). This is the diameter above and below which half the mass of water is concentrated.

3.4.3 In general, as the ambient temperature reduces there will be a tendency for the diameter of the super-cooled droplets to reduce, since super-cooling is difficult to maintain in large droplets at low temperature. Hence 1 mm diameter super-cooled droplets would not be expected to exist at –20°C. Similarly, for a given cloud, the percentage of the water contained in droplets of diameter above or below the VMD will in general reduce, so that while 40 μm droplets may be present in a cloud which has a VMD of 20 μm, they will nevertheless be relatively few in number. Conversely, droplets with diameter below 10 μm may be numerous, but the mass of water associated with them will be small.

3.4.4 Though this spectrum may vary, historically, the Langmuir 'D' distribution (Reference 2) has generally been assumed in analyses to represent the spread likely to be found in practice. A similar distribution of droplets is produced by most spray nozzles in icing wind tunnels. As a very rough guide, the maximum diameter of the droplet in a cloud is usually of the order of twice the VMD.

3.4.5 The JAR-29 icing envelope requires a range of cloud VMD to be considered. The applicant must assess which combination of droplet diameter and water concentration leads to the maximum impact of water. The range of diameters (Mean Effective Droplet Diameter which equates to VMD) specified in JAR-29 extends from 15 μm to 40 μm (50 μm for intermittent icing). However, this range may be more appropriate to fixed-wing aircraft requirements because the collection efficiency associated with small droplets ($<$15 μm) impacting on large chord wings (e.g. 5m to 7m root chord on large transport aircraft) is likely to be very low. In addition, the larger droplet sizes are also more likely to be encountered at high altitude, beyond that at which rotorcraft will normally operate. Hence it is appropriate for manufacturers of large fixed wing aircraft to consider the larger droplet sizes. In contrast, the collection efficiency of water droplets on a rotor travelling at high subsonic Mach number is still significant for VMD values below the range covered by JAR-29. Hence the adverse effect of ice accretion on the performance of a rotorcraft can remain significant in clouds with a VMD less than 15 μm .

3.4.6 For helicopters operating below 10,000 ft altitude, the cloud VMD encountered is more likely to be in the range 5 μm to 20 μm. Of course, passage through hazardous conditions such as freezing drizzle, rain and active cumulus clouds will cause the aircraft to experience much larger droplets. Since water collection efficiency increases with VMD, it is appropriate to concentrate on the higher value of VMD for certification purposes, since exposure to these clouds is likely to produce the largest performance degradation within a given exposure time and cloud LWC.

3.4.7 The icing definition provided in BCAR paper G 610 represents a design condition in which a single diameter is specified for consideration (the document refers to 'mean' diameter; however, this should read VMD, the value of which is 20 μm). This value is therefore considered most appropriate to rotorcraft and is thought to represent a reasonable compromise as to the upper bound of the VMD that is likely to be encountered in practice whilst cloud flying.

3.5 Liquid water concentration (LWC)

3.5.1 This is normally expressed as the number of grams of water per cubic metre of air. The term 'liquid' reflects the super-cooled nature of the droplets and also acts to distinguish the state of the cloud from the ice crystal alternative. For helicopter operations with a limited icing clearance capability, which would normally involve flight through stratoform clouds or small cumulus clouds, the average LWC encountered is most likely to be between 0.1 g/m^3 and 0.5 g/m^3. However, the JAR-29 and BCAR paper G 610 both specify a larger range of LWC values that must be considered. The magnitude of the LWC, like the droplet diameter, tends to reduce with ambient temperature.

3.5.2 In general, the mass of water at the surface of a body will increase linearly with the LWC. Hence the greater the value of the LWC, the greater is the potential for a large accumulation of ice. However, this is not strictly correct since the collection efficiency of the surface will have an equally important significance in determining the actual mass of water that is incident at the surface. If a large mass of water is contained in droplets of a diameter sufficiently small to have no or little capability to impact the surface, then the resulting accretion will be small. There is therefore an optimum combination of droplet diameter and LWC which leads to the maximum water impact on the surface for a body of a given size and shape.

3.6 Airspeed

3.6.1 This is not in itself an 'icing condition', although clearly it has an effect on the handling and performance of the aircraft. The primary influence in terms of icing severity lies in the fact that the faster the airspeed the greater the intercepted volume of air in a given time and hence the greater the mass of water that will be intercepted. It is therefore the product of the collection efficiency, the LWC and the speed of the aircraft/rotor which determines the mass of water that will impact the surface and hence the amount of accretion.

3.6.2 In contrast, the degrading effects on performance caused by ice accretion (see section 4), primarily a large increase in profile drag, will be more pronounced at high forward speed, when the excess power available is reduced. Combined with the potential for the loss in maximum thrust due to early stall, the rotorcraft is not expected to be operated at the limiting speed available to the rotorcraft in clear air. Experience to date suggests that a 10 to 20 knots reduction in maximum speed over the corresponding clear air values is necessary to allow sufficient margin for flight safety when operating within the envelope of a limited icing clearance.

3.7 Altitude

3.7.1 As with airspeed, the altitude of the aircraft is not itself directly relevant to the icing severity in terms of the rate of ice accretion. There are, however, a number of important indirect influences of altitude on the icing severity (accretion rate) and the performance and handling of the rotorcraft.

3.7.2 The primary influence of altitude on the rate of ice accretion arises from consideration of the likely occurrence of icing conditions in the first instance. Since the air temperature will normally reduce with altitude, the potential for condensation of water droplets and hence icing conditions will increase with height. The study in reference 3 concludes that, over the UK, the most probable occurrence of icing is in the altitude band of 3000 ft to 5000 ft. With other icing parameters (OAT, LWC, VMD, speed) held constant therefore, the rate of ice accretion is not expected to be appreciably influenced by the altitude of the rotorcraft.

3.7.3 Because of the uplift provided in cumulus clouds, there is some evidence to suggest that the potential for large water concentrations may exist, particularly near the tops of clouds. Also in stratocumulus layers, because of their dynamics, the LWC will increase with height and the highest LWC's will be found, in general, a few metres from the tops of these layers.

3.7.4 The altitude capability of a rotorcraft for a given mass will be limited by a number of considerations, including the installed power and/or the maximum thrust capability of the rotor. It is therefore the existence of an excess power or thrust which enables a rotorcraft to climb. Routine helicopter operations are not normally expected above 10,000 ft, though some helicopters may have the capability in clear air for excursions to 15,000 ft and higher altitudes with appropriate role (oxygen) fits. It is, however, unlikely that a limited icing clearance will be required for routine operations at altitudes above 10,000 ft. Operations over mountainous terrain offer the potential for significant additional hazards from air turbulence and poor visibility and are not therefore addressed further in this report. It is also less likely that the required escape route into clear air will be available when operating over mountainous terrain.

3.7.5 If a rotorcraft is operating close to its maximum thrust capability (maximum thrust coefficient) it is possible for the iced rotor to stall early and, in addition large power/torque requirements and increased vibration may well limit the capability of the rotorcraft to climb. There have been a number of reports during military helicopter operations when the aircraft lost the ability to climb further during flight in icing cloud. Furthermore, on levelling after climbing through cloud, whilst accreting ice, it has often been found that the power required to maintain level flight was in excess of that allowable. This phenomenon is believed to be a consequence of ice that has accreted on the leading edge of the blade during climbing flight which on entering level flight has a greater significance to drag or lift loss associated with the pitch change and change in the inflow angle of the air through the rotor disc.

4 EFFECTS OF ICING

4.1 General

This section provides a description of the likely effects of ice accretion on the performance and handling of the rotorcraft and the measures which should be undertaken to ensure flight safety.

4.2 Performance related issues

4.2.1 The performance of the rotorcraft will be restricted predominantly as a result of ice accretions on the leading edge of rotor blades (assuming unprotected rotors). The ice shapes modify the lift, drag and pitching moment characteristics of the sections. Degradation of the lift characteristics will result in the need for increased collective input to the main rotor, with consequent increased power requirement (torque) for a given flight condition and blade stall margins will be eroded. Changes to pitching moment characteristics may manifest in increased control loads which may not be obvious to the pilot unless special instrumentation is available. However, by far the most significant effect of ice accretion is likely to be its effect on the profile drag of the section. Large increases in drag, sometimes over very short time periods (e.g. less than 1 minute) result in a significant torque rise and care needs to be taken to avoid reaching the limit imposed by either the transmission or the engines. The torque rise may be accompanied by changes in the handling and vibration characteristics of the aircraft.

4.2.2 Most new rotorcraft types employ advanced composite blade technology. Indeed, modern rotor blade design is such that composite materials are almost essential to provide spanwise distribution of section, twist, aeroelastic stiffness and advanced anhedral tips integrated with the rotor blades. Whilst advanced blade design offers significant performance improvements in normal, non-icing, conditions, it should not be assumed that the modern technology rotor will be more tolerant to icing, or will provide benefits over the more traditional designs.

4.2.3 As noted above, the torque rise is likely to be a restrictive factor in any limited icing release for a cold bladed rotor and results in the need for appropriate torque margins for flight throughout the envelope, including manoeuvres. Clearly, exceeding torque limits would be potentially hazardous to the rotorcraft even allowing for permissible transient levels.

4.2.4 Under certain icing conditions, the torque rise may stabilise due to self-shedding of the ice from the rotor. At the warmer air temperatures, this may result in a torque which remains within acceptable limits. At colder air temperatures, the torque rise is less likely to stabilise within the acceptable limits and the aircraft may be forced to vacate the icing conditions.

4.2.5 A secondary icing influence on rotorcraft performance is the effect of increased parasite drag arising from accretions on the airframe. This is unlikely to be a significant feature and it will not normally be practical to discriminate this from the overall increase in torque (power) required to sustain flight in the icing conditions. Only by a detailed analysis of torques measured during prolonged flight in icing may it be possible to discern the level of secondary torque rise.

4.2.6 A detailed performance analysis should therefore be conducted for each icing encounter and great care will be required in the interpretation of the data. Ideally this should include analysis of torque measurements from each of the engines, and at the main and tail rotor mast. It is however recognised that in practice special torque measuring instrumentation may not be available on all these subsystems and the analysis possible may therefore be limited. The processing of the torque data will be greatly simplified if steady-state conditions exist, and though not easy to achieve, every effort should be made to maintain smooth level flight conditions at constant speed. The aim of each flight should be to reduce the variables to those imposed by the icing condition while controlling all others.

4.2.7 In order to determine the torque rise, the clear air datum performance of the aircraft must be known. This data must be appropriate to the intended operation and configuration of the trials aircraft. This is particularly true if the trials aircraft has additional camera equipment fitted for the purpose of the trials. The trials icing instrumentation may therefore pose a significant increase in the parasite drag relative to the non-trials aircraft.

4.2.8 When analysing the performance degradation the effect of any air turbulence needs to be considered. If present, the value of the clear air datum performance may be limited, and hence datum performance checks should be conducted prior to entering the icing cloud.

4.2.9 Data reduction will necessitate a systematic approach. Initial analysis will require selection of samples of data for stable conditions within the icing encounter, ideally in excess of 60 seconds, and preferably much longer. Consideration should be given to the nominal torque rise as well as any transient peaks. For each icing encounter, the aim should be to relate a given icing condition to the measured performance of the aircraft.

4.2.10 All conditions for which unacceptable performance has been demonstrated should be identified as they represent regions of potentially unsafe flight and thus define the boundaries of the release either in terms of temperature, altitude or severity. It is possible that specific occurrences are experienced within an otherwise apparently acceptable region of operation. Provided the incident is isolated and clearly definable boundaries can be expressed, it may be possible to reason that the test point is unusual due, perhaps, to a short duration high severity, or large droplet encounter for which recurrence is considered highly remote. Most such occurrences may be experienced in a very short time period and may occur following a climb through icing conditions, particularly when the rotorcraft enters level flight. At such times, the flight condition sought may be unattainable within allowable torque limits.

4.2.11 It is likely that examination of acceptable performance in icing conditions will result in a speed restriction to ensure adequate power margins are maintained. Speed limitations will need to be established over the envelope for which the release is sought.

4.2.12 The degrading effects of ice on performance means that performance data in the flight manual may not be relevant, and may thus have to be re-scheduled. This relates to all aspects of performance, including flight with one engine inoperative.

4.3 Handling related issues

4.3.1 To ensure flight safety is not compromised, static and dynamic stability must be demonstrated to be consistent with the requirements BCAR G2-6 to G2-10, including relevant Appendices, for all conditions for which release is sought. (JAR 29.141 to 29.181 and Appendix B paragraphs I to VI also refer). Sufficient data should thus be gathered over the intended icing envelope for an appropriate comparison with the non-iced aircraft for any critical all-up-weight (AUW) and CG combination.

4.3.2 The comparison should be conducted against the longitudinal and lateral directional static stability curves over the speed range and an assessment made to ensure that dynamic stability damping characteristics have not been significantly affected.

4.3.3 It may be necessary for a rotorcraft that has an active stabilator type device or is sensitive to horizontal (or vertical) stabiliser performance to be assessed in non-icing conditions with simulated ice shapes attached. Such investigation should be progressive and final ice shapes should reflect the maximum achievable accretion within the constraints of the icing release sought.

4.3.4 Whilst static and dynamic stability may remain within acceptable limits it is possible for any automatic flight control system (AFCS) employed to be subject to conditions outside normal parameters of operation. Any installed AFCS should therefore be monitored to ensure operation remains stable over all conditions encountered with due consideration to any possible limits that may be exceeded or met.

4.3.5 AFCS performance assessment would need to accommodate all appropriate manoeuvre cases as well as steady state level flight conditions. The emphasis on all AFCS performance investigation should be in determining any possible onset of instability in operation and to ensure that once such regions are identified, appropriate margins of safety can be defined.

4.3.6 An appropriate manoeuvre block should be conducted at intervals throughout data gathering activities in all conditions. The manoeuvre block should be most informative when rotor effects have stabilised, i.e. torque rise and any self shedding effects have demonstrated repeatable cyclic characteristics, and airframe ice accretions (particularly on aerodynamic surfaces) are maximised.

4.3.7 The manoeuvre block should consist of bank turns leading to roll reversals, climbs and descents and increasing/decreasing speeds. In addition, and of major importance, the ability to enter into and recover from autorotation should be demonstrated over the widest range of conditions possible. During such manoeuvre blocks, the general stability and handling of the rotorcraft may require increased caution and all manoeuvre cases so covered should be undertaken to progressively expanded limits to ensure any destabilising influences are encountered equally progressively.

4.3.8 It is possible that margins against the rotorcraft blade stall envelope may be eroded such that particular flight conditions in icing may define a revised boundary. It is thus necessary to have an understanding of the baseline rotorcraft blade stall envelope such that some degree of margin may be demonstrated to be maintained for a minimum number of critical conditions with due consideration to any possible variability in result that may be experienced.

4.3.9 Accretion of ice on rotor blades may also induce aerodynamic flutter, although this is likely to be a rare occurrence and is not applicable to all helicopter types. Only by obtaining a wide range of data in various icing conditions and assessing all aspects of rotor and rotorcraft handling over those conditions, may sufficient confidence be obtained to eliminate such possibilities from any limited icing envelope. The chance of encountering such potentially hazardous conditions also demonstrates the need to conduct investigative data gathering flights in conditions with adequate escape routes and safe areas for emergency landings particularly for any initial encounters until confidence in aircraft behaviour can be gained.

4.3.10 It is important that flight crew employed for the data gathering activities are appropriately trained and experienced to identity and subjectively assess any degradation of rotorcraft handling and have a thorough knowledge of base line criteria and the piloting actions required.

4.4 Stress and fatigue life issues

4.4.1 Aircraft loads generated within both static and dynamic components require particularly careful consideration for flight in icing conditions. Whilst performance or handling degradation may be quantifiable by aircrew in flight, changes in airframe and component loads are not likely to be directly discernible. Critical components and relevant areas of the airframe are likely to require monitoring and to undergo data gathering activities to ensure that loads remain within acceptable limits and that safe life is consequently not compromised.

4.4.2 Basic structural airframe static loads are unlikely to be significantly affected by ice accretion. Load paths for any aerodynamic surfaces (fixed or moving) should be considered with respect to the possible limit size/mass of ice that may accrete within the constraints of the possible icing flight envelope and any associated increase in aerodynamic loading that may result from the accretions. Concern regarding possible increase in loads should not necessarily be assumed. It is possible for loads to be reduced as a result of ice accretion but consideration to possible dynamic effects should still be maintained.

4.4.3 Dynamic loads within the basic structure require more careful consideration due, primarily, to the possible change in dynamic characteristics of components arising from the change in mass distribution, stiffness distribution, and aerodynamic forcing produced by the accreted ice. Reference should also be made to Section 4.5 regarding vibration aspects related to flight in icing conditions. Of particular relevance under this category would be the example of an unprotected horizontal tail stabiliser which, when subject to ice accretion, would generate increased static loads on attachment points due to mass and drag rise. The example would also be subject to a change in dynamic characteristic due to mass, CG and inertial changes thus influencing forcing frequencies and amplitudes of cyclic loads generated.

4.4.4 Basic structural dynamic loads may also be modified by loads generated through rotor forcing frequencies passing directly through main lift frames as a result of rotor imbalances arising from ice accretion and shedding.

4.4.5 These basic precepts for the airframe equally apply to all ancillary equipments attached to that airframe such as aerials, scoops, fairings and windscreen wipers.

4.4.6 Dynamic components including flight controls may be particularly susceptible to increased loads due to rotor icing and a thorough understanding of critical load paths within the control system will be essential. Experience has shown that flight control loads can exceed safe limits within 60 seconds of entry into icing conditions and an additional flight instrument display of a critical load to aircrew may prove to be necessary for a limited icing release.

4.4.7 It is possible for the cyclic loading on a dynamic component to increase as a result of rotor icing such that safe life of that component is reduced to minutes. A full analysis of any impact on safe life should be eased by a close working relationship with the rotorcraft manufacturer where component life data and endurance capability should be available. This analysis may require detailed load cycle counts and extensive strain gauge data is thus likely to be necessary. The extent of data for evaluation will need to be considered prior to flight into icing and may demonstrate the need for instrumented rotor blades, heads and mast as well as critical flight control components.

4.4.8 Unless all loads can readily be referenced to a number of key channels available and monitored in real time during data gathering flights the nature of the possible impact of those load paths on flight safety is such that an assessment of loads will be necessary between flights. This may have a significant impact on the defined scope of any necessary data gathering required to support a limited icing release and on the definition of a cautious and progressive expansion of investigation into the intended envelope of operation.

4.4.9 It must be remembered that the envelope to be explored must encompass the speed range for all AUW and CG configurations sought and that due consideration to manoeuvre cases must also be made. The icing release may result in restrictions to various aircraft manoeuvre cases if this is necessary to contain loads within acceptable criteria.

4.5 **Vibration related issues**

4.5.1 The rotorcraft is particularly and inherently subject to high levels of induced vibration resulting from the rotors and associated transmission systems employed. With high forcing characteristics over a wide range of frequencies, normally acceptable levels of response within the airframe can be compromised by any changes to those forcing influences.

4.5.2 The result of flight in icing conditions can be to change both forcing characteristics and airframe response arising from ice accretions and their associated mass and distribution of mass. Shedding of such accretions from rotors will be almost inevitable owing to the loading environment. Without some form of active de-icing system, shedding is most unlikely to be equally and simultaneously balanced on all blades of any one rotor and may normally be considered asymmetric to one degree or another. The resultant out of balance of the rotating system may then lead to unacceptable levels of vibration within the airframe.

4.5.3 The vibration may be subjectively noticeable to aircrew and may demonstrate consistent cyclic features. Such cyclic effects are likely to be at blade forcing frequencies rather than rotor forcing frequencies and may result in a momentary rotor forced 'shrug' at the end of the cycle. These effects will differ with rotor system and may not be discernible in all rotorcraft types. It may be found that some conditions encountered result in a marked level of asymmetric shed leading to high levels of subjective 1R vibration which may be so high as to make continued flight impractical. Every effort should be made during the trials to explore any such limiting conditions. It is possible they may be related to particularly cold conditions when increased ice adhesion leads to an increased mass of ice on the rotor, prior to shedding. The increased mass of the accretion may also result from exposure to a cloud containing large droplets. Any such condition encountered within an otherwise fully acceptable envelope should be subject to a careful assessment with respect to the probability of repeated experience and the ease of escape and recovery from that condition.

4.5.4 The effects described above are predominantly those that may be readily assessed subjectively by aircrew and may be differentiated into those which impact on acceptable levels of ride comfort through to, as indicated, the ability by the aircrew to continue flight. Such subjective treatment should be based on an agreed rating system for vibration level.

4.5.5 Against any subjective level of assessment there is also a need to conduct an associated measured analysis based upon recorded data from critically located transducers. A relatively low subjective level may result in a locally high measured value within a critical component (such as within the flight control system) which may then have an unacceptable impact on the safe life of that equipment as discussed earlier (4.4 refers). It is also possible for such effects to be recognised within the activity of the AFCS or similar control system.

4.5.6 The dynamic response of a particular part or component of the rotorcraft may be further modified or exacerbated owing to direct ice accretion on that component with resultant mass distribution. Parts of the rotorcraft particularly vulnerable to these effects are aerodynamic stabilising surfaces and antennae. In these instances, the component may develop a resonant characteristic not previously recognised without ice accretion and in response to normal and subjectively acceptable forcing conditions. The location of any recording instrumentation transducers thus requires careful consideration prior to the flight programme to facilitate detection and measurement of such responses.

4.5.7 If possible, following prolonged exposure to ice and/or snow conditions, rotor track and balance should be checked to ensure potentially significant unshed accretions are not retained. Dependant upon blade and rotor head design, pockets may be incorporated which though provided with a means of water drainage, may become blocked by ice and thus result in the pockets filling. The chordwise balance of rotor blades is normally critical and the addition of a significant mass of ice in a root end pocket may affect the track and balance. In addition to a track and balance assessment, a visual examination for retained ice should be conducted as quickly as possible following rotor shut down.

4.5.8 Whilst conducting an evaluation of vibration levels during and after flight in icing conditions, consideration should also be given to any active response damping systems that may be employed on the rotorcraft. The safety criticality of such systems should already be recognised but further consideration is required of possible failure modes that may arise. An active response system should be equally effective in icing conditions and is likely to mask possible subjective features. Although the failure of that system may be sustainable in normal flight, in icing conditions the cumulative vibration arising following failure may prove unacceptable. In consequence, consideration should be given to testing the aircraft in icing conditions with the active vibration reduction system in its failure mode. This testing should be done in a progressive manner, leading to testing at cold temperatures and/or high LWC only after experience is gained in less severe icing conditions.

5 TEST EVIDENCE REQUIREMENTS

5.1 General

5.1.1 This section provides a brief description of the test evidence, both of rig and flight trial origin, which will be required to support a limited icing clearance. It is important to note that a clearance can only be granted on the basis of the test evidence provided. The sections which follow attempt to describe the minimum level of evidence below which certification is unlikely to be obtained. Since the effect of ice accretion will vary with aircraft type, and even with the modification standard of the aircraft, it is not possible to specify precisely the thresholds of data in terms of simple pass or fail criteria. The test data will therefore be considered on its merits and in relation to the extent of the limited clearance requested.

5.1.2 The test data requirements in section 5.2 take account of the expected difficulty in finding the extreme LWC conditions within a practical trials period. The test data requirements given are therefore considered to be a compromise between the need to ensure adequate flight safety, and the time and costs involved with testing over the full icing environment specified in JAR-29 Appendix C, and in BCAR Paper G 610.

5.1.3 Demonstration of the point performance requirements identified below should be achieved with the aircraft iced to the most critical condition required for operating in icing conditions.

5.1.4 It is important that flight crew employed for the data gathering activities are appropriately trained and experienced to identify and subjectively assess any degradation of rotorcraft handling and have a thorough knowledge of base line criteria and the piloting actions required.

5.2 Test data required

5.2.1 For a limited icing release, satisfactory test experience and demonstration of safe flight should be gained in each of the following temperature bands:-

0°C to –2°C
–2°C to –4°C
–4°C to –6°C
–6°C to –8°C
–8°C to –10°C
–10°C to –12°C

5.2.2 The lowest temperature certificated for flight is likely to be the lowest achieved in the lowest temperature band. There should be no gaps in the test data in each temperature band above the lowest temperature at which certification is sought.

5.2.3 For each of the above temperature bands, the test experience should meet the following requirements:

(a) A minimum total of 1.5 hr should have been flown in conditions in which the LWC was greater than 25% of the continuous maximum value specified in JAR 29 Appendix C for the appropriate altitude and temperature of the test. In selecting the LWC, no alleviation of severity with horizontal extent should be allowed. Two separate flights should contribute at least 30 consecutive minutes each to the total duration.

(b) A minimum of 10 consecutive minutes should have been spent in LWC's in excess of 60% of the continuous maximum value appropriate to altitude and temperature of the test.

5.2.4 The cloud volume median diameter should be measured for each icing encounter. Test data should include at least one flight in a cloud with an average VMD of 15 mm and preferably at least one flight in cloud with an average VMD of 20 mm or larger since the effect on the performance of the rotorcraft is more likely to be discernible at the larger values.

5.2.5 The maximum altitude certified for flight in icing will normally be the lowest that was found acceptable in any of the temperature bands. The aircraft will not be allowed to fly at altitudes higher than those tested in order to avoid potential handling difficulties arising from premature blade stall.

5.2.6 Where significant airframe accretions are identified, the case should be made to demonstrate that these have no adverse effect on the aircraft. Dependent on the outcome of this investigation, accretion limits may be necessary.

5.2.7 Test data should cover the range of speed, aircraft mass and CG range appropriate to the clearance sought.

5.2.8 Evidence should be provided that the helicopter can safely enter into, and exit from autorotation when the rotors are iced. This should include demonstrations with the rotor iced to the limit of the torque rise allowed for icing flight.

5.2.9 A detailed performance analysis should be conducted for each icing encounter in order to provide quantitative evidence of the torque increase incurred. Refer to Section 4.2 for additional requirements and advice on performance aspects.

5.2.10 Within the envelope for icing flight, the test data should indicate that the appropriate engine and transmission power ratings will not be exceeded or, alternatively, the pilot should be given direct indication of power or torque so that he can take action to avoid exceeding the rating.

5.2.11 To ensure flight safety is not compromised, static and dynamic stability must be demonstrated to be consistent with the requirements BCAR G2-6 to G2-10, including relevant Appendices, for all conditions for which release is sought. (JAR 29.141 to 29.181 and Appendix B paragraphs I to VI also refer). Sufficient data should thus be gathered over the intended icing envelope for an appropriate comparison with the non-iced aircraft for any critical AUW and CG combination. Refer to Section 4.3 for additional requirements and advice on gathering handling data.

5.2.12 Any installed AFCS should be monitored to ensure operation remains stable over all conditions encountered with due consideration to any possible limits that may be exceeded or met.

5.2.13 As the presence of snow is difficult to detect whilst in cloud, and the effect may be damaging, specific snow flying tests clear of cloud are deemed to be a necessary part of the process of acquiring a limited icing clearance. Snow clearance requirements and advisory material may be found in JAR 29.1093, AC 29-2A paragraph 532 sub paragraph C, and Paper G610.

5.2.14 Similarly, it must be shown that the engine operation is satisfactory and that the engine protection system will prevent, with an acceptable level of probability, engine damage or flame-out from snow or ice ingestion. The engine response rates achieved in icing must be suitable for power changes appropriate to instrument flight. In addition to checking satisfactory engine behaviour in each of the temperature bands given above, evidence must be provided that flight in precipitation such as rain and/or cloud at temperatures between 0°C and +10°C does not promote any engine intake icing problems which may arise due to local pressure variations[4].

5.2.15 If the engines are protected from shed ice by the use of mesh screens, filters, vortex tubes etc., consideration must be given to the potential for air intake blockage by ice or slush and any likely adverse effects on the engine or mechanical integrity of the protection system itself produced by this. Before undertaking practical trials in icing,

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[4] Cases of engine damage have been attributed on certain engine/intake configurations due to ice ingestion resulting from intake pressure variation causing ice accretions to form and shed at ambient temperatures well above 0°C.

it may be necessary to undertake rig, ground or flight tests in clear air with simulated blockage of the intake representative of the maximum envisaged in icing. Use of pressure monitoring instrumentation during such testing may provide essential data and limitations to be used during icing trial encounters to avoid hazardous blockage conditions.

5.2.16 A separate demonstration of satisfactory engine performance in snow conditions will be necessary covering the temperature range from +2°C to the coldest temperature of the limited icing clearance. Great importance is likely to be placed on the provision of data proving satisfactory operation in wet, heavy[5] snow in the temperature range +1°C to -2°C, since practical experience has shown that large slush accretions can grow rapidly in this temperature band.

5.2.17 The validity of a test point will depend, in part, on whether the effects of the icing on the helicopter have resulted in a stabilised condition being achieved. For instance, demonstration of an acceptable torque increase due to icing after a three minute icing encounter, say, is significant only if both the icing conditions were stable and if the torque increase had reached an equilibrium during this period. There is therefore evidence to show that exposure to an icing encounter of longer duration would not have led to an unacceptable torque increase had this condition been met. This concept applies equally to other parameters such as engine performance, component stress levels, the blockage of intake screens, blockage of drains and vents, and in the level of visibility achievable through transparencies. Furthermore, where heating is used for protection, it should be shown that for the conditions experienced, the surface temperature was not decreasing to the point such that ice accretion would have formed had the condition existed for a longer period.

5.2.18 If certain test points give unsatisfactory results, i.e. the specified handling or performance criteria cannot be demonstrated, then it should be possible to construct a flight envelope for operational use which excludes such points. If unsatisfactory points cannot be so excluded then it is probable that the release for flight in icing conditions will not be approved.

5.2.19 During flight in icing conditions the blade stall envelope of the rotorcraft is likely to be degraded compared to that of the baseline aircraft. Evidence should be provided to demonstrate that an adequate margin is present during flight in icing, to avoid possible exceedence of the blade stall envelope of the rotorcraft.

5.2.20 Critical components and relevant areas of the airframe should be monitored and undergo data gathering activities to ensure that loads remain within acceptable limits and that safe life is consequently not compromised. Refer to Section 4.4 for additional requirements and advice on gathering stress and fatigue life data.

5.2.21 Evidence should be provided to demonstrate that vibration levels remain acceptable during flight in icing, both in relation to the crew and any passengers, and the airframe and its installed equipments. This will involve both a subjective treatment and an associated measured analysis based upon recorded data from critically located transducers. Refer to Section 4.5 for additional requirements and advice on gathering vibration data.

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[5] Associated with forward flight in falling snow clear of cloud with an accompanying reduction in visibility due to the precipitation alone to 400 metres or less.

5.2.22 Evidence should be provided as to the satisfactory positioning of any ice detection and measuring systems fitted, whether for trials or in service use. This may be by a combination of analysis and/or test evidence which should confirm that the detection equipment is not sited in an area of local enrichment or, more importantly, depletion of the icing conditions. All ice detection and measuring equipment (temperature, LWC, droplet size) must be adequately calibrated before use.

5.3 Use of supporting analysis data

5.3.1 While the use of rig and analytical data is unlikely to be accepted in isolation as evidence to support a limited icing clearance, the data is nevertheless seen as important to the process of obtaining a clearance since this may allow a better understanding of the aircraft and system characteristics in conditions that have not been tested in the natural environment.

5.3.2 Testing in icing wind-tunnels of items such as icing instruments (LWC meter if fitted) and sub-system components (pitot-static systems, fuel vents, aerials etc.) is therefore encouraged. In practice, some of these items such as icing LWC instrumentation and pitot static systems would normally have been tested by the instrument manufacturers.

5.3.3 Icing instrumentation must be adequately calibrated and this will normally require testing in an icing wind tunnel. The LWC, OAT and VMD measuring systems must be calibrated, even if, in the case of VMD measuring systems, they are only fitted to the trials aircraft.

5.3.4 The performance of larger systems, such as engine intakes, will normally need to be evaluated in an icing wind tunnel in order to test to the full extremes of the icing atmosphere. However, such testing is unlikely to be comprehensive, since snow, and in particular wet snow, is very difficult to simulate and therefore will require testing in natural conditions. Furthermore, due to the constraints on the size of the component that can be tested in the rig (i.e. potentially limited to the immediate vicinity of the intake lip) the trajectories of ice shed from components mounted forward of the intakes may not have been fully evaluated and hence this aspect will need to be investigated during flight in natural icing conditions.

5.3.5 The engines will have been qualified by the manufacturer for operation in icing conditions to the full JAR-29 Appendix C conditions, and this evidence will be essential in support of a limited icing clearance. However, as noted above, the likelihood of snow and ice ingestion must be evaluated on the installed engine(s), and hence evidence in natural snow and icing conditions will need to be provided before a snow and icing release can be granted. The availability of test evidence providing an indication of the engine's tolerance to water, slush and ice ingestion may ease establishing a limited clearance, particularly if accretions areas are identified that could build and shed ice into the engines. Without such information, it is likely that the certificating authority will take a pessimistic view as to the likelihood of engine damage and flame out whilst flying in snow or icing, particularly when accretions are seen during testing to grow in and shed from areas that represent a potential hazard to the engine.

5.3.6 In recent years, analytical tools have been used increasingly to predict ice formation on components of fixed-wing aircraft. Two-dimensional methods for aerofoils and wings are now well established in Europe and in America. Three-dimensional models are less well developed and are not yet routinely applied in support of icing clearances. For rotorcraft, prediction methods can be useful as a guide to the likely size and extent, both chordwise and spanwise, of ice accretions on rotors. In addition, icing codes for three-dimensional flow are finding increasing application to the assessment of engine intake icing.

5.3.7 The prediction of the torque increase produced by ice accretion on an unprotected rotor provides an invaluable insight into the physics of the icing process, and are essential tools in the cost-effective development of rotor ice protection systems. However, their role in the certification of a limited icing clearance is less clear at this time, since it is likely that the performance code would simply confirm the highly degrading effects on performance of the ice accretion. At this time, any limited clearance will be granted in the certain knowledge that under conditions within the permitted envelope for icing flight, the aircraft may be forced to vacate icing on occasions. The need to exit icing could be due to large torque rise, severe vibration, because the accretions on the airframe are of a size likely to cause a hazard to the aircraft, or to observe other limitations imposed by the manufacturer. The ice accretion and performance degradation methods are therefore likely to confirm that the rotorcraft would be forced to vacate the icing conditions had the particular severity and duration been encountered in practice. Although the ability to forecast icing has improved considerably in recent years, the variability and unpredictability of the weather is such that, for the foreseeable future, aircraft with limited clearances will meet icing conditions that are identified by analytical methods as being beyond the continuous flight capability of the aircraft. This likelihood places considerable importance on the need for diligent flight planning to maintain an escape route at all times for such eventualities.

5.3.8 Analysis may also be used to confirm that a report of satisfactory handling and performance in a particular icing condition is truly a generally applicable feature. For example, the merits of a satisfactory demonstration of operation in a high liquid water concentration cloud would be significantly reduced if analysis suggested that, due to the small diameter of the droplets experienced in practical tests, little of the water actually impinged on the rotor or other critical components.

5.3.9 A particularly useful role of analysis is in the use of water droplet trajectory calculations around the fuselage to confirm the correct placement and heating intensities of electrothermal anti-icing mats used in areas requiring protection. Such techniques are also of much value in the siting of ice detection and measuring equipment. Inertial separation of water droplets as they pass close to the nose of the aircraft can lead to an ice detector either over or under sensing the severity of the condition (see paragraph 5.2.22). The calibration of an LWC meter in an icing wind tunnel does not guarantee that the equipment will measure accurately the icing conditions when in flight. An analysis should therefore be used to support the placement of ice detection equipment. If no suitable analysis method is available, then an alternative is to evaluate different positions on the aircraft during the icing trial. Strategically placed, small diameter, cylindrical rods have been successfully used on military helicopter icing trials to investigate variations in water concentration and hence to confirm the best placement of detectors. Actual placement of instruments will, however, be restricted to locations in which the appropriate electrical, mechanical, and air systems services can be provided. Clearly, the site of such LWC sensing devices used during trials work, should remain unchanged on an aircraft with a limited icing clearance if the instrument is to be fitted and used to respect limitations or to provide advisory information.

5.3.10 For the case of fixed-wing aircraft, ice accretion prediction codes are used to establish the shape and size of accretions on unprotected areas. Replicas of these ice shapes are then tested on a wing section in a conventional tunnel, prior to the flight test evaluation, in order to establish that the handling and performance characteristics remain satisfactory. A similar approach could be applied to the stabiliser and fin of the rotorcraft if a problem was thought to exist with these components. At the present time, such techniques are, however, unlikely to be feasible for in-flight identification of rotor performance degradation associated with blade icing. This is due to the multiplicity and complexity of ice shapes that can occur, coupled with the mechanical difficulties of carrying out the tests.

5.4 Trials method and flight test techniques

5.4.1 The trials method and instrumentation fit should be agreed with the certificating authority before the flight trials commence. Outlined below is a suggested trials method which reflects experience gained during icing trials for the clearance of military helicopters. The trials method may, however, be modified as appropriate. A check list covering some of the areas to be considered is provided at Appendix 3.

5.4.2 Before launching on a trials flight looking for icing conditions it is essential that the crew seek a clear understanding of the weather anticipated and operating constraints in the trials area. Where possible a prior knowledge of the level of cloud base, cloud top, layers present, cloud types, temperatures in cloud, forecast and pilot reports of icing severity's and details of precipitation should be sought.

5.4.3 Tests should be made in a controlled, cautious and progressive manner, starting, where possible, with conditions of very light icing severity with the ability to escape the icing condition quickly should unexpected effects occur, or higher than the required LWC be present.

5.4.4 Clear air flight performance tests should be flown with the aircraft in the trials configuration over a range of gross mass throughout the level flight speed range and for the appropriate CG range. This data will provide an accurate datum for the trials aircraft which will enable the effect of icing on aircraft performance to be assessed.

5.4.5 A typical icing sortie may include the following legs:

(a) Transit to the operating area.

(b) Datum performance checks clear of cloud.

(c) Initial climb through cloud to above the maximum anticipated test altitude.

(d) Flight in the optimum icing conditions as identified in leg (c).

(e) Return to base and land.

5.4.6 The datum run should include a range of speeds expected to be used in icing. The datum check provides an indication of the scatter in the test data (e.g. due to air turbulence) and allows ready identification to aircrew of the torque rises. A duration of around 2 minutes is likely to be required to record the relevant parameters. Any anticipated failure testing to be undertaken whilst in icing, such as total or partial loss of protection system, should be checked prior to entering the condition. The period associated with datum runs may provide the ideal opportunity.

5.4.7 The climb through cloud should be used to identify the best, or desired, icing conditions present in the layers. The aircraft can then be flown at the altitude which offered the most desirable combination of LWC and temperature conditions. It is important that the test airspeed is maintained by appropriate use of the collective. If airspeed is allowed to fall during the encounter, the true aerodynamic performance degradation may be masked.

5.4.8 In addition to the recording of LWC and OAT, it is essential that cloud droplet size measurements are recorded during the encounter; the reasons for this are explained in Section 3.4. These may be either continuous measurements obtained using Knollenburg nephelometers, or discrete measurements using a soot gun or oil slide method, as preferred. When Knollenburg instruments are used, it is advisable to check their continued accuracy by occasional use of a soot gun or oil slide method. Failure to measure the droplet size of the cloud at regular[6] intervals during the encounter will place an unacceptable risk on the validity of the test evidence. Throughout each encounter, the presence of any precipitation should be noted as this may present adverse effects peculiar to precipitation or the consequence of mixed conditions.

5.4.9 Also at intervals during the encounter, various manoeuvres should be performed in order to assess any changes in aircraft handling due to accreted ice. Manoeuvres are likely to include, climbs, descents, speed changes, banked turns, roll reversals and descending turns. In addition, safe entry into and exit from autorotation should be demonstrated with an iced rotor. Such autorotations should be undertaken in a progressive manner with increasing levels of torque rise present, up to the maximum permitted.

5.4.10 Throughout icing encounters the observers should monitor those areas of the airframe where accretions may occur that could hazard specific systems or the aircraft as a whole. This includes accretions that build directly due to the impingement of super-cooled droplets or snow, or indirectly in the form of runback ice accretions which form from ice melting at an upstream location. Records of all observed accretions must be kept along with details of shedding characteristics.

5.4.11 Where ice protection systems are employed, it may be necessary, dependent upon the likely failure probability, to undertake a series of controlled failure tests in icing to verify the adequacy of backup systems or the rate at which the onset of adverse affects to systems or the aircraft may occur.

5.4.12 If the torque value or the torque increase approaches the designated limit, then action should be taken to alleviate the condition, initially by reducing airspeed, and ultimately by vacating the icing cloud. Such occasions may provide the opportunity to check autorotative capability as noted in 5.4.9.

5.4.13 It is recommended that initial flights are conducted at low aircraft mass, and as experience is gained, aircraft mass is increased up to the maximum take-off mass allowed.

5.4.14 Immediately after landing and shut down, a close inspection and detailed notes should be made of any residual ice accretions. Particular emphasis should be placed on the inspection of vents, drains, engine intakes, hub and control linkages. Engines, rotor blades and the airframe in general should be inspected for shed ice damage,

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[6] Eight to ten slides have typically been taken during icing encounters lasting 60 minutes on military aircraft trials.

dents etc. Photographs and video records should be taken of all significant accretions remaining.

5.4.15 If the flight in icing is interrupted, possibly due to broken or patchy cloud cover, the flight should be analysed in terms of separate and discrete encounters. When analysing the flight data, the average should be based on the individual encounter time rather than the total duration of the flight. The encounter duration should not be less than around one minute in order to allow a sufficient period over which to produce a representative average for the conditions. However, it is likely that a longer period in icing conditions may be necessary in order to establish the true effect on the rotorcraft.

5.5 Instrumentation requirements

5.5.1 In addition to the normal instrumentation required for flight performance and loads measurement along with that peculiar to any ice protection systems fitted, the trials aircraft should be fitted with the following icing specific instrumentation. An appropriate recording system will be needed to provide a continuous record of data for the display of selected parameters in flight and for subsequent ground based analysis.

5.5.2 The icing trials aircraft must be fitted with instrumentation to measure the following parameters:

(a) OAT

(b) LWC

(c) VMD

5.5.3 Consideration should be given to fitting the following optional photographic equipment:

(a) Still cameras – synchronised to rotor for in flight recording of ice on main and tail rotor blades.

(b) Video cameras – to record/monitor the engine/APU intake performance in icing along with other areas where accretions may present a hazard to the aircraft. The use of a handheld video camera to record all accretions present at landing is advisable.

6 PROCEDURES AND DOCUMENTATION

6.1 Introduction

6.1.1 This section is intended to give guidance on appropriate procedures and documentation to be used and provided to assist in obtaining a Limited Icing Clearance. Although this section provides guidance, the large number of variables possible when establishing an icing programme mean that early discussion should take place with the Authority to ensure there is a mutual understanding of all aspects of the programme and approval procedures.

6.1.2 Icing trials are complex and potentially dangerous. Any organisation intending to carry out such trials must have an appropriate level of Design and Flight Test Approval.

6.2 Outline

6.2.1 The key procedural and documentation elements are:-

(a) Certification Basis.

(b) Test Plan and Means of Compliance.

(c) Reporting and showing of Compliance.

(d) Definition of Series Aircraft build standard.

(e) Flight Manual.

6.2.2 These elements will be discussed below.

6.3 Certification Basis

The applicable requirements must be established before the trials begin. The rotorcraft must have IMC/IFR, CAT A and snow flying clearances and will have to continue to meet all the requirements applied to the original approvals when operating in icing conditions. In addition the appropriate icing requirements as contained in BCAR Paper G610 will have to be met. If the rotorcraft or it's systems have any unique features, it may be necessary to develop appropriate Special Conditions.

6.4 Test Plan and Means of Compliance

6.4.1 A detailed Test Plan should be submitted for agreement with the Authority. This plan must include the means by which compliance with the requirements established in the certification basis will be shown.

6.4.2 The Test Plan should include, although not necessarily in the format of or limited to, the following:

(a) Certification Basis.

(b) The tests to be carried out should be detailed.

(c) Means of Compliance, e.g. Flight Test in natural icing conditions, wind tunnel testing, analysis etc. An introductory summary statement would be helpful but a means of compliance will have to be related in detail to each applicable requirement. This could be done using a Compliance Check List (CCL) approach, or other detailed method to ensure that the tests proposed cover the relevant requirements in a way acceptable to both the Applicant and the Authority. This is important as it can be very difficult to repeat icing trials to complete inadvertently missed test points.

(d) For Flight Tests in natural icing conditions, trial locations, proposed timescales, expected weather and range of temperatures of interest, details of topography, site facilities e.g. instrumentation ground station and outline of operating procedures should be detailed.

(e) Details of the trials aircraft should be given. This should include the build standard, any differences from the series production build standard, justification that any such differences will not invalidate the trials results and details of instrumentation fit.

(f) The means and procedures, including for example a Trials Risk Assessment, to ensure maximum trials safety should be given. This should include details of any telemetry or on board monitoring of critical parameters, safety and survival equipment, crew survival training, weather limits, flight procedures, post flight review of critical data and means of achieving some degree of incremental approach. Any other factors deemed necessary to assist trials safety should be included by the Applicant.

6.5 **Reporting**

6.5.1 A detailed report should be submitted. This should give details of the testing carried out and the data gathered. The applicant must be able to show compliance with the requirements and there should be a clear link within the report between the relevant data used for showing compliance and the appropriate rule.

6.5.2 The report should include details of the required build standard for icing, and form the basis for the Flight Manual limitations and information that will be required.

6.6 **Flight Manual**

Adequate Flight Manual information must be provided to ensure safe operation of the rotorcraft. This can be part of the basic Flight Manual or in the form of a Flight Manual Supplement (FMS) and should incorporate specific icing information in relation to the relevant parts of the basic Flight Manual. For example:

(a) *Limitations*

The Limitations Section must include the appropriate limitations derived from the trials work. Any limitations must be clear and straightforward to observe by the crew using readily available information. For example, it would not normally be acceptable to have to observe Liquid Water Content limitations by measuring the rate of ice accretion on a visual ice accretion rod. Limitations might include:

Minimum temperature.

Maximum weight.

Maximum Airspeed.

Maximum Altitude

Maximum Liquid Water Content.

Maximum torque (or other measure of rotor blade ice effect) rise during icing.

Maximum total ice accretion.

Minimum depth of non icing atmosphere above minimum operating altitude.

Minimum modification standard for flight in icing.

Any prohibited conditions, e.g. freezing rain.

Relationship of icing limits to other relevant limitations, e.g. flight in snow, engine anti ice system operating conditions.

(b) *Normal Procedures*

The Normal Procedures section should deal with the general operation of the rotorcraft, as modified by flight in icing conditions. The following areas should be considered:

Pre flight testing of icing equipment, e.g. ice detectors.

Normal operation of icing equipment.

Planning considerations before entering icing conditions.

Signs of icing in flight.

Effects of icing on rotorcraft.

Monitoring required for icing flight.

Means to respect icing limitations.

Reduction in autorotative Rotor RPM.

Guidance on when the rotorcraft can be considered free from icing effects on leaving an icing environment.

Following icing encounters, consideration to be given to ice shedding hazard to Third Parties during final approach and landing, ground taxi and hazard to passengers from ice covered boarding steps if applicable.

(c) *Emergency Procedures*

Emergency procedures applicable to flight in icing conditions should be specified giving consideration to the following:

Actions in event of encountering icing conditions that exceed the limitations.

Failure of icing equipment.

Rapid engine relight in the event of ice induced flame out.

Symptoms and actions in the event of excessive ice accretion or severe icing effects, e.g. high vibration, asymmetric shedding, excessive torque rise or degradation in handling qualities.

(d) *Performance*

The effects of icing will have been determined during trials and revised performance information must be published. All the performance information, both Regulatory and Additional is likely to be affected. It is up to the Applicant to propose how to quantify the changes and past clearances have used both revised graphs or factors to be applied to existing graphs.

7 GLOSSARY

AC	Advisory Circular.
AFCS	Automatic flight control system.
AUW	All up weight.
APU	Auxiliary Power Unit.
BS	British Standard.
BCAR	British Civil Airworthiness Requirements.
Beak ice	Slushy ridge of ice which forms on the upper surface of a rotor, close to the leading edge.
CAT A	Category A.
CG	Centre of gravity.
FMS	Flight Manual Supplement.
FOD	Foreign Object Damage.
Freezing rain	Form of icing precipitation characterised by the presence of very large super-cooled water droplets.
Freezing drizzle	Form of icing cloud characterised by droplets significantly larger than normal icing cloud, but smaller than freezing rain.
Glaze ice	Ice type indicative of droplets which on impact form a water layer which only part freezes, the rest running aft to freeze and possibly leading to the formation of 'horns'.
IFR	Instrument Flight Rules.
IMC	Instrument Meteorological Conditions.
JAR	Joint Aviation Requirements.
LWC	Cloud Liquid Water Concentration, normally measured in grams of water per cubic metre of air.
Mixed conditions	Cloud in which both ice crystal and super-cooled water conditions exist.
MVD	Median Volumetric Diameter, same as VMD.
Mean Effective Diameter	Approximation equivalent to VMD.
OAT	Outside (static) air temperature.
Rime ice	Ice type indicative of droplets which freeze on impact which tends to be white and opaque in appearance.
VMD	Cloud Volume Median Diameter, the significance of which is that it is the diameter above and below which half the total mass of water is contained. Any one cloud will normally contain a spectrum of droplets; the VMD provides a single parameter to characterise the statistical significance of the different droplet sizes that are present in the cloud.
1R	Once per rotor revolution.

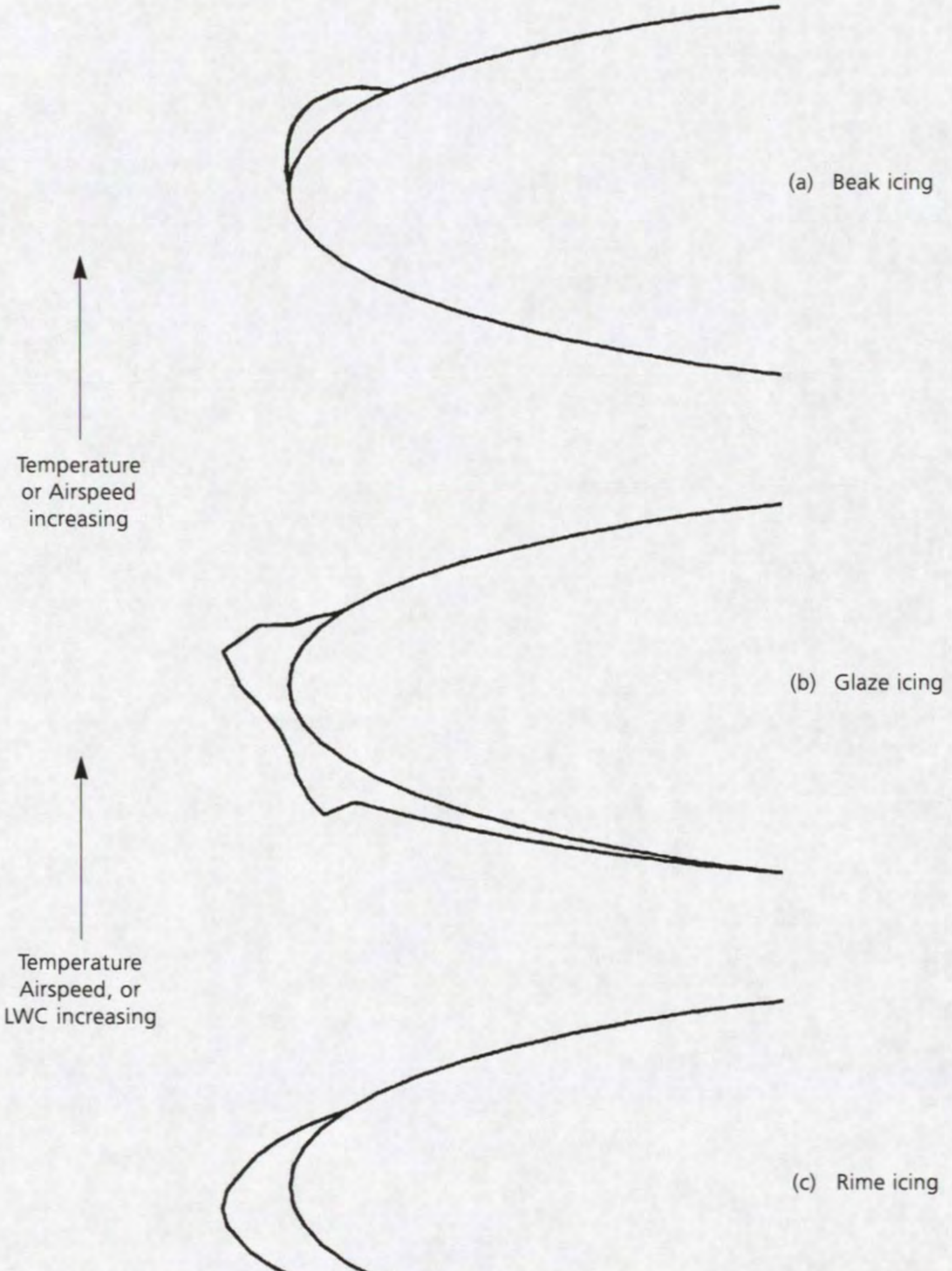
8 REFERENCES

1	B.J. Mason	The physics of clouds. Second edition, Oxford monographs on meteorology, Oxford University Press, 1971
2	Dr I. Langmuir Dr K.B. Blodgett	A mathematical investigation of water droplet trajectories. Army Air Forces Technical report 5418, 1946
3	W.T. Roach D.A. Forrestor M.E. Crewe K.F. Watt	An icing climatology for helicopters. Meteorological Office Special Investigations Memorandum 112, 1984

Appendix 1 Examples of rotorcraft components which need to be considered as part of any ice and snow clearance

Component	*Possible method of protection*	*Remarks*
Engines	Bleed air, screens, IPS	Likely to be provided by engine manufacturer. Must be cleared to JAR 29.1093 requirements. Need to against shed snow/ice FOD hazard.
Engine intakes	Electrothermal, fluid, mesh screens, vortex tubes	
Other intakes (e.g. APU, engine bay cooling)	FOD screens, electrothermal	Not necessarily heated.
Cockpit windscreens Transparencies Wiper blades	Electrothermal	Must be cleared to JAR 29.773 requirements. Wiper blades not normally protected.
Pitot systems, probes and static vents (Air data systems)	Electrothermal	Must be cleared to JAR 29.1323, 29.1325 requirements.
Rotor hub, flight controls (e.g. droop stops)	Physical shielding	The operation of droop stops can be particularly adversely affected by ice accretion.
Sensors: Aerials OAT probes	Electrothermal, shielding	Normally left unprotected.
Vents and exhaust ports	Shielding	Need to avoid blockage/source of FOD.
External stores flotation gear	–	If fitted.
Landing gear	–	
Emergency access/exits	–	Functionality must be demonstrated.

Appendix 2 Example of ice accretion that may occur on a rotor blade



Appendix 3 Flight Test Check List

The following check list provides a general guide to areas that should be considered prior to and during rotary wing aircraft snow and icing trials. The list is not exhaustive and many additional points may need to be introduced to cover specific trial's requirements; whereas other considerations listed here may not be appropriate for some trials.

1 PRE-TEST ACTIVITIES, PAPER ASSESSMENT AND THE IDENTIFICATION OF RISK REDUCTION METHODS

(a) It is essential that trial's staff and aircrew receive training to gain knowledge of the issues associated with operations in snow and icing conditions. This should include an understanding of weather considerations, including the physics associated with snow and icing, icing instrumentation, trial's methods, the effects of such weather on the aircraft and its systems along with methods of protection and beneficial operating procedures.

(b) Identification of, and contact with other operators, test agencies, aircraft and system manufactures and others who have experience in the subject of operation or testing in snow and icing conditions will be beneficial.

(c) Knowledge of the potential snow and icing related problems for the aircraft under test; this may be generated from earlier in service problems, ground and flight trials experience on type, manufacturers advice or testing and similarity to other aircraft types cleared for such operation or otherwise.

(d) Identification of the aircraft and its systems' specification requirements relating to their operation in snow and icing.

(e) A clear understanding of both the authority's and operator's clearance criteria and requirements.

(f) The production of trials plans, risk assessments, and test procedures.

(g) Survival training for the trials aircrew is an essential prerequisite for a snow or icing trial. In addition to knowledge of abandon aircraft procedures, use of parachutes, dinghies etc., it is important to have formal tuition in the area of cold weather survival.

2 CHOICE OF TRIALS OPERATING AREA

(a) Choice of a flat operating area devoid of high rising ground, mountains, tall masts and built up areas where people may complain should ice or slush accretions fall from the aircraft is desirable. It will be normal to carry out a reconnaissance of the trial's venue from maps and by flight over the intended operating area to ensure the crew have full understanding of the local hazards. Where snow flying trials are to be undertaken with the associated need for low level operation, it is essential to have previously flown the routes so that the pilots have full knowledge of all tall buildings. In order to take full advantage of the weather, several race track type routes using well defined line features such as roads and railway lines should be available for use. These will normally need to be approved by the authorities.

(b) Choice of an airfield and operating area likely to provide the weather conditions sought. It is essential to gain an understanding of the weather conditions that may prevail, based on a survey of local area meteorological records, the weatherman's and local operators experience. Care should be taken to ensure that weather statistics give an indication that the chosen area will provide a non-icing escape route to be used in the event of an emergency or precautionary descent. This is normally a band of clear air or positive temperature cloud for at least 500 ft and preferably 1000 ft above the surface. Consideration should also be given to test flying hours that may be lost due to fog, high winds and other 'no go' flying restrictions such as airfield closure due to weather limitations.

(c) Choice of an operating area that minimises air traffic and other aircraft operators embarrassment due to the trials needs. It is essential that all local services are aware of the possibility of sudden deviation from flight plans. This may involve the changing of flight levels, the need to maintain operation within a small area when suitable weather conditions are found and the frequent necessity for the trials crew to obtain information in flight from ATC, weather stations and other operators in the test flying area. It will be normal for the trials aircraft to be under positive radar control whilst in cloud throughout each icing sortie, irrespective of the test altitude. Designated, named areas for flight in icing conditions will normally be agreed with the area authorities.

3 BRIEFING CONSIDERATIONS

Formal briefings in the presence of aircrew, groundcrew representatives and supporting staff are essential. Briefings will normally cover the following areas:

(a) Meteorological conditions, existing and forecast; 'go'/ 'no go' considerations.

(b) Aircraft and instrumentation serviceability; 'go'/ 'no go' considerations.

(c) Aircraft and trials configuration changes and associated precautions and new limitations.

(d) Test flight objectives and specific test points to be sought.

(e) Weather, aircraft and system limitations to be respected whilst in flight.

(f) Feedback from earlier trials experience, with identification of the tightening or relaxation of limitations as a consequence of that test experience.

(g) Crew responsibilities, also groundcrew and support staff requirements, e.g. preparation of aircraft, removal of snow, slush and ice accretions, the points of contact in an emergency, on board video, the possible need to land away from base, post flight photography, etc.

(h) Necessary notification of any involvement of external agencies, authorities, contractors etc.

(i) Documentation and Flight Plan.

(j) Safety procedures to be used in the event of approaching limits or system failures.

(k) Fallback briefing/plans in the event of meeting unexpected but desirable test conditions.

4 TRIALS FLIGHT OPERATING PROCEDURES, SAFETY PRECAUTIONS AND EMERGENCY ACTIONS

(a) Crew/team briefing must ensure that the actions in the event of approaching limits or system failures are well defined and that procedures are in place to minimise the associated risks.

(b) All test conditions must be approached in a cautious and progressive manner. Initial test flying should be conducted at the lowest possible mass, conducive to the test requirements, to provide the maximum margin in the event of partial power loss. Generally, and certainly during initial icing tests, the lower altitudes should be flown and airspeeds that maintain a large power margin are advised.

(c) Prior to entering cloud, level flight datum runs at the desired encounter speeds should be undertaken to gain a general guide to power required with an uniced aircraft.

(d) During the flight survey of weather conditions it is important for the crew to identify cloud base, thickness and tops and layers, temperatures, LWC, precipitation and the visibility beneath cloud within the permitted trials operating area and altitude range.

(e) Whilst flying in cloud, crew must endeavour to ensure that they maintain an adequate escape path in the event of the need to vacate the condition in an emergency or for other reasons. For example, the monitoring of ice accretions in areas which might hazard the aircraft on reaching a certain size, or indications from aircraft and systems parameters affected by icing, where their limits may be approached, may cut short the encounter. Hence, whenever possible it is preferable to conduct the icing encounter just within 1000 ft of the base of the cloud or within 500 ft of the layer's cloud top.

(f) As snow or precipitation may be difficult to identity whilst in cloud (i.e. mixed conditions) and because of the need to maintain adequate visibility beneath cloud when descending from it, it may be necessary to exit the cloud at intervals to establish if precipitation is present and the associated severity. When such conditions are forecast for the test area, the need for and frequency of these checks will increase.

(g) With the exception of testing in 'mixed conditions', all snow flying should be conducted whilst in visual contact with the ground, either over the airfield or along pre-recced and familiar routes.

(h) Test flying in freezing fog, rain or drizzle should be carried out in the immediate vicinity of an airfield again visual contact with the ground must be maintained at all times. If such freezing precipitation is encountered inadvertently, the condition should be vacated as soon as practicable.

(i) Anticipate the need to vacate icing conditions due to excessive vibration, excessive torque rise or unacceptable ice accretions. If and when any of these conditions are approached, the icing condition must be vacated. Normally for vibration and torque rise, some reduction in speed will alleviate the condition and provide extra time to initiate descent from cloud or to a lesser icing severity where the level of performance degradation may stabilise or reduce. Whilst vacating the condition only gentle manoeuvres are advisable.

(j) Unless pilots are confident that they are close to the cloud tops and have sufficient power to climb clear, exiting the icing condition should normally involve descent to beneath the test cloud layer.

(k) Avoid high rates of descent, as passage into clear air or positive OAT at a high rate of descent is more likely to cause ice to shed from the airframe and damage rotor blades.

(l) Following icing flight the ground crew, observers and photographers must remain at least 50m clear of the aircraft until the rotors have stopped. This is to ensure that ice shed from the rotors does not cause injury.

(m) When climbing on the aircraft for inspection or servicing purposes following a snow or icing encounter, care must be taken as the surfaces may be slippery due to the presence of water, slush and ice.