Temporary Deviation on CS-E 650 – Vibration surveys / High cycle fatigue endurance limits

Introductory Note

The following Temporary Deviation has been classified as an important Temporary Deviation 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-E650 (f) states:

"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."

AMC E 650 (1) Definitions states:

"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."

The Applicant reported service occurrences where high cycle fatigue led to compressor blade cracking; up to blade release and cracking in compressor drum post with no propagation to failure. This issue has been dealt with in a continued airworthiness context, mainly through the implementation of compressor blade and disc inspections. However, even with such inspection programmes in place, direct compliance to CS-E650 cannot be claimed by the applicant for major changes involving affected compressors, as initiation of a crack is normally not in line with "essentially infinite high cycle fatigue life to failure" in the context of CS-E650.

Applicant's Proposal

The Applicant proposes that equivalent safety is achieved however, if it can be shown that crack initiation and propagation mechanisms are sufficiently well understood to claim that cracks will not propagate to failure.

In the instance of compressor blades, this is proposed to be achieved through the implementation of a repeat inspection programme. The Applicant argues that significant service experience including cracked, service-run part fractography, combined with engine testing, rig testing and analytical modelling have provided an adequate level of understanding to underwrite a conservative inspection programme.

Regarding the compressor drum, the Applicant proposes to justify the non-propagation to failure for the entire declared life of the compressor drum, with no credit taken for any inspection. This is achieved through a combination of service experience, engine testing and analytical modelling.

EASA Position

The Agency considers that full compliance with CS-E 650(f) must eventually be re-established, but understand that the corresponding changes in design require adequate development and validation time. In the meantime, justifying the absence of crack propagation to failure in service could temporarily provide an acceptable level of safety with the following compensating factors:

The applicant must use a combination of testing, analytical modelling, and service experience to demonstrate full understanding of the sequence of multiple failure modes, including crack initiation and propagation mechanisms, subsequent effects on the assembly integrity, failure and outcomes. The applicant must use sufficient conservatism to prevent any component failure in service. In particular:

- The loading spectra used must be as severe as those expected in operation and must be based on loads or stresses for the operating conditions specified in paragraphs CS-E 650 (b) and (c). The loading spectra must be determined by engine test, flight test, and validated analysis. In addition, consider the worst loading for one engine inoperative (OEI) conditions, extended takeoff and/or climb conditions, repeated use of takeoff ratings per flight (go-around, rejected takeoffs), and any other atypical flight conditions.

- Maximum steady and vibratory stresses and minimum material properties must be considered, and it must be shown that the material properties are well understood and characterised when considering any partial degradation, wear, or damage beyond the assumed typical flight cycle.

- Assure that the assumed time exposure to the resonant damaging conditions is not exceeded in service.

- Assure that the engine is capable to complete a flight with a full diversion and capable to complete two 10-minute takeoffs with one engine inoperative (OEI) at any time.

- The applicant must provide adequate data to show that the assumed sequence of crack initiation, propagation, redistribution of loads, and subsequent effects on crack growth rate under high cycle and low cycle fatigue up to and including failure are predictable and repeatable throughout the ranges of operating conditions, including when considering exposures to abnormal flight conditions.

- The applicant must identify and account for the variables affecting the predicted outcomes, to assure a suitable margin to conditions or configurations resulting in IFSD or hazardous engine effects. Specific to the interval of flight cycles predicted to propagate a crack to the size for which compliance with the CS-E is shown, the suitable margin must account for the HCF sensitive variables and must be justified.

- Applicability of service experience and of tests carried out on test vehicles other than the engine to be certified must be fully justified.

For each component, the applicant must identify the largest possible crack predicted to be encountered in service. Compliance with all other CS-E requirements must be shown with the identified largest possible crack. In particular:

- For the purpose of demonstrating compliance with CS-E 1040, the applicant must show capability to perform 3 ETOPS diversion cycles defined as the most severe with respect to crack propagation with the largest possible crack size. In addition, the applicant must provide adequate supporting data from service experience and representative engine testing covering the geometrical and operational variables affecting the risk of an IFSD.

- For the purpose of demonstration of compliance with CS-E515 for those critical parts affected by this deviation to CS-E 650 compliance, it must be shown that cracking of the affected feature does not alter the function of the part, does not lead to material loss, and does not lead to hazardous effect should the crack propagate to failure.

Service management actions should be established under CS-E 25 in such a way that:

- Any inspection or life limit necessary to prevent propagation to failure be included in the Airworthiness Limitation Section.

- Any in-service crack finding result in the cracked part being immediately removed from service.

- The applicant must determine the interval between the time when any partial failure (crack) becomes readily detectable at a 90% probability of detection with 95% confidence and the time when any such failure is expected to invalidate compliance with any CS-E regulation.

- The applicant must establish a programme of inspections, furnished under CS-E 25, to maximise the probability of detection of cracking occurring in the interval identified according to the preceding paragraph, to essentially preclude IFSD risk from this cause.

- Any crack findings in the drum/blades and operator usage profile changes must be evaluated for consistency with the formalised assumptions and technical understanding on which this program was based. Findings inconsistent with the assumptions must be communicated to EASA.

The Applicant must propose a timescale for restoring full compliance with CS-E 650(f) for new production engines and refurbishment of engines in service which will be agreed with the Agency.

Applicants Safety Equivalency Demonstration

The applicant will substantiate that, despite the expected initiation of cracks in service in the compressor blades and drum; an adequate and fully justified service management plan can be implemented to ensure that none of these cracks can propagate to failure in service. In accordance with 21.A.21(c) 2, these measures, under the conditions laid out in the above EASA Position, are adequate to substantiate the equivalent safety for the purposes of a Temporary Deviation to CS-E 650 (f) compliance.