European Aviation Safety Agency — Rulemaking Directorate

Notice of Proposed Amendment 2014-03

Engine vibration surveys

RMT.0176 (E.004) — 5.2.2014

EXECUTIVE SUMMARY

This Notice of Proposed Amendment (NPA) addresses a clarity/economic issue related to compliance with CS-E 650 'Vibration Surveys'.

The NPA proposes amending CS-E 650 and AMC E 650 in order to clarify both and reflect current practice. Certain prescriptive requirements in the rule are moved to the AMC, but the scope and intent of the rule are not changed. The AMC is reorganised and expanded.

CS-E 650 requires that each engine undergo vibration surveys to demonstrate the satisfactory vibratory characteristics of 'those components that may be subject to mechanically or aerodynamically induced vibratory excitations'.

There are practical difficulties related to compliance with CS-E 650. In accordance with AMC E 650, 'survey' has generally been interpreted to mean a full engine test. Recent certification experience is that the speed range defined for the surveys may not be achievable during test cell testing without modifying the test engine to an extent that makes it unrepresentative of the type design configuration. On the other hand, the gas turbine industry has been investing heavily in developing analytical methods with the objective of being able to predict vibratory characteristics accurately over a wide range of conditions.

Clarification is provided on the intent of the speed range requirement and the extent to which analysis may supplement test.

The proposed changes are expected to maintain safety, reduce regulatory burden and increase cost-effectiveness.

Applicability		**Process map**	
Affected regulations and decisions:	CS-E	Concept Paper:	No
Affected stakeholders:	Turbine engine manufacturers	Terms of Reference:	22.6.2011
Driver/origin:	Clarity of rules and cost-effectiveness	Rulemaking group:	Yes
Reference:		RIA type:	Light
		Technical consultation during NPA drafting:	Yes
		Duration of NPA consultation:	3 months
		Review group:	Yes
		Focussed consultation:	TBD
		Publication date of the Opinion:	N/A
		Publication date of the Decision:	2014/Q2

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1. Procedural information

1.1. The rule development procedure

The European Aviation Safety Agency (hereinafter referred to as the 'Agency') developed this Notice of Proposed Amendment (NPA) in line with Regulation (EC) No 216/2008[1] (hereinafter referred to as the 'Basic Regulation') and the Rulemaking Procedure[2].

This rulemaking activity is included in the Agency's Rulemaking Programme for 2014–2017 under RMT.0176 (former task number E.004)[3].

The text of this NPA has been developed by the Agency based on the input from the stakeholder-led Rulemaking Group RMT.0176 (E.004) 'Engine Vibration'. It is hereby submitted for consultation of all interested parties[4].

The process map on the title page contains the major milestones of this rulemaking activity to date and provides an outlook of the timescale of the next steps.

1.2. The structure of this NPA and related documents

Chapter 1 of this NPA contains the procedural information related to this task. Chapter 2 (Explanatory Note) explains the core technical content. Chapter 3 contains the proposed text for the new requirements. Chapter 4 contains the Regulatory Impact Assessment showing which options were considered and what impacts were identified, thereby providing the detailed justification for this NPA.

1.3. 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/**[5].

The deadline for submission of comments is **5 May 2014.**

1.4. The next steps in the procedure

Following the closing of the NPA public consultation period, the Agency will review all comments with the support of the stakeholder-led Review Group RMT.0176 (E.004).

The outcome of the NPA public consultation will be reflected in the respective Comment-Response Document (CRD).

The Agency will publish the CRD with the Decision containing Certification Specifications (CSs) and Acceptable Means of Compliance (AMC).

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1 Regulation (EC) No 216/2008 of the European Parliament and the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1), as last amended by Commission Regulation (EU) No 6/2013 of 8 January 2013 (OJ L 4, 9.1.2013, p. 34).

2 The Agency is bound to follow a structured rulemaking process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as the 'Rulemaking Procedure'. See Management Board Decision concerning the procedure to be applied by the Agency for the issuing of Opinions, Certification Specifications and Guidance Material (Rulemaking Procedure), EASA MB Decision No 01-2012 of 13 March 2012.

3 http://easa.europa.eu/agency-measures/docs/agency-decisions/2013/2013-023-R/Final%204-year%20Rulemaking%20Programme%202014-2017.pdf

4 In accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

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

2. Explanatory Note

2.1. Overview of the issues to be addressed

In accordance with AMC E 650, 'survey' has generally been interpreted to mean a full engine test. Recent certification experience is that the speed range defined for the surveys may not be achievable during test cell testing without modifying the test engine to an extent that makes it unrepresentative of the type design configuration.

This NPA amends CS-E 650 'Vibration Surveys' and AMC E 650 to clarify both and reflect current practice.

This proposal maintains the current level of safety and brings potential — but not easily quantifiable — economic benefit.

For more detailed analysis of the issues addressed by this proposal, please refer to the RIA in Section 4.1. 'Issues to be addressed'.

2.2. Objectives

The overall objectives of the EASA system are defined in Article 2 of the Basic Regulation. This proposal will contribute to the achievement of the overall objectives by addressing the issues outlined in Chapter 2 of this NPA.

The objective of this NPA is to clarify the requirements of CS-E 650 'Vibration Surveys' and the corresponding guidance in AMC E 650 to addresses practical difficulties related to compliance with CS-E 650.

The specific objectives of this proposal are given in the ToR[6], and reproduced in Section 4.2 below.

2.3. Summary of the Regulatory Impact Assessment (RIA)

Only one option (Option 1) was considered (aside from the zero or Baseline Option of no change in the rule or AMC), which was to clarify the rule and provide guidance on the use of analysis to supplement engine or rig testing, in accordance with the ToR.

The main impact of Option 1 was judged to be economic. There is no safety impact, and no significant social or environmental impacts.

Option 1 could be seen as introducing disharmonisation with the FAA vibration rule, FAR 33.83. The Agency believes, however, that the effect is minimal due to the fact that the proposal merely standardises what has become accepted practice, and the scope and intent of the rule are unchanged.

Since Option 1 does not introduce any new requirements, and some needed flexibility is introduced with regard to compliance, no other negative impact is foreseen.

For the industry, it is anticipated that the cost of compliance with CS-E 650 could be reduced by as much as 30–50 %, if analysis is used to supplement engine testing per Option 1. The clarification of the rule and the provision of a standardised approach to the allowable use of analysis are expected to reduce the administrative burden.

Based on the foregoing, the preferred choice is Option 1.

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[6] http://easa.europa.eu/rulemaking/docs/tor/e/EASA-ToR-E.004-00-22062011.pdf

2.4. Overview of the proposed amendments

2.4.1. This NPA proposes amending CS-E 650 and AMC E 650 in order to clarify both and reflect current practice. Certain prescriptive requirements in the rule are moved to the AMC, but the scope and intent of the rule are not changed. The AMC is reorganised and expanded. It incorporates some words and ideas from the FAA Advisory Circular 33.83A, 'Turbine Engine Vibration Test', and the FAA Policy ANE-2006-33.94-2 'Use of Structural Dynamic Analysis Methods for Blade Containment and Rotor Unbalance Tests'. The debt to the authors of those documents is hereby acknowledged.

Objective vs prescriptive

2.4.2. The proposed changes to the rule follow the general principle that a good rule is one which sets safety targets rather than requiring specific actions. This is often stated as follows: rules should aim to be objective rather than prescriptive. The AMC may further support the accomplishment of the objective requirement by providing guidance to develop a compliance plan.

2.4.3. Nevertheless certain rules are prescriptive, perhaps since departing too far from prescriptive requirements leaves the rule with no significant content. A subordinate reason is that the safety intent is so bound up with a specific means of compliance that it is pointless to attempt to separate the two: to put it another way, no acceptable alternative means of compliance is envisaged. The argument was also advanced that the more prescriptive a rule, the more robust it is against different interpretations.

2.4.4. In the last revision[7] to the vibration rule some of the foregoing rationale, when introducing prescriptive requirements concerning corrected speed (currently CS-E 650(b)), was used.

Safety Recommendation from AAIB Report 4/1990

2.4.5. The prescriptive requirements concerning corrected speed along with an objective requirement concerning the avoidance of flutter (currently CS-E 650(c)(2)) were introduced in response to a safety recommendation from a B737-400 accident investigation[8].

2.4.6. The recommendation from the accident investigation was as follows: 'The type certification requirements for gas turbine engines should be amended so that it is mandatory to perform instrumented flight tests to demonstrate freedom from damaging vibratory stresses at all altitude conditions and powers which an engine will encounter in service.'. This also contains both prescriptive and objective elements.

2.4.7. The prescriptive element of the recommendation (i.e. mandatory instrumented flight tests) was converted into the corrected speed requirement. It would not have been appropriate to introduce a flight test requirement into the engine rules. The intent was to prescribe an engine test that could be conducted at sea level.

2.4.8. The objective requirement of the recommendation (i.e. freedom from damaging vibratory stresses at all altitude conditions and powers) became CS-E 650(c)(2).

[7] JAR-E Change 10, 15 August 1999.

[8] AAIB Report 4/1990 'Report on the accident to Boeing 737-400, G-OBME, near Kegworth, Leicestershire on 8 January 1989'.

Corrected speed

2.4.9. The corrected speed requirements into the vibration rule are now considered too prescriptive. For some gas turbine components, there are more appropriate ways of meeting the rule objective requirement of avoiding flutter and other damaging aeromechanical phenomena.

2.4.10. The highest values of corrected speed occur at altitude. Reproducing these at sea level requires elevated physical speeds. In general, this is achievable for compressors, but may be impractical for other assemblies or components. Nevertheless, a literal reading of the current rule is apt to lead to the conclusion that a sea level test requires shaft speeds in excess of what is practically achievable.

2.4.11. There is anecdotal evidence that this literal reading of the corrected speed requirement is not what was intended when the requirement was introduced. This is supported by the current definition of corrected speed in the AMC, which makes reference to 'compressor inlet conditions'.

2.4.12. The Rulemaking Group debated addressing this issue by adding the words 'where applicable' in parentheses before each occurrence of 'corrected speed', and by adding guidance on applicability to the AMC. A parenthetical 'where applicable', however, undermines the rationale for including a prescriptive requirement. Inclusion of the prescriptive requirement says, in effect, that no alternative means of achieving the safety goal can be envisaged. Adding 'where applicable' is an acknowledgement that alternatives may be required.

2.4.13. Alternatively, the proposed guidance on applicability could be included within the rule and the prescriptive material in the rule expanded such that it covers all cases. This would have the advantage of retaining the historical emphasis on corrected speed. It is, however, counter to the general principle of writing rules that, as far as possible, are objective rather than prescriptive.

2.4.14. The preferred approach is to remove the prescriptive corrected speed requirement from the rule and treat it entirely within the AMC. Correspondingly, more prominence is given within the rule to the objective requirement of CS-E 650(c)(2).

2.4.15. The value of the corrected speed concept in the context of the vibration rule is not thereby diminished, nor is the importance of the contribution to aviation safety made by those who first introduced the concept. No doubt there was a clear understanding of how the concept should be applied, and the limits of its applicability, at the time of its introduction, but that clarity has dulled with the passage of time. The current proposal simply aims to restore that clarity.

Lists of components and fault conditions

2.4.16. It is proposed to move certain other prescriptive elements of the current rule to the AMC. These are the list of components to be included in the survey in the current CS-E 650(a) and the list of fault conditions to be considered in the current CS-E 650(e).

Validated analysis concept

2.4.17. The proposed revision to the rule introduces the concept of validated analysis as a means to extend the applicability of existing results from a so-called baseline test. Fundamentally, the proposed rule still requires compliance by test. It has always been the case, though, that the complementary concepts of baseline test plus validated analysis may be accepted as equivalent to a new test. The more the configuration for which approval is sought differs from the configuration in the baseline test, the greater the dependence on analysis. The difficulty lies in deciding how much reliance may be placed on analysis, and this has been, and always will be, a matter requiring some judgment. For the vibration rule, it seems that such judgment is particularly difficult and may have resulted in the past in a lack of standardisation. The proposed new AMC therefore attempts to set some boundaries.

2.4.18. The proposed new AMC also introduces the possibility of alternative ways to demonstrate the margins inherent in the requirement to test beyond 100 % speed. Forcing the current generation of multi-spool engines to run at these off-design conditions is increasingly problematical, and the problem is compounded in the case of corrected speed. That of itself is not a sufficient reason for offering alleviation, but it does justify questioning the intent of the rule and acknowledging the possibility of meeting that intent by other means.

2.4.19. An explicit speed range was first introduced in the vibration rule at BCAR Issue 5, and subsequently carried over into JAR-E First Issue, in the form of a requirement for the vibration survey to extend from ground idle to 105 % maximum take-off speed. Anecdotal evidence suggests that the 5 % margin at high speed was to accommodate overshoot associated with the characteristics of contemporary control systems. At JAR-E Change 1 (BCAR Issue 8) the margin at high speed was split into two components. The first component extended the survey to maximum overspeed (presumably not less than overshoot), and the second component, presumed to be for engine-to-engine variability, extended the range further should there be any indication of a rising stress peak. The 105 % was retained in the sense that the sum of the two components was required to be not less than 5 %. It would seem that the same basic concept is retained in the current wording: that is, the 103 % is for transient overshoot, and the additional 2 % in the event of a rising stress peak is for engine-to-engine variability.

2.4.20. That being the case, it may be possible to accept an alternative to the 103 % speed test requirement, based on current proven control system performance. In connection with that, it may also be noted that there is no provision within CS-E for approval of normal use speed transients: if they exist, they must be accommodated within the approved steady-state rating. It may also be possible to accept an alternative to the additional 2 % speed test requirement, based on selection of components at the extreme end of the permissible tolerance band for the test. In general, it would be expected that if such alternatives are allowed, the required speed margins would still be demonstrated by validated analysis. The proposed new AMC includes these possibilities.

<u>EASA–FAA harmonisation</u>

2.4.21. Currently, the EASA rule and the corresponding FAA rule (FAR 33.83) are considered harmonised. Therefore, the changes proposed by this NPA could be seen as a loss of harmonisation. EASA believes, however, that any such loss is minimal. It is emphasised that the proposed revision does not change the scope and intent of the rule.

3. Proposed amendments

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

(a) deleted text is marked with ~~strike through~~;

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

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

3.1. Draft Certification Specifications (Draft EASA Decision)

Certification Specifications for Engines (CS-E)

Book 1 — Airworthiness Code

SUBPART E — TURBINE ENGINES TYPE SUBSTANTIATION

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

~~(a) Each Engine must undergo vibration surveys to establish that the vibration characteristics of those components that may be subject to mechanically or aerodynamically induced vibratory excitations are acceptable throughout the declared flight envelope. The Engine surveys and their extent must be based upon an appropriate combination of experience, analysis and component test and must address, as a minimum, blades, vanes, rotor discs, spacers and rotor shafts.~~

~~(b) The surveys must cover the ranges of power or thrust and both the physical and corrected rotational speeds for each rotor system, corresponding to operations throughout the range of ambient conditions in the declared flight envelope, from the minimum rotational speed up to 103% of the maximum physical and corrected rotational speed permitted for rating periods of two minutes or longer and up to 100% of all other permitted physical and corrected rotational speeds, including those that are Over-speeds. If there is any indication of a stress peak arising at the highest of those required physical or corrected rotational speeds, the surveys must be extended sufficiently to reveal the maximum stress values present, except that the extension need not cover more than a further 2 percentage points increase beyond those speeds~~

~~(c) Evaluations must be made of:~~
~~(1) The effects on vibration characteristics of operating with scheduled changes (including tolerances) to variable vane angles, compressor bleeds, accessory loading, the most adverse inlet airflow distortion pattern declared by the manufacturer and the most adverse conditions in the exhaust duct(s); and~~
~~(2) The aerodynamic and aeromechanical factors, which might induce or influence flutter in those systems susceptible to that form of vibration.~~

~~(d) Except as provided by CS-E 650 (e), the vibration stresses associated with the vibration characteristics determined under this CS-E 650, when combined with the appropriate steady stresses, must be less than the endurance limits of the materials concerned, after making due allowances for operating conditions and for the materials' permitted variations in properties. The suitability of these stress margins must be justified for each part. If it is determined that certain operating conditions, or ranges, need to be limited, operating and installation limitations must be established.~~

~~(e) The effects on vibration characteristics of excitation forces caused by Fault conditions (such as, but not limited to, out-of-balance, local blockage or enlargement of stator vane passages, fuel nozzle blockage, incorrectly scheduled compressor variables, etc.) must be evaluated by test or analysis or by reference to previous experience and be shown not to result in a Hazardous Engine Effect.~~

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

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

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

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

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

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

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

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

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

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

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

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

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

(g) *Incremental Periods*

(1) If a significant peak blade vibration is found to exist at any condition within the operating range of the Engine (not prohibited under CS-E 650 ~~(d)~~ (f)) …

Book 2 — Acceptable Means of Compliance (AMC)

SUBPART E — TURBINE ENGINES TYPE SUBSTANTIATION

AMC E 650 Vibration Surveys

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

~~Physical rotational speed (Nr):~~	~~The raw uncorrected rotational speed of a rotor system measured in revolutions per minute (rpm).~~
~~Corrected rotational speed (Nc):~~	~~The rotational speed of a rotor system corrected by normalising the compressor inlet conditions to a standard condition of air at 15□C. The correction values are empirically determined and are applied by the formula:~~
	~~Nc = Nr/(T inlet/288)^e Where T inlet is the compressor inlet temperature in Kelvin and the exponent e is determined empirically but has a typical value of 0.5.~~
~~Resonance:~~	~~A condition that results when the exciting force frequency coincides with one of the component's natural frequencies. A unique vibratory mode exists for each resonant response.~~
~~Endurance limit:~~	~~The maximum value of alternating stresses, in combination with the appropriate steady-state stresses, that will not result in material fatigue Failure.~~
~~Flight envelope:~~	~~All airborne and non-airborne conditions of operation, including start-up and shutdown, both on the ground and in flight, and windmilling rotation in flight.~~
~~Flutter:~~	~~Flutter in a system having blades or vanes is a self-excited vibration that occurs at one of the system's natural frequencies and at the associated natural vibratory mode. It is independent of any external excitation source but is dependent upon the aerodynamic conditions over the blade and upon the system's aeroelastic properties.~~

~~(2) Selection of Components.~~

~~Analyses should be conducted to identify the Engine components whose vibration characteristics require verification by Engine test or by other means shown to be equivalent or more appropriate. The selected components would normally include:~~

- ~~The most critical blades and vanes, from a vibration point of view, in the fan and each compressor and turbine.~~

- ~~All blade rows adjacent to variable incidence vanes.~~

- ~~All fan discs, and the most critical disc, from a vibration point of view, in each compressor and turbine.~~

- ~~All main rotor shaft systems (and gears when included in such systems).~~

- ~~Any other component specifically identified as requiring Engine test to substantiate analysis and/or to supplement component tests.~~

~~(3) Test Conditions.~~

~~The following alterations to the test conditions may be necessary to adequately assess the Engine's vibratory characteristics.~~

~~(a) Rig testing.~~

- ~~Normally a full Engine test is the preferred means to complete the survey. However, an applicant may elect to use rig tests for overcoming limitations associated with a full Engine test, such as the amount of instrumentation or range of inlet conditions that can be tested. If rig tests are employed, the applicant should demonstrate that all pertinent interface conditions and physical hardware closely model actual Engine operations.~~

~~(b) Speed extensions.~~

- ~~The full stress survey should be the goal and the test programme arranged accordingly to cover at least the ranges of conditions required under CS-E 650 (b). Where extensions to those ranges are considered necessary for the identification of the effects of the rising vibratory stress peak, as required under CS-E 650 (b), but it proves physically impracticable to achieve the appropriate extended test conditions, the effects of the rising vibratory stress peak should be adequately assessed by other means to be agreed with the Agency.~~

~~(c) Instrumentation survivability.~~

- ~~Where the Engine operates at such high rotor speeds and gas path temperatures that test instrumentation can only survive the environment for short periods of time, some form of analysis acceptable to the Agency would be expected to complete the substantiation.~~

~~(4) Altitude Effects.~~

~~Engine tests may be conducted by flight test or in altitude facilities or in other facilities such that the effects of flight and altitude are properly represented and can be evaluated. Suitable test equipment and instrumentation should be used for each situation. Any alterations made to the Engine for the purpose of achieving test conditions should be evaluated to show that the alterations are acceptable.~~

~~(5) Flutter.~~

~~Testing required to demonstrate satisfactory vibratory clearance from flutter boundaries may be accomplished by compressor rig and/or Engine sea-level or altitude test. In both cases the test procedure needs to recognise that some systems' susceptibilities to~~

~~flutter will not be revealed during tests if the relevant operating conditions are not sustained long enough for the flutter to develop.~~

~~(a) The hardware standard, the intake conditions and margins to account for Engine deterioration should be taken into consideration. Further, the methods used to verify the absence of damaging levels of flutter throughout the declared flight envelope should include consideration of applicable combinations of the following:~~

~~(i) The ranges of physical and corrected rotational speeds for each rotor system.~~

~~(ii) The simultaneous occurrence of maximum compressor inlet air total temperature and maximum corrected rotational speed (i.e. maximum reduced velocity).~~

~~(iii) The range of compressor operating lines within the flight envelope; and~~

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

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

~~(6) Variations in Material Properties and Natural Frequencies.~~

~~Allowance should be made for the usual variations in material properties and natural frequencies of production components when interpreting test results or analytical predictions.~~

~~(7) Resonant Dwell.~~

~~If any significant resonance is found within the operating conditions prescribed in CS-E 650, then the relevant components should be subjected to sufficient cycles of vibration close to, and/or on, the resonance peak to demonstrate compliance with CS-E 650 (d). This resonant dwell testing would normally be incorporated into the incremental periods of the CS-E 740 Endurance Test as required by CS-E 740 (g)(1). Components subjected to such resonant dwell testing should subsequently also meet the specifications of CS-E 740 (h) endurance test final strip inspection.~~

~~(8) Instrumentation Incompatibility.~~

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

~~(9) Installation Compatibility.~~

~~The intent of CS-E 650 (f) is to ensure vibratory compatibility between the Engine and each intended installation configuration when the Engine is installed and operated in accordance with the manufacturer's approved instructions. The applicant will normally be expected to provide sufficient information in the Engine instructions for installation to enable the aircraft manufacturer(s) to establish that the installation does not unacceptably affect the Engine's vibration characteristics. In establishing vibratory compatibility between the Engine and the installation, consideration should be given to~~

~~the need to declare operating limitations and procedures. Where appropriate, at least the following aspects and installation features should be considered:~~
~~- Each Propeller approved for use on the Engine.~~
~~- Each thrust reverser approved for use on the Engine.~~
~~- Installation influences on inlet and exhaust conditions.~~
~~- Mount stiffness; and~~
~~- Rotor drive systems.~~

~~(10) Inspection Specifications.~~

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

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

Vibration Survey	A vibration survey is a test or series of tests which, either alone or in conjunction with validated analysis, establishes the vibratory characteristics of engine components.
Baseline Test	A baseline test is one which was performed for the purpose of establishing experimentally the dynamic characteristics of engine components using hardware, and/or under conditions, different from those for which approval is currently sought, and is an essential requirement for a complementary validated analysis.
Validated Analysis	A validated analysis is one with demonstrated predictive capability within a specified domain of applicability that encompasses one or more complementary baseline tests.
Module	A module is either a compressor or a turbine and may be single or multi-stage. If multi-stage, the rotating elements are mechanically joined and rotate at the same speed. The gas path entry and exit points are clearly defined, and are frequently nodal points in a performance model.
Physical Rotational Speed (Nr)	The physical rotational speed of the rotating elements of a module is the raw uncorrected rotational speed. It is rotational speed as normally understood. The descriptor ‘physical’ is added in order to differentiate it clearly from corrected speed.
Minimum Rotational Speed (Min Nr)	The minimum rotational speed of the rotating elements of a module is the lowest steady state

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

(2) Introduction

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

(3) Selection of Components

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

— the most critical blades and vanes, from a vibration point of view, in the fan and each compressor and turbine module;

— all blade rows adjacent to variable incidence vanes;

— all fan, compressor and turbine discs and spacers;

— all main rotor shaft systems (and gears, when included in such systems);

— any other component specifically identified as requiring Engine test to substantiate analysis and/or to supplement component tests;

(4) Test Conditions

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

(a) Rig testing

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

(b) Speed requirements

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

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

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

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

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

(c) Instrumentation

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

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

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

(d) Instrumentation survivability

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

(e) Engine modifications

During testing the Engine may be modified or adjusted in an effort to achieve the desired physical and corrected speeds, or any other test conditions. Any alterations made to the Engine for these purposes should be evaluated to show that their effects are not detrimental, or compromise the intent of the test and test results.

(5) Altitude and Temperature Effects

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

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

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

(6) Fault Conditions

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

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

Effect. Applicants may also use field experience or other means to show that certain Fault conditions are Extremely Remote because of specific Engine configurations, design features or operating conditions. The requirements of CS-E 650(g) apply to the same components that are considered under CS-E 650(a). When the effects of these Fault conditions extend to the rest of the Engine, they must be addressed under the requirements of *CS-E 100 Strength* and/or *CS-E 520 Strength* (for example, the out-of-balance effects on the Engine structural components).

(7) Inlet Airflow Distortion

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

(8) Flutter

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

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

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

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

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

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

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

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

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

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

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

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

(9) Variations in Material Properties and Natural Frequencies

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

(a) Material allowable stresses

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

(b) Stress margins

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

(c) Modal Response

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

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

(10) Dwell Testing

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

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

(11) Transient Response

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

(12) Instrumentation Incompatibility

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

(13) Installation Compatibility

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

— each Propeller approved for use on the Engine;

— each thrust reverser approved for use on the Engine;

— installation influences on inlet and exhaust conditions;

— mount stiffness; and

— rotor drive systems.

(14) Modelling and Analysis

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

(a) Baseline test

A baseline test is usually one of the following:

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

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

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

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

(b) Validated analysis

(i) Development of the validated analysis.

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

For each baseline test on which the validation is based, it must be shown that the analysis consistently predicts vibratory responses of the components to an acceptable precision and accuracy, or alternatively that predictions are always conservative. For mode shapes, a measure of accuracy that is often employed is the Modal Assurance Criterion (MAC). Typically an MAC value greater than 0.9 indicates close agreement between measured and calculated mode shapes.

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

— Engine architecture

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

- number, location and type of bearings.

— Module type, for example HP turbine or LP turbine, axial or radial compressor

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

— Structural dynamic characteristics
- materials;
- restraints, for example blade or vane attachment design, snubbers or dampers;
- mode shape similarity.

— Source of vibratory excitations
- upstream or downstream stators;
- flow characteristics;
- mechanical sources, for example gearbox.

— Operating conditions
- rotational speeds, temperatures, pressures experienced by subject components.

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

(ii) Use of the validated analysis

For each new Engine certification programme, for which the use of validated analysis is proposed, the applicant must show that the design characteristics and operating conditions of the Engine fall within the domain of applicability of the analysis previously established and accepted by the Agency.

The demonstration of compliance will be considered to be the combination of the baseline test(s) used to create the validated analysis, and the analysis performed on the Engine for which approval is currently sought.

Cases in which validated analysis may be used are as follows:

— Test speeds required by CS-E 650(b) and (c) not achieved, by agreement with the Agency as described in paragraph (4)(b) above. The validated analysis would be expected to cover the speed range(s) not achieved during testing.

— Loss of instrumentation at extreme test conditions. The validated analysis would be expected to cover the speed range(s) for which instrumentation was lost.

— Sufficient similarity of the Engine, module or component(s) to be certified with previously tested and certified designs. Similarity applies to both design and operational characteristics of the Engine, module or component(s).

— Stresses not measured directly at critical locations. When stresses are not directly measured at critical locations, they may be derived based on the measurements taken at reference locations. This requires a detailed understanding of the modal composition of the response and the associated mode shapes.

— Justification of acceptability of a significant response.

(iii) Update of the validated analysis

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

(15) Inspection Specifications

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

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

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

4. Regulatory Impact Assessment (RIA)

This RIA was developed following the first formal meeting of the Rulemaking Group and the promulgation of the Terms of Reference (ToR), published on 22 June 2011 on the Agency's website. It is based on presentations and discussions that were an inherent part of the rulemaking process.

4.1. Issues to be addressed

The issues that this proposal addresses are described in detail in the Explanatory Note, paragraph 2.4, and summarised in the following. There is no safety impact. The main intent, in accordance with the ToR (see also 4.2), is to clarify the compliance requirements, with some potential — but not easily quantifiable — economic benefit.

CS-E 650 requires that each engine must undergo vibration surveys to demonstrate the satisfactory vibratory characteristics of 'those components that may be subject to mechanically or aerodynamically induced vibratory excitations'.

In accordance with the current AMC, 'survey' has generally been interpreted to mean a full engine test, to be completed as part of the type certification programme for a new engine, or, for a change in type design, on a case-by-case basis, depending on the nature and scope of the change. Recent certification experience is that the speed range defined for the surveys is not achievable during test cell testing (particularly with regard to the core spools of high bypass ratio engines) without modifying the test engine to an extent that makes it unrepresentative of the type design configuration, which raises legitimate questions about the intent of the test requirements. On the other hand, the gas turbine industry has been investing heavily in developing analytical methods with the objective of being able to predict vibratory characteristics accurately over a wide range of conditions.

Clarification is provided on the intent of the speed range requirement and the extent to which analysis may supplement test. The concept of using validated analysis to supplement a baseline engine or rig test has already been accepted by the Agency on a case-by-case basis. The aim of this proposal is to provide a standardised approach.

4.1.1. Safety risk assessment

It is the goal of this rulemaking exercise to retain the current level of safety. The Rulemaking Group carefully considered every proposed change with this goal in mind to ensure that it is achieved. There is therefore no safety impact and no risk assessment.

4.1.2. Who is affected?

The proposed changes affect the manufacturers of gas turbine aircraft engines and the regulatory authorities. Since both stakeholders were represented in the Rulemaking Group, the proposed changes are not expected to stir controversy.

4.1.3. How could the issue/problem evolve?

The trend towards increasing difficulty with off-design running is expected to continue. The industry's analytical capability will continue to grow and the current CS-E 650/AMC regulatory framework may not provide clarity regarding the use of this capability.

If CS-E is not amended as proposed, the issues that this proposal addresses are therefore likely to persist, and even to intensify.

4.2. Objectives

The overall objectives of the Agency are defined in Article 2 of Regulation (EC) No 216/2008 (the Basic Regulation). This proposal will contribute to the overall objectives by addressing the issues outlined in Section 4.1. The specific objectives of this proposal, as presented in the ToR, are as follows:

To review and amend, as appropriate, CS-E 650 and associated AMC to clarify the safety objective and to detail Acceptable Means of Compliance and, in particular, to:

(1) clarify the vibratory mechanisms and influencing factors to be considered when establishing safe vibratory characteristics;

(2) clarify the purpose of the survey extending 3 % (and further 2 % in case of a stress peak arising) beyond the maximum permissible speeds and outline Acceptable Means of Compliance with this intent;

(3) provide more detailed advice about allowable test configurations;

(4) provide more detailed advice about means of compliance other than full engine test including (but not limited to) the use of analysis as evidence of compliance;

(5) clarify the relevance of high aerodynamic speeds ($N/\sqrt{T}$) to component response;

(6) clarify the definition of 'maximum permitted corrected rotational speed';

(7) clarify the use of corrected speed versus mechanical speed assessments for the turbine core;

(8) wherever possible, retain harmonisation with the FAA requirements.

4.3. Policy options

Table 1: Selected policy options

Option No	*Short title*	**Description**
0	No change	Baseline option (no change in the rule or AMC; issues remain as outlined in the issue analysis).
1	Amend CS-E	Clarify the rule and provide guidance on the use of analysis to supplement engine or rig testing. This option addresses the specific objectives identified in the ToR for this task.

4.4. Methodology and data

4.4.1. Applied methodology

The proposal is judged to offer increased clarity and some potential economic benefit. With regard to clarity, the issues are clearly identified in the ToR. The approach of the Rulemaking Group was to research the background to the current wording, review other EASA and FAA rules and guidance material for useful ideas, and debate various proposals for improved wording until a consensus was achieved. The potential economic benefit was also extensively debated and data was sought that would enable a quantitative assessment to be made. A structured process to quantify the benefit, however, such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), or multi-criteria analysis (MCA) was not used.

4.4.2. Data collection

Data was collected mainly from the industry members of the Rulemaking Group, but details were limited due to the proprietary nature of such data. Only the European industry was represented in the Group. Attempts to interest the US industry in the work of the Group were unsuccessful.

4.5. Analysis of impacts

4.5.1. Safety impact

The current level of safety (for Option 0) is considered acceptable. The use of analysis to complement testing has become an accepted practice and has already been used on a case-by-case basis.

Option 1 will not change the safety intent, but rather offer clarity in the rule and allow for some flexibility when demonstrating compliance. The restructured rule/AMC describes more clearly when analysis would be accepted in conjunction with testing. Option 1 reduces the practical difficulties and potentially eliminates deviations from type design made for the sole purpose of enabling the required tests to be conducted. No safety benefit is claimed, however.

Safeguards are in place to preserve the current level of safety. A key concept is that analysis used to supplement testing must be validated against other test data. Furthermore, the AMC specifies that the Agency should be involved in the validation of an analysis and the extent of its use in a certification programme.

4.5.2. Environmental impact

Aircraft noise and emissions are not affected by the proposed changes. Reduction of engine testing has a favourable environmental impact at the test site.

4.5.3. Social impact

The social impacts are not relevant.

4.5.4. Economic impact

For the industry, it is anticipated that the cost of compliance with CS-E 650 could be reduced by as much as 30–50 %, if analysis is used to supplement engine testing per Option 1. It should be acknowledged that the savings are difficult to estimate, the 'euro' value being different on a case-by-case basis and contingent on factors like engine size and the nature and scope of the certification programme.

The cost reduction will be the result of an optimised use of resources (e.g. less instrumentation, fewer test points). These cost savings will more than compensate for the costs associated with the additional analysis that will be required. The clarification of the rule and the provision of a standardised approach to the allowable use of analysis are expected to reduce the administrative burden for the applicant and for the Agency. No potential for further simplification is identified, that maintains the existing level of safety.
Considering the nature of the proposed regulatory changes and the current practices, the minor disharmonisation with the FAA on this rule is not expected to have a serious economic impact on the industry, although it may impose an additional administrative burden.

4.5.5. General Aviation and proportionality issues

The proposal does not introduce any new requirements. Compliance with the rule is affected only to the extent that the range of options for compliance is formally extended. It is therefore not expected that any sector will be negatively impacted.

4.5.6. Impact on 'Better Regulation' and harmonisation

Currently the EASA and the FAA rules are considered harmonised. Since the changes proposed by this NPA will not be followed at this time by a change to the corresponding FAA rule (FAR 33.83), this proposal could be seen as a loss of harmonisation.

The Agency believes, however, that the effect is minimal due to the fact that the proposal merely standardises what has become accepted practice, and the scope and intent of the rule are unchanged.

4.6. Comparison and conclusion

4.6.1. Comparison of options

Although Option 1 could be seen as introducing a minor disharmonisation with the FAA, it also ensures clear and relevant requirements and guidance material, plus the economic benefit of potentially reduced compliance cost, while preserving the existing safety level. Therefore, the Agency's preferred choice is Option 1.

5. References

5.1. Affected CS, AMC and GM

Certification Specification for Engines (CS-E)

5.2. Reference documents

JAR-E Change 10, 15 August 1999

AAIB Report 4/1990 'Report on the accident to Boeing 737-400, G-OBME, near Kegworth, Leicestershire on 8 January 1989'

FAA Advisory Circular 33.83A, 'Turbine Engine Vibration Test'

FAA Policy ANE-2006-33.94-2, 'Use of Structural Dynamic Analysis Methods for Blade Containment and Rotor Unbalance Tests'

6. Appendices

N/A