U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Comparative Endurance Test Method to Show Durability for Parts Manufacturer Approval of Turbine Engine and Auxiliary Power Unit Parts

Date: 6/25/09

Initiated by: ANE-110

AC No: 33.87-2

1. PURPOSE. This advisory circular (AC) describes a comparative endurance test method to support showing compliance of certain turbine engine or auxiliary power unit (APU) parts when produced under Parts Manufacturer Approval (PMA). This method may be used when PMA applicants introduce changes that could affect the durability of their proposed designs. It may also be used when an applicant has insufficient comparative data to show that the durability of their proposed PMA part is at least equal to the type design. The applicant can use this method when requesting PMA under test and computation, per part 21 of Title 14 of the Code of Federal Regulations, and using the comparative test and analysis approach detailed in Federal Aviation Administration (FAA) Order 8110.42, Part Manufacturer Approval Procedures. This method supports showing that the engine or APU still complies with part 33 or Technical Standard Order (TSO) C77.

2. APPLICABILITY.

a. This guidance is for applicants proposing a comparative endurance test for PMA of turbine engine or APU parts that come in contact with the engine or APU gas flow path. Examples of gas flow path parts include blades, vanes and shrouds.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes an acceptable means, but not the only means, for showing compliance with the applicable engine or APU requirements using the comparative test and analysis approach for PMA under test and computations. 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. While these guidelines are not mandatory, they are derived from FAA and industry experience in determining compliance with the relevant regulations. On the other hand, if we become convinced 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 document does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

3. RELATED REFERENCES.

a. FAA Order 8110.42C, Parts Manufacturer Approval Procedures; June 23, 2008.

b. AC 33.87-1, Calibration Test, Endurance Test and Teardown Inspection for Turbine Engine Certification (§§ 33.85, 33.87, 33.93); April 13, 2006.

4. BACKGROUND.

a. During the past several years, the FAA has evaluated several comparative endurance test plans in which PMA applicants proposed testing due to changes in materials, coatings, and cooling designs. Those changes could affect part and as a result engine durability. We have also evaluated proposals made because complex manufacturing processes were involved and reverse engineering data was insufficient. Without sufficient data, applicants could not substantiate that the durability of their proposed PMA part was at least equal to that of the type design.

b. Due to the increase in complex PMA test proposals, we are providing this guidance to assist applicants in developing a suitable test for demonstrating the durability of their proposed PMA parts. This guidance uses the example of an engine turbine blade and associated requirements of § 33.87, but the approach for other gas flow path parts is similar (see paragraph 7).

5. BLADE DURABILITY. Applicants must show that their proposed PMA blade is as durable as the type design blade when using the comparative test and analysis approach. The proposed PMA blade must be as durable as the type design blade when subjected to the same operational environment: the same rotational speeds, temperatures, airflow rates, and pressures associated with the location and function of the blade when installed. These operating conditions can cause blade thermo-mechanical fatigue, high cycle fatigue, oxidation, hot corrosion and reduce the blade creep rupture capability. Accordingly, one method of determining if the PMA blade has equivalent durability is to evaluate the blade after testing under the following requirements of § 33.87:

a. Test values - see § 33.87(a)(3). Blade stresses are a function of the temperature gradient within the blade, and the centrifugal and aerodynamic loads on the blade during engine operation. Thus, the stresses are greatest during engine acceleration from ground idle to 100% of the values (power or thrust, maximum permissible gas temperature and maximum permissible rotor speed) associated with the particular engine power or thrust operation being tested (see § 33.87(b)(1), (b)(2), (b)(3) and (b)(5)).

b. Cycles and time durations - see § 33.87(b)(1), (b)(2), (b)(3), and (b)(5). Engine cycling between ground idle and the rotor speeds and gas temperature limits associated with its approved power or thrust ratings and back to ground idle can contribute to blade thermo-mechanical fatigue failure. Time-at-high gas temperature can cause oxidation, hot corrosion and reduce a blade's creep rupture capability.

c. Incremental speed and running time - see § 33.87(b)(4). Engine vibration can increase blade stresses and affect blade high cycle fatigue capability. Effects of engine vibration will vary with rotor speed and running time, with maximum blade vibration stresses occurring at resonant frequencies.

d. Starts - see § 33.87(b)(6). Engine starting conditions can affect blade durability. For example, cold start conditions can affect blade thermo-mechanical fatigue and tip wear. In addition, false starts and restarts can affect blade protection systems like blade coatings and cooling configurations.

6. COMPARATIVE ENDURANCE TEST METHOD. This section outlines a comparative test method that supports showing that a PMA blade is at least as durable as the type design blade. It applies those elements of § 33.87, such as speed, thrust, time at temperature and cycling, that affect blade durability. An alternate blade approach is discussed in paragraph 6.d. The appendix provides a graphical and tabular representation of the § 33.87 six-hour endurance test cycle.

a. <u>Test conditions</u>.

(1) Operating values. Testing is at 100% of the engine rated power or thrust, maximum permissible gas temperature, and maximum permissible rotor speed, either high rotor or low rotor as applicable, for each rating. These values are defined on the type certificate data sheet (TCDS) of the engine model on which the proposed PMA blade is eligible for installation. If multiple models are identified, the applicant must test the blades for the engine model with the highest rated values. If the TCDS does not define a separate maximum permissible rotor speed for the maximum continuous power or thrust rating, then the applicant must test the blades at the rotor speed defined for rated takeoff power or thrust during the hours and cycles prescribed in paragraph 6.a.(2).

(2) Hours and cycles. The following are the cycles and accumulated times associated with the engine power or thrust conditions. See Figure 2 in the appendix for a breakdown of the following:

(a) Rated takeoff power or thrust. A total of 180 cycles accumulating 18.75 hours as prescribed in § 33.87(b)(1), (b)(2)(ii) and (b)(5).

(b) Maximum continuous power or thrust. A total of 120 cycles accumulating 45 hours as prescribed in § 33.87(b)(2)(i) and (b)(3).

(c) Incremental cruise power or thrust. At least 15 approximately equal speed and time increments between maximum continuous engine rotational speed and minimum idle rotational speed accumulating 62.5 hours. If the engine exhibits significant peak vibration anywhere between the minimum idle and maximum continuous rating conditions, the applicant must increase the number of increments as discussed in § 33.87(b)(4). For each increment, we recommend applicants demonstrate a minimum of 10 million dwell cycles.

(3) Starts. Testing includes the sequence of engine starts prescribed in § 33.87(b)(6).

(a) Twenty-five cold starts. These starts require a cooling down period of at least two hours to allow the engine temperature to approach a stabilized test cell ambient temperature condition.

(b) Ten false starts, pausing for the engine's minimum fuel drainage time, if specified, before attempting a normal start.

(c) Ten normal restarts with not longer than 15 minutes since engine shutdown.

(d) Fifty-five normal starts. The applicant must include an appropriate rationale if all of the remaining 55 starts are not proposed in its test plan.

b. Number of specimens. We recommend the following when determining how many type design and proposed PMA blades the applicant uses to complete the blade set and establish the basis for comparison.

(1) Type design blade. The applicant should consider testing at least 5 type design blades from a minimum of 3 different batches for a total of at least 15 blades. The applicant should select these blades from multiple manufacturing lots (batches) to capture as many blade variables as possible, including tolerance, manufacturing, and raw material sources. To accomplish this, the applicant may need to obtain type design blades from different sources, at different times, or both. This will help ensure that the normal range of population variation is achieved. Additionally, the type design blade samples should be zero-time blades acquired from approved traceable sources.

(2) Proposed PMA design. The remaining blades of the blade set should be new (unused) proposed PMA blades manufactured using the PMA production process. The applicant should test a sufficient number of PMA blades to ensure that production process variability is represented.

c. Pass/Fail criteria. The applicant should establish suitable blade inspection pass/fail criteria to compare the durability and functional characteristics of the proposed PMA blades with the type design blades and associated mating hardware. We recommend the following minimum criteria:

- Airfoil surface condition: missing coatings, evidence of high temperature-induced erosion and oxidation, discoloration, or evidence of "necking" that may be caused by creep;
- Blade tip condition: evidence of heavy rubs, erosion, missing material, or cracking;
- Blade trailing edge: cracking, and high temperature induced erosion and oxidation;
- Blade height: creep;

- Blade and disk retention features: fretting, cracking, or deformation on the blade and on surfaces that contact the disk's blade retention features;
- Blade pressure and suction surfaces: necking or other deformation that may also indicate the onset of creep or temperature-induced deformation;
- Blade root fillet: cracking;
- Cooling hole condition: hole deformation, blockage, burned edges, or cracks emanating from the holes, especially holes in or near the blade root fillet;
- Platform condition: deformation that may indicate an over-temperature condition, lack of sufficient cooling, or excessive mechanical loads;
- Metallurgical evaluation to check for any over-temperature exposure; and
- Inspections to evaluate any observed base metal cracking or other defects.
- If the blade employs a purging hole to clear internal debris, check to see if internal debris is purged or accumulated.

(1) Pre-test. Inspect all (PMA and type design) blade specimens to these criteria to establish a pre-test baseline for later comparisons. Record the pre-test inspection results for all blades. Identify and reconcile any non-conformances of the PMA blades and include that discussion in the test plan.

(2) Post-test. Repeat the pre-test inspection for all blade specimens and record post-test findings for both the type design and PMA blades. Use the type design blade results to establish the range of variation in which the proposed PMA blades are expected to fall. If the variation of the PMA blade falls within that of the type design, then the PMA blade durability is considered equivalent.

d. Alternate equivalent blade comparative endurance test. The comparative endurance engine test requirements presented in paragraph 6.a. may be modified. For example, specific test conditions, such as the number of cycles, time at maximum permissible gas temperatures, power or thrust settings, vibration dwell segments and number of starts may differ. The Larson-Miller method provides a means to develop alternative time-at-temperature test requirements of equal severity. Using this method, an applicant identifies the minimum metal temperatures at which blade creep, oxidation and hot corrosion can occur and adjusts the § 33.87 test times and temperatures to achieve equivalent exposure conditions.

7. COMPARATIVE ENDURANCE TEST METHOD FOR OTHER GAS PATH PARTS. Applicants can develop a comparative endurance test method for other gas path parts to show their proposed PMA part is at least as durable as the type design. The test method must allow for a meaningful comparison of the performance and durability characteristics of the proposed PMA part relative to the type design part and should consider the standards of § 33.87 or TSO C77. When doing so, the applicant should provide a rationale for any associated endurance test requirements, in either § 33.87(a) and (b) or TSO C77b sections 6.3.2, 6.3.3 and 6.3.5, proposed as unnecessary for the comparison.

//signed by Peter A. White//
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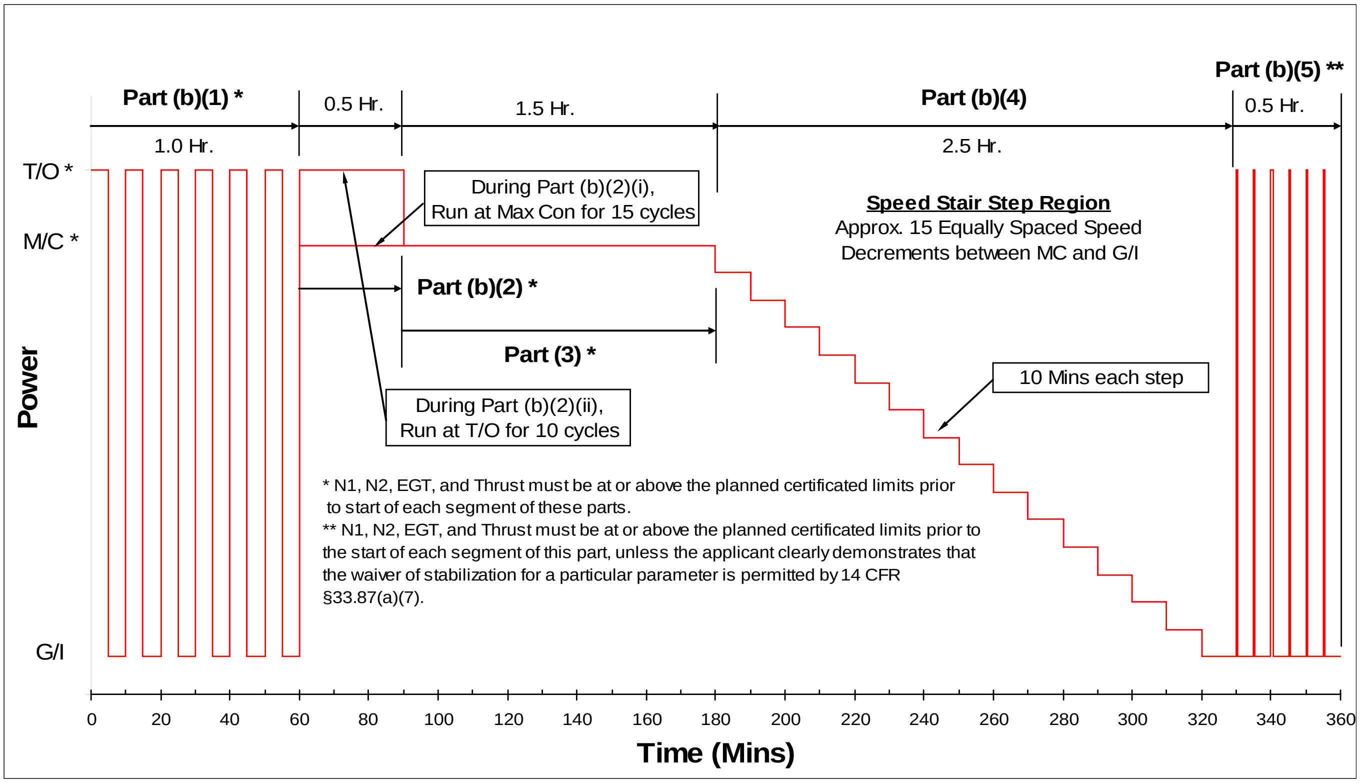
APPENDIX. ENDURANCE TEST CYCLE.

1. Each § 33.87(b) sub-paragraph, such as (b)(2)(i) or (b)(5), defines a different part or segment of the six-hour endurance test cycle. For simplicity, these sub-paragraph test requirements are labeled as Part (b)(1), Part (b)(2)(i), etc., through Part (b)(5) in Figure 1 and Figure 2.

a. For reference, the six-hour endurance test cycle defined in § 33.87(b) is presented below graphically in Figure 1.

Figure 1. Endurance Cycle Profile for Turbofan Engines
6 Hours per Cycle; 25 Cycles; 150 Hours Total Run Time



Note: This figure is not intended to represent engine in-service operation.

b. The cumulative run times at the Takeoff and Maximum Continuous rating power levels and other non-rating power levels are summarized below in Figure 2.

Figure 2. Tabulation of Time at Power

		Time at Takeoff (T/O) Power		Time at Max Continuous (M/C) Power		Time at Ground Idle (G/I) Power		Stair Step Time	
Part	No. of Cycles	Mins/Cycle	Total Mins	Mins/Cycle	Total Mins	Mins/Cycle	Total Mins	Mins/Cycle	Total Mins
(b)(1)	15	30	450			30	450		
(b)(1)	10	30	300			30	300		
(b)(2)(i)	15			30	450				
(b)(2)(ii)	10	30	300						
(b)(3)	15			90	1350				
(b)(3)	10			90	900				
(b)(4)	15							150	2250
(b)(4)	10							150	1500
(b)(5)	15	3	45			27	405		
(b)(5)	10	3	30			27	270		
		Each Part Time (Mins)->	1125		2700		1425		3750
		T/O Time (Hrs)->	18.75	M/C Time (Hrs)->	45.00	G/I Time (Hrs)-->	23.75	Stair Step Time (Hrs)->	62.5
		Total Testing Time (Hrs)->	150						

c. For additional information regarding the intent of these criteria, see AC 33.87-1 Calibration Test, Endurance Test and Teardown Inspection for Turbine Engine Certification (§§ 33.85, 33.87, 33.93).