Equivalent Safety Finding on CS-E 810 – Compressor and Turbine Blade Failure / Fan Integrally-Bladed Rotor (IBR) Airfoil Release

Introductory Note

The hereby presented Equivalent Safety Finding has been classified as an important Equivalent Safety Finding and as such shall be subject to public consultation, in accordance with EASA Management Board decision 12/2007 dated 11 September 2007, Article 3 (2.) of which states:

"2. Deviations from the applicable airworthiness codes, environmental protection certification specifications and/or acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings, shall be submitted to the panel of experts and be subject to a public consultation of at least 3 weeks, except if they have been previously agreed and published in the Official Publication of the Agency. The final decision shall be published in the Official Publication of the Agency."

Statement of Issue

CS-810 (a) Compressor and Turbine Blade Failure states:

"It must be demonstrated that any single compressor or turbine blade will be contained after Failure and that no Hazardous Engine Effect can arise as a result of other Engine damage likely to occur before Engine shut down following a blade Failure."

AMC E 810 Compressor and Turbine Blade Failure states (extracts):

"(2) Containment

> *(b) Test Conditions. Separate tests on each compressor and turbine stage adjudged to be most critical from the point of view of blade containment (account being taken of blade size, material, radius of rotation, Rotational Speed and the relative strength of the adjacent Engine casing under operating temperature and pressure conditions) should be carried out in accordance with the conditions of (i) and (ii).*
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> > *(i) Number of blades to be detached. One blade should be released at the top of the retention member."*

AWM 533.94 and FAR 33.94 Blade Containment and Rotor Unbalance tests state (extracts):

"(a) Except as provided in paragraph (b) of this section, it must be demonstrated by engine tests that the engine is capable of containing damage without catching fire and without failure of its mounting attachments when operated for at least 15 seconds, unless the resulting engine damage induces a self-shutdown, after each of the following events:

(1) Failure of the most critical compressor or fan blade while operating at maximum permissible r.p.m. The blade failure must occur at the outermost retention groove or, for integrally-bladed rotor discs, at least 80 percent of the blade must fail."

While AWM 533.94 and FAR 33.94 specify that for integrally-bladed rotors (IBR) "at least 80 percent of the blade must fail", EASA CS-E 810 / AMC E 810 does not distinguish between bladed disks and IBRs. Achieving most critical conditions from the point of view of blade containment and meeting the intent of release at the top of the retention member is commonly understood as releasing the IBR airfoil at the inner annulus flow path line, i.e. at the point where the airfoil section meets the disk hoop continuum, hence releasing 100 percent of the airfoil in mass and in length.

The Applicant performed a fan IBR airfoil release test where at least 80% of the airfoil mass was released, with a release location well above the inner annulus flow path line. This was considered as meeting the minimum criteria of AWM 33.94 and FAR 33.94. Direct compliance to CS-E810 can however not be claimed as containment of the full airfoil and absence of subsequent Hazardous Engine Effect cannot be guaranteed.

Applicant's Proposal

The Applicant proposes that equivalent safety can be shown through conservative design and manufacturing precautions combined with extensive supporting service experience, ensuring a level of integrity commensurate with an extremely improbable failure rate below the demonstrated blade release location down to and including the inner annulus flow path (10^{-9} failure per engine flying hour, or less).

EASA Position

For the purpose of this ESF, the fan IBR airfoil under the demonstrated blade release location down to and including the inner annulus flow path will be referred to as "the Critical Airfoil Section".

The Agency considers that justifying an extremely improbable failure rate (10^{-9} failure per engine flying hour, or less) of the Critical Airfoil Section could be accepted as equivalently safe to direct compliance with CS-E810 (a). Recognising that such a low failure rate cannot be sensibly demonstrated in numerical terms for a single structural component, the following compensating factors are deemed adequate to provide assurance that the failure rate of the considered part meets the intent of the extremely improbable failure rate definition:

A life shall be established for the Critical Airfoil Section using a procedure approved by the Agency. If the operating limitation is less than 100,000 cycles and more

restrictive than that of all other lifed features in the IBR, that limitation must be specified in Chapter 5 of the Engine Manual Airworthiness Limitation Section. The procedure used to establish the maximum allowable number of start-stop stress cycles for the IBR airfoil will account for possible extreme environmental conditions, recognising that they do not occur on every flight, and it will incorporate:

a. The combined effects of static stress, high-cycle and low-cycle fatigue.

High cycle fatigue stresses should be the maximum levels determined in accordance with CS-E 650.

b. The impact of in-service deterioration, manufacturing variations, minimum material properties, and environmental effects, such as lightning strike attachment, temperature and moisture cycling should all be addressed.

c. Capability to withstand impact by birds, ice or other small hard FOD at the end of airfoil life.

d. Failure of other components if it could affect the airfoil.

As a feature whose failure could result in a hazardous engine effect, the Critical Airfoil Section shall be treated as an integral part of the IBR, which is an Engine Critical Part, when complying with CS-E 515 and hence be subject to:

a. An engineering plan, which establishes and maintains that the combination of loads, material properties, environmental influences, and operating conditions, including the effects of parts influencing these parameters, are well known or predictable through validated analysis, test, or service experience.

b. A manufacturing plan that identifies the specific manufacturing constraints necessary to consistently produce the IBR, including the airfoil, with the attributes required by the engineering plan, and includes permanent marking of part and serial number.

c. A service management plan that defines the in-service processes for maintenance and repair of the IBR airfoil, including required inspections, which will maintain the attributes consistent with those required by the engineering plan.

A system of design and manufacturing attributes and service processes sufficient to ensure a design goal of no failure of the Critical Airfoil Section within the service life shall be established. This shall be achieved through prevention, detection or retardation of reasonably foreseeable damage mechanisms. The applicant should evaluate all single credible impacts, defects or failures which could occur within the designated region of the airfoil, and show for each of them that propagation to blade separation is practically precluded through its whole declared life. Particular attention should be given to FOD, given that the entire airfoil is directly exposed to the airflow. Circumstances which would inherently destroy the engine, such as running the engine into solid obstructions, are excluded.

Appropriate attribute redundancy shall be defined and agreed with EASA. This may be practically achieved through a combination of a number of the following approaches:

a. Redundancy or Multiple Load Path or crack stopping features to enable continued function after any single and likely combination of failure;

b. Low probability of multiple concurrent damage which could contribute to common fracture path;

c. Design features that allow failure detection before loss of residual load carrying capability;

d. Inspectability and appropriate Mandatory Maintenance instructions contained in the Airworthiness Limitations Section (ALS) of the instructions for continued airworthiness.

Where the desired level of integrity relies on inspections, due allowance should be considered for the possibility of detectable damage being missed during an inspection.

In addition to the above design considerations, service experience shall be gathered, and found commensurate in support of the demonstration. The applicability and sufficiency of the extent of the supporting service experience must be fully justified, subject to review and acceptance by the Agency.

Applicants Safety Equivalency Demonstration

The applicant will substantiate that the failure rate of the Critical Airfoil Section will be sufficiently unlikely, i.e. extremely improbable (10^{-9} failure per engine flying hour, or less). This level of integrity provides an equivalent level of safety as compared with direct compliance to CS-E810 (a), hence satisfying the requirement of 21.A.21(c) 2.