U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Turbine Engine Vibration.

Date: 7/25/07
Initiated by: ANE-110

AC No: 33.63-1

1. What is the purpose of the Advisory Circular? This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the vibration requirements of § 33.63 of Title 14 of the Code of Federal Regulations (14 CFR part 33).

2. Who does this AC apply to?

a. The guidance provided in this document is directed to you, the applicant engine manufacturer or modifier.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. We, the Federal Aviation Administration (FAA), will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as “should,” “shall,” “may,” and “must” are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. On the other hand, if we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation as the basis for finding compliance.

c. This material does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

3. Related Regulations.

a. Section 33.4 – Instructions for continued airworthiness.

b. Section 33.5 – Instruction manual for installing and operating the engine.

c. Section 33.7 – Engine ratings and operating limitations.

d. Section 33.28 – Electrical and electronic engine control systems.

e. Section 33.68 – Induction system icing.

f. Section 33.83 – Vibration test.

g. Section 33.87 – Endurance test.

h. Section 33.91 – Engine component tests.

i. Section 33.97 – Thrust reversers.

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CHAPTER 1. INTRODUCTION

1.1. Background.

a. The requirements of § 33.63 apply to the engine, its components, and systems operating throughout the declared flight envelope and ranges of rotational speeds and power/thrust. All engine components are exposed to some level of vibration, which depends on the components' design characteristics, such as geometry or materials, and the operating environment, such as the sources of excitations or aerodynamic forces. For example, when excited, the engine components vibrate at specific frequencies and the amplitude response is specific to that component and its operating environment. Components directly in the airflow, such as the blades or vanes, are excited by disturbances from the wakes of stators, vanes, struts, but also by inlet distortions and other sources. Blades may also be subjected to vibration driven by instabilities such as stall or flutter. The amplitude of blade and vane resonant response depends on damping and aerodynamic forces. Other components, like those installed on the engine case, are excited by rotor unbalance and vibrate at frequencies associated with the source of excitation.

b. Your demonstration of compliance with other part 33 regulations for which vibration is examined may also provide substantiation for compliance with § 33.63. On the other hand, engine vibration accepted or observed during compliance with other part 33 standards should be verified against the engine vibratory characteristics and vibration envelope for which compliance with § 33.63 is shown.

1.2. Definitions. For the purpose of this AC, the following definitions apply:

a. Critical component. A component whose failure could result in a hazardous engine effect.

b. Declared flight envelope. All airborne and non-airborne conditions of operation, including start-ups and shutdowns.

c. Engine configuration. The type design, including the rotor unbalance specified in the production specifications and the engine manuals.

d. Engine manual(s). Manuals issued in compliance with §§ 33.4 and 33.5, including the maintenance manual, installation manual, and operating instructions.

e. Excessive vibration. Vibration that results in mechanical failure, damage or wear in excess of approved limits or prevents the engine from operating as intended.

f. External components ("externals"). The components of an engine directly or indirectly mounted on the engine exterior casing. External components are addressed in chapter 4 and include:

(1) Components and Accessories ("C&As"). The individual components and accessories that are part of the engine and its systems. Examples include: the Full Authority

Digital Engine Control, Fuel Management Unit, pumps, actuators, igniters, temperature probes, filters, sensors, or valves; and the engine accessories, such as the accessory gear box.

(2) Engine systems. The various engine systems, such as the electrical, lubrication, or fuel systems, which include C&As and associated components. For example, the fuel system includes C&As like fuel pumps, filters, and flow-meters and components like hoses, tubes, valves, and connectors. Another example is the electrical system, which includes C&As (like generators) and the connecting cables.

(3) Assembly hardware. The brackets, supports, ducts, spacers, tubes, hoses, and all the other assembly and clamping elements used to attach, mount, or connect C&As and engine systems. For the purposes of this AC, we are referring only to assembly hardware that are sensitive to engine vibration and whose failure would interfere with the functional and structural integrity of the C&As and engine systems or would cause a hazardous engine effect.

(4) Externals may also include components in the engine flow-path that provide data to components on the engine case. For example, temperature, pressure, and speed probes or pick-ups.

g. Hazardous engine effect. Any of the conditions listed in § 33.75, Safety analysis.

h. Internal components. Vibration sensitive components internal to the engine casing (see chapter 5).

i. Operating range of rotational speeds. The physical and, when applicable, corrected speeds up to and including the rated and maximum permissible operating limitations established under § 33.7.

j. Vibration. Includes the vibratory characteristics or dynamic phenomena exhibited by the engine, its components, systems, or assemblies.

CHAPTER 2. GENERAL VIBRATION REQUIREMENTS.

2.1. The Engine.

a. For the purpose of this guidance, we distinguish between the external and internal engine components, discussed in chapters 4 and 5, respectively. When assessing engine vibration, you should consider the following:

(1) The elements of design, such as tolerances and resulting geometrical variability, that have a measurable effect on the natural frequencies, amplitude response, or other vibration characteristics of the engine. For example, the blade geometrical tolerances may result in a range of frequencies for each normal mode which should be considered when assessing the blades resonant stresses.

(2) The manufacturing or production specifications and the recommendations in the engine manuals that affect engine vibration. For example, to account for the variability in rotor unbalance due to manufacturing, assembly, or maintenance, you may test, or perform analysis, at or above the highest levels of unbalance permitted to occur.

(3) The engine configurations resulting from certain fault conditions created by likely mechanical failures, such as partial airfoil loss (see paragraph 3.4).

2.2. The Flight Envelope and Operating Conditions.

a. You should consider the following aspects of the declared flight envelope and the operating range of rotational speeds and power or thrust required under § 33.63:

(1) Power or thrust up to and including the maximum rating values, and rotational speeds up to and including the rated and maximum permissible physical and corrected speeds. Maximum permissible speeds include any declared transients. Some components, such as the externals, are vibration sensitive to only physical rotational speeds; other components, such as the internals, may be vibration sensitive to the flowpath conditions associated with the rated thrust/power and represented by the corrected speeds. The corrected rotational speed of a rotor system is determined 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 formula:

$$N_c = \frac{N_r}{\sqrt{\frac{T_{inlet}}{518.67}}}$$

Where:

- N_c and N_r are the corrected and physical rotational speeds, and

- T_{inlet} is the rotor module inlet temperature in degrees Rankine.

(2) Engine operations and maneuvers that affect vibration, such as engine starts, shutdowns, accelerations, decelerations, idles, chops, and bursts. For example, during engine vibration signature testing, snap accelerations may highlight impulse driven transient responses, while slow accelerations and decelerations allow sufficient time for steady state vibratory peaks to develop.

(3) Flight envelope parameters, such as altitudes, ambient temperatures, or any other parameter that may affect engine vibration. For example, ambient temperatures affect corrected speeds which, in turn, may affect amplitude response.

(4) Operating conditions, such as icing and ice accretion, that affect vibration and that may produce rotor unbalances in excess of that resulting from the rotor(s) design, manufacturing, and maintenance shown to comply with § 33.63 (see paragraph 3.2.b).

2.3. The Engine Vibratory Stresses.

a. As required by § 33.63, you must demonstrate that the engine and its components, when operating throughout the declared operating envelope, including any declared maximum rotational speeds, are free from excessive vibration (see paragraph 1.2.e for a definition of "excessive vibration").

b. Your demonstration should address the vibratory loads representative of normal or typical engine operations, as well as those associated with adverse conditions expected to occur within the declared flight envelope. You should demonstrate that vibratory stresses are not excessive under any of these representative conditions.

c. Engine designs or operating restrictions that allow and manage accumulation of high cycle fatigue damage for any component are not acceptable if the failure of that component would cause a hazardous engine effect. Vibration stresses above endurance limits result in high cycle fatigue damage. Continued or repeated operation at these stress levels results in cumulative fatigue damage and, ultimately, component fatigue failure. However, the components tested under § 33.83 must demonstrate vibratory stresses lower than the endurance limits by a suitable margin as noted in § 33.83(d).

2.4. The Vibratory Forces Imparted to the Aircraft. To comply with the requirement of § 33.63 that no excessive vibration forces be imparted to the aircraft structure, you should disclose in the engine installation or operation manuals the vibration forces imparted to the aircraft. At a minimum, disclose the vibration caused by rotor unbalance for which engine compliance with part 33 requirements has been shown. This is necessary because there are no engine level criteria for what constitute excessive forces for the aircraft. During engine certification, we recommend that you coordinate with the aircraft manufacturer to identify the engine vibration forces that would be excessive for an aircraft installation.

2.5. Acceptable Methods of Compliance.

a. You must show compliance to § 33.63 based on engine and/or component test, analysis, or a combination of test and analysis. Consider testing as the means of compliance for all components that:

(1) Are critical;

(2) Have significant resonances that fall within or close to the rotational speeds declared as operating limitations under § 33.7; or

(3) Are exposed to complex vibration that cannot be adequately determined by analysis.

b. The compliance methods may be specific to certain components, or category of components, i.e., external or internal and rotating or non-rotating components. Specific compliance issues are discussed further in chapter 4 for external components and in chapter 5 for internal components. You should use the same or similar methods to show compliance for all other components not discussed in chapters 4 and 5. These include engine cases, frames, and combustors; and airframe interface components, such as engine mounts, exhaust nozzles, and thrust reversers.

c. Data produced for compliance with other airworthiness requirements may be used, when applicable, to satisfy the requirements of § 33.63, as illustrated in Table 1.

d. You may use prior experience to show compliance for certain components with sufficient service history and predictable vibratory characteristics. For example, certain hardware may have been proven in operation on other engine models and for the broad range of frequencies that cover the certification engine.

e. Analytical methods are acceptable if they are validated by other testing, including testing done to evaluate vibration in compliance with other part 33 requirements. The analytical methods should include prediction of the vibratory environment to which the components are subjected and the assessment of these components vibratory responses. The goal is to show that the vibration stresses are not excessive.

Table 1. Engine components that may be assessed for vibration under part 33[1].

Engine Components	**§ 33.28**	**§ 33.68**	**§ 33.83**	**§ 33.87**	**§ 33.91**	**§ 33.97**
	Electrical and electronic engine control systems	**Induction system icing**	**Vibration test**	**Endurance test**	**Engine component tests**	**Thrust reversers**
Components & Accessories (C&As)[2]	X	X	X	X	X	
Engine systems[2]	X	X	X	X	X	
Assembly Hardware[2]		X	X	X	X	
Blades, vanes, rotor disks, spacers, and rotor shafts		X	X	X		
Engine cases, frames, combustors, exhaust structures, and thrust reversers			X	X		X

(1) The vibration data obtained in compliance with any of the indicated rules may also apply to § 33.63.
(2) The externals are sensitive to the level of rotor unbalance; see chapter 4. Data in compliance with these regulations is applicable if is representative of the vibratory environment required under § 33.63, including the effects of rotor unbalance.

CHAPTER 3. ROTOR UNBALANCE

3.1. General.

a. Rotor mass imbalance, commonly known as unbalance, is due to the eccentricity of the rotor mass center relative to its axis of rotation. This unbalance is generally the result of rotor manufacture and assembly, and, although unavoidable, can be reduced through compensating techniques. Limitation of rotor unbalance is needed because rotating mass unbalance results in synchronous vibration at rotor speed frequencies. The acceptable limits for rotor unbalance are usually identified in the production specifications and/or engine manuals.

b. In this chapter, we discuss how to achieve the engine level of unbalance and how to determine the effects of this unbalance by engine test. At a minimum, we recommend an engine test for certification of new engines. Analysis, or a combination of analysis and test, may be used if it shows that the rotor unbalance and its effects can be adequately characterized. The analytical methods are acceptable if validated and supported by the data acquired during an engine test. The goal is to establish the vibration environment at the locations of components to be certified, throughout the frequency range of the engine's rotors rotational speeds, and for the unbalance levels identified in this chapter.

3.2. Level of Unbalance.

a. The engine's low speed, high speed, and any intermediate speed main rotors must be unbalanced with the goal of accomplishing the highest permissible vibration levels for all rotors when measured at the engine vibration monitoring sensors. For example, to achieve this unbalance for an engine having two-speed rotor systems, we recommend that you build the test engine with the highest permissible unbalance for the high speed rotor system, then trim balance the low speed fan and turbine rotors to the levels permitted for the low speed rotor. This combination of high and low speed rotor unbalances will constitute the unbalance condition for subsequent unbalance testing.

b. In addition to the rotor unbalance permitted by design and maintenance practice, you should also address unbalances that develop in operating environments, such as icing and ice accretion, if more severe. You may determine the level of unbalance caused by ice accretion based on that observed during § 33.68 icing test.

3.3. Effect of Rotor Unbalance - Engine Vibration Signature.

a. The vibration signatures for the engine, its accessory gearbox, or any other assembly system if necessary, should be determined with representative unbalanced rotors, as noted above. You should identify the vibration signatures representative of an engine operating throughout its declared envelope and ranges of rotational speeds. These signatures, particularly their significant vibratory peaks, can then be used in assessing engine vibration.

b. The rotor unbalance effects and engine vibration signature should be determined by engine test and measured by means of vibration sensors placed at specific locations on the engine. Place these vibration sensors, accelerometers, or condition monitoring units at the locations on the engine that are sensitive to rotor system unbalances, and, when necessary, near or on specific components.

c. You should obtain each vibration signature during slow accelerations and decelerations that cover the speed ranges from minimum to maximum rated or permissible rotational speeds, including any declared transients. The time duration for each slow acceleration and deceleration should be at least 2 minutes. In addition, consider maneuvers such as throttle bursts and chops. Vibratory surveys of multiple engines and repeated accelerations and/or decelerations may be needed to capture a representative engine vibration signature. The engine configuration must be representative of its installed mass and stiffness and account for the airframe interfaces and accessories that might affect engine vibration.

d. You should ensure that each rotor system unbalance used to demonstrate compliance with § 33.63, including that used to determine the engine vibration signatures, is representative of the instructions for rotor balancing prescribed in the engine manuals. This is to ensure that the rotor unbalance introduced during engine maintenance will maintain engine vibration within the bounds shown to meet the safety standards of § 33.63.

3.4. Unbalance Caused by Fault Conditions. Certain fault conditions, such as the out-of-balance caused by partial airfoil loss, must not result in vibration leading to hazardous engine effects. You should address these fault conditions if the resulting engine vibration may not be recognized as abnormal, so adequate action can be taken, and if continued operation in this condition could cause a hazardous engine effect. For example, after the loss of a blade tip, the level of vibration may not be recognized as abnormal if it is below the limits in the engine manuals; but continued engine operation in this configuration could trigger multiple failures causing a hazardous engine effect before adequate action can be taken. Consider the extent of blade loss associated with the level of vibration that may not be recognizable, yet may be sufficient to produce a hazardous engine effect if no immediate action is taken. The fault conditions effects addressed in compliance with § 33.83(e) may qualify for compliance with these requirements. When an out-of-balance rotor continues to rotate after the engine is shutdown, this falls under the requirements of § 33.74, Continued rotation.

CHAPTER 4. EXTERNAL COMPONENTS VIBRATION

4.1. General.

a. Since externals are primarily mounted on the engine casing, they are exposed to vibration defined by engine rotational speeds and rotor unbalances. Excessive vibration could lead to structural or functional failure of the externals.

b. The externals' vibratory characteristics may be determined by test, analysis, or a combination of both. The decision to test or conduct analysis should be based on the criteria identified in paragraph 2.5.a. If testing is needed, the procedures outlined in this chapter may be used to demonstrate compliance with § 33.63. If analysis is acceptable, see paragraph 2.5.e for a discussion of analytical methods.

c. Consider the vibratory environment produced by rotor unbalance discussed in chapter 3. Avoid assessing the effects of vibration differently because they occur in a transient or a steady state regime when these regimes may be specific to an aircraft installation and operation. For example, consider that steady regimes may vary with engine multiple thrust ratings, engine deterioration, operators' derate practices, flight profiles, and other considerations.

d. You should assess the vibratory stresses at the level of system assembly and consider the interactions between system components. For example, assess the vibratory characteristics of harnesses at the electrical system level or as assembled on the engine. You should also assess the effects of a system's operation on its vibratory characteristics. For example, consider the fuel system pressure effects on the natural frequencies of the flexible fuel lines and their resonant responses.

4.2. Vibration Test.

a. Vibration testing may be conducted on an engine and/or by laboratory test (shake table). The decision to perform a full engine test, a laboratory test, or both, should at least consider whether the external component vibratory environment is already known and whether the laboratory test equipment can accommodate that component and accurately represent its vibratory environment. For example, for a new engine model, consider running a full engine test because the vibratory environment is not fully known for all externals. Vibration tests performed in compliance with other part 33 regulations may be eligible for a showing of compliance with § 33.63. See Table 1 for compliance shown to other part 33 regulations that may also apply to § 33.63.

b. You should run a stair-step endurance test with representative rotor unbalances (see chapter 3) and cover the entire range of component frequencies. However, for those components for which the ranges of natural frequencies and the vibration environment are well known, you may perform only dwell endurance tests. For a new engine model, consider running the stair-step test for the high speed rotor frequencies and the dwell test for the low speed rotor frequencies.

c. The tested components must be able to function as intended and must be free of any damage and wear beyond the acceptable limits when subjected to a representative vibration test.

4.3. Stair-Step Endurance Test.

a. The objective of a stair-step endurance test run for an engine is to excite the engine resonances, i.e., the resonances of all components and systems, and to maintain the level of resulting vibration for a number of cycles sufficient to demonstrate endurance. To accomplish this, the test should be run with the unbalance levels discussed in paragraph 3.2 and should cover the operating range of rotational speeds. The test should be conducted during acceleration and then deceleration, in step increments and with dwell times on each step. You should choose a small enough step size and an adequate step dwell time to ensure that sufficient number of cycles are accumulated at each frequency in the range. We recommend incremental steps of 120 rpm of the high rotor speed and a dwell time on each step equivalent to one million (1E6) one-per-revolution cycles of the high speed rotor.

b. When stair-step testing is conducted, you should obtain both pre- and post-test engine vibration signatures. Significant differences in the engine vibration signatures must be explained.

4.4. Dwell Endurance Test. This test is usually conducted to assess the engine components and the frequencies not covered in the stair-step test or to assess any component for which a vibratory assessment is necessary. These components should be subjected to the significant vibration identified during the engine signature test, the stair-step tests, or any other applicable testing or analysis. The significant vibration is usually associated with the highest amplitude peaks, but certain lower peaks may require further assessment if they fall within or close to the rotational speeds declared as operating limitations under § 33.7. Whenever specific frequencies are targeted and dwell endurance tests are conducted, the dwell time should be equivalent to a minimum of ten million (1E7) cycles to demonstrate endurance strength. When test durations would be unreasonably long because of the low frequency vibration, you may shorten the test if an appropriate compensation is applied. For example, you may shorten the test by increasing the vibratory stress based on the material fatigue properties.

CHAPTER 5. INTERNAL COMPONENTS VIBRATION

5.1. General. In addition to vibration resulting from excitations of natural frequencies (resonances), if applicable, consider the effect of rotor unbalance on internal components (see chapter 3).

5.2. The Blades, Vanes, Rotor Disks, Spacers, and Rotor Shafts.

a. Blades, vanes, rotor disks, spacers, and rotor shafts shown to comply with § 33.83, Vibration test, also satisfy the § 33.63 requirement that engine components must not be subjected to excessive stresses because of vibration. The blades, vanes, rotor disks, spacers, and rotor shafts not tested in compliance with § 33.83 should be addressed under § 33.63. In addition, the design aspects or operating conditions that affect vibration and that were not assumed for compliance with § 33.83 should be addressed under § 33.63. For example, you should consider the ranges of geometric tolerances, tip clearances, and other factors affecting natural frequencies and amplitude response, if these were not examined in compliance with § 33.83. To demonstrate that the stresses are not excessive, we recommend that you use the criteria of § 33.83(d). Otherwise, you should justify different criteria.

b. You should address the effects on vibration that are anticipated or determined to occur in operating conditions like icing, rain, and hail, and for which repeated or continuous engine operation is expected. These conditions might affect, for example, blade vibratory amplitude responses or flutter margins. Repeated exposure to high cycle fatigue stresses in excess of endurance limits for even short periods of time could lead to cumulative fatigue damage and subsequent component failure. If these vibratory stresses exceed the levels demonstrated during § 33.83 compliance, § 33.63 requires that you show they are not excessive.

5.3. The Fan Case. You should show by analysis, test, or experience that the fan case and fan rotors are not sensitive to rotor-case interactions, and no conditions exist that may cause this phenomenon to develop. Fan rotor-case interaction is a dynamic phenomenon that must be avoided since it is potentially hazardous. This interaction could rapidly produce destructive and unavoidable vibration, rendering the vibration monitors ineffective for any timely action or response.

5.4. Other Components. You should assess any other internal components sensitive to engine vibration not referenced in paragraphs 5.2 and 5.3 and show that they are not subjected to excessive stresses. The compliance methods may be based on test or analysis and may use data or observation collected during certification testing in compliance with other part 33 regulations (see Table 1).

CHAPTER 6. CONDUCT OF TESTING

6.1. Configuration.

a. The engine and its components, including mountings, attachments, and vibration isolators, that are tested for compliance with § 33.63 must be representative of their type design. For testing purposes for every component and engine system, you should create the vibratory environment that adequately represents the engine. You should also configure any test to account for the engine installation features or interfaces that might affect engine vibration. Examples of installation features are the cowling; the engine mounts; and airframe elements, such as inlet and exhaust structures, for which the weight, center of gravity, or stiffness would affect engine vibration. When the installation features are not entirely known, you should provide in the installation instructions required by § 33.5 the methods to evaluate their effects on engine vibration.

b. Certain components, such as fluid-filled lines and hoses, should be configured to assess the effects on vibration of pressures, temperatures, or any other functional parameters.

6.2. Instrumentation.

a. You must ensure that sufficient instrumentation is present to monitor engine vibration throughout the test. The instrumentation must be capable of, and located, so that it properly identifies the critical vibratory environment for those components subjected to test. For example, the vibration monitor units must be placed based on their sensitivity response to rotor unbalance. The comparison of vibratory signatures of the nominal versus unbalanced rotors may constitute an indicator for the sensitivity response of the vibration monitor units. You should consider placing accelerometers or vibration sensors on or near the fan case, compressor case, combustor case, exhaust frame, and accessory gearbox to determine their vibratory environment.

b. Additional instrumentation may be required to identify the vibratory environment for specific components and accessories.

6.3. Test Sequence and Success Criteria.

a. Prior to testing, you must identify the pass/fail criteria, such as engine or component performance, vibration levels, and acceptable post-test inspection criteria. The pass/fail criteria must include the capability to detect the engine vibration with an acceptable level of accuracy.

b. You should plan the test sequence to ensure that significant vibration is found and addressed in subsequent testing. For example, the vibration signature test must precede the stair-step and dwell tests to ensure that all peak and significant vibration emerging during the vibration signature test are considered during the stair-step and dwell tests.

6.4. Post Test Inspection. You should perform all necessary post-test evaluations and inspections with the goal of detecting any component structural or functional failures. Because high cycle fatigue damage may not be detected by a simple visual inspection, remove the vibration sensitive components and thoroughly inspect them. Your test plan should identify the inspection methods, including visual, non-destructive inspections, or functional tests. You should explain any damage, distress, or wear beyond the limits set for post-test inspection and provide an analysis of the impact that it presents.