U.S. Department of Transportation

Federal Aviation Administration

Advisory Circular

Subject: Turbine Rotor Strength Requirements of 14 CFR 33.27.

Date: 9/27/04

Initiated By: ANE-110

AC No: 33.27-1

Change:

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, for demonstrating compliance with the rotor strength (overspeed) requirements of 14 CFR § 33.27.

2. 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. The 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 the FAA becomes 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. 14 CFR §§ 33.4 and 33.27.

4. RELATED DOCUMENTS.

a. AC 33-2B, Aircraft Engine Type Certification Handbook, dated 9/10/93.

b. AC 33-3, Turbine and Compressor Rotors Type Certification Substantiation Procedures, dated 9/9/68.

5. DEFINITIONS. For the purposes of this AC, the following definitions apply:

a. Approved Dimensional Limits. Approved dimensional limits (also known as acceptable growth limits) are the maximum allowable dimensional growth at various disk locations that do not result in a hazardous condition. These approved dimensional limits are used to support the selection of the actual serviceable limits versus rotor overspeed level established within the Instructions for Continued Airworthiness (ICA) under § 33.4.

b. Burst Margin. The burst margin is the predicted burst speed divided by the maximum permissible speed. This ratio is expressed as a percentage.

c. Maximum Permissible Rotor Speed. Maximum permissible rotor speed is the maximum approved rotor speed, including transients, for the maximum approved rating, including emergency ratings.

d. Rotor. A rotor is an individual stage of a fan, compressor, or turbine assembly (some assemblies may consist of only one stage), including but not limited to bolted or welded assemblies.

e. Sample Rotor. A sample rotor is a test rotor or rotor assembly (including, as appropriate, coverplates, spacers, blade retention devices, etc.) that meets the following criteria:

(1) Represents the standard to be certified; and

(2) Has known material properties and dimensions.

f. Shaft System. A shaft system is defined as the system of components that transmits torque between the disk driving flange or shaft attachment members of the system that produce power (for example, turbine) and the system that uses this power (for example, compressor, fan or propeller). Although the shaft system transmits mainly torsional loads, it consists of all rotating parts that are necessary for the rotor(s) to perform their function, whether or not such parts transmit torque. Therefore, the shaft system may include, but may not be limited to, the following:

(1) Drive shafts;

(2) Gears;

(3) Gearboxes;

(4) Rotor wing arms;

(5) Stub shafts; and

(6) Rotor hubs.

6. INTENT. The safety objectives of the overspeed (strength) requirements are to ensure that the rotors:

a. Possess sufficient strength margin above certified operating conditions and above failure conditions leading to rotor overspeed; and

b. Do not exhibit a level of growth or damage that could lead to a hazardous condition due to such growth, such as fire, uncontainment, or loads greater than the ultimate loads of the engine mounts.

7. GENERAL.

a. The applicant may comply with the overspeed (strength) requirements by using the required tests and necessary analysis to meet the objectives identified in section 6 of this AC.

b. The applicant should define and validate the analysis technique necessary to support compliance with § 33.27 before use. The applicant should base the calibration and validation of the analytical technique on prior overspeed tests which may include the current rotor being certified. An analysis is considered validated if it can accurately:

(1) Predict rotor burst speed;

(2) Identify the rotor stage with the lowest burst margin within each engine module; and

(3) Predict the dimensional growth versus rotor speed at critical rotor locations.

c. Any assumptions made during the testing or analysis should be conservative.

d. The applicant should submit the appropriate substantiation to determine which of the overspeed conditions listed in § 33.27(c) is the most critical with respect to rotor integrity for each rotor module (fan, low pressure compressor (LPC), high pressure compressor (HPC), high pressure turbine (HPT), low pressure turbine (LPT)). This substantiation should consider the entire flight envelope. Once this condition and the critical rotor stage have been identified, the applicant must perform a test to demonstrate compliance.

e. If deliberate blade shedding limits the peak overspeed:

(1) The conditions of §§ 33.27(c)(v) and (c)(vi) apply to a fully bladed rotor at that speed; and

(2) The blade failure speed should consider an adverse combination of dimensional tolerances, temperatures, and material properties of the blades and rotor. Consequently, the most critical speed with respect to rotor integrity might not coincide with the highest achievable blade shedding speed.

f. If blade shedding or turbine blade/vane meshing and clashing is used as a means to limit the maximum attainable overspeed, the applicant must demonstrate the following by test, analysis, or a combination of both:

(1) The maximum attainable overspeed; and

(2) That a hazardous engine condition does not occur at such speed.

g. While considering the most adverse combination of dimensional tolerances and material properties, as required in § 33.27(a), the applicant should also consider the tolerances of other components that adversely influence stress levels in the rotor, such as overspeed limiter.

h. Compliance with § 33.27 (c) requires an overspeed test of the most critical rotor stage for each engine module. This will require the applicant to determine the burst speed for each rotor stage in order to select the most critical stage (the one that has the smallest burst margin). If the applicant is unable to identify the critical stage within each engine module by an acceptable method, then multiple tests are required, or a single test of the entire rotor module.

i. For each individual rotor stage, the applicant must consider the most adverse combination of temperatures and temperature gradients that is possible throughout the entire operating envelope.

j. The most critical rotor with respect to burst might not be the most critical with respect to growth. To determine the most critical rotor with respect to growth for compliance with § 33.27(c), the applicant should consider the components surrounding each rotor.

k. Appropriate tests or analysis based on tests should establish the burst speed of each fan, compressor, and turbine rotor stage in relation to the most critical condition prescribed in § 33.27(c). The certification documentation should report these speeds. These burst speeds should be based on the most adverse combination of dimensional tolerances, temperature, and material properties.

8. ACCEPTABLE MEANS OF COMPLIANCE. The following is an acceptable method, but not the only method, for demonstrating compliance with the rotor strength (overspeed) requirements of § 33.27. The applicant is free to propose a different way of meeting the regulatory requirement. However, if the applicant chooses to use the method in this AC, the applicant must conform to the AC in all-important respects.

a. The applicant must test the most critical stage of each rotor module (fan, LPC, HPC, HPT, LPT) for five minutes at the most critical speed of § 33.27(c) and at its maximum operating temperature (except as provided in § 33.27(c)(2)(iv)). To demonstrate compliance with § 33.27(a), the applicant must use a validated analysis and the overspeed test results of the sample rotor to show that all rotors, accounting for the most adverse combination of the dimensional tolerances, temperature, and material property variations, will have sufficient strength to meet the test requirements.

b. The pass/fail criteria following the test are that the test rotor must not be cracked and must be within approved dimensional limits for the overspeed condition. To validate that the sample rotor is within approved dimensional limits for the overspeed condition, the applicant must measure rotor growth at the end of the test. The applicant must then show that at the test conditions the sample rotor would not incur excessive growth that could lead to a hazardous condition during engine operation.

c. Any test may be continued to rotor burst after the required time duration by increasing the speed until the rotor bursts. If the applicant chooses this method, the applicant must show that:

(1) The test rotor was initially run at conditions not less severe than those required for compliance with § 33.27(c); and

(2) Sections 33.27(a) and (c) can be complied with using an approved analytical modeling method.

d. The engine control devices, systems, and instruments referred to in § 33.27(b) are usually implemented in modern engines by overspeed protection or circuits which, although they may be independent devices, are generally provided as part of the electronic engine control (EEC) system. One acceptable method for demonstrating reasonable assurance of the functionality of the protection systems or circuits is to test them with a built-in test equipment (BITE) test or a periodic functional test. For the overspeed protection system, the BITE test should test 100% of the electrical/electronic part of the protection system. Because in some overspeed protection systems there are multiple protection paths in the overspeed protection system, there will always be uncertainty that all paths are functional at any given time. Where multiple paths can invoke the overspeed protection system, a test of a different path must be performed each engine cycle. The objective is that a complete test of the overspeed system is achieved in a minimum number of engine cycles. This is acceptable as long as the system meets a 10^{-4} failure rate. The applicant may use a periodic functional test for the mechanical or actuating part of the overspeed system.

9. FACTORS TO BE CONSIDERED IN DETERMINING TEST CONDITIONS.

a. Temperature. The applicant should establish temperatures and temperature gradients by temperature surveys on an engine or should derive them from a validated analysis. Adjustments of test speed or blade mass or both should be applied to compensate for any deviation from the required temperatures and temperature gradients. The rotor temperatures required by § 33.27(c) are as follows:

(1) For §§ 33.27(c)(2)(i), (c)(2)(ii), (c)(2)(iii) and (c)(2)(iv), the material temperatures and temperature gradients equal to the most adverse that could be achieved when operating in the engine at the required limiting condition.

(2) For §§ 33.27(c)(2)(v) and (c)(2)(vi), the material temperatures and temperature gradients equal to the most adverse that could be achieved when operating in the engine at the required limiting condition immediately prior to the failure(s).

b. Sample Rotor Material Properties.

(1) The applicant may determine the material properties of the sample rotor from attached test rings/bars when the correlation of their properties has been established by a validated method using coupons obtained from forgings/castings of the type to be approved.

(2) When attached test rings/bars are not available to determine the material properties of the sample rotor, the applicant may establish a value for the material properties by assuming that the sample rotor possesses material properties equal to known average properties of similar rotors from the same manufacturing process lot, if the applicant can show that the assumption is valid within acceptable confidence limits. Such limits should be based on the same statistical methods used to define the average and minimum material properties used in the design of the rotor.

10. FAILURE CASES.

a. Introduction. Section 33.27(c)(2)(v) states that rotor structural integrity must be demonstrated at: "105% of the highest speed that would result from failure of the most critical component or system in a representative installation of the engine." This single component may not necessarily be in the rotor itself; instead, it may be some part of another engine sub-system that, upon failure, could cause a rotor overspeed. Examples of such components might include certain key elements of the engine control system and its related sensors. A failure modes effect analysis (FMEA) or other similar engineering assessment would generally be required to identify such components.

b. Loss-of-load Events.

(1) The preamble to Amendment 10 of part 33, § 33.27, states that the intent was to not allow the use of probabilistic arguments for the purposes of determining the critical failure location for the overspeed assessment. For example, in a loss-of-load event, under the current rule all shaft failure locations must be considered, and compliance must be shown at the most critical location.

(2) Although the original intent of the rule is clear, a review of historical practices and methods of compliance indicates that the FAA has consistently accepted engineering assessments that support the applicant's findings that certain locations on the shaft are not required for failure assessment when complying with § 33.27(c)(2)(v).

(3) When addressing loss-of-load events (that is, any failure of the shaft system that effectively uncouples the turbine from its load), the applicant is required to determine the highest terminal speed of the rotor resulting from the failure of any shaft element, regardless of probability of failure, throughout its flight envelope. Once the highest terminal speed is determined, the applicant should design and demonstrate that disks have 5% margin above that speed. In other words, shaft failure at any location along the shafting system must be considered in determining the highest rotor terminal speed.

(4) To determine the highest overspeed resulting from a loss of load under §§ 33.27(c)(2)(v) and (c)(2)(vi), the applicant must consider, for possible failure locations, factors that include, but are not limited to, the following:

(a) System inertia;

(b) Available gas energy;

(c) Whether the rotor is held in plane; and

(d) Overspeed protection devices.

(5) The following guidance describes two acceptable approaches for determining the maximum terminal rotor speed for shaft failure cases when complying with §§ 33.27(c)(2)(v) and (c)(2)(vi).

(a) For any component or element that forms part of the rotor shaft system, identify all single point failures that can lead to an overspeed condition and determine by test the resulting terminal rotor speed. The applicant may use analysis if it has sufficient validation prior to testing or service events. This determination cannot include the use of probability arguments to exclude certain shaft failure locations.

(b) If the applicant proposes to exclude certain shaft element(s) from failure consideration in determining the terminal rotor speed, the applicant must show by engineering assessment that failure of this shaft element(s) cannot be expected to occur during the life of the engine. The applicant and the FAA must establish and agree upon the structural integrity criteria used for this assessment on a case-by-case basis. In general, the assessment should:

1. Identify and consider all failures that can lead to an overspeed condition. Examples of shaft element failure modes include, but are not limited to, fatigue (LCF/HCF), torsional overload, bearing failure, shaft rub, overtemperature, and loss of rotor centerline. The assessment should also include failure or combinations of failures in the surrounding environment that could result in failure of the shaft element(s). The assessment of the

environment should take into account possible wear, corrosion, fire, and contact with adjacent components or structure that could lead to the failure of the shaft element(s).

2. Show that the shaft element(s) complies with the requirements of § 33.14.

3. Show that the material and design features of the shaft element(s) are well understood, as evidenced by significant test and service experience.

4. Show that any stress and failure analysis methods used are adequately validated.

5. Identify any assumptions regarding engine installation. Installation assumptions should be noted in the Installation Instructions required by § 33.5.

6. Consider test and service experience with parts of similar design.

(c) Shaft system elements meeting the agreed-upon criteria can be excluded from consideration, and the applicant would then determine the maximum terminal rotor speed from the failure of the remaining shaft system elements.

//Original signed by FAF on 9/27/04//
Francis A. Favara
Acting Manager, Engine and Propeller Directorate
Aircraft Certification Service