NOTICE OF PROPOSED AMENDMENT (NPA) 2012-23

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE EUROPEAN AVIATION SAFETY AGENCY

amending Decision 2003/9/RM of the Executive Director of the European Aviation Safety Agency of 24 October 2003

Certification Specifications and Acceptable Means of Compliance, for engines (CS-E)

'Turbine Engine Certification Specifications in Icing Conditions — Advisory Material'

EXECUTIVE SUMMARY

The Notice of Proposed Amendment (NPA) 2011-04 proposed to update turbine engine certification specifications for operation in icing conditions (CS-E 780). The proposed amendment was mainly triggered by the need to update the icing conditions used to evaluate turbine engines installed on CS-25 aircraft. A new icing environment, including supercooled large drop (SLD) icing conditions, mixed phase and ice crystal icing conditions, is being concurrently introduced in CS-25; these changes were proposed under NPA 2011-03. The proposed CS-E rule update requires the engine to function satisfactorily throughout the conditions of atmospheric icing, including freezing fog, and in falling and blowing snow which are defined in the air intake system ice protection specifications of the Certification Specifications applicable to the aircraft on which the engine is to be installed.

This NPA proposes amending AMC E 780 to provide advisory material corresponding to the amendment of CS-E 780 that was proposed under NPA 2011-04.

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A. Explanatory Note

I. General

1. The purpose of this Notice of Proposed Amendment (NPA) is to envisage amending ED Decision 2003/9/RM[1]. The scope of this rulemaking activity is outlined in the Terms of Reference (ToR) E.009 and in NPA 2011-04 dated 22 March 2011.

2. The European Aviation Safety Agency (hereafter the 'Agency') is directly involved in the rule-shaping process. It assists the Commission in its executive tasks by preparing draft regulations, and amendments thereof, for the implementation of Regulation (EC) No 216/2008 (hereafter the 'Basic Regulation')[2] which are adopted as 'Opinions' [Article 19(1)]. It also adopts Certification Specifications, including Airworthiness Codes and Acceptable Means of Compliance and Guidance Material to be used in the certification process [Article 19(2)].

3. When developing rules, the Agency is bound to follow a structured process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as 'The Rulemaking Procedure'[3].

4. This rulemaking activity is included in the Agency's Rulemaking Programme for 2013–2016. It implements the rulemaking task RMT.0179 (E.009).

5. The text of this NPA has been developed by the Agency. It is submitted for consultation of all interested parties in accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

6. This NPA proposes acceptable means of compliance (AMC) corresponding to the Certification Specifications that were proposed in NPA 2011-04 and updated through CRD to NPA 2011-04 (published in parallel to this NPA).

II. Consultation

7. To achieve optimal consultation, the Agency is publishing this NPA on its website. Comments should be provided within 3 months in accordance with Article 6(4) of the Rulemaking Procedure.

8. Please submit your comments using the automated Comment-Response Tool (CRT) available at http://hub.easa.europa.eu/crt/[4].

9. The deadline for the submission of comments is **6 March 2013.**

III. Comment-Response Document

10. All comments received in time will be responded to and incorporated in a Comment-Response Document (CRD). The CRD will be available on the Agency's website and in the Comment-Response Tool (CRT).

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[1] Decision 2003/9/RM of the Executive Director of the European Aviation Safety Agency of 24 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for engines ('CS-E'), Decision as last amended by Executive Director Decision 2010/015/R of 16 December 2010 (CS-E Amendment 3).

[2] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1). Regulation as last amended by Commission Regulation (EC) 1108/2009 of the European Parliament and of the Council of 21 October 2009 (OJ L 309, 24.11.2009, p. 51).

[3] EASA MB Decision 01-2012 of 13 March 2012 amending and replacing MB Decision 08-2007 concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material ('Rulemaking Procedure').

[4] In case the use of the Comment-Response Tool is prevented by technical problems, please report them to the CRT webmaster (crt@easa.europa.eu).

IV. Content of the draft Decision

11. NPA 2011-04 proposed to update turbine engine certification specifications for operation in icing conditions (CS-E 780). The proposed amendment was mainly triggered by the need to update the icing conditions used to evaluate turbine engines installed on CS-25 aircraft. A new icing environment, including supercooled large drop (SLD) icing conditions, mixed phase and ice crystal icing conditions, is being concurrently introduced in CS-25; these changes were proposed under NPA 2011-03. The proposed CS-E rule update requires the engine to function satisfactorily throughout the conditions of atmospheric icing, including freezing fog, and in falling and blowing snow which are defined in the air intake system ice protection specifications of the Certification Specifications applicable to the aircraft on which the engine is to be installed.

    This NPA proposes amending AMC E 780 to provide advisory material corresponding to the amendment of CS-E 780 that was proposed under NPA 2011-04.

    After reviewing the comments received on NPA 2011-04, the Agency updated the proposed amendment of CS-E 780 which is available in CRD to NPA 2011-04.

    In AMC E 30, a reference is amended to reflect the new title of CS-E 780.

12. When drafting the below proposed AMC E 780 material, the Agency mainly considered the following elements:

    - The existing AMC E 780 and previous turbine engine projects certification experience;
    - The applicable comments received on NPA 2011-04;
    - Federal Aviation Administration (FAA) draft Advisory Circular (AC) 20-147A[5];
    - The proposed amendment of CS-25 Powerplant icing certification specifications and advisory material for large aeroplanes (CS/AMC 25.1093(b)) under NPA 2011-03 and NPA 2012-23 providing Book 2 amendments corresponding to Book 1 amendments from NPA 2011-03 (RMT.0058 (25.058)).

V. Regulatory Impact Assessment

A regulatory impact assessment was provided in NPA 2011-04[6], please refer to this document.

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5 This draft FAA Advisory Circular was published on the FAA Website page "Aviation Safety Draft Documents Open for Comment - Aircraft Certification Service & Flight Standards Service", accessible using the following link: http://www.faa.gov/aircraft/draft_docs/

6 See: http://easa.europa.eu/rulemaking/docs/npa/2011/NPA%202011-04.pdf

B. Draft Decision

The text of the amendment is arranged to show deleted text, new text or new paragraph as shown below:

1. deleted text is shown with a strike through: ~~deleted~~
2. changed or new text is highlighted with grey shading: new
3. […] indicates that remaining text is unchanged in front of or following the reflected amendment.

I. Draft Decision amending CS-E

CS-E Book 2

SUBPART A — GENERAL

Amend AMC E 30 as follows:

AMC E 30

Assumptions

[...]

TURBINE ENGINES	
[...]	[...]
~~Test in ice forming conditions~~ Icing Conditions CS-E 780	Intake conditions and configuration. Aircraft speeds and appropriate Engine powers.
[...]	[...]

SUBPART E — TURBINE ENGINES; TYPE SUBSTANTIATION

Replace the existing AMC E 780 by the following text:

AMC E 780 Icing Conditions

(1) *Introduction*

This AMC provides guidance material and acceptable means of compliance for showing compliance with CS-E 780.

Test evidence is normally required for Supercooled Liquid Water (SLW) icing conditions. For other applicable icing conditions, compliance may be demonstrated by a combination of test, analysis and service experience.

(1.1) *Definitions*

Auto-Recovery Systems. Engine systems that ensure that Engines operate after a failure without operator intervention. Auto-recovery systems include auto-relight systems, stall recovery systems, and other Engine system intended to recover the operability of an Engine following a flameout, surge, stall, or a combination of these.

Freezing Fraction. The ratio or percentage of water that impacts a surface and freezes. The fraction is defined as a number between 0 and 1, and will determine the type of ice formation.

Highlight Area. The area bounded by the leading edge of the nacelle inlet.

Ice Formations. Ice formations resulting from the impact of supercooled water droplets on propulsion system surfaces are classified as follows:

(a) *Glaze Ice*. This is a clear, hard ice, which forms at temperatures close to (but below) freezing, in air with high liquid water content and large droplet sizes. Droplets impacting the surface do not freeze immediately, but run back along the surface until freezing occurs. Glaze ice typically has a non-aerodynamic shape and is more susceptible to aerodynamic forces that result in shedding. Glaze ice typically has both a lower freezing fraction and lower adhesive properties than rime ice. Glaze ice is often a concern for static hardware while rime ice is often a concern for rotating hardware.

(b) *Rime Ice.* This is a milky white ice which forms at low temperatures, in the air with low liquid water content and small droplet sizes. Rime ice typically forms in an aerodynamic shape, on both rotating and static Engine hardware. The freezing fraction is high for rime ice, typically approaching a value of 1.0. Rime ice typically has greater adhesion properties than glaze ice but often a lower density. Adhesion properties increase with lower temperature up to a test point where no additional adhesion is gained with additional lower temperature.

(c) *Mixed or Intermediate Ice.* A combination of glaze and rime ice which forms with rime patches slightly aft of the glaze ice portions. This ice forms at temperatures, liquid water content, and droplet sizes between those that produce rime and glaze ice.

Ice Shed Cycles. The time period required to build up and then shed ice on a propulsion system surface for a given power and icing condition. A shed cycle can be identified visually (for example, high-speed cameras), and Engine instrumentation such as vibration pickups, temperature probes, speed pickups, etc.). The ice shed cycle for rotating surfaces, such as fan blades, is strongly influenced by rotor speed and the adhesive strength of the ice to the surface. Ice adhesive strength generally increases with decreasing surface temperature.

Icing conditions. Meteorological conditions defined by the following parameters:

- *Liquid Water Content* (LWC). This defines the concentration of liquid water in air, typically expressed in grams of water per cubic meter of air.
- *Median Volume Diameter* (MVD). The drop diameter which divides the total water volume present in a droplet distribution in half (that is, half the water volume is in larger drops and half the volume in smaller drops).
- *Median Mass Dimension* (MMD). The particle size (sphere of equivalent mass) which divides the total ice mass present in an ice particle distribution in half (that is, half the ice mass is in larger particles and half the ice mass is in smaller particles).
- *Total Temperature*. The ambient temperature plus the ram rise. For icing testing in test cells, the total Engine inlet temperature includes static temperature of the cloud from the applicable icing environment, plus the assumed flight airspeed.
- *Static Temperature*. The local measured temperature minus the temperature rise from velocity effects.

Power/thrust Loss Instabilities. Engine operating anomalies that cause Engine instabilities. These types of anomalies could include non-recoverable or repeating surge, stall, rollback, or flameout, which can result in Engine power or thrust cycling.

Scoop Factor (concentration factor). The ratio of nacelle inlet highlight area (A_H) to the area of the captured air stream tube (A_C) [scoop factor = A_H/A_C]. Scoop factor compares liquid water available for ice formation in the inlet, to that available in the low-pressure compressor or Engine core, as a function of aircraft forward airspeed and Engine power condition. The scoop factor affect depends on the droplet diameter, the simulated airspeed and the Engine power level as well as the geometry and size of the Engine.

Sustained Power/Thrust Loss. This is a permanent loss in Engine power or thrust. Power or thrust losses that are not sustained are temporary in nature and may be related to the effects of ingesting super-cooled water or ice particles, or possibly the effects of ice accumulation or ice shedding. The Engine's momentary response during shedding may be from the thermodynamic Engine response to the ice ingestion and is not a sustained power loss.

Water Impingement Rate. The rate of water collection on an Engine surface during specific period of time. The units for water impingement rate are g/m^2/min.

Airfoil Span. The length of an Engine compressor airfoil (rotor or stator) measured from the flowpath inner diameter to the flowpath outer diameter.

(1.2) *References*

1. U.S. Department of Transportation. Federal Aviation Administration. Report No. DOT/FAA/AR-98/76, Mixed Phase Icing Condition, A review, by James T Riley.

(1.3) *Test Configuration – Engine*

Because the Engine behaviour cannot easily be divorced from the effects of the Engine air intake and Propeller, where possible, it is recommended that the tests be conducted on an Engine complete with representative air intake, Propeller (or those parts of the Propeller which affect the Engine air intake), and Engine air data probes. Separate assessment and/or testing of the air intake, Propeller and air data probes are not excluded, but in such circumstances the details of the assumed Engine installation will be defined in the manuals containing instructions for installing and operating the Engine (under CS-E 20(d)). It would then finally be the responsibility of the aircraft manufacturer to show that the Engine tests would still be valid for the particular installation, taking into account:

- Distortion of the airflow and partial blockage of the air intake as a result of, for example, incidence or ice formation on the air intake and Propeller;
- The shedding into the Engine of air intake and Propeller ice of a size greater than the engine is able to ingest;
- The icing of any Engine sensing devices or other subsidiary air intakes or equipment contained within the Engine air intake;
- The time required to bring the protective system into full operation.

Apart from tests carried out under paragraph (6) of this AMC, the icing tests should be carried out with all ice protection systems operating, unless dispatch is to be permitted with some ice protection systems inoperative, in which case the tests should be carried out using the minimum dispatch configuration for flight in icing conditions.

CS-E 780(b) requires that Engine bleeds and mechanical power offtakes permitted during icing conditions be set at the level assumed to be the most critical, or their effect must be simulated by other acceptable means. If it is not possible to establish clearly which position is most critical, the test should be repeated to ensure satisfactory operation in all permitted configurations.

(1.4) *Test Configuration – Facility*

The tests may be completed with adequately simulated icing conditions either in an altitude test facility capable of representing flight conditions, or in flight, or under non-altitude test conditions, with adequately simulated icing conditions.

Where non-altitude testing is used to simulate altitude conditions, appropriate justification should be presented to demonstrate that the test conditions are not less severe for both ice accretion and shedding than the equivalent altitude test points. The effects of ice density, hardness, and adhesion strength as it sheds should be assessed to realistic flight conditions. For example, in realistic flight conditions the ice shed cycle for rotating surfaces, such as fan blades, is strongly influenced by rotor speed and the adhesive strength of the ice to the surface. The adhesive strength of ice generally increases with decreasing surface temperature. The ice thickness and rotor speed at the time of the shed defines the impact threat.

(1.5) *Flight Testing*

Flight testing is an acceptable method of demonstrating Engine operation in icing conditions. Under these conditions, two important flight testing considerations are the measurement of ambient meteorological data and the ability to correlate the measured Engine performance to the most critical icing point.

In practice, it may not be feasible to test the Engine in flight under natural icing conditions. However testing in flight with simulated icing conditions could be possible and is not excluded. In this case, the applicant should define an acceptable means to establish and control the icing conditions.

(1.6) *Applicable Icing Environments*

The applicable icing environments are those applicable to the aircraft on which the Engine is to be installed, defined in CS 23.1093(b), CS 25.1093(b), CS 27.1093(b) and CS 29.1093(b) as appropriate. This includes atmospheric icing conditions (including freezing fog on ground) and falling and blowing snow conditions. Falling and blowing snow conditions are defined in AMC 25.1093(b).

The test altitude need not exceed any limitations proposed for aircraft approval, provided that a suitable altitude margin is demonstrated, and the altitude limitation is reflected in the manuals containing instructions for installing and operating the Engine.

(1.7) *Compliance of rotorcraft Engines to icing conditions*

Specific provisions for rotorcraft Engines are currently not included in this AMC. Until guidance has been established, the necessary compliance method required for rotorcraft Engines should be agreed by the Agency.

(2) *Supercooled Liquid Water Icing Conditions*

(2.1) *Critical Point Analysis*

(a) *General principle*

A Critical Points Analysis (CPA) is one analytical approach to determine suitable Engine test conditions in view of showing compliance of the Engine to certification specifications in Supercooled Liquid Water (SLW) icing conditions (including Supercooled Large Drops if applicable).

The CPA test points can replace the standard Table 1 test points below when they can be shown to be equivalent or more severe. Otherwise they supplement the Table 1 standard test points.

The applicant should consider pertinent service experience as well as the anticipated use of the aircraft when selecting critical icing test points.

Compliance with the requirements of CS-E 780 includes identifying, through analysis, the critical operating test points for icing within the declared operating envelope of the Engine. The CPA should relate icing conditions with the aircraft speed range and Engine powers/thrusts as defined by the applicant. It should also include prolonged flight operation in icing (for example, in-flight hold pattern), or repeat icing encounters. These combined elements within the CPA should identify the most critical operational icing conditions.

(i) Applicants should ensure that their analysis is supported by test data. It should also include environmental and Engine operational effects on accumulation, accretion locations, and the most critical Engine operating conditions for ice shed and ingestion. The CPA may also be supplemented with development test data (for example wet and dry testing with thermocouple components).

(ii) The CPA should include ice accretion calculations that account for freezing fraction and aerodynamic effects of the ice as it moves into the air inlet. For example, water ingestion into fan module and core inlets, water impingement rates for critical surfaces, forward aircraft airspeed effects, Engine configuration effects such as inter-compressor bleed, and altitude effects such as bypass ratio effects. The CPA should also include an energy balance of critical Engine surfaces (for example, latent heat and heat of fusion effects, metal-to-ice heat transfer effects, and ice insulating effects).

(iii) For anti-iced parts, the CPA should identify a critical test point determined from energy balance calculations of required heat loads encompassing the range of possible combinations of icing condition and Engine power/thrust. In glaze ice conditions, assessing the effects of non-aerodynamic ice formations and their shedding is more complex.

(iv) As part of the analysis the CPA should contain an assessment of the assumptions and any limitations of the models used and their validation.

(b) *Elements of the CPA*

The CPA should address, at minimum, the following icing issues:

(i) *Ice Shed Damage*. Shed ice can cause Engine damage if it impacts an Engine surface with sufficient mass and velocity. The following types of damage are common, and applicants should include them in their CPA with an assessment of each:

(A) *Fan Module*

Various parts of the fan module, both non-rotating and rotating, are susceptible to ice shed damage. For example, acoustic panels, fan rub strips, and fan blade tips are susceptible to ice shed from air intake probe(s), spinner, and fan blade roots.

In determining the critical conditions for fan module damage, the surface temperature, exposure time and rotor speed are important considerations as well as atmospheric icing condition and scoop factor. In particular, extended operation in a holding condition in very cold continuous maximum icing conditions, will maximize the adhesion of ice on rotating fan components. This can result in large ice accretions and resulting sheds which can damage the Engine or cause power/thrust loss.

(B) *Compressor Damage*

When ice formations on static components shed, they often result in damage to the next downstream rotor stage. For instance, this type of damage has occurred on the first blade set in the high pressure compressor (intermediate pressure compressor for three spool Engines). Establishing the critical conditions for these glaze ice accretions therefore, requires careful consideration as they occur at specific limited conditions of low freezing fractions over a range of local Mach numbers and air densities. The critical conditions may not occur during any of the power settings discussed in this AMC (for example, flight-idle, 50 %, 75 % or 100 % of maximum continuous power/thrust), and so the power/thrust setting at the critical condition should be evaluated. Applicants should evaluate any Engine compressor damage that results from ice testing against the possibility of multiple occurrences, since icing is a common environmental condition.

(ii) *Engine Operability and Compressor Rematch*. Ice shed from upstream components may enter the core compressor. The presence of ice or water from melted ice in the gas path may cause Engine component cycle changes. Additionally, the Engine should be capable of accelerating from minimum flight idle and ground idle to take-off power/thrust in any icing condition, without power/thrust loss or instability (surge or stall). Ice sheds should not result in flameout, rollback, or surge. Any anomalous Engine behaviour should be reported to the Agency for evaluation and if found acceptable, it should be documented in the manuals containing instructions for installing and operating the Engine. The applicant should consider as part of their CPA Engine accelerations and decelerations relative to operability challenges (for example, surge and stall). The minimum Engine bleed schedule allowed for the condition being tested should be assumed to minimize the operability margin. CPA testing should demonstrate those conditions where the minimum operability margin is expected.

(iii) *Core and Booster Ice Blockage*. Ice accretion on internal Engine vanes from glaze ice accretions may affect airflow capacity and rematch of the Engine cycle. This should be considered in the CPA. At Engine powers/thrusts that can sustain flight, ice accretion should be reconciled through a demonstration of several ice build shed cycles to demonstrate no adverse operating effects of either the ice builds or sheds.

(2.2) *Establishment of Test Points for In-Flight Operation*

The test conditions outlined below are intended as a guide to establish the minimum testing necessary to comply with CS-E 780. These test points should be supplemented or, if applicable replaced, by any test points identified by the CPA as applicable.

The conditions of horizontal and vertical extent and water concentration defined below are somewhat more severe than those implied by the icing atmospheric conditions of CS-Definitions. Encounters with icing conditions more severe that those defined are considered possible, and it is therefore appropriate to ensure that a margin is maintained.

(a) *Tests points to demonstrate icing capability at a power/thrust at or above that required for sustained flight*

One test point should be run to simulate each of the conditions of Table 1 at an Engine operating condition no higher than the minimum power/thrust to maintain sustained flight in the intended installation. For turbofan Engines, a second point should be run at a higher power/thrust condition, if it is predicted to result in a higher energy of ice shed from the fan blades. If an acceptable means to predict the critical fan speed is not available tests at 50 %, 75 % and 100 % of maximum continuous power/thrust should be run.

The minimum duration of each test point should be determined by repetitions of either the cycle:

(i) 28 km horizontal extent in the liquid water content conditions of Table 1 Column (a) appropriate to the temperature, followed by 5 km in the liquid water content conditions of Table 1 Column (b) appropriate to the temperature, for a total duration of 45 minutes, or 30 minutes if clear evidence of repeat build-shed cycles has been observed.

or the cycle:

(ii) 6 km horizontal extent in the liquid water content conditions of Table 1 Column (a) appropriate to the temperature, followed by 5 km in the liquid water content conditions of Table 1 Column (b) appropriate to the temperature, for a total duration of 20 minutes, or 10 minutes if clear evidence of repeat build-shed cycles has been observed.

At the conclusion of each test point, the Engine should be run up to the maximum power/thrust corresponding to the test conditions using a one second thrust/power lever movement, to demonstrate any effect of ice shedding. If repeat build/shed cycles have been established, the acceleration should be delayed to maximise the impact energy of the ice shed.

Table 1 – Standard test points

Ambient Air Temperature °C	Altitude		Liquid Water Content g/m^3		Mean Effective Droplet Diameter (μm)
	(ft.)	(m)	(a) Continuous Max	(b) Intermittent Max	
-10	17 000	5 182	0.6	2.2	20
-20	20 000	6 096	0.3	1.7	20
-30	25 000	7 620	0.2	1.0	20

(b) *Tests points at power/thrust below that required for sustained flight*

If the test points of (2.2)(a) are carried out at the minimum power/thrust for descent in icing or lower, no further test points are necessary.

Otherwise, an additional test at the minimum power/thrust associated with descent in icing conditions should be conducted at an ambient temperature of -10°C, or lower if necessary to ensure core icing, consisting of repetitions of the following cycle:

> A 6 km horizontal extent in the liquid water content condition of Table 1 Column (a) appropriate to the temperature, followed by 5 km in the liquid water content condition of Table 1 Column (b) appropriate to the temperature, for a total duration of 10 minutes.

If the temperature required to ensure core icing is below an ambient temperature of -10°C the LWC should be determined by interpolating between the conditions defined in Table 1.

At the conclusion of the test, the Engine should be set to flight idling power and then subjected to a timed acceleration, using a one second power/thrust control lever movement, to maximum power/thrust conditions, so as to simulate a balked landing. The maximum power/thrust conditions should then be maintained for a sufficient period to ensure all ice is shed, or alternatively, it may be established by visual inspection that any remaining ice is insignificant.

Whenever a minimum power/thrust is required for safe operation of the Engine in icing conditions, the applicant should ensure that this minimum power/thrust will be selected when the aircraft is operating in icing conditions. If any action is required from the installer to fulfil this requirement, then the minimum power/thrust should be declared as a limitation in the manuals containing instructions for installing and operating the Engine.

(c) *Test Installation Considerations*

Altitude and ram effect have a significant impact on the Engine operating conditions, ice accretion and ice shedding. Therefore use of an altitude test cell is the preferred method of compliance because this approach enables the test to be carried out in the most representative way, requiring the minimum of correction to correlate Engine and icing test conditions to the real operating environment. It also allows accurate control of the icing conditions. However, it is recognised that such facilities are not always available, and alternative test methods are also considered acceptable, providing that evidence demonstrates that such testing is at least as severe.

When a non-altitude test is used, any differences in Engine operating conditions, LWC and ice accretion between the altitude condition to be simulated and test conditions, and which could affect icing at the critical locations for accretion or shedding, should be taken into account when establishing the test conditions. This could involve modification of other test conditions of this paragraph in order to generate equivalent ice accretion. Effects which should be considered and corrected for include, but are not limited to:

- Engine shaft speeds;
- Ice concentration and dilution effects at Engine and core inlet (i.e. scoop factor);
- Mass flow (total and core Engine);
- Temperature effects.

Justification should be provided to demonstrate that altitude conditions for ice accretion and shedding are adequately replicated under test conditions at all critical Engine locations. If there is more than one critical location for any given test condition, and it is not possible to adequately simulate the icing conditions at both locations, separate test points may need to be run.

(2.3) *Establishment of Test Points for Ground Operation*

The Engine should demonstrate the ability to acceptably operate at minimum ground idle speed to be approved for use in icing conditions, for a minimum of 30 minutes at each of the following icing conditions shown in Table 2, with the available air bleed for ice protection at its critical condition, without adverse effect, followed by acceleration to take-off power or thrust. During the idle operation the Engine may be run up periodically to a moderate power/thrust setting in a manner acceptable to the Agency.

The conditions established during the test, in terms of time, temperature and run up procedures will be deemed to be the limitations necessary for safe operation in the applicable environment, provided that the acceptance criteria of CS-E 780(a) are met.

In order to avoid any unsafe condition resulting from operation outside the demonstrated conditions, these limitations will be defined in the manuals containing instructions for installing and operating the Engine.

For rime and glaze ice conditions as defined in Table 2, approval for operation below -18°C may be substantiated by analysis. A reduced liquid water concentration may be acceptable subject to appropriate substantiation.

The applicant should demonstrate, with consideration of expected airport elevations, the following:

Table 2 – Demonstration Methods for Specific Icing Conditions

Condition	Total Air Temperature	Liquid Water/Snow Concentrations (minimum)	Mean Effective Particle Diameter	Demonstration
1. Rime ice condition	-18 to -9 °C (0 to 15 °F)	Liquid - 0.3 g/m^3	15-25 μm	By Engine test
2. Glaze ice condition	-7 to -1 °C (20 to 30 °F)	Liquid - 0.3 g/m^3	15-25 μm	By Engine test
3. Snow condition	-3 to 0 °C (26 to 32 °F)	Snow - 0.9 g/m^3	100 μm (minimum)	By test, analysis or combination of the two.
4. Large drop glaze ice condition (Turbojet, turbofan, and turboprop only)	-9 to -1 °C (15 to 30 °F)	Liquid - 0.3 g/m^3	100 μm (minimum)	By test, analysis or combination of the two.

(3) *Mixed phase/Ice crystal conditions*

This paragraph is provided for certification of turbine Engines to be installed on aircraft which have mixed phase and ice crystal icing conditions included in their Certification Specifications.

Validated full scale ground test facilities for mixed phase and ice crystal icing conditions are currently not available. Therefore compliance should be based on flight test and/or analysis (supported by Engine/component tests as necessary).

(a) *Design precautions*

The applicant should show that design precautions have been taken to minimize the susceptibility of the Engine to mixed phase/ice crystal accretions.

The analysis should also identify remaining features or locations in which ice accretion could not be excluded. Design features which may increase the susceptibility include, but are not limited to:

(i) Stagnation points which could provide an increased accretion potential;

(ii) Exposed core entrance (as opposed to hidden core);

(iii) High turning rates in the inlet, in the booster and core flow path (particularly compound turning elements);

(iv) Protrusions into the core flow path (for example, bleed door edges and measurement probes);

(v) Unheated surfaces on booster and front core stages;

(vi) Narrow vane-to-vane circumferential stator spacing leading to a small stator passage hydraulic diameter;

(vii) Variable stator vanes can accrete ice and shed it when rotated;

(viii) Extraction capability of high stage core bleeds (not combustor / P3).

(b) *Comparative analysis*

If service experience of comparable Engine design(s) is available, the applicant should use a comparative analysis between previous designs and the new design in mixed phase/ice crystal icing conditions. The analysis should compare both design features and operational factors.

Where the analysis under paragraph (a) above identifies potential for ice accretion from design features then the applicant should conduct an analysis to review the service experience of the comparable Engine design(s) identifying any evidence indicating susceptibility to ice crystal/mixed phase accretion.

The applicant may demonstrate that the identified potential susceptibility to ice accretion is acceptable based on the good service experience demonstrated on comparable Engine design. Good service experience means the absence of event involving Engine malfunction or unacceptable damage caused by ice crystal or mixed phase conditions. To validate the credit from comparable Engine design, the applicant should demonstrate the design feature on the new design is similar in all pertinent aspects.

When comparable Engine design has experienced field events determined to have been caused by mixed phase or ice crystal icing conditions, the analysis should show that measures have been taken on the new design to address these field events and result in acceptable Engine operation. Acceptable operation includes the absence of rollback, rundown, stall, flameout, and unacceptable compressor blade damage.

(c) *Novel design features*

Where the analysis under paragraph (a) above identifies potential for ice accretion from novel design features for which a comparative analysis cannot be performed, additional tests as may be necessary to establish satisfactory operation should be made.

(4) *Ice ingestion*

(a) *Intent of Ice Slab Ingestion Test*

The intent of the ice slab ingestion test required per CS-E 780(f) is to demonstrate tolerance to ice ingestion from ice shedding from nacelle surfaces. In addition, it also establishes limits for ice released from other aircraft surfaces during CS-23 and CS-25 certification.

The minimum ice slab dimensions for the ice slab ingestion test are provided in the Table 3 below. The dimensions are related to Engine size (defined by inlet highlight area), based on service experience. The applicant should determine the ice slab dimensions by linear interpolation between the values of Table 3, based on the actual Engine’s inlet highlight area.

Table 3 – Minimum ice slab dimensions based on Engine inlet size

Engine Inlet Highlight area (inch² / m²)	Thickness (inch / mm)	Width (inch / cm)	Length (inch / cm)
0 / 0	0.25 / 6.35	0 / 0	3.6 / 9.144
80 / 0.0516128	0.25 / 6.35	6 / 15.24	3.6 / 9.144
300 / 0.193548	0.25 / 6.35	12 / 30.48	3.6 / 9.144
700 / 0.451612	0.25 / 6.35	12 / 30.48	4.8 / 12.192
2800 / 1.806448	0.35 / 6.35	12 / 30.48	8.5 / 21.59
5000 / 3.2258	0.43 / 10.922	12 / 30.48	11.0 / 27.94
7000 / 4.51612	0.50 / 12.7	12 / 30.48	12.7 / 32.258
7900 / 5.096764	0.50 / 12.7	12 / 30.48	13.4 / 34.036
9500 / 6.12902	0.50 / 12.7	12 / 30.48	14.6 / 37.084
11300 / 7.290308	0.50 / 12.7	12 / 30.48	15.9 / 40.386
13300 / 8.580628	0.50 / 12.7	12 / 30.48	17.1 / 43.434
16500 / 10.64514	0.50 / 12.7	12 / 30.48	18.9 / 48.006
20000 / 12.9032	0.50 / 12.7	12 / 30.48	20.0 / 50.8

Note: Applicants should use a minimum ice slab density equivalent to a 0.9 specific gravity, unless a different value is considered more appropriate.

The applicant should also include in its compliance plan, an analysis of the potential installation effects of the Engine induction system.

The applicant and the installer should closely coordinate the ice slab sizing. This coordination ensures that potential airframe ice accumulation sites that can be ingested by the Engine are addressed under CS-E 780(f).

(b) *Compliance considerations*

Compliance may be demonstrated by the standard Engine ice slab ingestion test or by means of a validated analysis procedure that uses equivalent soft body testing.

The test demonstration should use ice slab trajectories aimed at critical Engine locations. Applicants should pick locations based on the ice accretion and shed characteristics of the induction system likely to be installed on the Engine. The most critical impact location should be tested.

(c) *Elements of a Validated Analysis*

This analytical model may be used alone or in conjunction with the results of a certification medium bird ingestion test. A validated analysis should contain sufficient elements to show compliance. These elements may include:

- Full fan blade model utilizing latest techniques such as finite element analysis;
- Blade material properties for yield or failure, or both, as appropriate;
- Dynamic and time variant capability;
- Thrust variance prediction if required to account for blade damage; and
- Appropriate Engine or component testing, or both, with impact in outer 1/3 fan blade span location to anchor results.

(i) The analysis of the ice slab impact on the fan should properly account for critical controlling parameters:

- Relative kinetic energy normal to the leading edge chord,
- Incidence angle – relative slab speed and blade speed,
- Slab dimensions, and
- Slab orientation.

(ii) Any predicted power/thrust loss or blade damage (distortion, cracking, tearing) should be assessed against the criteria of this AMC.

(iii) The relative kinetic energy of the ice slab should be determined from an assessment of flight conditions that control Engine rotor speed and ice slab velocity; as influenced by the air stream velocity and density at the corresponding ice slab test point. Engine test results from previous ice slab testing may be used to support the predicted ice slab velocity. The applicant's analysis should assume the most critical orientation unless it can be shown that an alternate ice slab orientation is more conservative relative to ice slab testing.

(d) Ice Slab Break Up.

Typically, the ice slab breaks up into smaller pieces during an ice slab ingestion. The applicant's analysis should use the largest slab size consistent with a conservative assessment of slab "break up" that can occur within the air stream ahead of the fan. Data derived from a number of tests shows that the largest ice piece is typically 1/3 to 1/2 the original size. For compliance purposes, the applicant should assume 1/2 of the original slab length unless evidence suggests that this is not conservative relative to ice slab testing.

(e) Test Results.

CS-E 780(f)(2) requires that following ice ingestion the Engine must comply with CS-E 780(a). The following elements should be considered:

(i) Engine Loss of Performance. Applicants should evaluate the impact of any fan blade bending or damage on potential sustained Engine power/thrust loss. Power/thrust loss associated with fan damage from the slab should be less than 1.5 %. As soft body fan damage is common from medium bird ingestion, applicants may use the medium bird ingestion test results to show compliance with this requirement. If the medium bird ingestion test results in less than 1.5 % permanent power/thrust loss, and no cracks, tears or blade piece breakout occurs due to a bird introduced at the outer 33 % of the fan blade span, then the CS-E 780(f)(2) requirement is met.

(A) If power/thrust loss exceeds 1.5 % when utilizing the bird test, the applicant should provide a validated analysis that shows consistency with the bird test results. The manufacturer should also demonstrate the standard ice slab would produce less than the 1.5 % power/thrust loss.

(B) Applicants should also demonstrate by test that any cracks, tears or blade piece breakout will not result in “unacceptable sustained power or thrust loss” within 100 cycles (considered sufficient to allow Engine operation to the next scheduled “A” check). Furthermore, any damage that results from this test should be documented within the manuals containing instructions for installing and operating the Engine.

(ii) Engine Operability/Handling characteristics. Engine damage should not cause surge, flameout, or prevent transient operation.

(iii) In-Service Capability. Engine damage should not result in a failure or a performance loss that would prevent continued safe operation for a conservative flight operations scenario (for example, within the time period for an “A” check or greater, if appropriate testing validates a continued period of in-service capability). The period of in-service capability to be demonstrated may vary with installation if the damage is not readily evident to the crew or visible on pre-flight inspection (for example, tail mounted engines).

(iv) Other Anomalies. Engine damage should not result in any other anomaly (for example, vibration) that may cause the Engine to exceed operating or structural limitations.

(v) Auto-Recovery Systems. If during ice slab ingestion testing, an Engine incurs a momentary flameout and auto-relight, then the acceptance of that test is predicated on including the auto-relight system as a required part of the Engine type design. However, additional dispatch criteria would also be required where the ignition system is fully operable before each dispatch. The reason for the additional dispatch criteria is to ensure the ignition system’s critical relight function is reliably available during the subsequent flight. The use of auto-recovery system is allowed during ice slab ingestion certification testing, to account for ice accretion and shedding as a result of an inadvertent delay in actuating the ice protection system. We consider this to be an abnormal operational result where operability effects, like momentary flameout and relight, may be accepted.

(f) Communication to the Installer. The manuals containing instructions for installing and operating the Engine should provide information on the Engine ingestion capability such as size, thickness, and density of the ice slab ingested.

(5) *Engine Air Data Probe Icing*

In accordance with paragraph (1.3) of this AMC, the accretion and shedding of ice from the Engine air data probe(s) should be evaluated either as part of the Engine test, or by separate assessment and/or testing.

In addition, if data from an Engine air data probe is critical to ensure acceptable Engine operation, then the applicant should demonstrate that Engine air data probe will operate normally without any malfunction under icing conditions. The icing conditions against which the Engine is tested may not cover the icing conditions that are critical for the Engine air data probe. The applicant should determine those critical icing conditions. In that respect the guidance material of AMC 25.1324 of CS-25 should be used. In doing that the substantiation may be limited to the icing environment applicable to the aircraft on which the Engine is to be installed.

In assessing whether data from an Engine air data probe is critical, the Engine system(s) response to erroneous in-range data and to data during transitions to/from icing conditions should be considered.

Note: When Engine air data probe signals are used by the aircraft system(s), the aircraft manufacturer should show that the involved Engine air data probe complies with CS 25.1324 (including rain conditions).

(6) *Inadvertent Entry into Icing Conditions or Delayed IPS activation*

The ice ingestion demonstration of paragraph (4) of this AMC addresses the threat of ice released from protected airframe surfaces, including the Engine air intake, following a delay in selection of ice protection system such as might occur during inadvertent entry into icing conditions.

However, if satisfactory operation in any icing condition relies on the activation of Engine ice protection system(s), such as a raised idle function and/or an internal ice protection system, it should be demonstrated that the Engine characteristics are not unacceptably affected by the introduction of a representative delay in the initiation of operation of the Engine ice protection system(s).

In assessing the representative delay, the applicant should consider all factors that contribute to a delay in activation of ice protection system(s).

This assessment should include the time for ice condition detection, pilot response time, time for the system to become operational, time for the system to become effective.

In the absence of other evidence a pilot response time of two minutes may be considered.

The assumed delay in activation of any ice protection system should be declared in the manuals containing instructions for installing and operating the Engine.

(7) *Instructions for installing and operating the Engine*

The applicant should declare all identified limitations to the installer in the manuals containing instructions for installing and operating the Engine. This should include, but is not limited to, the following items (see background in the previous paragraphs of this AMC):

- Details of the assumed Engine installation, including protection device(s);
- Operational altitude limitation;
- Engine ingestion capability such as size, thickness, and density of the ice slab ingested,
- Engine ice ingestion protection device to be provided by the installer (when not part of the Engine configuration);
- Damage observed after the ice slab ingestion test;
- Anomalous Engine behaviour that has been found acceptable following ice shed ingestion,
- Minimum power/thrust required for safe operation of the Engine in icing conditions (if necessary);
- For ground icing operation, the conditions established during the test, in terms of time, temperature and run up procedures;
- The assumed delay in activation of any ice protection system.

If the Engine is certified under the assumption that the protection device considered under CS-E 780(f)(3) is provided by the aircraft installation, and if (with respect to ice formed forward of the protection device) the compliance with CS-E 780 (f)(1) to (f)(2) is waived, then the Engine approval would be endorsed accordingly and the Engine instructions for installation would need to impose the conditions of CS-E 780 (f)(3)(i) to (iii) to the installation.