Advisory Circular

Subject: TURBINE ENGINE VIBRATION TEST

Date: 9/29/06

Initiated by: ANE-111

AC No: 33.83A

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the vibration test requirements of § 33.83 of Title 14 of the Code of Federal Regulations (14 CFR part 33).

2. CANCELLATION. Advisory Circular 22.38, dated February 14, 1997 is cancelled.

3. APPLICABILITY.

a. The guidance provided in this document is directed to engine manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) engine type certification engineers and their designees.

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 FAA") will consider other methods an applicant may present to demonstrate compliance. 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 method 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. If we find that following this AC would not result in compliance with the applicable regulations, we will not be bound by 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.

4. DEFINITIONS. For the purpose of this AC, the following definitions apply:

a. Physical rotational speed (Nr). The raw uncorrected rotational speed of a rotor system measured in revolutions per minute (rpm).

b. 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 formula:

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

c. Resonance. A condition that occurs when the exciting force frequency coincides with one of the component's natural frequencies (f_n) resulting in an increase of the vibratory amplitude. A unique vibratory mode exists for each resonant response.

d. Endurance limit. The stress range that can be repeated indefinitely without material fatigue failure. The endurance limit depends on the steady-state stresses, temperatures, and other factors.

e. Flight envelope. All approved conditions of operation, including ground and flight operations, and windmilling rotation in flight.

f. Flutter. Flutter in a system having blades or vanes, is a self-excited vibration that 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 upon the airstream as an external source of energy, and the structure aeroelastic properties.

5. TEST PREPARATION.

a. Selection of components. Section 33.83 requires vibration surveys by engine test for all components subject to mechanically and aerodynamically induced vibrations. This requirement applies to at least the engine blades, vanes, rotor disks, spacers, and rotor shafts. Therefore, the components selected for vibration surveys will normally include:

(1) The blades and vanes in each stage of the low, intermediate, and high pressure rotors that are identified most critical because of their vibratory characteristics.

(2) All stages of disks and spacers.

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

(4) Any other component specifically identified critical because of their vibratory characteristics.

b. Supporting data and activity. In support of the certification test, you must have achieved an appropriate experience and engineering knowledge based on a combination of experience, analysis, and component tests, as required by § 33.83(a). Therefore, before certification testing, you should conduct substantive tests and analyses to identify the components and systems that are vibration sensitive, and determine their vibratory characteristics, including the natural frequencies, mode shapes, and steady state (mean) stresses. However, the combination of experience, analysis, and component tests required by § 33.83(a), constitutes a supporting activity that we consider exempt from formal FAA test plan approval.

c. Rig testing. Section 33.83 requires running a full engine test for the engine vibration survey. Further, separately running entire engine modules would be the same as a full engine test, providing certain conditions are met. You may propose to use rig tests to overcome potential limitations associated with a full engine test, such as the amount of instrumentation or range of inlet conditions. In that case, you must demonstrate that the rig interfaces and boundary conditions are representative of the engine, and the operating conditions achieved for that particular engine module are the same as if the module would have been run in a full engine test.

6. ENGINE TEST CONDITIONS.

a. Test speeds. The physical and corrected speeds must be at least equal to or higher than the maximum permitted values. For example, § 33.83(b) requires testing at 103-percent of the maximum physical and corrected speeds permitted for rating periods of two minutes or longer, and at 100-percent of all other speeds. To determine the test speed, the 103-percent value applies independently to each physical and corrected speed, 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.

b. Corrected speeds. For testing, the requirements for corrected speeds are to address significant 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 with achieving the physical speeds.

c. Speed extensions. The test program is intended to accomplish a stress survey for the ranges of conditions required under § 33.83(b). They include speed extensions to investigate the effects of rising vibratory stress peak.

d. Altitude effects. The effects of altitude may be represented and evaluated during an engine test conducted in an altitude facility, or by the means of flight test. Usually, flight surveys are conducted to supplement those in test facilities for which desired altitude conditions cannot be achieved. Unless proven otherwise, altitude data acquired in flight surveys is valid only for the engine operating conditions in existence during the flight test and the specific aircraft installations. For example, if the flight test is conducted to acquire altitude data related to the inlet distortion requirements but the most adverse inlet distortion is not present during the flight test, then additional testing may be necessary.

e. Engine modifications. During testing, you may choose to modify or adjust the engine 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 to the engine, or compromise the intent of the test and test results. You must identify the engine operating parameters or characteristics affected by these modifications, and evaluate their effects on the component vibratory behavior. Before a certification test, you may need to assess these adjustments by test or analysis, or both.

f. Inlet airflow distortion. Inlet airflow distortion may be associated with crosswinds, or other operating and aircraft installation conditions. Whether the engine test is performed in a test cell or flight test bed, the inlet distortion must be consistent with the most adverse pattern declared by the manufacturer, as required by § 33.83(c)(1). The most adverse inlet airflow distortion must be declared in the engine installation manuals, operating manuals, or any other similar documents as required by § 33.7(c)(13). During testing, inlet distortion may be achieved by various means, such as external cross-wind devices or inlet distortion plates or suppression screens.

g. Combined effects. In addition to the individual effects that variable vane angles and compressor bleeds have on vibrations, you should also consider the effects of their concurrent usage throughout engine operation.

7. FLUTTER.

a. 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 test should be configured to address the effects of hardware design variability, intake conditions, and the margins associated with engine deterioration. As a minimum and where appropriate, the following should be considered:

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

(2) The ranges of operating lines within the flight envelope.

(3) 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).

b. Flutter is a phenomenon sensitive to even small variations of those design factors that determine the engine system response. You 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.

c. You should ensure the engine is free of flutter. In extreme transient regimes, flutter may be acceptable providing that a thorough investigation of the flutter and its effects are completed, and there are no negative effects on the engine structural and operational integrity.

8. VIBRATORY STRESSES AND MATERIAL ALLOWABLES.

a. Measured stresses. The applicant should aim at taking stress measurements at critical or limiting locations. When these locations are not suitable or accessible for that purpose, stresses may be measured nearby, providing 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, use experience, analyses, or testing to gain a detailed knowledge of each mode and associated stress distributions. This investigation is usually done before the certification test.

b. 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 adding-up the resonant stresses, you 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 $f_n \pm 2.5\%$, then the amplitudes within this range should be considered.

c. Material allowable stresses. The material properties to meet the requirements of § 33.83(d) are the minimum endurance stresses 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.

d. Stress margins. Section 33.83(d) requires suitable stress margins for each part 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 for that location and the measured 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 criteria for stress margin suitability should account for the variability in design, operation, and other mitigating factors identified during the certification test. In addition, you should consider the effects of expected damages during operation. For example, fan and compressor blades are often subject to debris ingestion that could cause nicks and surface discontinuities. These may increase local stresses or may lower the component fatigue strength.

9. RESONANT DWELL. The applicant should determine all significant resonances and allow sufficient time for the resonant modes to respond. This is usually accomplished during slow accelerations and decelerations 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 close to, or on the resonance peak. This resonant dwell testing would normally be incorporated into the incremental periods of § 33.87 Endurance Test, as required by §§ 33.87(b)(4), (c)(4), and (d)(5). The components subject to resonant dwells must meet the requirements of § 33.93 Teardown inspection.

10. FAULT CONDITIONS.

a. Section 33.83(e) applies to those fault conditions that would cause abnormal vibrations difficult to identify in a timely manner for appropriate action. Although instrument connections are required by § 33.29(b) to indicate engine vibrations, certain low vibrations caused by fault conditions would not be recognized as associated with an engine fault and may not prompt an immediate response. Subsequently, these faults may escalate to engine hazard effects, described in § 33.75 Safety analysis. For example, the loss of an airfoil tip would likely result in an increased vibration. Although indicated by the means required under § 33.29(b), this vibration might not be immediately recognized as abnormal or 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 air distortions and changes in the airflow or pressure distributions that in turn may affect the engine vibratory response and characteristics. To address these fault conditions, you may use prior experience with faults that occurred with other similar engines. Successful experiences are when, after a fault condition, the engine was able to either continue a safe operation or be shut down without creating a hazard. You may also use field experience or other means to show that certain fault conditions are very unlikely to occur because of specific engine configurations or operating conditions.

b. The requirements of § 33.83(e) apply to the same components considered under § 33.83(a). When the effects of these fault conditions extend to the rest of the engine, it must be addressed under the requirements of § 33.63 Vibration (for example, the out-of-balance effects on the engine external components and accessories).

11. INSTALLATION COMPATIBILITY. Section 33.83(f) ensures the vibratory compatibility between the engine and each intended installation configuration providing the engine is installed and operated in accordance with the approved manuals and instructions. You must provide installation instructions as required under § 33.5. Sufficient instructions will assure that no aircraft installation would adversely affect the engine's vibration characteristics when these instructions are followed. You may also consider imposing operating limitations and procedures when establishing the vibratory compatibility between the engine and its installation. As a minimum, and where appropriate, the following features should be considered:

a. Each propeller approved for use on the engine.

b. Each thrust reverser approved for use on the engine.

c. Installation influences on inlet and exhaust conditions.

d. Mount stiffness.

e. Rotor drive systems.

f. Accessory components.

12. INSTRUMENTATION.

a. Types of instrumentation. To acquire the data required under § 33.83, when conducting vibration surveys you should use suitable instrumentation, data acquisition, and analyzer systems. Vibration specific instrumentation may include dynamic strain gages, accelerometers, and time of arrival sensors.

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

(2) Other measurement means could be acceptable. For example, time of arrival sensors, such as optical sensors or light probes, may prove convenient alternatives to strain gages, providing they are properly calibrated and their capabilities are clearly understood. The most common application for time of arrival sensors is to measure blades tip displacements, then converting them to stresses at specific blade locations. Converting displacements to stresses requires a detailed knowledge of the blade normal modes, mode shapes, and associated tip displacements.

b. Instrumentation survivability. Some form of analysis is acceptable when test instrumentation can only survive for short periods of time because the test engine operates at such high rotor speeds and gas path temperatures. But, the loss of instrumentation should be minimal and the associated analysis should be primarily based on the surviving instrumentation data.

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