U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Engine and Turbosupercharger Rotor Overspeed Requirements of 14 CFR § 33.27.
Date: 7/18/11
Initiated By: ANE-111
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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 Title 14 of the Code of Federal Regulations (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, 33.27 and 33.70.

4. Related Documents. Please check the FAA's website at http://www.faa.gov/regulations_policies/ for the latest revision of the following documents:

a. AC 33-2B, Aircraft Engine Type Certification Handbook, September 10, 1993.

b. AC 33-3, Turbine and Compressor Rotors Type Certification Substantiation Procedures, September 9, 1968.

c. AC 33.64-1, Guidance for Pressurized Static Parts, September 13, 2010.

d. AC 33.70-1, Guidance for Aircraft Engine Life-Limited Parts Requirements, July 31, 2009.

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

a. Approved Dimensional Limits. The maximum allowable dimensional growth at various disk locations that does not result in a hazardous condition. These approved dimensional limits, also known as "acceptable growth limits," 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 minimum rotor burst speed divided by the maximum permissible speed. This ratio is expressed as a percentage.

c. Engine Module. Each fan, compressor and turbine is considered an engine module. An engine may have several modules, such as a High Pressure Compressor (HPC), High Pressure Turbine (HPT), Intermediate Pressure Compressor (IPC), Intermediate Pressure Turbine (IPT), Low Pressure Compressor (LPC), and Low Pressure Turbine (LPT).

d. Extremely Remote. Failure conditions having a probability of occurrence in the range of 10^{-7} to 10^{-9} per engine flight hour.

e. Maximum Permissible Rotor Speed. The maximum approved rotor speed, including transients, for the maximum approved rating, including emergency ratings.

f. Rotor. 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.

g. Rotor Integrity. The capability of a rotor to withstand the overspeed conditions defined in § 33.27.

h. Sample Rotor. A test rotor or rotor assembly (including, for example, coverplates, spacers, or blade retention devices) that meets the following criteria:

(1) Represents the standard to be certified; and

(2) Has known material properties and dimensions.

i. Shaft System. The system of components that transmits torque between the disk driving flange or shaft attachment members of the system that produce power (for example, the turbine) and the system that uses this power (for example, the compressor, fan or propeller). Although the shaft system transmits mainly torsional loads, it consists of all rotating parts 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. Objectives. The safety objectives of the overspeed (strength) requirements ensure that the rotors:

a. Possess sufficient strength with a margin to burst 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, 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/or necessary analysis to meet the objectives identified in paragraph 6 of this AC.

b. The demonstration of compliance with §§ 33.27(a) and (d) may be made separately, or be combined, as described in this AC.

c. Sections 33.27(a) and (d) allow various means of compliance (“tests, analysis or a combination”) in order to meet the objectives identified. The applicant must propose the appropriate means of compliance, in accordance with the guidance defined in this AC.

d. The applicant should define and validate the analysis techniques necessary to support compliance with § 33.27 before use. The applicant should base the calibration and validation of the analytical techniques 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.

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

f. Any analysis approach allowed under § 33.27 should be defined and validated before usage.

g. The applicant should submit the appropriate substantiation to determine which of the overspeed conditions listed in § 33.27(b) is the most critical for each individual rotor stage with respect to the requirements of § 33.27(a). This substantiation should consider the entire flight envelope. A similar analysis should be submitted with respect to the requirements of § 33.27(d).

h. If deliberate blade shedding is used to limit the maximum overspeed:

(1) The conditions of §§ 33.27(b)(3) and (b)(4) apply to a fully bladed rotor at the shedding speed; and

(2) The analysis to determine the most critical overspeed condition of §§ 33.27(b)(3) and (b)(4) with respect to rotor integrity should consider blade shedding throughout the flight envelope. 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.

i. If blade shedding or turbine blade/vane meshing and clashing is used 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 a speed.

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

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

l. The appropriate percentage rotor speed of § 33.27(b) should be applied after making the necessary speed adjustments for temperatures, material properties and tolerance effects. The necessary speed adjustments for temperature and material properties will normally be established on the basis of appropriate ratios of material properties.

m. Failure conditions which are sudden and transient (reference §§ 33.27(a) and (d)) are typified by loss of load failures, i.e., characterized by high rates of acceleration and deceleration with no dwell period at the highest overspeed attained. The applicant should examine all possible failure conditions to determine if any case exists which would result in a dwell period at speeds close to that of the transient short duration failure condition. If such a case exists, the applicant should determine which condition is the most critical with respect to rotor integrity.

n. The analysis to determine the highest rotor overspeed during failure conditions needs to consider the worst case control system response time including system tolerances.

o. When several rotors are of similar design, are made of materials to the same specification, and subjected to similar stress conditions, temperature levels and gradients, applicants may demonstrate compliance to § 33.27(a) by testing only the most critical rotor with respect to burst. This requires determining the burst speed for each rotor to select the most critical rotor, which has the smallest margin to burst above the speeds specified in § 33.27(b). For multistage rotors in which the rotors do not meet the conditions of similarity as described above, applicants should substantiate compliance of each rotor stage with § 33.27 by using representative test data.

p. Appropriate testing, or analysis based on testing, should establish the burst speed of each fan, compressor, and turbine rotor stage in relation to the most critical condition prescribed in § 33.27(b). 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.

q. The most critical rotor with respect to burst might not be the most critical rotor with respect to growth. To determine the most critical rotor with respect to growth for compliance with § 33.27(d), the applicant should consider the consequences of rotor growth if the rotor was operating in an engine.

r. The consequences of rotor growth sufficient to cause significant contact or displacement between engine components should be assessed to determine if the requirements of § 33.27(d)(1) can be met.

s. When determining compliance with the requirements of § 33.27(d)(2), the applicant should consider whether the rotor would exhibit any condition likely to prevent the safe operation of the engine in service following any failure or combination of failures considered under §§ 33.27(b)(3) or (b)(4). This period of time might equal that required to recognize the event and shut the engine down or to that required for continued safe flight and landing. The length of time might also depend upon the operating instructions for an overspeed event.

8. Acceptable Means of Compliance. The following is an acceptable method for demonstrating compliance with the rotor overspeed requirements of § 33.27. If the applicant chooses to use this method of compliance, the applicant must conform to the guidance in this AC.

a. The applicant must test the most critical stage of each rotor module (fan, LPC, IPC, HPC, HPT, IPT, LPT) on a rig or engine at the conditions necessary to demonstrate that a minimum strength rotor would meet the requirements of §§ 33.27(a) and (d).

b. Compliance to § 33.27(d) requires that each rotor which has been subjected to single or double failure event of §§ 33.27(b)(3) or (b)(4) must not exhibit conditions such as cracking or growth which preclude continued safe operation. The applicant must determine the magnitude of rotor growth which will occur during the overspeed events of §§ 33.27(b)(3) and (b)(4) and if that growth can be safely tolerated by the engine as described in paragraph 7(s) above.

c. An analytical modeling method based on representative test data may be acceptable provided that:

(1) the model has been validated by comparison with results from specimen and rotor tests;

(2) its use is limited to rotors with material, geometry, stress, and temperature conditions encompassed by those used to construct the model; and

(3) its predictions show that the certification standard rotor is not more critical, with respect to burst and growth, than any similar rotor for which substantiation has been demonstrated both by rotor test and model prediction.

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

(1) the sample rotor was initially run at conditions not less severe than those required for compliance with § 33.27(a), and

(2) Section 33.27(d) can be complied with using an approved analytical modeling method.

e. The engine control devices, systems, and instruments referred to in § 33.27(e) are usually provided in modern engines by overspeed protection or circuits which, although they may be independent devices, are generally part of the electronic engine control 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. The applicant may use a periodic functional test for the mechanical or actuating part of the overspeed system.

9. Factors to be Considered when Determining Test Conditions.

a. Temperature. The applicant should establish temperatures and temperature gradients by temperature surveys on an engine or by deriving 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(b) are as follows:

(1) For §§ 33.27(b)(1) and (b)(2), the material temperatures and temperature gradients equal to the most adverse that could be achieved when operating in the engine at the required rating condition.

(2) For §§ 33.27(b)(3) and (b)(4), the material temperatures and temperature gradients equal to the most adverse that could be achieved when operating in the engine at the required rating condition immediately prior to the failure(s).

b. Sample Rotor Material Properties.

(1) The applicant should determine the material properties of the sample rotor from attached test rings/bars.

(2) When attached test rings/bars are not available to determine the material properties of the sample rotor, the applicant should establish a value for the material properties. The applicant may establish this value by assuming the sample rotor possesses material properties are equal to known average properties of similar rotors from the same manufacturing process lot. If using this method, the applicant must also show that this assumption regarding material properties 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.

c. Dimensional Tolerances. Analysis of dimensional tolerances should be made to identify the most adverse combination with respect to the integrity of the rotors.

10. Failure Cases.

a. Introduction. Sections 33.27(b)(3) and (b)(4) state the test speeds at which the rotor structural integrity requirements must be demonstrated for all engine ratings during single or dual engine failure conditions. Examples of a single engine failure condition are a failure of a control system or shaft failure that can cause an overspeed condition. With respect to combinations of failures, at any rating, if the likelihood of a combination is not greater than “extremely remote” (see definition above), the case need not be considered.

b. Loss of Load Events.

(1) To determine the highest overspeed resulting from a loss of load event to be considered under § 33.27(c), applicants should consider, for all possible failure locations, factors such as system inertia, available gas energy, whether the rotor is held in the rotational plane, and overspeed protection devices.

(2) Applicants cannot exclude the failure of the shaft system when considering single failure events. However, applicants can provide engineering assessments supporting their finding that certain locations on the shaft system are not required for failure assessment when complying with § 33.27(c).

(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, according to § 33.27(c), must determine the highest terminal speed of the rotor resulting from a failure of any segment of the shaft system. This failure must be assessed at all flight segments that describe a complete flight cycle. Once the highest terminal speed is determined, the applicant should design and demonstrate that disks have 5% margin above that speed.

(4) The following guidance describes two acceptable approaches for determining the maximum terminal rotor speed for shaft failure cases when complying with §§ 33.27(b)(3) and (b)(4).

(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 to prior testing or service events.

(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 the excluded shaft element(s) cannot be expected to occur during the life of the engine. The applicant must establish 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 (including mating or adjacent hardware) 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 § 33.70.

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

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

5 Identify the effect on the shaft of loads which could be transmitted by shock loading resulting from, for example, bird strikes or blade failure.

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

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

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