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NATIONAL TRANSPORTATION SAFETY BOARD

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Aircraft Performance Group Chairman

NPA 25F-219 Issue 2 (1992): Flight in Icing Conditions - Acceptable Handling Characteristics and Performance Effects

(16 pages)

Relevant paragraphs: JAR and ACJ 25.1419

INTRODUCTION

Service experience, particularly on turboprop aeroplanes, has shown the need to provide guidance on flight testing for the investigation of flight characteristics (ie performance and handling qualities) in icing conditions.

The Flight Study Group agreed that such guidance is necessary and some preliminary papers were discussed. At the same time the French Authorities were developing Special Conditions for the icing clearance of a turboprop aeroplane. The FSG established a Sub-Group to review all this material and prepare advisory material for publication in JAR 25.

This NPA, therefore, proposes that an AMJ to JAR 25.1419 covering flight characteristics in icing conditions be published in Section 3 of JAR 25. This AMJ would be complementary to the existing ACJ 25.1419.

PROPOSALS

AMJ 25.1419

FLIGHT IN ICING CONDITIONS - ACCEPTABLE HANDLING CHARACTERISTICS AND PERFORMANCE EFFECTS

1. PURPOSE

This AMJ provides acceptable means of compliance, recommendations, guidelines, and information for the demonstration of flight handling characteristics and performance effects for flight in icing conditions in accordance with JAR 25.1419(b). Other means of compliance may be acceptable.

JAR 25.1419(b) requires that the aeroplane must be able to operate safely in the continuous maximum and intermittent maximum icing conditions determined under Appendix C. Consequently, the impact on aircraft flight characteristics and performance should be determined for flight in icing conditions.

It is the intention of this AMJ that JAR 25, Subpart B should be used as a guide to define the appropriate flight conditions to be considered.

This AMJ also deals with continued safe flight following a failure or malfunction of the ice protection equipment.

2. CONDITIONS TO BE CONSIDERED

2.1 Types of Artificial Ice

a) Ambient atmospheric conditions are those defined in JAR 25 Appendix C.

b) In addition to ACJ 25.1419 for the determination of different ice accumulation shapes, a degree of roughness should be agreed with the Authority as being representative of natural ice accretion.

In the absence of any other approved definition the following may be used:

i) For small amounts of ice (for example the amount of ice built up during de-icing systems rest time) the roughness should not have characteristics less severe than :

- roughness height : 1 mm, and
- particle density : 8 to 10/cm^2

ii) For large amounts of ice (for example on an unprotected, exposed surface) the roughness should not have characteristics less severe than:

- roughness height : 3 mm, and
- particle density : 8 to 10/cm^2

c) Experience has shown that a thin, rough layer of ice can cause handling difficulties. For this "sand paper ice" the roughness should not have characteristics less severe than Carborundum Paper No.40 (giving a roughness of about 300 microns).

2.2 Ice Accumulation

2.2.1 Unprotected parts

The ice buildup to be considered should be determined in accordance with JAR ACJ 25.1419, para 2.5.4 for unprotected parts. (typically 3 inches/75 mm).

"Unprotected parts" consist of the unprotected airfoil leading edges and all unprotected airframe parts on which ice accretion may develop. The effect of ice accumulation on normal protuberances such as antennae or flap hinge fairings need not be specifically investigated. However aeroplanes which are characterised by unusual unprotected airframe protuberances, eg. fixed landing gear, large engine pylons or exposed control surface horns or winglets etc., may experience significant additional effects which should therefore be taken into consideration.

2.2.2 Protected Parts With Operative Ice Protection

The ice protection systems are normally assumed to be operative. However the applicant should consider the effect of ice accumulation on the protected surfaces which results from:

- the rest-time of a de-icing cycle or when runback ice occurs.

Note: Performance may be established on the basis of the average drag increment over the de-icing cycle.

- a delay in the system activation (for handling characteristics only)

Note: In establishing the maximum icing exposure time prior to crew recognition and system activation, the nature of the detection means and the type of ice protection system should be taken into account. (For example visual cues or ice-warning system).

2.2.3 Protected parts following system failure.

A failure and safety analysis of the ice protection system should be carried out in accordance with JAR 25.1309. Some failures may necessitate leaving icing conditions.

A failure condition which does not require the aeroplane to leave icing conditions is a failure in which there is no further significant deterioration of the aeroplane performance or handling characteristics compared to that established with a fully operative system.

For failure conditions which require the aeroplane to leave icing conditions as soon as possible, it should be shown that the aeroplane is capable of safe continued flight and landing.

For this purpose the ice accumulation on normally protected parts where the ice protection has failed, should be taken as one half of the accumulation specified in para. 2.2.1 above for unprotected parts (ie. typically 1.5 inches/35 mm) unless another value is substantiated.

The effect on the performance and handling characteristics, if noticeably greater than that established with the systems fully operative, should be stated as part of the Aircraft Flight Manual procedures following failures.

3. DEMONSTRATION OF COMPLIANCE

Compliance with AMJ 25.1419 should be shown by flight testing in natural icing conditions supplemented by a suitable combination of the following methods.

1. Flight testing using ice shapes.

2. Icing tunnel test data.

3. A read across of equivalent results from an earlier version, model or ancestor of the subject aircraft.

It is expected that no one method will provide sole evidence for compliance and any programme methods and content must be agreed.

With the exception of the stall warning margin (paragraph 4.2.1(b)) the performance and handling tests required by this AMJ may be based on flight testing in dry air with artificial ice shapes, provided these ice shapes are validated in natural icing conditions with respect to location, general shape and, where possible, thickness.

The artificial ice shapes should be established by a proven technique validated for the type of aerofoil geometry used and for aerodynamic parameters such as speed and angle of attack appropriate to the subject aeroplane (see ACJ 25.1419).

The ice accumulation shape for performance shall be the one which has the most adverse effect on drag and lift. Similarly the ice shape for handling characteristics shall be the one which has the most adverse effect on lift and pitching moment. Nevertheless the ice accumulation shape having the most adverse effect on flight handling characteristics may be used for performance provided the drag difference can be easily or conservatively taken into account.

4. FLIGHT TESTING

4.1 General

The certification programme for flight in icing conditions should address all phases of flight, including take-off, climb, cruise, holding, descent, landing and go-around.

Power or thrust appropriate to a particular phase of flight should take into account any loss due to:

- bleed air or power extraction as needed for the proper functioning of the ice protection system operated in accordance with AFM procedures, and

- propeller efficiency.

Lift, drag and pitching moment changes due to the most critical ice accumulation shape on the unprotected and protected surfaces should be considered, together with any drag increment due to the ice protection system configuration, for example inflated de-icing boots.

4.2 Handling Flight Tests

4.2.1 Handling Tests With Natural Ice

a) The objective of certification flight testing to assess handling characteristics in natural icing conditions may be limited to a qualitative assessment for comparison with the results from tests with artificial ice shapes. It is not, therefore, the intention of this AMJ that the handling characteristics be systematically checked through a series of controlled flight tests with natural accretion.

b) There should be however a specific verification of the stall warning margin (see also para. 4.2.2.6) associated with natural ice shapes, to demonstrate satisfactorily the capability of the stall warning to prevent inadvertent stalling of the aeroplane when operating in icing conditions. This demonstration should be performed in a critical condition in terms of lift loss, that is:

- with natural glaze ice,
- with various quantities of ice on the unprotected surfaces (between 0 and 3 inches) and,
- with a quantity of ice on the protected surfaces, if applicable, dependent on the ice protection system.

The ice accretion on protected parts need not exceed the quantity which is naturally left at the time of the demonstration by the normal functioning of the system.

c) An investigation should be made to show that flight controls are free of jamming due to ice within the normal flight envelope.

4.2.2 Handling Tests with Artificial Ice Shapes

4.2.2.1 General

Adequate stability and control of the aeroplane with the most critical ice accretion pertinent to each flight phase and related configuration should be demonstrated. This includes longitudinal and lateral control capability, static longitudinal and lateral/ directional stability and dynamic stability.

Normal procedures for configuration changes should be demonstrated to be safe.

4.2.2.2 Longitudinal Controllability and Manoeuvrability

4.2.2.2.1 Background

Elevator hinge moment becomes more sensitive to angle-of-attack as the tailplane stall is approached. This is particularly noticeable with elevators having significant aerodynamic balancing (leading edge and/or horn balance). In flight these effects become apparent by lightening stick pull forces in stall manoeuvres and lightening stick push forces in nose down pitching manoeuvres. Tailplane leading edge state can also have a significant effect on the available angle-of-attack range and frost and ice can also degrade the tailplane stall margins available. The loss-of-control, transient or sustained, due to flow separation at the tailplane can thus occur with both manually operated and irreversible powered controls.

Experience has shown that aeroplanes with non-powered elevators are most at risk from the phenomenon of large stick-force changes but it is considered that all aeroplanes should be assessed for controllability problems in this respect. For aeroplanes unlikely to be critical in certain icing conditions, it may be possible to show adequate longitudinal controllability by means other than flight test.

All parameters which have an influence on the phenomenon (eg. aeroplane configuration, change of configuration, speed, weight, c.g., power setting and pitch rate) have to be considered. The manoeuvre specified in sub-paragraphs 4.2.2.2.2 and 4.2.2.2.3 takes these factors into account.

Longitudinal control problems have been encountered in service and it has been observed that a thin layer of rough ice on the tailplane can have a greater effect than horn ice. The applicant must, therefore, determine the critical icing accretion with regard to location, shape, thickness and texture.

4.2.2.2.2 Demonstration

A push stick-force must be required throughout the following manoeuvre.

With the aeroplane in trim, or as nearly as possible in trim, at the specified speed, perform a continuous manoeuvre to reach 0g load factor, or, if limited by elevator power so that 0g cannot be reached, the lowest load factor attainable.

4.2.2.2.3 Conditions

a) Configuration : with wing flaps and landing gear in all normal positions other than the cruise configuration.

b) Speeds : all speeds from 1.2 V_s or V_{REF} -5 knots, appropriate to the configuration, up to V_{FE} but limited to the extent necessary to accomplish the manoeuvre and recovery without exceeding V_{FE} or V_{LE}, whichever is applicable.

c) Power or thrust : from flight idle to maximum take-off power or thrust.

d) Loading : most critical.

e) Icing Condition : the applicant should specify the critical ice case(s) to be investigated. The ice case(s) should be defined in terms of location, shape, thickness and texture. The applicant should include allowance for any time delays in the activation of the ice protection system that may reasonably be expected in service. Ice accretion thickness greater than that resulting from application of Appendix C ·eed not be considered.

4.2.2.3 Manoeuvring Capability

This paragraph is only applicable to aeroplanes which exhibit a stall speed increment of more than 5 kt or 5% V_{S1G}, whichever is greater. (see 4.3.3.1, below).

There should be no reduction in the manoeuvring capability to stall warning in icing conditions from that required of the "clean" aeroplane (see JAR 25.143(g) as introduced by NPA 25B-215).

4.2.2.4 Ability To Trim

The aeroplane should be able to maintain longitudinal, lateral and directional trim or to reduce the corresponding remaining control forces to a level compatible with safe operation in icing conditions.

4.2.2.5 Stall Handling Characteristics

Any form of wing or aerodynamic surface ice "contamination" increases the stall speed, whilst reducing the stall angle of attack. This effect should be compensated for by either ensuring that the inherent aerodynamic qualities of the aeroplane for the case in question always give an adequate warning, or by providing a change in the artificial stall warning threshold as defined for the "clean" aeroplane.

It is recognised that criteria relevant to acceptable stall characteristics for the "clean" aeroplane cannot be strictly applied with ice accumulation on the airfoils due to the wide range of ice shapes and their subsequent effects on aerodynamic characteristics and stall. The stall warning should therefore, as a compensating factor, have a sufficient margin to prevent an inadvertent stall under any form of ice accretion. Only straight stalls with an entry rate not exceeding -1 kt/sec need be investigated. The action of the aeroplane after the stall should not be so violent or extreme as to make it difficult to effect a prompt recovery and to regain control of the aeroplane using normal piloting skills.

4.2.2.6 Stall Warning

There should be no reduction in the stall warning margin above the stall speed in icing conditions from that required for the "clean" aeroplane. The distinctiveness of the stall warning should be that required for the stall warning of the "clean" aeroplane (see JAR 25.207 as amended by NPA 25B-215).

4.2.2.7 Vibration and Buffeting

The aeroplane should be demonstrated free from excessive vibration or buffeting over a range of speeds adequate for normal operation.

4.3 Performance Flight Tests

4.3.1 General

Aircraft performance information for each flight phase should consider the most critical ice accretions on unprotected surfaces. In addition, consideration should be given to ice accretions accumulating during the rest time of cyclic de-icing systems and to the possiblity of runback ice existing with some ice protection systems. Except as described in 4.3.4 for take-off, the performance data should be based on the most critical ice accretion and hence aerodynamic degradation that is expected to occur during a particular flight phase.

In consideration of the margins provided in performance requirements for expected variations of performance, the effect of ice accretion should be considered to be significant if it amounts to more than 5 kt or 5% (V_{S1G}) increase in stall speed, whichever is the greater, or more than 5% increase in drag, as applicable, in the particular flight phase.

4.3.2 Performance Tests with Natural Ice

Given the difficulty of obtaining accurate measurements of performance in a natural icing environment, the validation of performance data by flight tests in natural icing conditions may be limited to the verification that actual performance degradations observed under all encountered icing conditions do not exceed those predicted from the results of flight tests with artificial ice shapes in dry air.

4.3.3 Performance Tests with Artificial Ice Shapes

4.3.3.1 Stall Speeds

One-g stall speeds should be demonstrated in each configuration to be certificated for use in the take-off, en-route, approach and landing phases, with the ice accretion expected for the particular flight phase in accordance with paragraph 2.2.

If the ice accretion in any configuration used during take-off causes a significant increase in stall speed the additional conditions of para. 4.3.4 should be investigated.

4.3.3.2 Drag Characteristics

The drag characteristics in each configuration to be certificated for use in the take-off, en-route, approach and landing phases should be determined with the ice accretion expected for the particular flight phase in accordance with paragraph 2.2.

If the ice accretion in any configuration used during take-off causes a significant increase in drag, the additional conditions of para. 4.3.4 should be investigated.

4.3.4 Additional Performance Tests with Artificial Ice Shapes for Take-off Conditions

If the flight tests conducted with the ice accumulation specified in para. 2.2 show that in any configuration used during take-off the stall speed is increased by more than the greater of 5 kt or 5% V_{S1G}, or that the aeroplane drag is increased by more than 5%, adjustments to the AFM take-off data should be determined and scheduled in the AFM corresponding to:

a) The increments of stall speed and drag determined in the flight tests conducted in accordance with paragraph 4.3.3, or

b) At the option of the applicant, the effects on stall speed and drag characteristics determined in additional flight tests with the lesser amounts of ice accumulated during take-off in accordance with paragraphs 4.3.4.1 and 4.3.4.2 below.

4.3.4.1 Ice accumulation

The amount of ice accumulation should be determined by calculation, assuming;

- aerofoils, control surfaces and, if applicable, propellers are free from adhering frost, snow or ice at the start of the take-off,
- maximum continuous intensity of atmospheric icing conditions exist throughout the take-off,
- critical ratio of thrust/power - to - weight,
- failure of the critical engine occurs at V_{EF}, and

no flight crew action to activate the ice protection systems, other than in accordance with AFM procedures, is taken after commencing the take-off roll until the aeroplane achieves a height of 400 ft above the take-off surface.

4.3.4.2 Effect of ice accumulation on aerodynamic characteristics

The effect of ice accumulation on stall speeds and drag should be determined with the ice accumulation existing at the point where the landing gear is fully retracted, at the point where the aeroplane reaches 400 ft height above the take-off surface and at the end of the take-off path in accordance with JAR 25.111(a). At each point, the effect should be considered to be significant if it amounts to more than 5 kt or 5% V_{S1G} in stall speed, whichever is greater, or more than 5% increase in drag, as applicable.

4.3.4.3 Effect of ice accumulation on AFM take-off data

(a) Take-off speeds

If the stall speed in the take-off configuration at the point where the aeroplane achieves 400 ft height above the take-off surface is increased by more than 5 kt or 5% (V_{S1G}), whichever is greater, the minimum take-off safety speed V_{2MIN} should be increased as necessary to maintain an adequate margin above the stall speed. If the stall speed in the en-route configuration at the end of the take-off path is increased by more than 5 kt or 5 % (V_{S1G}), whichever is greater, the flap retraction speed and the final take-off climb speed V_{FTO} should be increased as necessary to maintain adequate margins above the stall speed.

(b) Minimum distances required for take-off

The effect of any increase in operating speeds (V_R and V_2, in accordance with (a) above) on the required take-off distance, take-off run and accelerate-stop distance should be determined and scheduled in the AFM. If the operating speeds are not increased, the effect of incremental drag due to ice accretion on these distances may normally be considered to be insignificant.

(c) Take-off flight path and related climb requirements

The effect of ice accretion on the take-off flight path and on the minimum gradients required by JAR 25.121(a), (b) and (c) should be scheduled in the AFM if the incremental drag exceeds 5% or if the operating speeds need to be increased due to an increase in the stall speed of more than 5 kt or 5% V_{S1G}, whichever is greater.

The computation of speed and drag should be based on the ice accretion existing at the following points:

The point where the landing gear is fully retracted, for showing compliance with JAR 25.121(a) and for the determination of the take-off flight path up to the point where the landing gear is fully retracted;

The point where the aeroplane reaches 400 ft height above the take-off surface, for showing compliance with JAR 25.121(b) and for determination of the take-off flight path from the point where the landing gear is fully retracted until the point where the aeroplane reaches a height of 400 ft above the take-off surface; and

The end of the take-off path in accordance with JAR 25.111(a), for showing compliance with JAR 25.121(c) and for determination of the take-off flight path from the point where the aeroplane reaches 400 ft until the end of the take-off path.

5. FLIGHT MANUAL

5.1 General

All the appropriate limitations, performance information and procedures for flight in icing conditions, should be established and provided in the Aeroplane Flight Manual.

5.2 Limitations

Where a specific limitation applies when operating in icing conditions, or observance of a limitation is necessary to ensure continued safe operation in icing conditions, these shall be stated in the AFM.

The AFM should state as a limitation, that an aeroplane should not initiate take-off when the airfoils, control surfaces or propellers are contaminated by frost, snow or ice.

5.3 Procedures

AFM procedures for flight in icing conditions should include both normal operation of the ice protection system and operation of the system taking into account protection system failures and aeroplane system failures.

5.4 Performance

Performance effects for all phases of flight should appear in the AFM. Where performance corrections are used, these should be expressed simply in AFM units and each affected AFM chart should be identified.

5.5 Regulatory Status of AFM Performance Information

AFM performance information produced in accordance with this AMJ should include the following statement:

This performance information has been prepared by the manufacturer and approved by the Authority to assist operators in developing suitable guidance, recommendations or instructions for use by their flight crews when operating in icing conditions.

JUSTIFICATION AND EXPLANATION

Flight in icing conditions is currently covered largely by JAR and ACJ 25.1419. For the most part, this material addresses clearance of ice protection systems and does not give any guidance on acceptable standards of aeroplane handling characteristics and performance. There is, for example, no advice regarding flight characteristics in ACJ 25.1419 on the interpretation of JAR 25.1419(b) "The aeroplane must be able to safely operate in the continuous maximum and intermittent icing conditions determined under Appendix C....."

Operation in icing conditions must be regarded as a normal operation for an aeroplane for which certification for flight in icing conditions is required. The general objective of the proposed AMJ is to maintain the same minimum standard of safety as in non-icing conditions and consequently no credit can be given for the probability of encountering icing conditions. However, it is recognised that all the detailed flight requirements of Sub-Part B cannot be expected to be met in icing conditions.

The depth of investigation will depend to some extent on the characteristics of the aeroplane and the effectiveness of the ice protection system. Aeroplanes which fly at lower altitudes and at lower speeds (e.g. turboprop aeroplanes) tend to fly for longer periods in an icing environment. Due to power demands, such aeroplanes generally are provided with de-icing systems (e.g. pneumatic boot systems) which will carry some ice accumulation before and during activation. Turbojet aeroplanes are usually fitted with anti-icing systems (e.g. hot air) which generally give more satisfactory protection and are often fitted with irreversible powered controls. They are likely, therefore, to have fewer control difficulties than aeroplanes with manual reversible controls (no control over-balance etc).

There will always remain, therefore, an element of engineering judgement in the extent to which compliance with the flight tests of Sub-Part B must be shown for icing certification. This AMJ aims to highlight areas of flight characteristics likely to be critical for safety and to define a common standard for JAA certification. It is acknowledged that some detailed tests are an extension of common current practice. These are considered necessary from the experience of individual Authorities.

Paragraph 2 - Conditions to be considered

The icing conditions of JAR 25 Appendix C, as interpreted by ACJ 25.1419, are to be considered. However, a particular type of ice accumulation is introduced (referred to as "sandpaper ice"). It has become clear that a thin, rough layer of ice has caused handling difficulties on several types of aeroplane. Hence the ice shapes critical for performance and handling may differ as performance effects are usually associated with a thicker build-up of ice.

In addition, it has been established that the surface roughness of the ice accumulation has an appreciable effect. Guidance on the roughness to be used on artificial ice shapes is therefore offered.

This paragraph details the ice accumulations to be considered for protected parts following failure of the ice protection system. For the ice accumulation appropriate to a failed ice protection system, the proposed AMJ follows Transport Canada's AMA525/5-X in allowing half the ice accumulation appropriate to an unprotected surface in the same conditions.

Paragraph 3 - Demonstration of Compliance

Compliance may be shown by a combination of methods e.g. flight testing in natural ice, the use of artificial ice shapes, results from testing in an icing tunnel or read across from the results from a previous model.

It is usually not feasible to carry out all handling and performance testing in natural icing and the use of artificial ice-shapes is therefore permissible. However, flight testing in natural icing is required not only for icing systems evaluation but also to validate the form of ice shapes used for artificial ice testing and the resulting flight characteristics.

The provisions of this AMJ are applicable to all types of aeroplane but the scope of the investigation may take account of the operating characteristics of the type and the nature of the protection systems.

Paragraph 4 - Flight Testing

All phases of flight should be addressed. In the past, the take-off phase has not been addressed, it being assumed that the airframe is clear of ice at the commencement of the take-off. However, it is apparent that a finite quantity of ice can build-up in this phase of flight, particularly on aeroplanes fitted with de-icing systems.

Guidance is offered on the extent of flight testing expected in natural icing conditions and tests that may be performed with the use of artificial ice shapes.

The push-over manoeuvre proposed in paragraph 4.2.2.2 has been developed to reveal any potential for tailplane stall or significant elevator control non-linearity, either following a deliberate or inadvertent pitch-over or associated with the downwash changes following selection of flap in level flight. Longitudinal control problems have been experienced on several types at load factors just below 0.5g absolute and a demonstration of un-reversed stick forces at 0g assures adequate characteristics between 0.5 and 0g. There is evidence from many thousands of hours of flight recorder data which shows, typically, that 0.5g is reached once every 1000 hours due to atmospheric causes and once every 10,000 hours due to pilot induced causes. In addition, 0g is reached once every 100,000 hours from any cause, usually a transient atmospheric event. It is considered, therefore, that a push-over to 0g demonstrates an adequate level of safety.

The demonstration of manoeuvring capability in icing conditions contained in paragraph 4.2.2.3 follows that of NPA 25B-215 "Stall and Stall Warning Speeds and Manoeuvre Capability". It is, however, only applicable to aeroplanes which demonstrate a significant increase in stall speed in icing conditions (defined as a 5% or 5 knots increase in V_{S1g}).

The stalling characteristics in slow, straight stalls should be investigated. It is considered that restricting stall testing to these types of stall is sufficient to show up any degradation of stalling behaviour.

It is important that the stall warning margin should be maintained for flight in icing conditions but it is accepted that performance need only be redefined if there is a significant effect on stall speed and/or drag. For this purpose it is proposed that a significant effect on stall speed is interpreted as a 5% or 5 knot increase in V_{S1g} (whichever is greater) and a significant effect on drag is interpreted as a 5% increase.

In general, the ice shapes to be considered are those appropriate to the phase of flight. However, if the ice accretion defined by paragraph 2.2 shows a significant increase in stall speed or drag for the take-off configuration, an ice shape which takes account of the duration of the exposure and so determines the performance for the take-off phase is defined in Paragraph 4.3.4.