Notice of Proposed Amendment 2021-13

in accordance with
Articles 6(3), 7 and 8 (‘Standard procedure’: public consultation) of MB Decision No 18-2015

Regular update of CS-E

RMT.0184

EXECUTIVE SUMMARY

The objective of this Notice of Proposed Amendment (NPA) is to address a safety recommendation involving the failure of engine fan blades, thus improving the certification of turbofan engines to better assess and mitigate the potential hazards from such failures, especially by better integrating the analysis and identification of the potential threats to the aircraft on which the engine is to be installed. The proposed amendments will therefore ensure a more robust certification process and will decrease the risk of substantial aircraft damage and fatalities.

In addition, the amendments proposed will reflect the state of the art of engine certification and improve the harmonisation of CS-E with the Federal Aviation Administration (FAA) regulations. To that end, this NPA proposes amendments to CS-E following the selection of non-complex, non-controversial, and mature subjects.

In particular, this NPA proposes amendments in the following areas:

Item 1: Compressor and turbine blade failure,

Item 2: Assumptions — oil consumption,

Item 3: Instrument provisions,

Item 4: Piston engine failure analysis,

Item 5: Approval of engine use with a thrust reverser,

Item 6: Fuel specifications for compression-ignition piston engine,

Item 7: Ice protection,

Item 8: Damage tolerance of critical parts,

Item 9: Engine critical parts — Static pressure loaded parts,

Item 10: Various corrections.

The proposed amendments are expected to improve safety, would have no social or environmental impacts, and would provide economic benefits by streamlining the certification process.

Domain:	Design and production		
Affected rules:	CS-E		
Affected stakeholders:	Engine manufacturers		
Driver:	Safety and efficiency/proportionality	**Rulemaking group:**	No
Impact assessment:	No	**Rulemaking Procedure:**	Standard

EASA rulemaking procedure milestones

Start Terms of Reference	**Public consultation** draft NPA 202X-13 (draft Decision)	**Proposal to the Commission** EASA Opinion	Adoption by the Commission Implementing Rules	**Decision** Certification Specifications, Acceptable Means of Compliance, Guidance Material
27.7.2015	**22.11.2021**	**N/A**	**N/A**	**2022 Q1**

Table of contents

1. About this NPA

1.1. How this NPA was developed

The European Union Aviation Safety Agency (EASA) developed this NPA in line with Regulation (EU) 2018/1139[1] (the 'Basic Regulation') and the Rulemaking Procedure[2]. This Rulemaking Task (RMT).0184 is included in the European Plan for Aviation Safety (EPAS) 2021-2025). The scope and timescales of the task were defined in the related Terms of Reference (ToR)[3].

The text of this NPA has been developed by EASA. It is hereby submitted to all interested parties for consultation in accordance with Article 115 of the Basic Regulation, and Articles 6(3), 7 and 8 of the Rulemaking Procedure.

1.2. How to comment on this NPA

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

The deadline for submission of comments is **22 February 2022**.

1.3. The next steps

Following the closing of the public commenting period, EASA will review all the comments received.

Based on the comments received, EASA will publish a decision to amend the related certification specifications and acceptable means of compliance for engines (CS-E).

The individual comments received on this NPA and the EASA responses to them will be reflected in a comment-response document (CRD), which will be published on the EASA website[5].

[1] Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91 (OJ L 212, 22.8.2018, p. 1) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1535612134845&uri=CELEX:32018R1139).

[2] EASA is bound to follow a structured rulemaking process as required by Article 115(1) of Regulation (EU) 2018/1139. Such a process has been adopted by the EASA Management Board (MB) and is referred to as the 'Rulemaking Procedure'. See MB Decision No 18-2015 of 15 December 2015 replacing Decision 01/2012 concerning the procedure to be applied by EASA for the issuing of opinions, certification specifications and guidance material (http://www.easa.europa.eu/the-agency/management-board/decisions/easa-mb-decision-18-2015-rulemaking-procedure).

[3] https://www.easa.europa.eu/sites/default/files/dfu/ToR%20RMT.0184%20%28E.015%29%20Issue%201.pdf

[4] In case of technical problems, please contact the CRT webmaster (crt@easa.europa.eu).

[5] https://www.easa.europa.eu/document-library/comment-response-documents

2. In summary — why and what

2.1. Why we need to amend the rules — issue/rationale

The aviation industry is complex and rapidly evolving. CSs and AMC need to be updated regularly to ensure that they are fit for purpose, cost-effective, and can be implemented in practice.

Regular updates are issued when relevant data is available following an update of industry standards, feedback from certification activities, or minor issues raised by the stakeholders.

Lessons learnt from accident and incident investigations may also be addressed in regular updates when the topic is not complex and not controversial.

Item 1: Compressor and turbine blade failure

The analysis and lessons learnt from occurrences involving the failure of fan blades indicates that the certification of turbofan engines could be improved to better assess and mitigate the potential hazards from such blade failures, especially by better integrating the analysis and identification of the potential threats to the aircraft on which the engine is to be installed.

On April 17, 2018 Southwest Airlines (SWA) flight 1380, a Boeing 737-7H4, experienced a left engine failure while climbing through flight level 320 en-route to the flight's assigned cruise altitude. The flight had departed from LaGuardia Airport, New York, about 30 minutes earlier. As a result of the engine failure, the flight crew conducted an emergency descent and diverted to Philadelphia International Airport (PHL), Pennsylvania. Portions of the left engine inlet and fan cowl separated from the aeroplane, and fragments from the inlet and fan cowl struck the left wing, the left-side fuselage, and the left horizontal stabiliser. One fan cowl fragment impacted the left-side fuselage near a cabin window, and the window departed from the aeroplane, which resulted in a rapid depressurisation. The aeroplane landed safely at PHL about 17 minutes after the engine failure occurred. Of the 144 passengers and 5 crew members aboard the aeroplane, 1 passenger received fatal injuries, and 8 passengers received minor injuries. The aeroplane was substantially damaged.

The National Transportation Safety Board (NTSB) determined that the probable cause of this accident was a low-cycle fatigue crack in the dovetail of fan blade No. 13, which resulted in the fan blade separating in flight and impacting the engine fan case at a location that was critical to the structural integrity and performance of the fan cowl structure. This impact led to the in-flight separation of fan cowl components, including the inboard fan cowl aft latch keeper, which struck the fuselage near a cabin window and caused the window to depart from the aeroplane, the cabin to rapidly depressurise, and the passenger fatality.

The NTSB issued the following safety recommendation (UNST-2019-007) to EASA (an equivalent recommendation was also issued to the US Federal Aviation Administration (FAA)):

'Expand your certification requirements for transport-category airplanes and aircraft engines to mandate that airplane and engine manufacturers work collaboratively to

(1) analyze all critical fan blade impact locations for all engine operating conditions, the resulting fan blade fragmentation, and the effects of the fan-blade-out-generated loads on the nacelle structure and

(2) develop a method to ensure that the analysis findings are fully accounted for in the design of the nacelle structure and its components.'

EASA analysed the existing certification specifications and acceptable means of compliance applicable to turbine engines in CS-E and identified the following issues that are considered eligible to be dealt with under the regular update of CS-E:

(a) The potential release of uncontained debris in the engine forward and rearward directions is not sufficiently addressed. It is limited to a provision in AMC E 810 ('Compressor and Turbine Blade Failure') related to the blade containment test, requiring to report the estimated size, weight, trajectory, and velocity of any debris ejected from the intake or exhaust during the test.

(b) CS-E 520(c)(2) requires that validated data (from analysis or test or both) be established and provided to enable the aircraft manufacturer to ascertain the forces that could be imposed on the aircraft structure and systems as a consequence of the out-of-balance running and during any continued rotation with rotor unbalance after shutdown of the Engine following the occurrence of blade failure as demonstrated in compliance with CS-E 810 ('Compressor and Turbine Blade Failure'). AMC E 520(c)(2) provides some guidance and acceptable means of compliance regarding the Engine model validation. However, it appears that the displacements and loads transmitted to the engine nacelle structure (certified at aircraft level) have not been sufficiently addressed during the certification of some engines and aircraft.

Item 2: Assumptions — oil consumption

AMC E 30 provides in its Table 1 the assumptions which should normally be provided in the Engine instructions for installation, as required under CS-E 30.

Regarding the oil system, Table 1 indicates the 'oil(s) approved for use'.

However, the oil consumption and the flight duration are also important assumptions that should be listed in Table 1.

Item 3: Instrument provisions

CS-E 60 requires the provision for the installation of instrumentation necessary to ensure operation in compliance with the Engine operating limitations.

According to AMC E 60, in addition to powerplant instrumentation required for aircraft certification, the Engine safety analysis might show the need for specific instrumentation providing information to the flight crew or maintenance personnel for taking the appropriate actions in order to prevent the occurrence of a Failure or to mitigate any associated consequences.

Such instrumentation typically includes the indication of the ice protection system activation, rotor system unbalance and fuel flow. This is not mentioned in AMC E 60, and EASA has identified the need to clarify this point.

Item 4: Piston engine failure analysis

CS E-210(a) requires a failure analysis of the engine, including its control system, in order to demonstrate that no single fault, or double fault if one of the faults may be present and undetected during pre-flight checks, could lead to unsafe engine conditions beyond the normal control of the flight crew.

CS E-210(b) specifies that this failure analysis may depend on assumed installation conditions and requires that such assumptions are stated in the analysis.

AMC E 210 specifies that the failure analysis 'would normally include investigation of those engine components that could affect the functioning and integrity of the major rotating assemblies, and for the control system, all manual and automatic controls such as refrigerant injection system, engine and fuel system speed governors, engine over-speed limiters, propeller control systems, propeller thrust reversal systems, etc.'

However, there is currently no AMC provision explaining how to interpret the CS E-210(a) specification 'unsafe engine conditions beyond the normal control of the flight crew'.

Therefore, during certification projects a generic Means of Compliance (MoC) has been agreed with applicants via Certification Review Items (CRIs) (entitled 'CS-E 210 Failure Analysis') in order to define the kinds of failure conditions to be taken into account. This MoC is considered mature enough to be introduced in AMC E 210.

Item 5: Approval of engine use with a thrust reverser

On many aeroplanes, the turbine engines are equipped with a thrust reverser. This thrust reverser is usually not part of the engine type design but is certificated with the aeroplane.

In many cases, the engine type certificate applicant does not plan to test the engine with the aeroplane thrust reverser during engine certification. Instead, an equivalent duct is used that simulates the mechanical and aerodynamic characteristics of a representative production thrust reverser. This duct generally cannot simulate all the thrust reverser functions.

EASA published Certification Memorandum CM-PIFS-002 Issue 1 dated 8 March 2012, entitled 'Approval of Engine Use with a Thrust Reverser'. This Certification Memorandum (CM) describes how it can be allowed that a turbine engine is equipped and used with a thrust reverser, even when this thrust reverser is not part of the engine type design.

EASA considers that the content of this CM is sufficiently mature to be reflected in CS-E.

Item 6: Fuel specifications for compression-ignition piston engine

EASA recommends that applicants for certification of compression-ignition engines use test fuels that comply with ASTM standard D8147 Standard Specification for Special-Purpose Test Fuels for Aviation Compression-Ignition Engines.

This is however not indicated in CS-E.

Item 7: Ice protection

Icing ground tests: These tests are performed at lower by-pass ratio conditions than actual altitude conditions, which is not representative for operability and surges. According to AMC E 780 paragraph (1.4), applicants should justify that non-altitude conditions are not less severe for both ice accretions and shedding than the equivalent altitude test points, but it does not address the engine operability.

Icing conditions: EASA has identified the need to bring clarifications on the range of icing conditions that are applicable under AMC E 780.

Icing induced vibrations: EASA has identified the need to clarify what effects should be taken into account when showing compliance with CS E 100(c) for turbine engines. This includes, among other items, the effect of ice ingestion.

Use of ice protection systems: EASA has identified the need to clarify what needs to be addressed as consequences from delayed activation or deactivation of ice protection systems in AMC E 780 (Section 6).

Item 8: Damage tolerance of critical parts

EASA had previously identified the need for clarification for compliance demonstration based on both deterministic and probabilistic surface damage tolerance, and this topic has been addressed under EASA Certification Memorandum CM-PIFS-007 Issue 1 dated 22 February 2013, entitled ‘Engine Critical Parts - Damage Tolerance Assessment - Manufacturing and Surface Induced Anomalies’.

The content of this CM can now be introduced in CS-E.

Item 9: Engine critical parts — Static pressure loaded parts

AMC E 515 (‘Engine Critical Parts’) paragraph (3) deals with the definition of an Engineering Plan which is one of the three elements required by CS-E 515 to ensure the integrity of Engine Critical Parts.

Sub-paragraph (e) of this paragraph addresses the establishment of the approved life for static pressure loaded parts.

Unlike the FAA Advisory Circular (AC) 33.70-1 (‘Guidance material for aircraft engine life-limited parts requirements’), AMC E 515(3)(e) does not indicate that the CS-E certification specifications applicable to static pressure loaded parts should be complied with assuming the presence of the maximum predicted size crack that can occur within the Approved Life of the part, and that it may be necessary to limit the crack size allowed in service to comply with certification specifications other than CS-E 515.

EASA agrees with the AC 33.70-1 guidance material on this topic (provided in Section 8(e)), which is also accepted by the industry. There is therefore an opportunity to harmonise AMC E 515 with FAA AC 33.70-1 to improve the efficiency of the EASA certification process.

Item 10: Various corrections

— Reference to Part 21 in CS-E 10

CS-E 10(c) refers to point 21.A.16 of Part 21, which has been deleted and replaced by a new point 21.B.75 by Regulation (EU) 2019/897[6].

— Reference to Part 21 in CS-E 25

CS-E 25(a) refers to point 21.A.61(a) of Part 21, which has been deleted and replaced by a new point 21.A.7 by Regulation (EU) 2021/699[7].

[6] Commission Delegated Regulation (EU) 2019/897 of 12 March 2019 amending Regulation (EU) No 748/2012 as regards the inclusion of risk-based compliance verification in Annex I and the implementation of requirements for environmental protection (OJ L 144, 3.6.2019, p. 1) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0897&qid=1634744922897).

[7] Commission Delegated Regulation (EU) 2021/699 of 21 December 2020 amending and correcting Regulation (EU) No 748/2012 as regards the instructions for continued airworthiness, the production of parts to be used during maintenance

— Reference to Part 21 in CS-E 160

CS-E 160(a) refers to point 21.A.21(c)(3) of Part 21. Point 21.A.21 has been amended by Regulation (EU) 2019/897 and the content of point 21.A.21(c)(3) has been relocated in point 21.A.20(d)2.

2.2. What we want to achieve — objectives

The overall objectives of the EASA system are defined in Article 1 of the Basic Regulation. This NPA will contribute to the achievement of the overall objectives by addressing the issues outlined in Section 2.1.

The specific objective of this proposal is to amend CS-E based on the above selection of non-complex, non-controversial, and mature subjects, with the ultimate goal being to increase safety.

2.3. How we want to achieve it — overview of the proposed amendments

Item 1: Compressor and turbine blade failure

(a) CS-E 520 ('Strength'), paragraph (c)(1) is proposed to be amended to require that compressor and turbine blades are 'radially' contained after their failure, instead of the current requirement to demonstrate no Hazardous Engine effect. This would better reflect the actual design and certification practices regarding engine casing strength. The effects of secondary effects associated with the blade failure are addressed by CS-E 810 ('Compressor and Turbine Blade Failure').

(b) AMC E 520(c)(2) ('Engine model validation') is proposed to be amended to:

(1) add provisions clarifying that the engine model validated data (to be provided to the aircraft manufacturer) include the dynamic displacement of nacelle attachment features;

(2) regarding engines designed for the failure of the rotor support structure following a blade failure, clarify that the effect on the engine and the aircraft structures of the most severe blade failure which would not cause the failure of the rotor structural support should also be evaluated; and

(3) specify that the engine model validation should consider any differences between the test configuration and the aircraft installation.

(c) AMC E 510 ('Safety analysis'), paragraph (3)(d)(iii) on 'Non-containment of high-energy debris' is proposed to be amended to:

(1) align with the amendment made to CS-E 520(c)(1) regarding the requirement for blades to be radially contained;

(2) add a link with the applicable certification specifications that allow to demonstrate the high level of integrity of critical parts which are considered as non contained; and

(3) add a paragraph specifying that some engine failures may result in debris being released from the engine, forward, rearward, or otherwise outside of the containment structure. If such failures may result in debris being released with an energy and trajectory that

and the consideration of ageing aircraft aspects during certification (OJ L 145, 28.4.2021, p. 1) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R0699&qid=1634745081017).

could cause a hazard to the aircraft, they should be considered as causing a Hazardous Engine Effect.

(d) CS-E 810 ('Compressor and Turbine Blade Failure') is proposed to be amended to align with CS-E 520(c)(1) regarding the 'radial' containment requirement and clarify that Hazardous Engine Effects that may be triggered by the blade failure must not occur at a rate greater than that defined as Extremely Remote. The current wording requiring to demonstrate that no Hazardous Engine Effect can happen is not considered as adequate as some debris may be released outside of the radial containment area and this must be addressed and mitigated.

(e) AMC E 810 ('Compressor and Turbine Blade Failure'), paragraph (2) (c), related to the conditions after the containment test, is proposed to be amended to:

(1) reflect the amendment made to CS-E 810; and

(2) add new sub-paragraphs explaining the elements that should be taken into account for the demonstration of the Extremely remote probability, highlighting the needed coordination with the aircraft manufacturer to ensure that the threat to the aircraft is adequately assessed, and indicating the information that should be provided in the manuals containing the instructions for installing and operating the engine.

Item 2: Assumptions — oil consumption

Table 1 of AMC E 30 is proposed to be amended to mention the flight duration and the engine maximum average oil consumption for the oil system.

Item 3: Instrument provisions

AMC E 60 is proposed to be amended to mention the engine ice protection system activation as an example of instrumentation that may be required for aircraft certification.

Item 4: Piston engine failure analysis

AMC E 210 is proposed to be amended to reflect the content of the above-mentioned generic MoC CRI.

Item 5: Approval of engine use with a thrust reverser

CS-E 10(b) and AMC E 10(b) are proposed to be amended to better specify how the approval for the use of an engine thrust reverser has to be handled and introduce the guidance provided in CM-PIFS-002 Issue 1.

Item 6: Fuel specifications for compression-ignition piston engine

AMC E 240 is proposed to be created to recommend the use of test fuels complying with ASTM D8147.

Item 7: Ice protection

Icing ground tests: AMC E 780 is proposed to be amended to add provisions recommending applicants to adequately justify and consider the engine propensity to surge and flameout when operating in icing conditions.

Icing conditions: CS-E 780 and AMC E 780 are proposed to be amended to clarify the range of icing conditions that are applicable.

Icing induced vibrations: AMC E 100 is proposed to be created to explain what is expected when showing compliance with CS E 100(c) for turbine engines.

Use of ice protection systems: AMC E 780 Section 6 is proposed to be amended to clarify what needs to be addressed as consequences from delayed activation or deactivation of ice protection systems.

Item 8: Damage tolerance of critical parts

AMC E 515 Section 3(d).v is proposed to be amended to introduce the content of CM-PIFS-007.

Item 9: Engine critical parts — Static pressure loaded parts

A sub-paragraph is proposed to be added to AMC E 515(3)(e)(i) ('General Principles') to clarify that the allowance of residual crack growth life within the Approved Life can only be accepted on the condition that compliance with other applicable CS-E certification specifications is unaffected.

The proposal allows to harmonise with the FAA AC 33.70-1 guidance material on this topic (provided in Section 8(e)).

Item 10: Editorial corrections

CS-E 10(c) is proposed to be amended to replace the reference to point 21.A.16 by a reference to point 21.B.75.

CS-E 25(a) is proposed to be amended to delete the reference to point 21.A.61(a).

CS-E 160(a) is proposed to be amended to replace the reference to point 21.A.21(c)(3) by point 21.A.20(d)2.

Other existing references to points of Part 21 are proposed to be updated in order to ensure editorial consistency of the references.

2.4. What are the expected benefits and drawbacks of the proposed amendments

The proposed amendments are expected to contribute to reflecting the state of the art of engine certification in CS-E and improve the harmonisation of CS-E with the FAA regulations.

The proposal also takes into account the lessons learnt from turbine engine occurrences involving a compressor or turbine blade failure in order to improve the identification and the mitigation of the hazards associated with such a failure. In particular, the threat represented by uncontained axial debris and the loads transmitted to aircraft structural elements would be better analysed and mitigated during certification of the engine. Also, the cooperation between the engine and the aircraft manufacturers would be enhanced to take into account the failure consequences at aircraft level. The proposed amendments do not mandate design changes relative to current industry practice, but would ensure a more robust certification process and would decrease the risk of substantial aircraft damage and fatalities. A reasonable cost impact for the turbine engine manufacturers and EASA is anticipated due to the additional efforts expected during certification of the engine. However, this impact would be compensated by the economic and safety benefits gained from the decrease of severity of blade failure occurrences.

Overall, this proposed amendments would improve safety, would have no social or environmental impacts, and would provide economic benefits by streamlining the certification process.

3. Proposed amendments

The text of the amendment is arranged to show deleted, new or amended, and unchanged text as follows:

— deleted text is ~~struck through~~;

— new or amended text is highlighted in blue;

— an ellipsis '[…]' indicates that the rest of the text is unchanged.

3.1. Draft certification specifications and acceptable means of compliance for engines (draft EASA decision amending CS-E)

Item 1: Compressor and turbine blade failure

Amend AMC E 510 as follows:

AMC E 510 Safety A~~a~~nalysis

(…)

(3) Specific means.

(…)

(d) Hazardous Engine Effects

(…)

(iii) Non-containment of high-energy debris.

~~Uncontained debris cover a large spectrum of energy levels due to the various sizes and velocities of parts released in an Engine Failure. The Engine has a containment structure which is designed to withstand the consequences of the release of a single blade (see CS-E 810(a)), and which is often adequate to contain additional released blades and static parts.~~ The design of the Engine must be such that the shedding of compressor or turbine blades, either singly or in likely combinations, will be radially contained by the Engine containment structure (see CS-E 520(c)(1)). However, ~~T~~the Engine containment structure is not ~~expected~~ required to contain major rotating parts should they be released ~~fracture~~. Failures resulting in the release of d~~D~~iscs, hubs, impellers, large rotating seals, and other similar large rotating components should therefore ~~always~~ be considered to represent potential high-energy debris. For such parts, the high level of integrity necessary for compliance with CS-E 510 (a)(3) is ensured through compliance with CS-E 515, 840 and 850.

Furthermore, Engine failures (including blade failures) can lead to debris being released from the Engine, forward, rearward, or otherwise outside of the Engine containment structure, with an energy and a trajectory that could cause a hazard to the aircraft. The release of such debris should be considered as a Hazardous Engine Effect.

Service experience has shown that, depending on their size and the internal pressures, the rupture of the high-pressure casings can generate high-energy debris. Casings may therefore need to be considered as a potential for high-energy debris.

Amend CS-E 520 as follows:

CS-E 520 Strength

(…)

(c) (1) The strength of the Engine must be such that the shedding of compressor or turbine blades, either singly or in likely combinations, will ~~not result in a Hazardous Engine Effect (e.g. as a long term effect in respect of those Failures which would not be detected by the declared instrumentation, such as vibration detectors) and within the likely shutdown time for those which would be detected, and during any continued rotation after shutdown~~ be radially contained by the Engine casing. (See AMC E 520(c)(1))

(…)

Amend AMC E 520(c)(2) as follows:

AMC E 520(c)(2) Engine Model Validation

(1) Validated data specifically for blade loss analysis typically includes:

— ~~F~~finite element model,

— ~~O~~out-of-balance,

— component failure,

— rubs (blade-to-casing, and intershaft),

— resulting stiffness changes,

— aerodynamic effects, such as thrust loss and engine surge, ~~and~~

— variations with time of the rotational speed(s) of the Engine’s main rotating system(s) after failure~~.~~, and

— dynamic displacement of interface features between engine and aircraft.

(2) Manufacturers whose engines fail the rotor support structure by design during the blade loss event should also evaluate the effect of the loss of support on engine structural response, as well as the effect on the engine and the aircraft structures and systems of the most severe blade failure which would not cause the failure of the rotor structural support.

(3) The model should be validated based on vibration tests and results of the blade loss test required for compliance with CS-E 810, giving due allowance for the effects of the test mount structure, and any other differences between the test configuration and the aircraft installation (e.g. flight inlet replaced by test intake). The model should be capable of accurately predicting the transient loads from blade release through run-down to steady state. In cases where compliance with CS-E 810 is granted by similarity instead of test, the model should be correlated to prior experience.

(4) Validation of the engine model static structure is achieved by a combination of engine and component tests, which include structural tests on major load path components, or by analysis, or both. The adequacy of the engine model to predict rotor critical speeds and forced response

behaviour is verified by measuring engine vibratory response when imbalances are added to the fan and other rotors (See CS-E 650). Vibration data is routinely monitored on a number of engines during the engine development cycle, thereby providing a solid basis for model correlation.

(5) Correlation of the model against the CS-E 810 blade loss engine test is a demonstration that the model accurately represents:

— initial blade release event loads,

— any rundown resonant response behaviour,

— frequencies,

— failure sequences, and

— general engine movements and displacements, including interface features between engine and aircraft.

(6) To enable this correlation to be performed, instrumentation of the blade loss engine test should be used (e.g.~~,~~ use of high-speed cinema and video cameras, accelerometers, strain gauges, continuity wires, and shaft speed tachometers). This instrumentation should be capable of measuring loads on the engine attachment structure.

(7) The airframe and engine manufacturers should mutually agree upon the definition of the model, based on test and experience.

Amend CS-E 810 as follows:

CS-E 810 Compressor and Turbine Blade Failure

(See AMC E 810)

(a) It must be demonstrated that any single compressor or turbine blade will be radially contained by the Engine casing after Failure and that the blade Failure will not lead to a ~~no~~ Hazardous Engine Effect ~~can arise as a result of other Engine damage likely to occur~~ before Engine ~~shut down~~ shutdown at a rate greater than that defined as Extremely Remote ~~following a blade Failure~~.

(…)

Amend AMC E 810 as follows:

AMC E 810 Compressor and Turbine Blade Failure

(…)

(2) Containment

(…)

(c) Condition after Tests. On completion of the tests, a complete power Failure is acceptable, but there should be:

(i) radial ~~C~~containment by the Engine within its containment structure without causing significant rupture or hazardous distortion of the Engine outer casing or the expulsion of blades through the Engine casing or shield~~;~~, and

~~NOTE: If debris is ejected from the Engine intake or exhaust, the approximate size and weight of the debris should be reported with an estimate of its trajectory and velocity, so that the effect upon the aircraft can be assessed.~~

(ii) no ~~hazard to the aircraft~~ Hazardous Engine Effect from possible internal damage to the Engine as a result of blades penetrating the rotor casings, even though they are contained within the external geometry of the Engine.

(ii) no other Hazardous Engine Effect resulting from the blade Failure, including due to debris being released from the Engine, forward, rearward, or otherwise outside of the containment structure, unless the probability of the Hazardous Engine Effect can be shown to be Extremely Remote. All relevant design features, test and service experience should be considered when estimating the likelihood of a blade failure, as well as the probability of the Failure progressing to cause a Hazardous Engine Effect. The hazard ratio associated with any potential threat to the safety of the aircraft should be assessed in coordination with the aircraft manufacturer. Any installation assumptions, including maximum hazard ratio, required to meet the required safety level should be included in the Manuals required by CS E-20(d).

NOTE (1): The approximate size and weight of debris released during the test, along with an estimate of its trajectory and velocity, should be recorded to enable a determination whether the debris could result in a Hazardous Engine Effect. This data should be documented in the Manuals required by CS-E 20(d).

NOTE (2): The above assessment is required to demonstrate that the likelihood of a Hazardous Engine Effect due to blade Failure is low enough to be accepted for engine certification (i.e. Extremely Remote). Additional considerations may be applied during aircraft certification to further mitigate the potential effects of blade Failures at aircraft level.

(iii) no evidence, either from the test, service experience or other analysis, indicating that the conditions of paragraphs (c)(i) and (c)(ii) above would not be satisfied under other possible blade Failure conditions (e.g. blade released at different angular position, partial blade failure, or release at speeds below the maximum to be approved).

(…)

Item 2: Assumptions — oil consumption

Amend Table 1 of AMC E 30 as follows:

AMC E 30 Assumptions

The details required by CS-E 30 concerning assumptions should normally include information on, at least, the items listed in Table 1.

TABLE 1

Specifications/References	Assumptions
(…)	(…)
Oil ~~S~~system CS-E 570	Oil(s) approved for use. Engine maximum average oil consumption. Flight duration.
(…)	(…)

Item 3: Instrument provisions

Amend AMC E 60 as follows:

AMC E 60 Provision for Instruments

(1) Under the specifications of CS-E 60(a), the Engine manufacturer should define the instrumentation which is necessary for Engine operation within its limitations and also make provision for installation of this instrumentation.

In addition to ~~powerplant~~ instrumentation which may be required for aircraft certification (for example, indication of engine ice protection system activation, rotor system unbalance, fuel flow), the Engine safety analysis might show the need for specific instrumentation providing information to the flight crew or maintenance personnel for taking the appropriate actions in order to prevent the occurrence of a Failure or to mitigate any associated consequences.

(…)

Item 4: Piston engine failure analysis

Amend AMC E 210 as follows:

AMC E 210 Failure Analysis

(1) The Failure analysis would normally include investigation of those Engine components that could affect the functioning and integrity of the major rotating assemblies, and for the control system, all manual and automatic controls such as refrigerant injection system, Engine and fuel

system speed governors, Engine over-speed limiters, Propeller control systems, Propeller thrust reversal systems, etc. as applicable.

(2) Unless the effects can be shown to be adequately mitigated in the assumed installation, and appropriate assumptions are detailed in the engine instructions for installation (as required under CS-E 30), the failure effects considered to lead to unsafe Engine conditions beyond the normal control of the flight crew should include, but not necessarily be limited to, the following ones:

— non-containment of high-energy debris,

— uncontrolled fire,

— failure of the Engine mount system leading to inadvertent Engine separation,

— release of the Propeller by the Engine,

— significant thrust in the opposite direction to that commanded by the pilot (e.g. unintended movement of the propeller blades below the established minimum in-flight low-pitch position),

— complete inability to shut the Engine down.

(3) The analysis should take into account the effects of failures of components that are part of the Engine type design on components that are not part of the Engine type design, and vice versa.

(~~2~~4) The Failure of individual components of the Engine and its installation need not be included in the analysis if the Agency accepts that the possibility of such Failure is sufficiently remote.

Item 5: Approval of engine use with a thrust reverser

Amend CS-E 10 as follows:

CS-E 10 Applicability

(a) This CS-E contains airworthiness specifications for the issue of type certificates, and changes to those certificates, for Engines, in accordance with Part 21.

(b) CS-E contains the specifications for the approval for use of the Engine with a thrust reverser, if fitted. If compliance is shown, the ~~specific~~ defined thrust reverser approved for use will be noted in the Engine certification documentation. Otherwise, the documentation will be endorsed to indicate that the use of a thrust reverser is prohibited.

(…)

AMC E 10(b) Thrust Reversers

If a thrust reverser is declared as being part of the Engine type design under CS-E 20(a), it should comply with all appropriate CS-E specifications and therefore be certificated as part of the Engine. However, the thrust reverser itself is, in addition, required to comply with the relevant aircraft specifications during the certification of the aircraft.

The intent of CS-E specifications is to give sufficient confidence that the use of the thrust reverser, where this is to be permitted, has no detrimental effects on the Engine itself, such as flutter in a fan, excessive vibrations or loads induced in the Engine carcass, etc.

This is addressed mainly under CS-E 500, CS-E 650, and CS-E 890.

If the Engine is intended to be used with a thrust reverser which is not included in the Engine type design, these CS-E specifications should nevertheless be addressed for approval of the use of the Engine with this thrust reverser. If this is not done, then the Engine certification documentation is endorsed so that the use of the thrust reverser is prohibited.

If CS-E is complied with by the Engine / thrust reverser combination, the Engine data sheet would contain a note to the effect that the Engine may be used with the specified thrust reverser.

(a) If a thrust reverser is declared as being part of the Engine type design under CS-E 20(a), it must comply with all appropriate CS-E specifications and therefore be certificated as part of the Engine.

(b) If the Engine is intended to be used with a thrust reverser which is not included in the Engine type design, these CS-E specifications must nevertheless be addressed for the approval of the use of the Engine with a thrust reverser. The thrust reverser definition must then be included in the Manuals required by CS-E 20(d). This may be a reference to the specific thrust reverser of the intended installation, or this may be limited to defining the key design characteristics that must be respected, including, but not limited to, mass, centre of gravity, aerodynamic flow lines and nozzle areas. In this case, the Engine data sheet would contain a note to the effect that the Engine may be used with the specified thrust reverser.

(c) If the engine is not intended to be used with a thrust reverser, then the Engine data sheet is endorsed so that the use of the thrust reverser is prohibited.

(d) Whilst compliance with CS-E may rely solely on testing using an equivalent duct, the compliance with applicable aircraft certification specifications (e.g. CS 25.934) typically requires testing of the actual Engine/thrust reverser combination.

Item 6: Fuel specifications for compression-ignition piston engine

Create AMC E 240 as follows:

AMC E 240 Ignition

The use of Special-Purpose Test Fuels for Aviation Compression-Ignition Engines per ASTM D8147 is recommended.

Item 7: Ice protection

Create AMC E 100 as follows:

AMC E 100 Strength

When showing compliance with CS-E 100(c) for turbine engines, the most severe vibration-induced effects that are predicted to occur in service should be evaluated. This includes the effects due to icing, rain, and hail, under which sustained engine operation is expected to occur, and which may lead to high rotor imbalance or severe rotor-case interaction.

For these applicable conditions, the following effects should be assessed under the full range of engine thrust or power and speed:

(1) For Engine parts, repeated exposure to high cycle fatigue stresses in excess of endurance limits for even short periods of time could lead to cumulative fatigue damage and subsequent component failure. If these vibratory stresses exceed the levels demonstrated during compliance with CS-E 650, it should be demonstrated under CS-E 100 that they are not excessive.

(2) Vibration forces imparted to the aircraft structure due to these conditions should be declared in the Manuals required by CS-E 20(d), and should include assumptions such as mass, stiffness and damping of the aircraft mount system.

Amend CS-E 780 as follows:

CS-E 780 Icing Conditions

(See AMC E 780)

(a)(i) It must be established by tests, unless alternative appropriate evidence is available, that the Engine will function satisfactorily in flight and on ground when operated throughout the applicable ~~conditions of~~ atmospheric icing conditions ~~(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) ~~I~~immediate or ultimate reduction of Engine performance,

(2) ~~I~~increase of Engine operating temperatures,

(3) ~~D~~deterioration of Engine handling characteristics, and/or

(4) ~~M~~mechanical damage.

(ii) The applicable atmospheric icing conditions shall include the supercooled liquid water conditions defined in CS-Definitions Amendment 2 under ‘Icing Atmospheric Conditions’, and any additional conditions (such as ice crystal icing conditions, supercooled large drop icing conditions, snow conditions) applicable to the Engine air intake system in the ice protection specifications (CS 23.1093(b) for CS-23 until Amdt 4 or CS 23.2415 for CS-23 from Amdt 5, CS 25.1093(b), CS 27.1093(b), 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).

(...)

Amend AMC E 780 as follows:

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

(…)

— 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.

— Unacceptable Mechanical Damage: The applicant should show that the engine is sufficiently robust to operate satisfactorily when repeatedly subject to icing-induced vibration loads at frequencies and magnitudes corresponding to the vibration spectrum predicted using available test evidence. The applicant should make appropriately conservative assumptions regarding the severity and duration of the icing encounters. When determining the acceptability of any damage arising as a result of operation in icing conditions, reference may be made to the inspection limits of the Instructions for Continued Airworthiness.

(…)

(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.~~

(…)

(1.6) Applicable ~~Icing~~ Environments

Due to the potential for inadvertent icing encounters, t~~T~~he applicable icing environments always include the SLW conditions defined in CS-Definitions Amdt 2 under 'Icing Atmospheric Conditions', even for aircraft not approved for flight in icing. The additional conditions to be addressed are dependent on the conditions applicable to the air intake system ~~are those applicable to~~ of 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~~ These conditions may include~~s atmospheric icing conditions (including freezing fog on ground)~~ ice crystal icing conditions, supercooled large drop icing conditions, 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.

(2) Supercooled Liquid Water (SLW) Icing Conditions

(…)

(2.2) Establishment of SLW 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) (…)

(c) Test Installation Considerations

(…)

When a non-altitude test is used to demonstrate compliance for in-flight icing, any differences in Engine operating conditions, LWC, ~~and~~ ice accretion and shedding between the altitude condition to be simulated and the test conditions, which could affect the icing threat ~~at the critical locations for accretion or shedding~~, should be taken into account when establishing the test points to be carried out ~~conditions~~. This could involve modification of Engine operating conditions and other test conditions of this paragraph in order to ~~generate equivalent ice accretion~~ adequately simulate all icing threats. This may also require running multiple test points to simulate all icing threats associated with a single atmospheric condition.

For instance, if more ice would accrete at a critical location under altitude conditions, then the test conditions (e.g. LWC) may need to be adjusted. Similarly, if the rotor speed in flight would be higher, this should be considered to ensure that the blade impact energy is at least as severe under test conditions. Furthermore, altitude effects on engine performance, including surge and flameout margins, should be taken into account, either in the tested conditions, or through post-test assessment.

Effects which should be considered and corrected for include but are not limited to:

— Engine shaft speeds;

— by-pass ratio;

— 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.~~

The effects of density, hardness, and adhesion strength of the ice as it sheds should be assessed in 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.

(2.3) Establishment of Test Points for Ground Operation

(…)

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 (Note 1)	-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) (Note 1)	-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.

Note 1: These conditions are provided as a guide, but they may need to be modified to address the requirements applicable to the intended installation. For instance, snow concentrations may need to be increased to address blowing snow, and large drop glaze ice conditions may not be applicable for installation on a given aircraft.

(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, such as frame leading edges especially if upstream vanes direct or concentrate impingement upon the frame leading edge;

(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), such as flowpath concavity;

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

~~(v) unheated surfaces on booster and front core stages;~~

(v~~i~~) narrow vane-to-vane circumferential stator spacing leading to a small stator passage hydraulic diameter;

(vi~~i~~) variable geometry with stagnation points outside flowpath that could lead to accreted ice re-entering the flowpath upon geometry movement ~~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.~~

(vii) airfoils with low tolerance to soft body damage immediately downstream of a potential ice accretion location;

(viii) Engine control sensors and measurement systems which may be affected by operation in ice crystal conditions and which may result in unacceptable control system response;

(ix) negative air temperature gradient along the gas path resulting in a potential accretion site downstream of melting; and

(x) surfaces with low temperatures downstream of or coincident with where melting could have occurred.

(…)

(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 occasional events of ~~ice ingestion from~~ ice shedding from nacelle surfaces, including due to representative delays in activation of ice protection systems (refer to paragraph (6) of this AMC). In addition, it also establishes limits for ice released from other aircraft surfaces in the frame of CS-23 or CS-25 certification.

Although the test demonstrates tolerance to ice shedding, it cannot be ensured that the ice slab impact results in the maximum possible energy transfer, and therefore this test should not be used to justify inlet designs which routinely accumulate and release ice during a continuous icing encounter.

(…)

(6) ~~Inadvertent Entry into Icing Conditions or Delayed IPS Activation~~ Ice Protection Systems Activation and Deactivation

The ice ingestion demonstration of paragraph (4) of this AMC addresses the threat of ice released from ice-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), whether the activation is automatic or manual.

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, as appropriate, 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~~ 2 minutes to switch on the IPS should be assumed. For thermal IPS, the time for the IPS to warm up should be added.

Consideration should also be given to the effects of delays in deactivating an ice protection system, or to inadvertent operation of an anti-ice system when the engine is not in icing conditions.

(…)

Item 8: Damage tolerance of critical parts

Amend AMC E 515 as follows:

AMC E 515 Engine Critical Parts

(…)

(3) *Means for defining an Engineering Plan*

(…)

(d) *Establishment of the Approved Life ~~-~~— Rotating parts*

(…)

The major elements of the analysis are:

(…)

(v) *Damage Tolerance ~~Assessment~~.*

1. General

Damage Tolerance Assessments should be performed to minimise the potential for Failure from material, manufacturing and service-induced anomalies within the Approved Life of the part. Service experience with gas turbine Engines has demonstrated that material, manufacturing and service-induced anomalies do occur which can potentially degrade the structural integrity of Engine Critical Parts. Historically, life management methodology has been founded on the assumption of the existence of nominal material variations and manufacturing conditions. Consequently, the methodology has not explicitly addressed the occurrence of such anomalies, although some level of tolerance to anomalies is implicitly built-in using design margins, factory and field inspections, etc. A Damage Tolerance Assessment explicitly addresses the anomalous condition(s) and complements the fatigue life prediction system. It should be noted that the 'Damage Tolerance Assessment' is part of the design process and not a method for returning cracked parts to service whilst monitoring crack growth.

2. Anomaly Types

— Material anomalies.

Material anomalies consist of abnormal discontinuities or non-homogeneities introduced during the production of the input material or melting of the material. Some examples of material anomalies that should be considered are hard alpha anomalies in titanium, oxide/carbide (slag) stringers in nickel alloys, and ceramic particulate anomalies in powder metallurgy materials unintentionally generated during powder manufacturing.

— Manufacturing anomalies.

Manufacturing anomalies include anomalies produced in the conversion of the ingot-to-billet and billet-to-forging steps as well as anomalies generated by the metal removal and finishing processes used during manufacture and/or repair. Examples of conversion-related anomalies are forging laps and strain-induced porosity. Some examples of metal-removal-related anomalies are tears due to broaching, arc burns from various sources and disturbed microstructure due to localised overheating of the machined surface.

— Service-induced anomalies.

Service-induced anomalies such as non-repaired nicks, dings and scratches, corrosion, etc. should be considered. Similarity of hardware design, installation, exposure and maintenance practice should be used to determine the relevance of the experience.

3. Probabilistic Damage Tolerance Risk Assessments.

The probabilistic approach to damage tolerance assessment is one of the two elements necessary to appropriately assess damage tolerance. The second element is service damage monitoring (see paragraph (g)). FAA Advisory Circular (AC) 33.14-1, Damage Tolerance for High Energy Turbine Engine Rotors, includes an example of the probabilistic process that applies to hard alpha material anomalies in titanium alloy rotor components.

The Damage Tolerance Assessment process typically includes the following primary elements:

(…)

— the i~~I~~nspector (such as their visual acuity, attention span, training, etc.).

4. Risk Prediction and Allowable Risk.

The inputs are integrated in a risk assessment which predicts the relative probability of failure (POF) for each part. The predicted POF is compared to allowable design target risk values (e.g. values provided in FAA Advisory Circular (AC) 33.70-2 Damage Tolerance of Hole Features in High-Energy Turbine). Designs that satisfy the allowable values will be considered to be in compliance with the damage tolerance requirements. Manufacturers may use a variety of options to reduce the POF and achieve the level of relative risk allowed by the damage tolerance risk assessment. These options include but are not limited to:

— component redesign,

— material change,

— material process improvements,

— manufacturing process improvements,

— manufacturing inspection improvements,

— enhanced in-service inspections, and

— life limit reduction.

5. ~~In addition, the following should be noted with regard to the above:~~

~~—~~ ~~appropriate~~ Damage Tolerance Assessment~~s~~ Methodologies.

When a specific damage tolerance risk assessment methodology has been established by industry or a company and accepted by the Agency, it may be used to meet the intent of the 'appropriate damage tolerance assessments' required under CS-E 515(a).

When an applicant chooses to pursue an industry-specific or company-specific probabilistic assessment, the applicant should provide and agree with the Agency such data that has an impact on the risk levels resulting from the analysis. This data may include but is not limited to the following items as appropriate to the component:

— Anomaly size / frequency distribution

— Fleet utilisation

— Maintenance practices

— Production / Assembly processes

— Anomaly growth characteristics

— Inspection techniques and intervals

— Inspection Probability Of Detection (POD)

The process utilised to carry out the analysis needs to be agreed with the Agency.

The probabilities of Hazardous Engine Effects that must be met are defined in CS-E 510(a)(3).

Note: When referring to CS-E 510(a)(3), an individual failure is considered to be a failure occurring anywhere in the engine as a result of a damage-tolerance-related cause and is not related to the failure of an individual component.

The applicant should demonstrate that adequate processes are in place in order to validate the assumptions utilised in the analysis. These assumptions should be validated throughout the life of the certified product.

Any departure from the original assumptions will require the applicant to repeat the analysis, and communicate the results to the Agency.

If the revised analysis shows that the safety objectives of CS-E 510(a)(3) can no longer be met, then corrective action must be implemented in accordance with point 21.A.3 of Part 21.

~~In the context of CS-E 515(a), "appropriate Damage Tolerance Assessments"~~ The Agency recognises that industry standards on suitable anomaly size and frequency distributions, and analysis techniques used in the Damage Tolerance Assessment process are not available in every case ~~listed in the paragraphs below~~. In such cases, compliance ~~with the rule~~ should be based on such considerations as the design margins applied, application of damage tolerance design concepts, historical experience, crack-growth rate comparisons to successful experience, fatigue testing of simulated damage, etc. ~~Anomalies for which a common understanding has been reached within the Engine community and the Authorities should be considered in the analysis.~~

~~*Material anomalies.*~~

~~Material anomalies consist of abnormal discontinuities or non-homogeneities introduced during the production of the input material or melting of the material. Some examples of material anomalies that should be considered are hard alpha anomalies in titanium, oxide/carbide (slag) stringers in nickel alloys, and ceramic particulate anomalies in powder metallurgy materials unintentionally generated during powder manufacturing.~~

~~*Manufacturing anomalies.*~~

~~Manufacturing anomalies include anomalies produced in the conversion of the ingot-to-billet and billet-to-forging steps as well as anomalies generated by the metal removal and finishing processes used during manufacture and/or repair. Examples of conversion-related anomalies are forging laps and strain-induced porosity. Some examples of metal-removal-related anomalies are tears due to broaching, arc burns from various sources and~~

~~disturbed microstructure due to localised overheating of the machined surface.~~

~~_Service-induced anomalies._~~

~~Service-induced anomalies such as non-repaired nicks, dings and scratches, corrosion, etc., should be considered. Similarity of hardware design, installation, exposure and maintenance practice should be used to determine the relevance of the experience.~~

6. Deterministic Surface Damage Tolerance Assessment.

If the required input data (anomaly size and frequency distributions, etc.) is not available to fully implement the probabilistic approach, the applicant may use the following deterministic method, which ensures a minimum level of damage tolerance.

An analysis should be provided that demonstrates that the surface fracture mechanics life for all critical parts exceeds 3 000 representative flight cycles or 50 percent of the Approved Life of the part, whichever is less.

This analysis should take account of the following assumptions:

(i) Analyses performed using Linear Elastic Fracture Mechanics;

(ii) Initial anomaly size is one of the following:

— 0.762mm x 0.381mm (0.030 inches x 0.015 inches) for an assumed (semi-circular) surface anomaly;

— 0.381mm x 0.381mm (0.015 inches x 0.015 inches) for an assumed (quarter-circular) corner anomaly;

(iii) Any additional assumptions used in this analysis (i.e. material properties, reference engine cycle, operating environment and its effect on the stress cycle, etc.) should be declared;

(iv) Anomalies should be treated as sharp propagating cracks from the first stress cycle.

7. Service Damage Monitoring.

The overall objective of Service Damage Monitoring is to review data obtained from field operation of the Engine type design to determine whether there are anomalous conditions which require corrective action(s). Appropriate action(s) may include the assessment of the impact of damage observed on one part/location on other parts/locations.

Applicants should determine whether the surface damage that has been detected is consistent with the serviceable and repairable limits and determine whether additional actions are required to prevent failure and rectify any potential unsafe condition which may be identified. Service damage monitoring consists of the following:

(i) Determine the serviceable and repairable surface damage limits using a process approved by the Agency and summarised within the service management plan. Damage size limits should be a function of part, part location, and damage type. Damage should include but may not be limited to nicks, dents, scratches and cracks. The serviceable and repairable limits must be published in the Instructions for Continued Airworthiness.

(ii) Establish a monitoring process to record damage that meets all of the following criteria:

— is inconsistent with or exceeds the repairable limits,

— is made available to the type certificate holder (TCH) or supplemental type certificate holder (STCH) through existing reporting channels.

Document the monitoring process in the service management plan. This activity should record at a minimum the damage size, type and location observed during service inspections for each Critical Part.

(iii) Assess damage meeting the criteria defined in (ii) above. This assessment should consider:

— the impact of the observed damage on the life of the damaged part,

— the likelihood for recurrence of similar damage,

— whether the damage has been determined as having flown,

— whether the damage is likely to escape to the field,

— recommended corrective actions to identify/prevent/eliminate the source of the damage.

During the service life of the part, a summary of the damage information obtained by the damage monitoring process, as well as the corrective actions implemented, should be made available to the responsible airworthiness authorities.

(…)

Item 9: Engine critical parts — Static pressure loaded parts

Amend AMC 515(e)(i) as follows:

AMC E 515 Engine Critical Parts

(…)

(e) Establishment of the Approved Life — Static, pressure loaded parts

(i) General Principles

The general principles which are used to establish the Approved Life are similar to those used for rotating parts.

However, for static pressure loaded parts, the Approved Life may be based on the crack initiation life plus a portion of the residual crack growth life. The portion of the residual life used should consider the margin to burst. If the Approved Life includes reliance on the detection of cracks prior to reaching the Approved Life, the reliability of the crack detection should be considered. If, as part of the Engineering Plan, any dependence is placed upon crack detection to support the Approved Life, this should result in mandatory inspections being included in the Service Management Plan and in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness. Crack growth analysis techniques should be validated experimentally.

If the Approved Life of the part includes a portion of the residual crack growth life, the compliance with applicable certification specifications should be demonstrated assuming the presence of the maximum predicted size crack that can occur within the Approved Life of the part. In some cases, it may be necessary to limit the crack size allowed in service in order to demonstrate compliance with certification specifications other than CS-E 515, such as the blade containment requirement in CS-E 810.

(…)

Item 10: Various corrections

Amend CS-E 10 as follows:

CS-E 10 Applicability

(…)

(c) The specifications of ~~s~~Subparts A, B and C apply to Piston Engines. Any necessary variations of the specifications of ~~s~~Subparts B and C for Piston Engines intended for use in rotorcraft will be decided in accordance with ~~21.A.16~~ point 21.B.75 of Part 21.

(…)

Amend CS-E 25 as follows:

CS-E 25 Instructions for Continued Airworthiness

(See AMC E 25)

(a) ~~In accordance with 21.A.61(a),~~ M~~m~~anual(s) must be established containing instructions for continued airworthiness of the Engine. They must be updated as necessary according to changes to existing instructions or changes in Engine definition.

(…)

Amend CS-E 40 as follows:

CS-E 40 Ratings

(…)

(e) The Engine's rated Powers/Thrusts and any operating limitations established under this CS-E 40 which must be respected by the crew of an aircraft must be listed in the Engine type certificate data sheet specified in point 21.A.41 of Part 21. The Engine type certificate data sheet must also identify, or make reference to, all other information found necessary for the safe operation of the Engine.

(…)

Amend CS-E 120 as follows:

CS-E 120 Identification

(a) The Engine identification must comply with points 21.A.801(a) and (b), and point 21.A.805 of Part 21.

(…)

Amend CS-E 160 as follows:

CS-E 160 Tests - History

(a) In order to enable compliance with point ~~21.A.21(c)(3)~~ 21.A.20(d)2 of Part 21, should a Failure of an Engine part occur during the certification tests, its cause must be determined and the effect on the airworthiness of the Engine must be assessed. Any necessary corrective actions must be determined and substantiated.

(…)

Amend AMC E 650 as follows:

AMC E 650 Vibration Surveys

(…)

(15) Inspection Specifications

(…). Inspection of type design hardware in accordance with the requirements of point 21.A.33 of ~~Part-21~~ 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. Impact assessment (IA)

There is no need to develop a detailed regulatory impact assessment.

5. Proposed actions to support implementation

N/A

6. References

6.1. Related EU regulation

Commission Regulation (EU) No 748/2012 of 3 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations (OJ L 224, 21.8.2012, p. 1)

6.2. Related EASA decision

Decision No. 2003/9/RM of the Executive Director of the Agency of 24 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for engines («CS-E»).

6.3. Other references

— National Transportation Safety Board (NTSB) investigation of accident to Southwest Airlines (SWA) flight 1380, a Boeing 737-7H4, on 17 April 2018. (https://www.ntsb.gov/investigations/Pages/DCA18MA142.aspx)

— EASA Certification Memorandum CM-PIFS-002 Issue 1, dated 8 March 2012, entitled 'Approval of Engine Use with a Thrust Reverser'.

— EASA Certification Memorandum CM-PIFS-007 Issue 1, dated 22 February 2013, entitled 'Engine Critical Parts - Damage Tolerance Assessment - Manufacturing and Surface Induced Anomalies'.

— ASTM standard D8147 Standard Specification for Special-Purpose Test Fuels for Aviation Compression-Ignition Engines.

— FAA Advisory Circular (AC) 33.70-1 ('Guidance material for aircraft engine life-limited parts requirements')

7. Quality of the NPA

To continuously improve the quality of its documents, EASA welcomes your feedback on the quality of this NPA with regard to the following aspects:

7.1. The regulatory proposal is of technically good/high quality

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.2. The text is clear, readable and understandable

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.3. The regulatory proposal is well substantiated

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.4. The regulatory proposal is fit for purpose (capable of achieving the objectives set)

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.5. The impact assessment (IA), as well as its qualitative and quantitative data, is of high quality

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.6. The regulatory proposal applies the 'better regulation' principles[1]

Please choose one of the options below and place it as a comment in CRT; if you disagree or strongly disagree, please provide a brief justification.
Fully agree / Agree / Neutral / Disagree / Strongly disagree

7.7. Any other comments on the quality of this NPA (please specify)

[1] For information and guidance, see:
- https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how_en
- https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox_en
- https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en

Note: Your comments on this Chapter 7 will be considered for internal quality assurance and management purposes only and will not be published in the related CRD.