CS-E Amendment 4 — Change Information

The Agency publishes amendments to Certification Specifications as consolidated documents. These documents are used for establishing the certification basis for applications made after the date of entry into force of the amendment.

Consequently, except for a note [Amdt No: E/4] under the amended paragraph, the consolidated text of CS-E does not allow readers to see the detailed changes introduced by the new amendment. To allow readers to also see these detailed changes this document has been created. The same format as for the publication of Notices of Proposed Amendments has been used to show the changes:

(a) deleted text is marked with strike through;

(b) new or amended text is highlighted in grey;

(c) an ellipsis (…) indicates that the remaining text is unchanged in front of or following the reflected amendment.

PREAMBLE

CS-E Amendment 4 Effective: see Decision 2015/009/R

The following is a list of paragraphs affected by this amendment.

Contents (General lay-out)

Subpart D

— CS-E 580 Editorial change

Book 1

Subpart E

— CS-E 650 Amended (NPA 2014-03)

— CS-E 740 Amended (NPA 2014-03)

— CS-E 780 Amended (NPA 2011-04)

Subpart F

— CS-E 1050 Created (NPA 2011-17)

Book 2

Subpart A

— AMC E 30 Amended (NPA 2012-23)

Subpart E

— AMC E 510 Editorial change

— AMC E 650 Amended (NPA 2014-03)

— AMC E 740 Amended (NPA 2014-03)

— AMC E 780 Amended (NPA 2012-23)

Subpart F

— AMC E 1050 Created (NPA 2011-17)

CONTENTS (General lay-out)

PREAMBLE

CS-E BOOK 1 — AIRWORTHINESS CODE

[…]

SUBPART D — TURBINE ENGINES; DESIGN AND CONSTRUCTION

[…]

[…]

CS-E BOOK 1 — AIRWORTHINESS CODE

SUBPART E — TURBINE ENGINES TYPE SUBSTANTIATION

1. **Replace the existing CS-E 650 by the following text:**

CS-E 650 Vibration Surveys
(See AMC E 650)

(a) It must be established by test or a combination of test and validated analysis that the vibration characteristics of all components that may be subject to mechanically or aerodynamically induced vibratory responses are acceptable throughout the declared flight envelope.

(b) The vibration surveys must cover the ranges of power or thrust and rotational speed for each rotor module, corresponding to operations throughout the range of ambient conditions in the declared flight envelope, from the minimum rotational speed up to at least the maximum of:

(1) 103 % of the maximum rotational speed permitted for rating periods of two minutes or longer;

(2) 100 % of the maximum rotational speed permitted for rating periods of less than two minutes;

(3) 100 % of any Maximum Engine Over-speeds declared under CS-E 830.

(c) If there is any indication that a rising response amplitude may lead to peak vibratory stresses occurring at a speed above the maximum rotational speed established under CS-E 650(b), the surveys must be extended sufficiently to reveal the maximum amplitude, except that the extension need not cover more than a further 2 percentage points increase beyond this speed.

(d) The surveys must also cover the aerodynamic and aeromechanical factors which might induce or influence flutter in those systems susceptible to that form of vibration.

(e) Evaluations must be made of the effects on vibration characteristics of operating with scheduled changes (including allowance for tolerances) to variable vane angles, compressor bleeds, accessory loading, the most adverse inlet airflow distortion pattern declared by the applicant and the most adverse conditions in the exhaust duct(s).

(f) Except as provided by CS-E 650(g), the vibratory stresses associated with the vibration characteristics determined under this CS-E 650, when combined with the appropriate steady stresses, must provide suitable margins to the endurance limit of each component, after making due allowances for operating conditions and for the permitted variations in properties of the associated materials. The suitability of these stress margins must be justified for each component. If it is determined that certain operating conditions, or ranges, need to be limited, operating and installation limitations must be established.

(g) The effects on vibration characteristics of excitation forces caused by Fault conditions must be evaluated and shown not to result in a Hazardous Engine Effect.

(h) Compliance with this CS-E 650 must be substantiated for each specific installation configuration that can affect the vibration characteristics of the Engine. If these vibration effects cannot be fully investigated during Engine certification, the methods by which they can be evaluated and compliance shown must be substantiated and defined in the Engine instructions for installation required under CS-E 20(d).

2. Amend CS-E 740 as follows:

CS-E 740 Endurance Tests
(See AMC E 740)

(g) *Incremental Periods*

(1) If a significant ~~peak blade~~ vibration response is found to exist on relevant components in the course of establishing compliance with CS-E 650 at any condition within the operating range of the Engine (not prohibited under CS-E 650 ~~(d)~~(f)), not less than 10 hours, but not exceeding 50 %, of the incremental periods of Part 4 of the endurance test…

3. Amend paragraph CS-E 780 as follows:

CS-E 780 ~~Tests In Ice Forming Conditions~~ Icing Conditions
(See AMC E 780)

(a) It must be established by tests, unless alternative appropriate evidence is available, that the Engine will function satisfactorily when operated ~~in the atmospheric icing conditions of CS-Definitions~~ throughout the conditions of atmospheric icing (including freezing fog on ground) and falling and blowing snow defined in the turbine Engines air intake system ice protection specifications (CS-23.1093(b), CS-25.1093(b), CS-27.1093(b) or CS-29.1093(b)) of the Certification Specifications applicable to the aircraft on which the Engine is to be installed, as specified in CS-E 20(b), without unacceptable:

(1) Immediate or ultimate reduction of Engine performance,

(2) Increase of Engine operating temperatures,

(3) Deterioration of Engine handling characteristics, and

(4) Mechanical damage.

~~(b) *(Reserved)*~~

(b~~c~~) ~~During the tests of~~ In showing compliance with the specifications of CS-E 780(a), all ~~optional~~ Engine bleeds and mechanical power offtakes permitted during icing conditions must be ~~in the position~~ set at the level assumed to be the most critical, or their effect must be simulated by other acceptable means. It must be established, however, that other likely use of bleed or mechanical power offtake will not lead to Engine malfunctioning.

~~(d) Where the Engine is considered to be vulnerable to operation in ice crystal cloud conditions, in mixed ice crystals and liquid water conditions, or in snow, such additional tests as may be necessary to establish satisfactory operation in these conditions must be made.~~

(c~~e~~) In showing compliance with the specifications of this paragraph CS-E 780, the conditions associated with a representative installation must be taken into account.

(d~~f~~) If after the tests it is found that significant damage has occurred, further running or other evidence may be required to show that subsequent Failures are unlikely to occur.

(eg) Where an air intake guard is fitted, compliance with the specifications of this paragraph CS-E 780 must be established with the guard in position, unless the guard is required to be retracted during icing conditions, in which case it must be established that its retraction is not affected immediately after a representative delay period.

(f) Ice ingestion

(1) *Objective*. To demonstrate that the Engine will function satisfactorily following the ingestion of defined quantities of ice, as part of compliance with CS-E 540. Ingestion of ice may result from ice released by the Engine air intake (including after delayed selection of the ice protection system) or from other aircraft surfaces. Compliance with the requirements of this sub-paragraph shall be demonstrated by an Engine ice slab ingestion test or by validated analysis showing equivalence to other means for demonstrating soft body damage tolerance.

(2) Following the ingestion of ice under the conditions of this paragraph, the Engine shall comply with CS-E 780(a).

(3) For an Engine that incorporates or requires the use of a protection device, compliance with this paragraph need not be demonstrated with respect to ice formed forward of the protection device if it is shown that:

(i) such ice is of a size that will not pass through the protection device;
(ii) the protection device will withstand the impact of the ice; and
(iii) the ice stopped by the protection device will not obstruct the flow of air into the Engine resulting in unacceptable effects under CS-E 780(a).

(4) In establishing the ice slab ingestion conditions, the assumed ice quantity and dimensions, the ingestion velocity and the Engine operating conditions must be determined. Those conditions shall be appropriate to the Engine installation on the aircraft. These assumptions must be included in the manuals containing instructions for installing and operating the Engine under CS-E 20(d).

SUBPART F — TURBINE ENGINES — ENVIRONMENTAL AND OPERATIONAL DESIGN REQUIREMENTS

4. Create CS-E 1050 as follows:

CS-E 1050 Exposure to volcanic cloud hazards
(See AMC E 1050)

(a) The susceptibility of turbine Engine features to the effects of volcanic cloud hazards must be established.

(b) Information necessary for safe operation must be provided in the relevant documentation.

Book 2 Acceptable Means of Compliance (AMC)

SUBPART A — GENERAL

1. 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. Engine ingestion capabilities.
[…]	[…]

SUBPART E — TURBINE ENGINES TYPE SUBSTANTIATION

2. <u>Amend AMC E 510 as follows:</u>

(5) Related documents.

[…]

— Society of Automotive Engineers (SAE)/EUROCAE, Document No. ARP4754A/EUROCAE ED-79A, ~~Certification Considerations for Highly Integrated or Complex Aircraft Systems~~ Guidelines for Development of Civil Aircraft and Systems.

3. <u>Replace the existing AMC E 650 by the following text:</u>

AMC E 650
Vibration Surveys

(1) Definitions. The following are defined for the purpose of this AMC:

Vibration Survey:	A vibration survey is a test or series of tests which, either alone or in conjunction with validated analysis, establishes the vibratory characteristics of Engine components.
Baseline Test:	A baseline test is one which was performed for the purpose of establishing experimentally the dynamic characteristics of Engine components using hardware, and/or under conditions, different from those for which approval is currently sought, and is an essential requirement for a complementary validated analysis.
Validated Analysis:	A validated analysis is one with demonstrated predictive capability within a specified domain of applicability that encompasses one or more complementary baseline tests.
Module:	A module is either a compressor or a turbine which may be single or multi-stage, or a gear box. If multi-stage, the rotating elements are mechanically joined and rotate at the same speed. The gas path entry and exit points are clearly defined and are frequently nodal points in a performance model. *Note*: A single stage or subset of stages isolated from a multi-stage compressor or turbine does not constitute a module.
Physical Rotational Speed (Nr):	The physical rotational speed of the rotating elements of a module is the raw uncorrected rotational speed. It is rotational speed as normally understood. The descriptor ‘physical’ is added in order to differentiate it clearly from corrected speed.
Minimum Rotational Speed (Min Nr):	The minimum rotational speed of the rotating elements of a module is the lowest steady state rotational speed which

	can be obtained within the limits imposed by the Engine Control System under Fault free conditions throughout the declared flight envelope.
Corrected Speed (Nc):	The corrected speed of the rotating elements of a module is the rotational speed normalised to a standard inlet temperature of 15°C in accordance with the formula: $Nc = Nr/(T\ inlet/288)^e$, where T inlet is the module gas path inlet temperature in Kelvin and the exponent e is determined empirically but has a typical value of 0.5. Corrected speed is a parameter widely used in performance modelling.
Declared Flight Envelope:	The declared flight envelope is the set of all airborne and ground conditions of operation to be approved, including start-up, shutdown and windmilling rotation in flight.
Resonance:	Resonance is a condition that occurs when an oscillatory force applied to a component has a frequency that coincides with one of the component's natural frequencies, resulting in an elevated vibratory response. A unique vibratory mode exists for each natural frequency.
Flutter:	Flutter is a self-excited vibration of a component in a gas flow, caused by a continuous interaction between the gas flow and the structure, in which energy from the flow is diverted to the structure such that the vibratory response is sustained or increased. In turbomachinery, it usually occurs at a natural frequency of the structure and in the associated mode shape.
Significant Response:	A significant response is one in which a vibratory stress exceeds the level that has been previously agreed by the Agency as providing acceptable margin under CS-E 70 and CS-E 100 for the type of feature concerned.
Endurance Limit:	The endurance limit of a component is the maximum value of alternating stress that, when repeated for an essentially infinite number of cycles, will not result in high cycle fatigue failure of the component. 10^7 cycles have generally been accepted as 'essentially infinite'. The endurance limit is a function of steady-state stress, temperature, geometry and material properties.

(2) Introduction

The intent of the rule is to ensure the acceptable dynamic behaviour of all components and assemblies in a gas turbine Engine. More specifically, the rule is aimed at the avoidance of damaging high cycle fatigue failures.

(3) Selection of Components

CS-E 650(a) requires that the survey covers all components that may be subject to mechanically or aerodynamically induced vibrations. Component selection for the survey should be based on an appropriate combination of experience, analysis, and component test. The selected components would normally include:

— the most critical blades and vanes, from a vibration point of view, in the fan and each compressor and turbine module;
— all blade rows adjacent to variable incidence vanes;
— all fan, compressor and turbine discs and spacers;
— all main rotor shaft systems (and gears, when included in such systems);
— any other component specifically identified as requiring Engine test to substantiate analysis and/or to supplement component tests.

(4) Test Conditions

A test or series of tests is an essential element of the survey. Whether the tests are new or baseline, the following conditions apply:

(a) Rig testing
Normally, a full Engine test is the preferred means to complete the survey. However, an applicant may elect to use rig tests for overcoming limitations associated with a full Engine test, such as the amount of instrumentation capable of being fitted or the range of inlet conditions that can be tested. Rig tests generally consist of testing full or part of Engine modules. If rig tests are employed, the applicant should demonstrate that all pertinent interface conditions and physical hardware closely replicate actual Engine conditions.

(b) Speed requirements
It should be the goal of the test programme to cover at least the ranges of conditions required under CS-E 650(b) and (c).

CS-E 650(b)(1) requires consideration of 103 % of the maximum rotational speed permitted for rating periods of two minutes or longer, but where it proves physically impracticable to achieve the appropriate extended test conditions, the Agency may accept an alternative that complies with the intent of the requirement. Historically, the 3 % margin has been imposed to account for transient overshoot. If it can be demonstrated that the characteristics of the Engine Control System are such that the maximum rated speed cannot be exceeded in fault-free operation, the required maximum tested speed may, with the agreement of the Agency, be adjusted downward, but may not be less than 100 %.

Where an extension to the range required by CS-E 650(b) is considered necessary for the identification of the effects of a rising vibratory stress peak, as required under CS-E 650(c), but it proves physically impracticable to achieve the appropriate extended test conditions, the Agency may accept an alternative that complies with the intent of the requirement. Historically, the requirement has been imposed to account for Engine-to-Engine variability. The Engine manufacturing and build tolerances can result in peak vibratory stresses occurring at slightly different rotor speeds for Engines and Engine parts (for example blades) of the same type design. If tested components are deliberately selected to cover an adverse range of manufacturing variability or any other effect normally captured by increasing the test maximum speed by a further 2 %, the required maximum tested speed may, with the agreement of the Agency, be adjusted downward, but may not be less than the maximum speed established for compliance with CS-E 650(b).

Any reduction in the speed range requirements of CS-E 650(b) and (c) proposed for the test programme should be justified by the applicant and agreed by the Agency. Normally, it would be expected that any test shortfall is covered by validated analysis.

Refer also to paragraph (5) 'Altitude and Temperature Effects' and (8) 'Flutter' for complementary guidance on affecting speeds.

(c) Instrumentation

To acquire the data required under CS-E 650 when conducting vibration surveys, the applicant should use suitable instrumentation, data acquisition, and analyser systems. Vibration-specific instrumentation may include dynamic strain gauges, accelerometers, dynamic pressure gauges and time-of-arrival sensors.

Vibratory stresses are most commonly calculated using dynamic strain gauges placed at predetermined locations and oriented to measure specific directional strains. These strain gauges should maintain their accuracy throughout the test conditions, particularly when repeatedly exposed to high temperatures for extended periods. The applicant should aim to take measurements at locations which are sensitive to the peak responses of interest but are also tolerant of a degree of mislocation/alignment variability. When these locations are not suitable or accessible for that purpose, stresses may be measured nearby provided that the relationships between the stresses at these locations and those at critical locations are known and predictable. To identify the accessible locations that best represent the critical stresses, knowledge of each natural mode and associated stress distributions is required, which may be gained from a combination of experience, analyses, or testing. This investigation is usually conducted before the certification test.

Time-of-arrival sensors, such as optical sensors or light probes, may prove convenient alternatives to strain gauges provided they are properly calibrated and their capabilities are clearly understood. The most common application for time-of-arrival sensors is to estimate blade tip displacements, which may then be converted to stresses at specific blade locations. Converting measured displacements or gauge strains to vibratory stresses requires a detailed knowledge of the blade normal mode frequencies, mode shapes, modal stress/strain distributions and associated tip displacements. This conversion should be shown to be sufficiently accurate or at least conservative. Time-of-arrival data for vibratory modes where measured displacements have low sensitivity in relation to stresses in critical areas should not be used in order to avoid excessive uncertainty in endurance limit calculations.

(d) Instrumentation survivability

Where the Engine operates at such high rotor speeds and gas path temperatures that test instrumentation can only survive the environment for short periods of time, validated analysis would be expected to complete the substantiation. The loss of instrumentation should be minimal and the associated analysis should be primarily based on the surviving instrumentation data.

(e) Engine modifications

During testing, the Engine may be modified or adjusted in an effort to achieve the desired physical and corrected speeds, or any other test conditions. Any alterations made to the

Engine for these purposes should be evaluated to show that their effects are not detrimental or do not compromise the intent of the test and the test results.

(5) Altitude and Temperature Effects

CS-E 650(a) requires that conditions throughout the declared flight envelope are evaluated when establishing that the dynamic behaviour of components and systems is acceptable.

Changes in operating conditions associated with ambient temperature and altitude variations affect Engine performance and airflow characteristics. This can have a significant effect on aerodynamic forcing and damping, which, in turn, affects the vibratory response and behaviour of certain components. Appropriate justification should be provided by the applicant that the worst operating conditions in the declared flight envelope have been fully explored.

Engine tests may be conducted by means of flight test or in altitude facilities or in other facilities such that the effects of altitude and temperature are properly represented and can be evaluated. Suitable test equipment and instrumentation should be used for each situation. The dependency of certain vibratory phenomena on temperature and altitude can be characterised as a dependency on corrected speed, which enables such phenomena to be investigated by means of sea-level testing, provided that the entire required corrected speed range can be achieved. In general, a high corrected speed implies that the airflow over the blading has a high Mach number, which is associated with higher aerodynamic forcing and lower aerodynamic stability.

(6) Fault Conditions

A number of common Fault conditions can have the effect of introducing additional excitation sources or changes to those existing under Fault-free conditions. Any change in vibration response should be evaluated and shown not to result in a Hazardous Engine Effect.

CS-E 650(g) applies to those Fault conditions that would cause abnormal vibrations that are difficult to identify in a timely manner so that appropriate mitigating action can be taken. Notwithstanding the provisions of CS-E 60 and CS-E 510 with regard to instrumentation, certain low-level vibrations caused by Fault conditions may not be recognised as associated with an Engine Fault and may not prompt an immediate response. Subsequently, these Faults may escalate to Hazardous Engine Effects. For example, the loss of an airfoil tip would be likely to result in a change in vibration due to the increased out-of-balance. Even if indicated by the means required under CS-E 60 and CS-E 510, this vibration might not be immediately recognised as abnormal or may not prompt immediate action, and could cause further damage. Other Faults include incorrectly scheduled compressor variables, stator vanes blockages or enlargement, and blockages of fuel nozzles. These Faults could produce local airflow distortions and changes in the airflow or pressure distributions that in turn may affect component vibratory response and characteristics. To address these Fault conditions, the applicant may use prior experience with Faults that occurred on other similar Engines. Successful experience is such that, after exposure to a Fault condition, the Engine was able either to continue in safe operation or to be shut down without creating a Hazardous Engine Effect. Applicants may also use field experience or other means to show that certain Fault conditions are Extremely Remote because of specific Engine configurations, design features or operating conditions. The requirements of CS-E 650(g) apply to the same components that are considered under CS-E 650(a). When the effects of these Fault conditions extend to the rest of the Engine, they must be addressed under the requirements of CS-E 100 Strength and/or CS-E 520 Strength (for example, the out-of-balance effects on the Engine structural components).

(7) Inlet Airflow Distortion

Fan and compressor vibration can be sensitive to inlet airflow distortion, and conditions consistent with the most adverse pattern declared by the applicant should be taken into account. Inlet airflow distortion may be associated with the air intake, crosswinds, or other operating and aircraft installation conditions. When an Engine test is performed, whether in a test cell or on a flight test bed, the inlet distortion may be achieved by various means, such as external crosswind devices, inlet distortion plates or suppression screens.

(8) Flutter

Testing required to demonstrate satisfactory vibratory clearance from flutter boundaries may be accomplished by rig and/or Engine sea-level or altitude test, subject to the following considerations:

(a) The presence of flutter may be acceptable in some circumstances, for example in a speed range encountered only briefly or infrequently, or where the flutter amplitude is limited to a safe level. However, the resulting vibration stresses must always satisfy the requirements of CS-E 650(f). A thorough investigation of the flutter response and its effects should be completed to show that the flutter does not result in a Hazardous Engine Effect. The investigation may include testing as required under paragraph (10) below for a significant response.

(b) In all cases, the test procedure needs to recognise that some systems' susceptibilities to flutter will not be revealed during tests if the relevant operating conditions are not sustained long enough for the flutter to develop.

(c) As flutter is a phenomenon which can be sensitive to small variations in those factors which could influence the response of the system, due consideration should also be given to possible variations between the nominal and extreme values of, for example, tip clearances, mechanical damping, operating lines and bleed flows. Experience has also shown that there are differences in susceptibility to flutter from one blade set to another and that 'tuned' blade sets might be more sensitive.

(d) If tests will be conducted at sea level only, the applicant should propose a procedure acceptable to the Agency to account for altitude effects. For certain Engine modules, especially fans and compressors, it is expected that this will be achieved by testing throughout the range of corrected speed that the module will encounter in service, in which case the requirements of CS-E 650(b) and (c) with regard to physical rotational speed should be considered to apply also to corrected speed. The provisions of paragraph (4)(b) of this AMC are also applicable.

(e) For some turbines, the propensity to flutter is not increased at maximum corrected speed, and other methods of demonstrating the absence of damaging flutter throughout the declared flight envelope may be more appropriate. It is important to ensure that the maximum stage inlet pressure at each physical speed is achieved, or compensation is provided. The strength of aerodynamic forcing on many turbine blades is predominantly driven by the total pressure levels, and the highest pressures are expected at the highest mechanical speed. Where turbines operate in aerodynamically choked conditions and the mass flow through the turbine is dictated by the fixed geometry of the blading, the corrected speed is essentially constant. Higher corrected speed (at an aerodynamic work level) will lower the blading Mach numbers (Mn) and, conversely, a lower corrected speed will increase blading Mn. This means that, in such cases, running up to 100 % of maximum mechanical speed will cover the worst case (highest forcing) condition.

(f) In general, the methods used to verify the absence of damaging levels of flutter throughout the declared flight envelope should include consideration of applicable combinations of the following:

(i) the ranges of physical and corrected rotational speeds for each rotor module;

(ii) the simultaneous occurrence of maximum fan or compressor inlet air total temperature and maximum corrected rotational speed (i.e. maximum reduced velocity);

(iii) the range of fan or compressor operating lines within the flight envelope;

(iv) the most adverse of other fan or compressor inlet air conditions encountered within the flight envelope (e.g. applicable combinations of total air pressure, density, temperature, and inlet distortion); and

(v) the hardware standard, the intake conditions and margins to account for Engine deterioration.

(9) Variations in Material Properties and Natural Frequencies

Allowance should be made as follows for the permitted variations in material properties, critical dimensions and resulting natural frequencies of production components when interpreting test results or making analytical predictions:

(a) Material allowable stresses

The material property that is important in relation to the requirements of CS-E 650(f) is the endurance limit associated with specific combinations of mean stress and alternating stress, usually represented on a Goodman diagram. The influence on the endurance limit of manufacturing processes, the local geometrical features, and temperatures should also be taken into account.

(b) Stress margins

Section CS-E 650(f) requires suitable stress margins for each part evaluated, usually represented by the stress margins at the critical or limiting locations. The stress margin is the difference between the material allowable at a particular location and the measured vibratory stress at that location. The criteria for stress margin suitability should account for the variability in design, operation and other mitigating factors identified during the certification test.

(c) Modal response

The total vibratory stress at any given location is the sum of the resonant stresses associated with all active and concurrent normal modes, plus any other vibratory stresses that occur at that particular rotational speed. Due to variability in properties (material and geometry) the frequencies and separation of the modes may be different from blade to blade (or other component). The applicant should consider the stress amplitudes that occur within permitted blade-to-blade variations of natural frequency. For example, if for a particular blade design the natural frequency (fn) range is fn ± 2.5 %, then the combined amplitudes within this range should be considered.

Where there is potential for more than one mode to be excited at the same time/speed, the overall amplitude will be a combination of contributions from each individual response. The combined stress is typically calculated by breaking down the vibratory stress of each mode into its stress components and then combining the modal contributions in proportion to the individual measured responses to obtain the overall principal or equivalent vibratory stresses.

(10) Dwell Testing

The applicant should determine all significant responses within the operating conditions prescribed in CS-E 650 and allow sufficient time for any associated resonant modes to respond. This is usually accomplished during slow acceleration and deceleration speed sweeps covering the range of required speeds.

If any significant response is found, then the relevant components should be subjected to sufficient cycles of vibration close to, and/or on, the response peak to demonstrate compliance with CS-E 650(f). This dwell testing would normally be incorporated into the incremental periods of the CS-E 740 Endurance Test as required by CS-E 740(g)(1).Components subjected to such dwell testing should subsequently also meet the strip inspection requirements of CS-E 740(h).

(11) Transient Response

Consideration should also be given to the speed range from zero to minimum rotational speed, especially in the case of supercritical shafts. Some predicted potentially damaging transient responses may require an aggressive control input to provoke a representative response.

(12) Instrumentation Incompatibility

If the dimensions of the components to be tested are incompatible with the necessary instrumentation, instrumented Engine tests to substantiate the vibration characteristics of these components and the variation of the Endurance Test incremental running as prescribed in CS-E 740(g)(1) may be waived wholly or in part if the Agency is satisfied that the total hours of operation accumulated on test beds or in flight, under representative conditions, prior to certification are sufficient to demonstrate that the vibration stress levels are acceptable.

(13) Installation Compatibility

The intent of CS-E 650(h) is to ensure vibratory compatibility between the Engine and each intended installation configuration when the Engine is installed and operated in accordance with the manufacturer’s approved instructions. The applicant will normally be expected to provide sufficient information in the Engine instructions for installation to enable the aircraft manufacturer(s) to establish that the installation does not unacceptably affect the Engine’s vibration characteristics. In establishing vibratory compatibility between the Engine and the installation, consideration should be given to the need to declare operating limitations and procedures. Where appropriate, at least the following aspects and installation features should be considered:

— each Propeller approved for use on the Engine;
— each thrust reverser approved for use on the Engine;
— installation influences on inlet and exhaust conditions;
— mount stiffness; and
— rotor drive systems.

(14) Modelling and Analysis

Acceptable analytical methods are based on the complementary concepts of a baseline test and validated analysis. The general principle is that a baseline test in conjunction with validated analysis is equivalent to a new test.

(a) Baseline test

A baseline test is usually one of the following:

(i) An Engine or rig test run on the first model of an Engine type during the type certification programme. The validated analysis developed on the basis of this test may then be used for derivative models that are added to the same type certificate.

(ii) An Engine or rig test run on a previously certified Engine type. The validated analysis developed on the basis of this test may then be used for Engines whose design characteristics and operating conditions are shown to be sufficiently similar to those of the Engine in the baseline test.

(iii) An Engine or rig test specifically run to support the creation of the validated analysis.

The design characteristics and operating conditions run in the baseline test(s) should be shown to be sufficiently similar and inclusive of the domain of applicability for the Engine being certified, as defined in this AMC, paragraph (14)(b)(i), (ii) and (iii).

A test from which the results are used to calibrate an analysis is not in general eligible to be considered a baseline test in relation to the validation of that analysis. The same test results cannot be used both to calibrate and validate an analysis.

(b) Validated Analysis

(i) Development of the Validated Analysis.

The analytical model should be validated against one or more baseline tests.

For each baseline test on which the validation is based, it should be shown that the analysis consistently predicts the observed behaviour and vibratory responses of the components investigated to an acceptable precision and accuracy. Alternatively, it could be shown that predictions reliably overpredict the vibratory response.

The applicant should clearly define the domain of applicability of the analysis, comprising the ranges of design characteristics and operating conditions for which the analysis will be deemed to be validated. Typical design characteristics and operating conditions which may constitute a definition of the domain of applicability are as follows:

— Engine architecture:

- general configuration, for example 2- or 3-shaft design, turboshaft, turbofan, open rotor, geared fan;

- secondary air system;
- number, location and type of bearings, including installation (inner/outer race grounded, inter-shaft, damped, etc.), and associated support structures.

— Module type, for example high or low pressure turbine, axial or radial compressor.

— Component geometry, for example shrouded or unshrouded blades, aerofoil aerodynamic shapes (‘2D’ or ‘3D’).

— Structural dynamic characteristics:

- natural frequencies, which will influence the resonance speeds and aerodynamic stability (flutter);
- mode shape similarity, for example a measure of accuracy that is often employed is the Modal Assurance Criterion (MAC). Typically, a MAC value greater than 0.9 indicates there is close agreement between measured and calculated mode shapes. Close matching of mode shapes implies that response to the same forcing will be similar;
- mechanical damping levels; any difference will be directly reflected in the resonant response level or flutter suppression;
- mistuning levels; the degree of scatter in frequency between blades will strongly influence the vibration amplitudes variability in a bladed disc and will have a stabilising influence on flutter.

— All structural dynamic characteristics affected by:

- materials and construction technique, for example composites, anisotropic metals, joining methods
- restraints, for example blade or vane attachment design, snubbers or dampers, flanges.

Similarity of the structural dynamic characteristics is frequently demonstrated by a combination of comparative analysis and modal testing in a laboratory.

— Aeroelastic characteristics:

- The Strouhal number (k) or reduced frequency which characterises the variation of flow with time, where $k = \omega.c/U$, ω = frequency, c = component length in flow direction and U = flow velocity, is relevant for flutter.

— Sources of vibratory excitations and forcing strength:

- upstream or downstream rotors, stators or struts, for example numbers off, aerodynamic style, axial gapping;
- gas stream characteristics, inlet or flow path asymmetry, main gas path and secondary flows;
- power or thrust levels, air density, Mach number and Reynolds number that can affect both flutter and forced response amplitudes,

- combustion system
- mechanical sources, for example gearbox and rotor out-of-balance.

— Operating conditions:

- rotational speeds, temperatures and gas pressures experienced by the subject components throughout the declared flight envelope.

The validated analysis and its domain of applicability should be acceptable to the Agency.

(ii) Use of the Validated Analysis

Similarity of the Engine, module or component(s) to be certified with previously tested and certified designs should be justified. For each new Engine certification programme, for which the use of validated analysis is proposed, the applicant should show that the design characteristics and operating conditions of the Engine fall within the domain of applicability of the analysis previously established and accepted by the Agency.
The demonstration of compliance will be considered to be the combination of the baseline test(s) used to create the validated analysis, and the analysis performed on the Engine for which approval is currently sought.
Examples where validated analysis may be used include but are not limited to the following:

— Where test speeds required by CS-E 650(b) and (c) are not achieved, by agreement with the Agency as described in paragraph (4)(b) of this AMC. The validated analysis would be expected to cover the speed range(s) or operating conditions not achieved during testing.
— Where instrumentation has been lost, for example due to the extreme test conditions. The validated analysis would be expected to cover the speed range(s) or operating conditions for which instrumentation was lost.
— Where stresses are not measured directly at critical locations. In that case, the peak stresses may be derived based on measurements taken at reference locations. This requires a detailed understanding of the modal composition of the response and the associated mode shapes to derive the relationship between each location.
— Where it proves necessary to justify the acceptability of any significant responses whether observed or predicted.

(iii) Update of the Validated Analysis
It is expected that the applicant may regularly update the validated analysis, for instance following new testing performed or service experience. The updated validated analysis and/or its domain of applicability should be reviewed and accepted by the Agency.

(15) Inspection Specifications

The pre-certification activity necessary for determining which Engine components require verification by Engine test and also for determining the proper location of Engine test instrumentation will typically include substantive tests and analyses for determining component (or system) natural frequencies, mode shapes, steady-state mean stress and vibratory stress distributions. These development activities will generate engineering data essential to supporting the certification test and should be exempt from formal Agency approval of test plans and reports. Inspection of type design hardware in accordance with the requirements of 21.A.33 of Part-21 should be limited to only those pertinent Engine components and associated instrumentation that constitute the certification Engine test or the baseline tests supporting the validated analysis.

4. <u>Amend AMC E 740 (g)(1) as follows:</u>

AMC E 740 (g)(1)
Endurance Tests — Incremental Periods

As an alternative to revising the incremental running as indicated in CS-E 740(g)(1), separate Engine running of appropriate severity may be completed (see also AMC E 650, paragraph ~~8~~10).

5. 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 just before or immediately after an upset (that is, power loss or stall) without operator intervention. Auto-recovery systems include auto-relight systems, stall recovery systems, and other Engine systems intended to recover the operability of an Engine following a flameout, surge, stall, or a combination of these.

Freezing Fraction: The ratio of the mass of water that freezes at a point on a surface to the total mass of incoming water at that point.

Highlight Area: The area bounded by the leading edge of the nacelle inlet. This may be different for turboshaft installations where complex inlet schemes are utilised.

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 transparent or translucent ice formed by liquid water droplets that do not freeze immediately on impact and has horns. 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 and opaque ice formed by liquid cloud droplets that freeze immediately on impact. 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.

Ice Shed Cycle: 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, with high-speed cameras), and with Engine instrumentation (such as vibration pickups, temperature probes, pressure 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. In general, ice adhesive strength increases as surface temperature decreases.

Icing Conditions: The presence of supercooled liquid water drops and temperature conducive to aircraft icing. These conditions are defined by the following parameters:

- Liquid Water Content (LWC): The total mass of water contained in liquid drops within a volume or mass unit of cloud or precipitation, usually given in units of grams of water per cubic meter or kilogram of dry air (g/m3, g/kg);
- Median Volumetric Diameter (MVD): The drop diameter which divides the total liquid water content present in the drop distribution in half, i.e., half the water volume will be in larger drops and half the volume in smaller drops. (Also sometimes called Median Volume Diameter). Note the MVD used in Appendices O and P to CS-25 is equivalent to the MED used in Appendix C to CS-25 and CS-29, CS-Definitions for an assumed Langmuir type droplet distribution);
- Mean Effective Diameter (MED): A term used with the rotating multicylinder method for measuring LWC in clouds. A droplet diameter which, when assigned to the midpoint of one of the Langmuir distributions, gives the best agreement between the computed and measured differential ice mass accumulations on a set of rotating multicylinders. The MED is approximately equal to the MVD;
- Total Air Temperature (TAT): The ambient air temperature plus the ram air temperature rise. For icing testing in test cells, the total Engine inlet temperature includes the static air temperature of the cloud from the applicable icing environment, plus the assumed flight airspeed; and
- Static Air Temperature (SAT): The local measured air temperature minus the air 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 the liquid water available for ice formation in the Engine 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 effect depends on the droplet diameter, the simulated airspeed and the Engine power level as well as the geometry and size of the Engine. This may be different for turboshaft installations where complex inlet schemes are utilised.

Sustained Power/Thrust Loss: This is a permanent loss in Engine power or thrust. Typically, sustained power loss is calculated at rated take-off power.

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

Note: Additional definitions can be found in Reference 2. — SAE ARP 5624.

(1.2) References

1. Mixed-Phase Icing Condition: A review (DOT/FAA/AR-98/76), Dr. Riley, James T, Office of Aviation Research, Washington D.C. 20591, U.S. Department of Transportation, Federal Aviation Administration, December 1998.

2. SAE Aerospace Recommended Practice (ARP) 5624 — 'Aircraft Inflight Icing Terminology', issued on 3.3.2008, reaffirmed on 23.4.2013.

(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 air intake and Propeller, 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; and

— 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 (IPS) operating. When dispatch is to be permitted with some ice protection systems inoperative, then the tests should address all configurations approved for aircraft dispatch.

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 test configuration is most critical, the test should be repeated, if necessary, in order 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.

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 density, hardness, and adhesion strength of the ice 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 the 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, ice properties and rotor speed at the time of the shed define 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 with 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 (SLW) Icing Conditions

(2.1) Critical Points Analysis (CPA)

(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 with Certification Specifications in Supercooled Liquid Water (SLW) icing conditions (including Supercooled Large Drops, if applicable).

Compliance evidence should include a description of the methodology and tools used as part of the CPA. The validation of tools should also be addressed.

Whilst the CPA is primarily intended to identify whether test points should be added to those defined in paragraph (2.2), the principles outlined below may also be used for justifying the testing necessary for approval of ground operation in SLW icing conditions.

Where a CPA test point is in a similar condition to a Table 1 test point, the more severe of the two should be demonstrated.

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 to the aircraft speed range and Engine powers/thrusts as defined by the applicant. It should also include prolonged flight operation in icing conditions (for example, in-flight hold pattern), or a repetition of 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 by-pass 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 conditions and Engine power/thrust. The effects of non-aerodynamic ice formations and their shedding as well as runback ice shedding should be assessed.

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

(b) Elements of the CPA

The CPA should address, at a 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 the atmospheric icing conditions and scoop factor. In particular, extended operation in a holding condition in very cold continuous maximum icing conditions will maximise 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 ice accretions therefore requires careful consideration as the critical condition may 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.

The applicant should consider Engine operability as part of their CPA. Engine accelerations and decelerations relative to operability challenges (for example, surge and stall) should also be considered. The most adverse Engine bleed settings for the condition being analysed should be assumed to minimise the operability margin. The establishment of CPA points should consider 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 SLW Icing Conditions in CS-Definitions, Appendix C to CS-25 and Appendix C to CS-29. 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 the Engine 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 LWC conditions of Table 1, Column (a), appropriate to the temperature, followed by 5 km in the LWC 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 LWC conditions of Table 1, Column (a), appropriate to the temperature, followed by 5 km in the LWC 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 (LWC) (g/m3)		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

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 splitter/core inlet icing, consisting of repetitions of the following cycle:

A 28 km horizontal extent in the LWC condition of Table 1, Column (a), appropriate to the temperature, followed by 5 km in the LWC condition of Table 1, Column (b), appropriate to the temperature, for a sufficient duration to cover an anticipated descent of 3 000 m.

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 subjected to an 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, the use of an altitude test cell is the most direct 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 with 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 the test conditions, 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); and

— 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. An acceleration to take-off power or thrust should be performed at the time when the maximum ice accretion is likely to have occurred. During the idle operation, the Engine may be run up periodically to a moderate power/thrust setting in a manner acceptable to the Agency.

Normally, 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.

However, an analysis may be used to demonstrate that ambient temperatures below the tested temperature are less critical.

Moreover, the applicant may demonstrate unlimited time operation if complete ice shedding is shown to have occurred during the test, either through repeatable ice build/shed cycles or by using a run-up procedure.

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, taking into consideration 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	-9 to -1 °C (15 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 (including comparative 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	100–3 000 µm	By test, analysis (including comparative 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.

Until validated full-scale ground test facilities for mixed-phase and ice crystal icing conditions are available, 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 minimise 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, 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 bleeds; and
(ix) runback ice formed downstream of internal Engine heated surfaces.

(b) Comparative Analysis. If service experience of comparable Engine design(s) is available, the applicant should perform 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 due to design features, the applicant should conduct an analysis to review the service experience of the comparable Engine design(s) in order to identify 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 any event involving Engine malfunction or unacceptable damage caused by ice crystal or mixed-

phase conditions. To validate the credit from the comparable Engine design, the applicant should demonstrate that the design feature on the new design is similar in all pertinent aspects.
When the 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 due to novel design features for which a comparative analysis cannot be performed, additional tests should be made to establish satisfactory operation.

(4) Ice Ingestion

(a) Intent of Ice Slab Ingestion Test

The intent of the ice slab ingestion test required by 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 in the frame of CS-23 or CS-25 certification.
The minimum ice slab dimensions for the ice slab ingestion test are provided in 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
2 800/1.806448	0.35/8.89	12/30.48	8.5/21.59
5 000/3.2258	0.43/10.922	12/30.48	11.0/27.94
7 000/4.51612	0.50/12.7	12/30.48	12.7/32.258

7 900/5.096764	0.50/12.7	12/30.48	13.4/34.036
9 500/6.12902	0.50/12.7	12/30.48	14.6/37.084
11 300/7.290308	0.50/12.7	12/30.48	15.9/40.386
13 300/8.580628	0.50/12.7	12/30.48	17.1/43.434
16 500/10.64514	0.50/12.7	12/30.48	18.9/48.006
20 000/12.9032	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 that can be ingested by the Engine are addressed under CS-E 780(f).

(b) Compliance Considerations

Compliance may be demonstrated through the standard Engine ice slab ingestion test or by means of a validated analysis procedure that uses an 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.
Engine operation will be at the maximum cruise power or thrust unless lower power or thrust is shown to be more critical.

(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 (fan Engines) or first stage compressor (non-fan Engines) blade model using the latest techniques such as finite element analysis;
— blade material properties for yield or failure, or both, as appropriate;
— dynamic and time variant capability;
— thrust or power variance prediction if required to account for blade damage; and
— appropriate Engine or component testing, or both, with impact at the outer 1/3 of the first stage blade span location. The fan is the first stage blade row for turbofan Engines.

(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,
— sab orientation, and
— impact location.

(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 the flight conditions that control Engine rotor speed versus ice slab velocity. 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 for ice slab testing.

(iv) 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 a 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 of the original size. For analysis purposes, the applicant may assume 1/2 of the original slab greatest dimension unless evidence suggests that this is not conservative relative to the ice slab testing.

(d) Test Results

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

(i) Engine Loss of Performance. Applicants should evaluate the impact of any first stage blade bending or damage on potential sustained Engine power/thrust loss. Sustained power/thrust loss associated with first stage damage from the slab should be less than 1.5 %. Ice and birds are 'soft body' objects in their impact behaviour, i.e. they are both highly deformable on impact and flow over the structure, spreading the impact load. They also have similar densities; thus they create similar strain footprints and, consequently, similar damage. 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 occur due to a bird ingested at the outer 33 % of the first stage blade span, then the CS-E 780(f)(2) requirement is met.

(A) If power/thrust loss exceeds 1.5 % when utilising the bird test, the applicant should provide a validated analysis that shows consistency with the bird test results. The applicant should also demonstrate that 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 flight cycles (considered sufficient to allow Engine operation until the next scheduled 'A' check). Furthermore, any damage resulting from this test should be documented in the manuals containing instructions for installing and operating the Engine.

(ii) Engine Operability/Handling Characteristics. Ice slab ingestion should not cause surge, flameout, or prevent transient operation.

(iii) In-Service Capability. Engine damage resulting from ice slab ingestion 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. Ice slab ingestion 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 that the ignition system's critical relight function is reliably available during the subsequent flight. The use of an auto-recovery system is allowed during ice slab ingestion certification testing, in order to account for ice accretion and shedding as a result of an inadvertent delay in actuating the ice protection system. This is considered as an abnormal operational result where operability effects, like momentary flameout and relight, may be accepted.

(e) 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 the 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, in particular if high airflow conditions like Maximum Continuous Thrust/Power were not selected for the Engine tests in paragraph (2.2) above. The applicant should determine those critical probe icing conditions. In that respect, the guidance material of AMC 25.1324 of CS-25 should be used along with appropriate consideration of the installation effects and dependence on Engine airflow. 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: If Engine air data probe signals are used by the aircraft system(s) on a CS-25 aeroplane, the aeroplane manufacturer will be responsible for showing 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 the selection of the ice protection system such as might occur during inadvertent entry into icing conditions.

However, if satisfactory operation in any icing conditions relies on manual 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 the 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 lack of other evidence, a delay of two minutes to switch on the IPS should be assumed. For thermal IPS, the time for the IPS to warm up should be added.

(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. These should include but are not limited to the following items (see background in the previous paragraphs of this AMC):

— the icing environment in which the engine has been certified;
— 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);
— effects that may be observed during or after the encounter of icing conditions, such as vibrations, temporary power/thrust loss, change in Engine power/thrust response;
— 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); and

— for ground icing operation, the conditions established during the test in terms of time, temperature (if any limitation exists) and run-up procedures.

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.

SUBPART F – TURBINE ENGINES – ENVIRONMENTAL AND OPERATIONAL DESIGN REQUIREMENTS

6. Create AMC E 1050

AMC E 1050
Exposure to volcanic cloud hazards

Acceptable means of establishing the susceptibility of Engine features to the effects of volcanic clouds should include a combination of experience, studies, analysis, and/or testing of parts, sub-assemblies or Engines.

Information necessary for safe operation should be contained in the relevant documentation. This information may be used to assist operators in producing operational data and instructions for their flight crews when operating in, or avoiding, airspace contaminated with volcanic clouds. The information should be readily usable by operators in preparing a safety risk assessment as part of their overall management system.

A volcanic cloud comprises volcanic ash together with gases and other chemicals. Although the primary hazard is volcanic ash, other elements of the volcanic cloud may also be undesirable to operate through, and their effect on airworthiness should be assessed.

In determining the susceptibility of turbine Engine features to the effects of volcanic clouds and the necessary information to operators to allow safe Engine operation, the following points should be considered:

(1) Identify the features of the turbine Engine that are susceptible to airworthiness effects from volcanic clouds. These may include but are not limited to the following:

   a. erosion of compressor blades and other internal parts;

   b. glassy deposits on hot section parts, which can result in loss of surge margins, Engine stall, flame out, and inability to restart Engines;

   c. clogging of turbine blade cooling channels;

   d. corrosion of metallic parts;

   e. oil and fuel circuit contamination; and

   f. electrical, hydraulic and pneumatic systems.

(2) The nature and severity of effects.

(3) The related pre-flight, in-flight and post-flight precautions to be observed by the operator including any necessary amendments to Engine Manuals, Dispatch Deviation, or equivalents, required to support the operator.

(4) The recommended continued airworthiness inspections associated with operations in volcanic cloud contaminated airspace; these may take the form of Instructions for Continued Airworthiness or other advice.