U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Turbine Engine Vibration Test

Date: February 2, 2023
Initiated By: AIR-624

AC No: 33.83-2B

1 PURPOSE.

This advisory circular (AC) provides an acceptable means for demonstrating compliance with the requirements of Title 14, Code of Federal Regulations (14 CFR) 33.83, *Vibration test*.

2 APPLICABILITY.

2.1 The guidance in this AC is for manufacturers, modifiers, and applicants for design approval of turbine engines for aircraft, Federal Aviation Administration (FAA) engine type certification engineers, and FAA designees.

2.2 The contents of this guidance document do not have the force and effect of law and are not meant to bind the public in any way. This guidance document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies. This AC is not mandatory and does not constitute a regulation. This AC describes an acceptable means, but not the only means, for showing compliance with § 33.83. When the method of compliance in this AC is used, terms such as “should,” “may,” and “must” are used only in the sense of ensuring applicability to this particular method of compliance. The FAA will consider other means of showing compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. If, however, the FAA becomes aware of circumstances that convince the agency that following this AC would not result in compliance with the applicable regulations, the agency will not be bound by the terms of this AC, and may require additional substantiation as a basis for finding compliance.

2.3 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes in, or permit deviations from, existing regulatory requirements.

3 CANCELLATION.

This AC cancels AC 33.83A, *Turbine Engine Vibration Test*, issued September 29, 2006.

4 SUMMARY OF REVISIONS.

Revisions to this AC include: (1) adding the content of PS-ANE-33.83-01, *Clarification for 14 CFR part 33.83, Vibration Test*, dated November 03, 2015; (2) providing compliance by similarity and validated analysis; and (3) clarifying the definitions for rig testing and endurance limit.

5 RELATED MATERIAL.

5.1 Title 14, Code of Federal Regulations.

- Section 21.21, *Issue of type certificate: normal, utility, acrobatic, commuter, and transport category aircraft; manned free balloons; special classes of aircraft; aircraft engines; propellers.*
- Section 21.41, *Type certificate.*
- Section 33.5, *Instruction manual for installing and operating the engine*.
- Section 33.7, *Engine ratings and operating limitations*.
- Section 33.15, *Materials*.
- Section 33.29, *Instrument connection*.
- Section 33.63, *Vibration*.
- Section 33.75, *Safety analysis.*
- Section 33.87**,** *Endurance test.*
- Section 33.93, *Teardown inspection*.

5.2 FAA Advisory Circulars.

AC 33.87-1, *Engine Overtorque Test, Calibration Test, Endurance Test, and Teardown Inspection for Turbine Engine Certification (§§ 33.84, 33.85, 33.87, 33.93)*.

5.3 FAA Orders.

Order 8110.112A, *Standardized Procedures for Usage of Issue Papers and Development of Equivalent Levels of Safety Memorandums*.

5.4 FAA Policy Statements.

PS-ANE-33.83-01, *Clarification for 14 CFR Part 33.83 Vibration Test*.

6 DEFINITIONS.

The following definitions apply to this AC.

- **Corrected rotational speed (Nc).** The physical rotational speed of a rotor corrected by normalizing the rotor module inlet conditions to a standard condition of air at 59° Fahrenheit (518.67° Rankine). The correction values are determined empirically and are applied by the following formula:

$$N_c = \frac{N_r}{\sqrt{\frac{T_{inlet}}{518.67}}}$$, where T_{inlet} = the rotor module inlet temperature in degrees Rankine.

- **Endurance limit**. The maximum stress range that can be repeated indefinitely without material fatigue failure or below which fatigue failure never occurs due to cyclic stresses. The endurance limit is a function of steady-state stress, temperature, geometry, and material properties.
- **Flight envelope**. All approved conditions of operation, including ground and flight operations, and windmilling rotation in flight.
- **Flutter**. In a system having blades or vanes, flutter is a self-excited vibration that usually occurs at one of the blade's natural frequencies and the associated mode shape. It is independent of any external excitation source, but is dependent on the airstream as an external source of energy and on the structure aeroelastic properties.
- **Physical rotational speed (Nr).** The raw uncorrected rotational speed of a rotor system measured in revolutions per minute (rpm).
- **Resonance**. A condition that occurs when the excitation frequency coincides with one of the component's natural frequencies (fn) resulting in an increase of the vibratory amplitude. A unique vibratory mode exists for each resonant response.

7 TEST PREPARATION.

7.1 Selection of Components.

Section 33.83 requires vibration surveys by engine test for all components subject to mechanically and aerodynamically induced vibrations, to include at least the engine blades, vanes and nozzles, rotor discs, spacers, and rotor shafts. Therefore, the components selected for vibration surveys will normally include:

- The blades and vanes in each stage of the low, intermediate, and high-pressure rotors. For each stage with identical blades and vanes, the survey needs to cover the blades and vanes that are identified as most critical because of their vibratory characteristics.

- All stages of discs and spacers.
- All main rotor shaft systems (and gears when included in such systems).
- Any other component specifically identified as critical because of its vibratory characteristics.

7.2 **Engine Test and Supporting Activity.**

7.2.1 Policy PS-ANE-33.83-01, referenced in paragraph 5.4 of this AC, clarifies that the required engine vibration surveys of § 33.83(a) are intended to be implemented by engine test. Furthermore, the requirement of § 33.83(a), stating "The engine surveys shall be based upon an appropriate combination of experience, analysis, and component test and shall address, as a minimum, blades, vanes, rotor discs, spacers, and rotor shafts," is intended to be applied to activities supporting the conduct of the engine vibration test.

7.2.2 In preparation for certification testing, the applicant should conduct the tests and analyses necessary to identify those components and systems that may be subject to mechanically or aerodynamically induced vibratory excitations and determine its vibration characteristics, including the natural frequencies and mode shapes. In addition, the applicant should determine the steady state (mean) stresses and the relationships between measured and peak vibratory stresses.

7.3 **Rig Testing.**

7.3.1 Section 33.83 requires running an engine test for the vibration survey (see paragraph 7.2.1). However, testing an engine module on a rig may replace the module being tested as part of the engine test, provided certain conditions are met. A rig test, as referenced here, consists of running an engine module test. A module is either a complete compressor or a complete turbine engine section, which may be single or multi-stage. For a multi-stage module, the rotating elements are mechanically joined and rotate at the same speed. A gearbox may also be tested as a module.

Note: A single stage or subset of stages isolated from a multi-stage compressor or turbine does not constitute a module. A gearbox may also qualify as a module.

7.3.2 The applicant may propose to run module tests to overcome potential limitations associated with running an engine test, such as the amount of instrumentation or range of inlet conditions. The applicant should demonstrate the following:

- The module interfaces and boundary conditions are representative of the engine.
- The operating conditions achieved for that particular engine module test are the same as if the module would have been run in an engine test.

8 ENGINE TEST CONDITIONS.

8.1 Test Speeds.

Section 33.83(b) requires vibration surveys from the minimum rotational speed up to 103 percent of the maximum physical and corrected rotational speed permitted for rating periods of two minutes or longer, and up to 100 percent of all other permitted physical and corrected rotational speeds, including overspeeds. To determine the test speed, the 103 percent value applies independently to each shaft system's physical and corrected speeds, as maximum physical and maximum corrected speeds are usually reached at different flight conditions. Where multiple modules are attached to one shaft, the shaft maximum corrected speed is the highest of the corrected speeds calculated for all modules on that shaft.

8.2 Corrected Speeds.

Testing to corrected speeds addresses operating conditions associated with ambient temperature variations throughout the flight envelope. These conditions have an effect on engine performance and airflow characteristics that in turn affect the vibratory response and behavior of certain components. Therefore, achieving the conditions associated with the corrected speeds is equally important as achieving the physical speeds.

8.3 Speed Extensions.

The test program is intended to accomplish a stress survey for the ranges of conditions required under § 33.83(b). These conditions include speed extensions to investigate the effects of a vibratory stress peak arising at the highest of those required physical or corrected rotational speeds.

8.4 Altitude Effects.

The effects of altitude may be represented and evaluated during an engine test conducted in an altitude facility, or by flight test. Usually, applicants will conduct flight surveys to supplement those in test facilities for which applicants cannot achieve the desired altitude conditions. Unless proven otherwise, altitude data acquired during flight surveys is valid for only the engine operating conditions in existence during the flight test and the specific aircraft installations. For example, if the applicant conducts a flight test to acquire altitude data related to the inlet distortion, but the most adverse inlet distortion required by §33.83(c)(1) is not present during the flight test, then additional testing may be necessary.

8.5 Engine Modifications.

During testing, the applicant may choose to modify or adjust the engine to achieve the desired physical and corrected speeds, or any other test conditions. The applicant should evaluate any alterations made to the engine to ensure that their effects are not detrimental to the engine, or compromise the intent of the test and test results. The applicant should identify how the engine operating parameters, as well as the components and system characteristics, are affected by these modifications, and evaluate their effects on the component or module vibratory behavior. Before a certification test, the applicant may need to assess these adjustments by test, analysis, or both.

8.6 Inlet Airflow Distortion.

Inlet airflow distortion as set forth in § 33.83(c)(1) may be associated with crosswinds, or with other operating and aircraft installation conditions. Whether the engine test is performed in a test cell or flight test bed, the evaluations must be conducted for the most adverse inlet airflow distortion pattern declared by the manufacturer, as required by § 33.83(c)(1). During testing, the applicant may achieve inlet distortion by various means, such as external crosswind devices, inlet distortion plates, or suppression screens.

Note: Section 33.7(c)(13) requires the applicant to establish the operating limitations for inlet air distortion at the engine inlet. The applicant must declare the inlet air distortion in the installation and operating manuals, as well as the type certificate data sheet per §§ 33.5 and 33.7(a), respectively.

8.7 Combined Effects.

Section 33.83(c)(1) requires evaluation of the effects on vibration characteristics of operating with scheduled changes (including tolerances) to variable vane angles and compressor bleeds. In addition to the individual effects that variable vane angles and compressor air bleeds have on vibrations, the applicant should also consider the effects of their concurrent usage throughout engine operation.

9 FLUTTER.

9.1 Sections 33.83(a) and (c)(2) require evaluation by engine test of the aerodynamic and aeromechanical factors that might induce or influence flutter. The applicant should configure the test to address the effects of hardware design variability, intake conditions, and the margins associated with engine deterioration. Applicants should consider the following:

- The ranges of physical and corrected rotational speeds for each rotor system;
- The ranges of operating lines within the flight envelope; and
- The most adverse of other inlet air conditions encountered within the flight envelope (for example, applicable combinations of total air pressure, density, temperature, and inlet distortion).

9.2 Flutter is a phenomenon sensitive to even small variations of those design factors that determine the engine system response. The applicant should consider these factors, including the variations between the nominal and extreme values of tip clearances, mechanical damping, operating lines, bleed flows, etc. Experience has also shown differences in susceptibility to flutter from one blade set to another.

9.3 The applicant should ensure the engine is free from flutter throughout the declared operating environment for the engine and show satisfactory vibratory clearance to flutter boundaries. In extreme transient regimes, flutter may be acceptable, providing the applicant completes a thorough investigation of the flutter and its effects. The investigation should show that the engine's structural and operational integrity are free from negative effects. However, the resulting vibration stresses must always satisfy the requirements of § 33.83(d).

10 VIBRATORY STRESSES AND MATERIAL ALLOWABLES.

10.1 Measured Stresses.

During the vibration surveys required by § 33.83(a), the applicant should take stress measurements at critical or limiting locations. When these locations are not suitable or accessible, applicants may measure the stresses nearby, providing 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, the applicant should use experience, analysis, or testing to gain a detailed knowledge of each normal mode and associated stress distributions, as required by § 33.83(a). The applicant should perform this investigation before the certification test.

10.2 Interpreting Test Results.

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. In addition, when calculating the resonant stresses, the applicant should consider the stress amplitudes that occur within the blade-to-blade variations of natural frequencies. For example, if for a particular blade design, the natural frequency range is fn ± 2.5 percent, then the amplitudes within this range should be considered.

10.3 Material Allowable Stresses.

The material properties or allowable stresses for showing compliance with § 33.83(d) are the minimum endurance limits associated with specific mean or steady stresses, usually represented on a Goodman diagram. In addition, these material properties should account for the effects of manufacturing processes, the local geometrical features, and temperatures, as applicable. The applicant should provide these material properties in compliance with § 33.15.

10.4 Stress Margins.

Section 33.83(d) requires suitable stress margins for each component evaluated, usually represented by the stress margins at the critical, or limiting locations. The stress margin is represented by the difference between the material allowable stresses for that location and the vibratory stress at that location. When stresses are not directly measured at critical locations, they may be derived based on the measurements taken at reference locations. The applicant should ensure the criteria for stress margin suitability accounts for the variability in design, operation, and other mitigating factors identified during the certification test. In addition, the applicant should consider the effects of expected serviceable damages during operation. For example, consider fan and compressor blades nicks and surface discontinuities caused by debris ingestion. These damages may increase local stresses or may lower the component fatigue strength.

11 RESONANT DWELL.

During the vibration surveys required by § 33.83(a), the applicant should determine all significant resonances and allow sufficient time for the resonant modes to respond. This is usually accomplished during slow acceleration and deceleration speed sweeps covering the range of required speeds. If any significant resonance is found within the operating conditions required under § 33.83, then the relevant components should be subject to sufficient cycles of vibration near or on the resonance peak. This resonant dwell testing would normally be incorporated into the incremental periods of § 33.87, as required by § 33.87(b)(4), (c)(5), and (d)(5). In this case, the components subject to resonant dwells under the endurance test of §33.87(b)(4), (c)(5), and (d)(5) must meet the teardown requirements of § 33.93(a) (see AC 33.87-1).

12 FAULT CONDITIONS.

12.1 Section 33.83(e) includes those fault conditions that would cause abnormal vibrations that are difficult to identify in a timely manner for appropriate action and may escalate to the hazardous engine effects identified in § 33.75. The fault conditions include rotor system out-of-balance, incorrectly scheduled compressor variables, blockage or enlargement of passages between stator vanes, and blockages of fuel nozzles. For example, the loss of a compressor airfoil tip would likely result in an increased vibration. Although rotor out-of-balance may be indicated by the connection required by § 33.29(b), the resulting vibration might not be immediately recognized as abnormal or prompt immediate action, and could cause further damage. Other fault conditions, such as incorrectly scheduled compressor variables or blockages of stator vanes or fuel nozzles could produce air distortions and changes in the airflow or pressure distributions that in turn may affect the engine vibratory response and characteristics.

12.2 To address these fault conditions, the applicant may use prior experience with faults that occurred with similar engines. Successful experiences are when, after a fault condition occurred, the engine was able to either continue a safe operation or be shut down without creating a hazardous condition. The applicant may also use field experience or other means to show that certain fault conditions are unlikely to occur because of specific engine configurations or operating conditions.

13 INSTALLATION COMPATIBILITY.

Section 33.83(f) ensures that the vibration surveys conducted in accordance with § 33.83 are representative of each intended installation configuration. The applicant should identify in the installation manual the necessary installation instructions, as required in compliance with § 33.5. Sufficient instructions will assure that the installation on the aircraft would not adversely affect the engine's vibration characteristics when the installer follows those instructions. The applicant may also consider imposing operating limitations and procedures when establishing the vibratory compatibility between the engine and its installation. The applicant should consider the following features:

- 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.
- Rotor drive systems.
- Accessory components.

14 INSTRUMENTATION.

14.1 Types of Instrumentation.

When conducting the vibration surveys required under § 33.83, the applicant should use suitable instrumentation, data acquisition, and analyzer systems. Vibration specific instrumentation may include dynamic strain gauges, accelerometers, and time-of-arrival sensors, as well as instrumentation indicating the airflow characteristics.

14.2 For the most part, vibratory stresses are measured with dynamic strain gauges placed at pre-determined locations and oriented to measure specific directional strains. These strain gauges should maintain their accuracy throughout the test conditions, particularly through repeated exposure to high temperatures.

14.3 Other measurement means may be acceptable. For example, time-of-arrival sensors, such as optical sensors or light probes, may be used as alternatives to strain gauges, or to supplement strain gauge data, provided they are properly calibrated and their capabilities are clearly understood. The most common application for time-of-arrival sensors is to measure the blade’s tip displacements, then convert them to stresses at specific blade locations. Converting displacements to stresses requires detailed knowledge of the blade’s normal modes, mode shapes, and associated tip displacements.

14.4 If during the vibration survey there is an accidental loss of test instrumentation, the missing data may be replaced by the use of validated analysis providing that the validation can be achieved using the data from the surviving instrumentation. Therefore, the loss of instrumentation should be minimal, and the data acquired by the surviving instrumentation should be adequate for the purpose of validating the analytical predictions.

15 COMPLIANCE FOR MAJOR CHANGES IN DESIGN BY SIMILARITY.

Major design changes for which compliance can be based on a similar engine vibration test (further referred to as the baseline engine test) does not require repeating a vibration survey test. The baseline engine test should be FAA-approved in accordance with § 33.83 requirements, at the same amendment level, and should be run on an engine or module (see paragraph 7.3 of this AC for rig or module testing).

15.1 Similarity Assessment.

15.1.1 The applicant should demonstrate the similarity between the engine undergoing certification and the baseline engine by using comparative test and analysis methods. Specifically, the hardware and test running conditions should be closely similar, and the differences should not significantly affect the vibratory behavior of the engine, its systems, or its components. The comparative test and analysis should show all of the following:

15.1.1.1 The differences relative to the baseline would result in only minor changes to the vibratory stresses of the baseline engine, which could be scaled with confidence.

15.1.1.2 The certification engine test conditions are not more severe than those of the baseline engine test. To assess the test conditions in the engine, the applicant should compare the certification engine vs. the baseline engine with regard to all of the following requirements —

- The test conditions required by § 33.83(b), for example, shaft rotational speeds (mechanical and corrected), gas path temperatures, thrust or power, and if applicable, torque.
- The test conditions required by § 33.83(c)(1), for example, variable vane angles, compressor bleeds, accessory loading, the most adverse inlet airflow distortion pattern, and the most adverse conditions in the exhaust duct(s).
- The aerodynamic and aeromechanical factors that might induce or influence flutter as set forth in § 33.83(c)(2).

15.1.1.3 The differences in configuration, geometrical characteristics, or material physical properties do not significantly affect the component’s natural frequencies and mode shapes, and no new resonances are introduced.

15.1.1.4 The component’s temperatures, pressures, excitation forces, and damping characteristics are closely similar throughout the ranges of the test parameters of § 33.83(b) and (c).

16 VALIDATED ANALYSIS.

For major design changes that do not qualify under the similarity criteria above, applicants may request approval of methods based on validated analysis in combination with engine vibration surveys as needed to validate the analysis and associated assumptions. The FAA has approved such methods on a case-by-case basis by issuing an equivalent level of safety under § 21.21(b)(1), and by using the procedures outlined in FAA Order 8110.112 for issue papers. Alternatively, the applicant may run a fully instrumented engine test in accordance with the requirements of § 33.83 and the guidance in this AC.

17 SUGGESTIONS FOR IMPROVING THIS AC.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback Form at the end of this AC.

Digitally signed by
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Advisory Circular Feedback Form

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Subject:____________________ Date: February 2, 2023

Please mark all appropriate line items:

☐ An error (procedural or typographical) has been noted in paragraph____________on page________________.

☐ Recommend paragraph__________on page____________be changed as follows:

☐ In a future change to this AC, please cover the following subject:
(Briefly describe what you want added.)

☐ Other comments:

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Submitted by:______________________Date: ________________