SECTION 5. SUBPART E--DESIGN AND CONSTRUCTION; TURBINE AIRCRAFT ENGINES

42. Section 33.62, Stress Analysis.

Section 33.62 Stress analysis.

A stress analysis must be performed on each turbine engine showing the design safety margin of each turbine engine rotor, spacer, and rotor shaft.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

43. Section 33.63, Vibration.

Section 33.63 Vibration.

Each engine must be designed and constructed to function throughout its operating range of rotational speeds and engine power without inducing excessive stress in any engine part because of vibration and without imparting excessive vibration forces to the aircraft structure.

***

Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

44. Section 33.65, Surge and Stall Characteristics.

Section 33.65 Surge and stall characteristics.

When the engine is operated in accordance with operating instructions required by Section 33.5(b), starting, a change of power or thrust, power or thrust augmentation, limiting inlet air distortion, or inlet air temperature may not cause surge or stall to the extent that flameout, structural failure, overtemperature, or failure of the engine to recover power or thrust will occur at any point in the operating envelope.

***

Guidance. The INTENT of this section is to assure that the engine be designed and fabricated to preclude harmful surge and stall characteristics.

Incorporations: AC 33.65-1, "Surge and Stall Characteristics of Aircraft Turbine Engines," dated December 1985.

References: None.

Note that this section addresses design and construction requirements; correlating block test requirements are prescribed in "Section 33.89, Operation Test".

45. Section 33.66, Bleed Air System.

Section 33.66 Bleed air system.

The engine must supply bleed air without adverse effect on the engine, excluding reduced thrust or power output, at all conditions up to the discharge flow conditions established as a limitation under Section 33.7(c)(11). If bleed air used for engine anti-icing can be controlled, provision must be made for a means to indicate the functioning of the engine ice protection system.

***

Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

The need to restrict bleed airflow, such as by orifice(s), should either be incorporated in the type design of the engine hardware, or be noted as appropriate in the engine installation instructions (and drawings) and in the engine type certificate data sheet (TCDS).

46. Section 33.67, Fuel System.

Section 33.67 Fuel system.

(a) With fuel supplied to the engine at the flow and pressure specified by the applicant, the engine must function properly under each operating condition required by this Part. Each fuel control adjusting means that may not be manipulated while the fuel control device is mounted on the engine must be secured by a locking device and sealed, or otherwise be inaccessible. All other fuel control adjusting means must be accessible and marked to indicate the functioning of the adjustment unless the function is obvious.

(b) There must be a fuel strainer or filter between the engine fuel inlet opening and the inlet of either the fuel metering device or the engine-driven positive displacement pump whichever is nearer the engine fuel inlet. In addition, the following provisions apply to each strainer or filter required by this paragraph.

(1) It must be accessible for draining and cleaning and must incorporate a screen or element that is easily removable.

(2) It must have a sediment trap and drain except that it need not have a drain if the strainer or filter is easily removable for drain purposes.

(3) It must be mounted so that its weight is not supported by the connecting lines or by the inlet or outlet connections of the strainer or filter, unless adequate strength margins under all loading conditions are provided in the lines and connections.

(4) It must have the type and degree of fuel filtering specified as necessary for protection of the engine fuel system against foreign particles in the fuel. The applicant must show:

(i) That foreign particles passing through the specified filtering means do not impair the engine fuel system functioning; and

(ii) That the fuel system is capable of sustained operation throughout its flow and pressure range with the fuel initially saturated with water at 80 degrees F (27 °C) and having 0.025 fluid ounces per gallon (0.20 milliliters per liter) of free water added and cooled to the most critical condition for icing likely to be encountered in operation. However, this requirement may be met by demonstrating the effectiveness of specified approval fuel anti-icing additives, or that the fuel system incorporates a fuel heater which maintains the fuel temperature at the fuel strainer or fuel inlet above 32 degrees F (0 °C) under the most critical conditions.

(5) The applicant must demonstrate that the filtering means has the capacity (with respect to engine operating limitations) to ensure that the engine will continue to operate within approved limits, with fuel contaminated to the maximum degree of particle size and density likely to be encountered in service. Operation under these conditions must be demonstrated for a period acceptable to the Administrator, beginning when indication of impending filter blockage is first given by either:

(i) Existing engine instrumentation; or

(ii) Additional means incorporated into the engine fuel system.

(6) Any strainer or filter bypass must be designed and constructed so that the release of collected

contaminants is minimized by appropriate location of the bypass to ensure that collected contaminants are not in the bypass flow path.

(c) If provided as part of the engine, the applicant must show for each fluid injection (other than fuel) system and its controls that the flow of the injected fluid is adequately controlled.

***

Guidance. The INTENT of this section is to assure that the engine fuel system is designed and fabricated to operate satisfactorily under all applicable operating conditions.

Incorporations: None.

References: Military Specification MIL-E-5007E(AS), "Engines, Aircraft, Turbojet and Turbofan, General Specification For," dated September 1, 1983.

a. An acceptable means of compliance with Section 33.67(b)(5) can be that the applicant show that the engine will continue to operate satisfactorily, for at least one-half of the maximum flight time (of the intended aircraft applications), beginning at first indication of impending filter blockage. Actual, or rig-simulation of, test engine operation should be at the most critical mission fuel flows expected to be used in service.

b. Table X of the reference provides an example of typical fuel contaminants, particle sizes, and quantities.

47. Section 33.68, Induction System Icing.

Section 33.68 Induction system icing.

Each engine, with all icing protection systems operating, must--

(a) Operate throughout its flight power range (including idling) without the accumulation of ice on the engine components that adversely affects engine operation or that causes a serious loss of power or thrust in continuous maximum and intermittent maximum icing conditions as defined in Appendix C of Part 25 of this chapter; and

(b) Idle for 30 minutes on the ground, with the available air bleed for icing protection at its critical condition, without adverse effect, in an atmosphere that is at a temperature between 15 degrees and 30 degrees F (between -9 degrees and -1 degrees C) and has a liquid water content not less than 0.3 grams per cubic meter in the form of drops having a mean effective diameter not less than 20 microns, followed by a momentary operation at takeoff power or thrust. During the 30 minutes of idle operation the engine may be run up periodically to a moderate power or thrust setting in a manner acceptable to the Administrator.

***

Guidance. The INTENT of this section is to assure that the engine induction icing protection system be designed and fabricated to operate satisfactorily during the icing conditions specified.

Incorporations: AC 20-73, "Aircraft Ice Protection," dated April 21, 1971.

References: None.

a. Certification of engine icing protection systems is conducted to the criteria of continuous icing. That is, engine certification for induction system icing does not recognize time-limited approvals for inadvertent icing encounters.

b. There may be instances where the engine manufacturer elects to design an aircraft induction system as part of the engine bill-of-material and then perform icing analyses and tests of the complete engine/aircraft induction system configuration. This, of course, "locks in" the induction system design, as part of the engine type design for all future applications of the engine. Subsequent deviations from this approved design configuration would invalidate the engine's anti-icing approval and, therefore, would violate the type certificate limitations of the engine.

c. The guidance material for icing protection of engines embodied in AC 20-73, dated April 21, 1971, is still considered valid and useful. In particular, the "two point" test method (Icing Conditions 1 and 2 in the Table of Paragraph 33b(2)) is considered adequate substantiation--when supported by design analysis of the critical conditions for icing protection.

d. The analysis should consider, in part:

(1) for engine bleed air systems, the requirements and limitations of the bleed air characteristic.

(2) the corresponding need to establish operating limitations (and/or minimums) of rotational speed, power or thrust, etc., to maintain the minimum required anti-icing bleed air characteristic.

(3) the affect of ice accretion on engine instrumentation probes or sensors located in the induction air stream.

(4) the maximum customer bleed air extraction on engines which utilize bleed air anti-ice systems.

e. The third test point of the Icing Conditions Table of Paragraph 33b(2) of AC 20-73 refers to the ground fog icing condition. Note that it has been modified by Amendment 10 of Part 33. Accordingly, column 3 of the table now reads "$\geq$ 0.3", "15-30", and "$\geq$ 20", respectively. Also note that Amendment 10 permits periodic engine accelerations during the idle icing condition of Section 33.68(b) to shed ice build-ups.

f. The icing test periods of 10 and 30 minutes suggested in the AC, Paragraphs 33b(2)(a) and (b) respectively, should be understood to be minimum test times. Nonstabilized engine operation, or continued ice build-up at the conclusion of the test period, would be cause to extend the basic 10 or 30 minute test period. Testing should continue until an ice build-up and shed cycle is established, or until engine operation is stabilized, or until the engine will no longer safely operate within limits.

g. Normal engine parameters of EPR, torque, high pressure rotor speed, low pressure rotor speed, gas path temperature, and fuel flow should be monitored to verify stability of engine operation during the icing test. Closed circuit television monitoring of the critical areas during the test is a useful method to verify the icing characteristics and ice build/shed cycle. Post test point icing characteristics are also typically documented by photographic means, immediately following engine shutdown after each test point of interest.

h. The characteristics and calibration of the icing test facility should be documented to substantiate proper liquid water content (LWC), droplet diameter, and atmospheric temperature.

i. Note that anti-icing certification of engines to FAR Part 33 does not include snow ingestion testing. The snow ingestion test requirements of subsection .1093(b)(ii) of FAR Parts 23, 25, 27, and 29 cannot be included in Part 33 since the principal purpose of snow testing is to evaluate the complete engine installation within the airplane or rotorcraft environment. For rotorcraft installations, this includes evaluation of the influences of engine inlet duct geometry and placement, bypass ratio, rotor-wash effects, etc., which are impossible to evaluate at the bare engine level.

48. <u>Section 33.69, Ignition System</u>.

Section 33.69 Ignition system.

Each engine must be equipped with an ignition system for starting the engine on the ground and in flight. An electric ignition system must have at least two igniters and two separate secondary electric circuits, except that only one igniter is required for fuel burning augmentation systems.

***

Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

The engine installation instructions should define the characteristics and the interface requirements of all aircraft sources of electrical power required by the engine ignition system.

49. Section 33.71, Lubrication System.

Section 33.71 Lubrication system.

(a) General. Each lubrication system must function properly in the flight attitudes and atmospheric conditions in which an aircraft is expected to operate.

(b) Oil strainer or filter. There must be an oil strainer or filter through which all of the engine oil flows. In addition:

(1) Each strainer or filter required by this paragraph that has a bypass must be constructed and installed so that oil will flow at the normal rate through the rest of the system with the strainer or filter element completely blocked.

(2) The type and degree of filtering necessary for protection of the engine oil system against foreign particles in the oil must be specified. The applicant must demonstrate that foreign particles passing through the specified filtering means do not impair engine oil system functioning.

(3) Each strainer or filter required by this paragraph must have the capacity (with respect to operating limitations established for the engine) to ensure that engine oil system functioning is not impaired with the oil contaminated to a degree (with respect to particle size and density) that is greater than that established for the engine in subparagraph (2) of this paragraph.

(4) For each strainer or filter required by this paragraph, except the strainer or filter at the oil tank outlet, there must be means to indicate contamination before it reaches the capacity established in accordance with paragraph (b)(3) of this section.

(5) Any filter bypass must be designed and constructed so that the release of collected contaminants is minimized by appropriate location of the bypass to ensure that the collected contaminants are not in the bypass flow path.

(6) Each strainer or filter required by this paragraph that has no bypass, except the strainer or filter at an oil tank outlet or for a scavenge pump, must have provisions for connection with a warning means to warn the pilot of the occurrence of contamination of the screen before it reaches the capacity established in accordance with subparagraph (3) of this paragraph.

(7) Each strainer or filter required by this paragraph must be accessible for draining and cleaning.

(c) Oil tanks.

(1) Each oil tank must have an expansion space of not less than 10 percent of the tank capacity.

(2) It must be impossible to inadvertently fill the oil tank expansion space.

(3) Each recessed oil tank filler connection that can retain any appreciable quantity of oil must have provision for fitting a drain.

(4) Each oil tank cap must provide an oil-tight seal.

(5) Each oil tank filler must be marked with the word "oil."

(6) Each oil tank must be vented from the top part of the expansion space, with the vent so arranged that condensed water vapor that might freeze and obstruct the line cannot accumulate at any point.

(7) There must be means to prevent entrance into the oil tank or into any oil tank outlet, of any object that might obstruct the flow of oil through the system.

(8) There must be a shutoff valve at the outlet of each oil tank, unless the external portion of the oil system (including oil tank supports) is fireproof.

(9) Each unpressurized oil tank may not leak when subjected to maximum operating temperature and an internal pressure of 5 p.s.i., and each pressurized oil tank may not leak when subjected to maximum operating temperature and internal pressure that is not less than 5 p.s.i. plus the maximum operating pressure of the tank.

(10) Leaked or spilled oil may not accumulate between the tank and the remainder of the engine.

(11) Each oil tank must have an oil quantity indicator or provisions for one.

(12) If the propeller feathering system depends on engine oil--

(i) There must be means to trap an amount of oil in the tank if the supply becomes depleted due to failure of any part of the lubricating system other than the tank itself;

(ii) The amount of trapped oil must be enough to accomplish the feathering operation and must be available only to the feathering pump; and

(iii) Provision must be made to prevent sludge or other foreign matter from affecting the safe operation of the propeller feathering system.

(d) Oil drains. A drain (or drains) must be provided to allow safe drainage of the oil system. Each drain must--

(1) Be accessible; and

(2) Have manual or automatic means for positive locking in the closed position.

(e) Oil radiators. Each oil radiator must withstand, without failure, any vibration, inertia, and oil pressure load to which it is subjected during the block tests.

***

Guidance. The INTENT of this section is to assure that the engine lubrication system is designed and constructed to operate satisfactorily under all applicable operating conditions.

Incorporations: None.

References: None.

50. Section 33.72, Hydraulic Actuating Systems.

Section 33.72 Hydraulic actuating systems.

Each hydraulic actuating system must function properly under all conditions in which the engine is expected to operate. Each filter or screen must be accessible for servicing and each tank must meet the design criteria of Section 33.71.

***

Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

51. Section 33.73, Power or Thrust Response.

Section 33.73 Power or thrust response.

The design and construction of the engine must enable an increase--

(a) From minimum to rated takeoff power or thrust with the maximum bleed air and power extraction to be permitted in an aircraft, without overtemperature, surge, stall, or other detrimental factors occurring to the engine whenever the power control lever is moved from the minimum to the maximum position in not more than 1 second, except that the Administrator may allow additional time increments for different regimes of control operation requiring control scheduling; and

(b) From the fixed minimum flight idle power lever position when provided, of if not provided, from not more than 15 percent of the rated takeoff power or thrust available to 95 percent rated takeoff power or thrust in not over 5 seconds. The 5-second power or thrust response must occur from a stabilized static condition using only the bleed air and accessories loads necessary to run the engine. This takeoff rating is specified by the applicant and need not include thrust augmentation.

***

Guidance. The INTENT of this section is to assure that the engine is designed and fabricated with a minimum standard of power/thrust response characteristics.

Incorporations: AC 33.65-1, "Surge and Stall Characteristics of Aircraft Turbine Engines," dated December 1985.

References: None.

52. Section 33.75, Safety Analysis.

Section 33.75 Safety analysis.

It must be shown by analysis that any probable malfunction or any probable single or multiple failure, or any probable improper operation of the engine will not cause the engine to--

(a) Catch fire;

(b) Burst (release hazardous fragments through the engine case);

(c) Generate loads greater than those ultimate loads specified in Section 33.23(a); or

(d) Lose the capability of being shut down.

***

Guidance. The INTENT of this section is to assure that the engine is designed and fabricated to preclude probable failure, malfunction, or operating conditions resulting in the hazards specified.

Incorporations: None.

References: SAE ARP926A, "Fault/Failure Analysis Procedure," Revised November 15, 1979.

a. The safety analysis should support the engine design goals, such that there would not be a likely single failure or failures that would result in fire, uncontained event, exceedance of engine ultimate loads, or prevent the engine from being shutdown.

b. The guidance provided in the reference above would be an acceptable methodology. The top-down technique is suggested based on the four critical failure modes identified in the rule. The analysis should cover:

(1) all major static and rotating components including mounts, seals, spacers, shafts, and bearings;

(2) all subsystems and components including fuel, lubrication, pneumatic, electronic, cooling, instrumentation, speed reduction, and fire protection.

c. A by-product of the safety analysis should be an assessment of all potentially hazardous conditions, individually and in combination including consideration of dormant failures, and the elimination of such conditions by redesign, required inspections, inspection intervals, specialized instrumentation, and/or finite lifing to support FAA findings of acceptable safety and durability levels.

53. Section 33.77, Foreign Object Ingestion.

Section 33.77 Foreign object ingestion.

(a) Ingestion of a 4-pound bird, under the conditions prescribed in paragraph (e) of this section, may not cause the engine to--

(1) Catch fire;

(2) Burst (release hazardous fragments through the engine case);

(3) Generate loads greater than those ultimate loads specified in Section 33.23(a); or

(4) Lose the capability of being shut down.

(b) Ingestion of 3-ounce birds or 1-1/2 pound birds, under the conditions prescribed in paragraph (e) of this section, may not--

(1) Cause more than a sustained 25 percent power or thrust loss;

(2) Require the engine to be shut down within 5 minutes from time of ingestion; or

(3) Result in a potentially hazardous condition.

(c) Ingestion of water, ice, or hail under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down. It must be demonstrated that the engine can accelerate and decelerate safely while inducting a mixture of at least 4 percent water by weight of engine airflow following stabilized operation at both flight idle and takeoff power settings with at least a 4 percent water-to-air ratio.

(d) For an engine that incorporates a protection device, compliance with this section need not be demonstrated with respect to foreign objects to be ingested under the conditions prescribed in paragraph (e) of this section if it is shown that--

(1) Such foreign objects are a size that will not pass through the protective device;

(2) The protective device will withstand the impact of the foreign objects; and

(3) The foreign object, or objects, stopped by the protective device will not obstruct the flow of induction air into the engine with a resultant sustained reduction in power or thrust greater than those values required by paragraphs (b) and (c) of this section.

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

Foreign Object	Test Quantity	Speed of Foreign Object	Engine Operation	Ingestion
BIRDS:				
3-Ounce Size..	One for each 50 square inches of inlet area or fraction thereof up to a maximum of 16 birds. Three-once bird ingestion not required if a 1-1/2-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff........	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
1-1/2-pound size..	One for the first 300 square inches of inlet area, it can enter the inlet, plus one for each additional 600 square inches of inlet area or fraction thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff........	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.

Foreign Object	Test Quantity	Speed of Foreign Object	Engine Operation	Ingestion
4-pound size..	One, if it can enter the inlet......................	Maximum climb speed of typical aircraft if the engine has inlet guide vanes.	Maximum cruise.........	Aimed at critical area.
		Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Takeoff........	Aimed at critical area.
Ice..........	Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in.............	Maximum cruise.........	To simulate a continuous maximum icing encounter at 25 °F.
HAIL: (0.8 to 0.9 specific gravity)	For all engines: With inlet area of not more than 100 square inches: one 1-inch hailstone. With inlet area of more than 100 square inches: one 1-inch and one 2-inch hailstone for each 150 square inches of inlet area or fraction thereof.	Rough air flight speed of typical aircraft.	Maximum cruise at 15,000 feet altitude.	In a volley to simulate a hailstone encounter. One-half the number of hailstones aimed at random area over the face of the inlet and the other half aimed at the critical face area.
	For supersonic engines (in addition): 3 hailstones each having a diameter equal to that in a straight line variation from 1 inch at 35,000 feet to 1/4 inch at 60,000 feet using diameter corresponding to the lowest supersonic cruise altitude expected.	Supersonic cruise velocity. Alternatively, use subsonic velocities with larger hailstones to give equivalent kinetic energy.	Maximum cruise........	Aimed at critical engine face area.
Water........	At least 4 percent of engine airflow by weight.	Sucked in..........	Flight idle, acceleration, takeoff, deceleration.	For 3 minutes each at idle and takeoff, and during acceleration and deceleration in spray to simulate rain.

NOTE:--The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

***

Guidance. The INTENT of this section is to assure that the engine is designed, fabricated, and tested to be structurally and operationally tolerant, to the degrees specified, following the specified ingestion events.

Incorporations: AC 33-1B, "Turbine Engine Foreign Object Ingestion and Rotor Blade Containment Type Certification Procedures," dated April 22, 1970.

References: None.

a. Previous to the Amendment 6 engine certification rules, the foreign object ingestion test requirements were generalized from Sections 33.13 and 33.19, Design Features and Durability, respectively. The incorporation above, and its earlier versions, in fact, provided the ingestion test requirements and procedures for the pre-Amendment 6 engines.

b. The certification rules subsequent to Amendment 5 are definitive. Although they have evolved to the current rules, the guidance embodied in the incorporation may be considered applicable, except where the AC conflicts with the rules. On this basis, the incorporation, with regard to ingestion testing (not containment), coupled with Amendment 10's Section 33.77 Preamble, and the following clarifying information should be useful.

c. It has become clear, through recent certification programs of various engine manufacturers, that the medium bird ingestion test procedures are not being uniformly conducted. Specifically, variations have occurred in the length of time required before throttle adjustments are allowed following ingestion.

d. Paragraph 10b(1)(e) of the incorporation states, "Duration of the engine running following ingestion of any Group II objects should be at least 5 minutes to determine whether the engine is in a condition of imminent failure but, in case of doubt as to actual engine condition or evident engine damage, longer post-ingestion test runs should be conducted."

e. Similarly, paragraph 11b(2) states, "The engine is acceptable if tests demonstrate...its continued safe operation after the ingestion tests. There should be no indication of need for immediate shutdown or imminent failure during the ingestion tests...." Also, FAR Section 33.77 was recently revised (Amendment 33-10) to specify the 5-minute minimum running period from the time of ingestion. If an engine is allowed to be manually throttled-back (to just over 75 percent power) prior to 5 minutes following ingestion, some conditions of imminent failure, which may be present, are much less likely to be detected. Since one of the purposes of the ingestion test is to demonstrate the absence of imminent failure, manual intervention within 5 minutes should not be accepted.

f. A question concerning foreign object ingestion testing is, "What is the definition of the term 'inlet area' as used in FAR Section 33.77, as applied to turbofan engines?" Amendment 10 added the definition of this term at the end of the table in Section 33.77. For the typical turbofan engine, this is the bare-engine inlet area calculated from D_e shown in Figure 1 (which follows paragraph 53j). D_s is the propulsion system feature that usually determines ingestion; that is, foreign object strikes outboard (relative to the duct centerline) of the highlight will usually be repelled, and strikes inboard of the highlight will usually be ingested. However, the nacelle design is not always known at time of engine certification testing and can change from one installation to another. Therefore, since D_e is a rough approximation of D_s for the typical turbofan engine, and since D_e is controlled by the engine manufacturer, it was chosen as the determinant of inlet area in the current rule.

g. Unfortunately, the definition in Amendment 33-12 is not without problems. For example, it is not clearly applicable to an aft-fan engine. Also, the nacelle inlet lip stagnation point area, A_s, (which as explained above, is the functional feature that normally determines ingestion, also known as the capture area) can be much larger than A_e, the bare-engine inlet area; and A_e is not particularly significant if the air inlet duct incorporates an inertial separator. Hence, judgement is required, and the following guidelines are recommended until a rule establishing an improved definition is promulgated.

(1) Typical turbofan engines should use A_e, as defined herein and in Amendment 33-10 for calculating foreign object ingestion quantities. Other engines should use the capture area of the installed engine, if that area is known at the time of engine certification testing. If the nacelle design is not known, or if the manufacturer elects to do so, the engine inlet area, A_e, or estimated nacelle inlet, A_s, may be used, as has been done historically.

(2) The TCDS or the FAA-approved engine installation manual (or similar document for non-domestic engines) should indicate which area was used for ingestion calculations. This area should be considered an installation limit. If a later engine installation results in a larger capture area, the foreign object ingestion test (quantities) should be re-evaluated for possible additional certification testing.

(3) In no case should the nacelle inlet throat area $A\{(f)D_t\}$, see Figure 1, be used for ingestion calculations as this may result in an invalid test.

h. The inlet area question is also most germane for the smaller mass-flow turboshaft (and some turboprop) engines. As in the turbofan engine case, the inlet area determinant for ingestion testing should be the free-stream capture area. This needs to be assumed as the front face area for the bare-engine case. If the engine design incorporates an inlet air separator system, then engineering judgement will need to be applied to define the ingestion area for calculating ingestion quantities and for determining target areas.

i. The guiding principle should be the same in all cases; the induction air stream projected area exposed to the ingestion hazard should be the determinant area. This area must include the projected areas of spinners, inertial separator housings, starter housings, inlet nose cones, etc., if it is possible for the foreign object(s) to still be ingested after impacting such devices. One expected outcome of the ingestion test of such inlet configurations is to ensure that they are ingestion impact tolerant and do not, of themselves, become ingestion objects in the engine flow path.

j. The engine manufacturer may elect to require that the airframe manufacturer install the engine, such that it is impossible for free-stream ingestion objects to enter the engine inlet. In such a case, the TCDS and the installation instructions will need to specify this as an installations limitation. This approach has mostly been applied to rotorcraft engine installations wherein there is no direct line-of-sight between the ambient free-stream and the engine's front face. This arrangement effectively creates a zero ram-recovery plenum for the engine flow stream. The airframers would need to demonstrate that this produces no unairworthy or undesirable characteristic, in accordance with the certification rules for the installation.

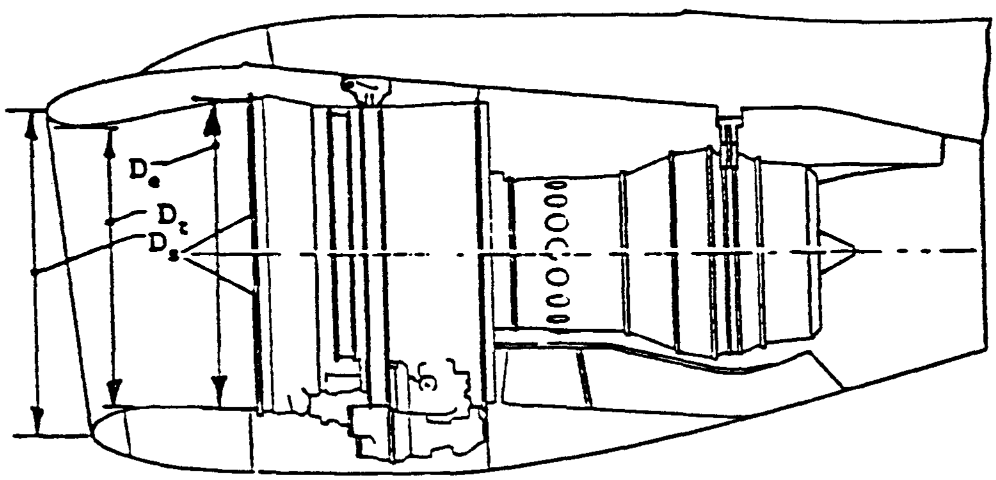

FIGURE 1. GENERIC TURBOFAN AND NACELLE CONFIGURATION

D_s = nacelle inlet lip stagnation point equivalent diameter, (a.k.a. highlight equivalent diameter).

D_t = nacelle inlet throat equivalent diameter.

D_e = engine front face inlet equivalent diameter, (a.k.a. bare-engine inlet equivalent diameter).

A = $nD^2/4$, where n=pi.

54. Section 33.79, Fuel Burning Thrust Augmenter.

Section 33.79 Fuel burning thrust augmenter.

Each fuel burning thrust augmenter, including the nozzle, must--

(a) Provide cutoff of the fuel burning thrust augmenter:

(b) Permit on-off cycling;

(c) Be controllable within the intended range of operation;

(d) Upon a failure or malfunction of augmenter combustion, not cause the engine to lose thrust other than that provided by the augmenter; and

(e) Have controls that function compatibly with the other engine controls and automatically shut off augmenter fuel flow if the engine rotor speed drops below the minimum rotational speed at which the augmenter is intended to function.

***

Guidance. The INTENT of this section is to assure that the afterburner system is designed and constructed to function satisfactorily and not impair the functioning of the rest of the engine.

Incorporations: None.

References: None.

SECTION 6. SUBPART F--BLOCK TESTS; TURBINE AIRCRAFT ENGINES

55. Section 33.82, General.

Section 33.82 General.

Before each endurance test required by this subpart, the adjustment setting and functioning characteristic of each component having an adjustment setting and a functioning characteristic that can be established independent of installation on the engine must be established and recorded.

***

Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

Collectively, the results of the block tests, combined with the design and analytical substantiation data, form the basis for the engine type certificate data sheet and engine instruction manuals statements concerning: ratings, steady-state and transient operating limits, critical parts retirement life, environmental envelope, inspection requirements, maintenance/overhaul requirements, operational requirements, and engine/airframe interface requirements.

56. Section 33.83, Vibration Test.

Section 33.83 Vibration test.

(a) Each engine must undergo a vibration survey to establish the vibration characteristics of the rotor discs, rotor blades, rotor shafts, stator blades, and any other components that are subject to vibratory exciting forces which could induce failure at the maximum inlet distortion limit. The survey is to cover the range of rotor speeds and engine power or thrust, under steady state and transient conditions, from idling speed to 103 percent of the maximum permissible speed. The survey must be conducted using the same configuration of the loading device which is used for the endurance test, except that the Administrator may allow the use of a modified configuration if that loading device type is incompatible with the necessary vibration instrumentation.

(b) The vibration stresses (or strain) of rotor and stator components determined under paragraph (a) of this section must be less, by a margin acceptable to the Administrator, than the endurance limit of the material from which these parts are made, adjusted for the most severe operating conditions.

(c) Each accessory drive and mounting attachment must be loaded, with the load imposed by each accessory used only for an aircraft service being the limit load specified by the applicant for the engine drive or attachment point.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

a. The engine vibration survey should be conducted with a representative inlet duct, or equivalent, if such is identified and available by time of test, while inducing the maximum inlet air distortion to be allowed by the engine installation instructions, for evaluating those components influenced by inlet distortion.

(1) The engine speed range to be surveyed is minimum idle speed to 103 percent of the maximum permissible speed. The maximum permissible speed is the highest rpm, including transients, for which the engine is to be approved.

(2) The principal result of the vibration survey is to demonstrate that an acceptable margin exists between the measured stresses and the endurance limit of the material being tested. Acceptable stress margins should exist throughout the operating envelope of the engine, including the worst case inlet air distortion levels to be approved for the engine. If inlet air distortion levels are found to be limiting, when correlated to vibratory stresses, then the engine installation instructions should specify those limits.

(3) Correspondingly, the recommended instrumentation, data acquisition and reduction methods, and coordination needs should also be provided in the engine installation instructions.

b. There are some engine designs which operate at such high rotor speeds and gas path temperatures that existing technology strain gages cannot survive this environment for very long. In such cases, the full stress survey should still be the goal and the test designed accordingly.

(1) If it becomes physically impossible to achieve the testing to 103 percent speed, then some form of analysis could be used to make up any difference.

(2) Additionally, if any significant resonances are found in the operating range of the engine, then the engine should be run, at least, 10 million cycles at each resonant point and at points bracketing the resonances to assure the stress endurance limit is not exceeded. This is normally covered as part of the endurance test's incremental running.

57. Section 33.85, Calibration Tests.

Section 33.85 Calibration tests.

(a) Each engine must be subjected to those calibration tests necessary to establish its power characteristics and the conditions for the endurance test specified in Section 33.87. The results of the power characteristics calibration tests form the basis for establishing the characteristics of the engine over its entire operating range of speeds, pressures, temperatures, and altitudes. Power ratings are based upon standard atmospheric conditions with no airbleed for aircraft services and with only those accessories installed which are essential for engine functioning.

(b) A power check at sea level conditions must be accomplished on the endurance test engine after the endurance test and any change in power characteristics which occurs during the endurance test must be determined. Measurements taken during the final portion of the endurance test may be used in showing compliance with the requirements of this paragraph.

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Guidance. The INTENT of this section is to determine the engine power characteristics by test calibrating the engine either before and during, or after, the endurance test.

Incorporations: None.

References: None.

The engine calibration tests, in combination with the other block test requirements, form the basis for the engine instrumentation statements to be included in the engine installation instructions. These statements should encompass types, ranges, precision (readability), and accuracies of those parameters required for safe in-service engine operation, including reverse thrust operations, for each of the ratings.

58. <u>Section 33.87, Endurance Test</u>.

Section 33.87 Endurance test.

(a) General. Each engine must be subjected to an endurance test that includes a total of 150 hours of operation and, depending upon the type and contemplated use of the engine, consists of one of the series of runs specified in paragraphs (b) through (f) of this section, as applicable. For engines tested under paragraph (b), (c), (d), or (e) of this section, the prescribed 6-hour test sequence must be conducted 25 times to complete the required 150 hours of operation. The following test requirements apply:

(1) The runs must be made in the order found appropriate by the Administrator for the particular engine being tested.

(2) Any automatic engine control that is part of the engine must control the engine during the endurance test except for operations where automatic control is normally overridden by manual control or where manual control is otherwise specified for a particular test run.

(3) Except as provided in paragraph (a)(5) of this section, power or thrust, gas temperature, rotor shaft rotational speed, and, if limited, temperature of external surfaces of the engine must be at least 100 percent of the value associated with the particular engine operation being tested. More than one test may be run if all parameters cannot be held at the 100 percent level simultaneously.

(4) The runs must be made using fuel, lubricants and hydraulic fluid which conform to the specifications specified in complying with Section 33.7(c).

(5) Maximum air bleed for engine and aircraft services must be used during at least one-fifth of the runs. However, for these runs, the power or thrust or the rotor shaft rotational speed may be less than 100 percent of the value associated with the particular operation being tested if the Administrator finds that the validity of the endurance test is not compromised.

(6) Each accessory drive and mounting attachment must be loaded. The load imposed by each accessory used only for aircraft service must be the limit load specified by the applicant for the engine drive and attachment point during rated maximum continuous power or thrust and higher output. The endurance test of any accessory drive and mounting attachment under load may be accomplished on a separate rig if the validity of the test is confirmed by an approved analysis.

(7) During the runs at any rated power or thrust the gas temperature and the oil inlet temperature must be maintained at the limiting temperature except where the

test periods are not longer than 5 minutes and do not allow stabilization. At least one run must be made with fuel, oil, and hydraulic fluid at the minimum pressure limit and at least one run must be made with fuel, oil, and hydraulic fluid at the maximum pressure limit with fluid temperature reduced as necessary to allow maximum pressure to be attained.

(8) If the number of occurrences of either transient rotor shaft overspeed or transient gas overtemperature is limited, the number of the accelerations required by paragraphs (b), (c), (d), and (e) of this section must be made at the limiting overspeed or overtemperature. If the number of occurrences is not limited, half the required accelerations must be made at the limiting overspeed or overtemperature.

(9) For each engine type certificated for use on supersonic aircraft, the following additional test requirements apply:

(i) To change the thrust setting, the power control lever must be moved from the initial position to the final position in not more than 1 second except for movements into the fuel burning thrust augmenter augmentation position if additional time to confirm ignition is necessary.

(ii) During the runs at any rated augmented thrust, the hydraulic fluid temperature must be maintained at the limiting temperature except where the test periods are not long enough to allow stabilization.

(iii) During the simulated supersonic runs, the fuel temperature and induction air temperature may not be less than the limiting temperature.

(iv) The endurance test must be conducted with the fuel burning thrust augmenter installed, with the primary and secondary exhaust nozzles installed, and with the variable area exhaust nozzles operated during each run according to the methods specified in complying with Section 33.5(b).

(v) During the runs at thrust settings for maximum continuous thrust and percentages thereof, the engine must be operated with the inlet air distortion at the limit for those thrust settings.

(b) Engines other than certain rotorcraft engines. For each engine, except a rotorcraft engine for which a rating is desired under paragraph (c), (d), or (e) of this section, the applicant must conduct the following runs:

(1) Takeoff and idling. One hour of alternate 5-minute periods at rated takeoff power and thrust and at idling power and thrust. The developed powers and thrusts at takeoff and idling conditions and their corresponding rotor speed and gas temperature conditions must be established by the power control in accordance with the schedule established by the manufacturer. The applicant

may, during any one period, manually control the rotor speed, power, and thrust while taking data to check performance. For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at takeoff must be at the augmented rating. For engines that do not materially increase operating severity, the amount of running conducted at the augmented rating is determined by the Administrator. In changing the power setting after each period, the power control lever must be moved in the manner prescribed in subparagraph (5) of this paragraph.

(2) Rated maximum continuous and takeoff power and thrust. Thirty minutes at -

(i) Rated maximum continuous power and thrust during fifteen of the twenty-five 6-hour endurance test cycles; and

(ii) Rated takeoff power and thrust during ten of the twenty-five 6-hour endurance test cycles.

(3) Rated maximum continuous power and thrust. One hour and 30 minutes at rated maximum continuous power and thrust.

(4) Incremental cruise power and thrust. Two hours and 30 minutes at the successive power lever positions corresponding to at least 15 approximately equal speed and time increments between maximum continuous engine rotational speed and ground or minimum idle rotational speed. For engines operating at constant speed, the thrust and power may be varied in place of speed. If there is significant peak vibration anywhere between ground idle and maximum continuous conditions, the number of increments chosen may be changed to increase the amount of running made while subject to the peak vibrations up to not more than 50 percent of the total time spent in incremental running.

(5) Acceleration and deceleration runs. Thirty minutes of accelerations and decelerations, consisting of 6 cycles from idling power and thrust to rated takeoff power and thrust and maintained at the takeoff power lever position for 30 seconds and at the idling power lever position for approximately 4-1/2 minutes. In complying with this subparagraph, the power-control lever must be moved from one extreme position to the other in not more than 1 second, except that, if different regimes of control scheduling of the power-control lever motion in going from one extreme position to the other, a longer period of time is acceptable, but not more than 2 seconds.

(6) Starts. One hundred starts must be made, of which 25 starts must be preceded by at least a 2-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There

must be at least 10 normal restarts with not longer than 15 minutes since engine shutdown. The remaining starts may be made after completing the 150 hours of endurance testing.

(c) Rotorcraft engines for which a 30-minute OEI power rating is desired. For each rotorcraft engine for which a 30-minute OEI power rating is desired the applicant must conduct the following series of tests:

(1) Takeoff and idling. One hour of alternate 5-minute periods at rated takeoff power and at idling power. The developed powers at takeoff and idling conditions and their corresponding rotor speed and gas temperature conditions must be as established by the power control in accordance with the schedule established by the manufacturer. During any one period the rotor speed and power may be controlled manually while taking data to check performance. For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented power rating. In changing the power setting after each period, the power-control lever must be moved in the manner prescribed in subparagraph (c)(5) of this paragraph.

(2) Rated 30-minute OEI power. Thirty minutes at rated 30-minute OEI power.

(3) Rated maximum continuous power. Two hours at rated maximum continuous power.

(4) Incremental cruise power. Two hours at the successive power-lever positions corresponding with not less than 12 approximately equal speed and time increments between maximum continuous engine rotational speed and ground or minimum idle rotational speed. For engines operating at constant speed, power may be varied in place of speed. If there are significant peak vibrations anywhere between ground idle and maximum continuous conditions, the number of increments chosen must be changed to increase the amount of running conducted while being subjected to the peak vibrations up to not more than 50 percent of the total time spent in incremental running.

(5) Acceleration and deceleration runs. Thirty minutes of accelerations and decelerations, consisting of 6 cycles from idling power to rated takeoff power and maintained at the takeoff power lever position for 30 seconds and at the idling power-lever position for approximately 4-1/2 minutes. In complying with this subparagraph, the power-control lever must be moved from one extreme position to the other in nor more than 1 second, except that, if different regimes of control operations are incorporated necessitating scheduling of the power-control lever motion in going from one extreme

position to the other, a longer period of time is acceptable, but not more than 2 seconds.

(6) Starts. One hundred starts, of which 25 starts must be preceded by at least a 2-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There must be at least 10 normal restarts with not longer than 15 minutes since engine shutdown. The remaining starts may be made after completing the 150 hours of endurance testing.

(d) Rotorcraft engines for which a continuous OEI rating is desired. For each rotorcraft engine for which a continuous OEI power rating is desired, the applicant must conduct the following series of tests:

(1) Takeoff and idling. One hour of alternate 5-minute periods at rated takeoff power and at idling power. The developed powers at takeoff and at idling conditions and their corresponding rotor speed and gas temperature conditions must be as established by the power control in accordance with the schedule established by the manufacturer. During any one period the rotor speed and power may be controlled manually while taking data to check performance. For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented power rating. In changing the power setting after each period, the power control lever must be moved in the manner prescribed in paragraph (c)(5) of this section.

(2) Rated maximum continuous and takeoff power. Thirty minutes at-

(i) Rated maximum continuous power during fifteen of the twenty-five 6-hour endurance test cycles; and

(ii) Rated takeoff power during ten of the twenty-five 6-hour endurance test cycles.

(3) Rated continuous OEI power. One hour at rated continuous OEI power.

(4) Rated maximum continuous power. One hour at rated maximum continuous power.

(5) Incremental cruise power. Two hours at the successive power lever positions corresponding with not less than approximately 12 equal speed and time increments between maximum continuous engine rotational speed and ground or minimum idle rotational speed. For engines operating at constant speed, power may be varied in place of speed. If there are significant peak vibrations anywhere between ground idle and maximum continuous conditions, the number of increments chosen must be changed to increase the amount of running conducted while being subjected to the peak vibrations up to not more than 50 percent of the total time spent in incremental running.

(6) Acceleration and deceleration runs. Thirty minutes of accelerations and decelerations, consisting of six cycles from idling power to rated takeoff power and maintained at the takeoff power lever position for 30 seconds and at the idling power lever position for approximately 4-1/2 minutes. In complying with this paragraph, the power control lever must be moved from one extreme position to the other in not more than 1 second, except that if different regimes of control operations are incorporated necessitating scheduling of the power control lever motion in going from one extreme to the other, a longer period of time is acceptable, but not more than 2 seconds.

(7) Starts. One hundred starts, of which 25 starts must be preceded by at least a 2-hour engine shutdown. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time, before attempting a normal start. There must be at least 10 normal restarts with not longer 15 minutes since engine shutdown. The remaining starts may be made after completing the 150 hours of endurance testing.

(e) Rotorcraft engines for which a 2-1/2 minute OEI power rating is desired. For each rotorcraft engine for which a 2-1/2 minute OEI power rating is desired the applicant must conduct the following series of tests:

(1) Takeoff, 2-1/2 Minute OEI, and idling. One hour of alternate 5-minute periods at rated takeoff power and at idling power except that, during the third and sixth takeoff power periods, only 2-1/2 minutes need be conducted at rated takeoff power and the remaining 2-1/2 minutes must be conducted at rated 2-1/2 minute OEI power. The developed powers at takeoff, 2-1/2 minute OEI, and idling conditions and their corresponding rotor speed and gas temperature conditions must be as established by the power control in accordance with the schedule established by the manufacturer. The applicant may, during any one period, control manually the rotor speed and power while taking data to check performance. For engines with augmented takeoff power ratings that involve increases in turbine inlet temperature, rotor speed, or shaft power, this period of running at rated takeoff power must be at the augmented rating. In changing the power setting after or during each period, the power control lever must be moved in the manner prescribed in paragraph (d)(6) of this section.

(2) The tests required in paragraphs (b)(2) through (b)(6), or (c)(2) through (c)(6), or (d)(2) through (d)(7) of this section, as applicable, except that in one of the 6-hour test sequences, the last 5 minutes of the 30 minutes at takeoff power test period of paragraph (b)(2) of this section, or of the 30 minutes at 30-minute OEI power test period of paragraph (c)(2) of this section, or

of the 1-hour at Continuous OEI power test period of paragraph (d)(3) of this section, must be run at 2-1/2 minute OEI power.

(f) Supersonic aircraft engines. For each engine type certificated for use on supersonic aircraft, the applicant must conduct the following:

(1) Subsonic test under sea level ambient atmospheric conditions. Thirty runs of 1 hour each must be made, consisting of--

(i) Two periods of 5 minutes at rated takeoff augmented thrust each followed by 5 minutes at idle thrust;

(ii) One period of 5 minutes at rated takeoff thrust followed by 5 minutes at not more than 15 percent of rated takeoff thrust;

(iii) One period of 10 minutes at rated takeoff augmented thrust followed by 2 minutes at idle thrust, except that if rated maximum continuous augmented thrust is lower than rated takeoff augmented thrust, 5 of the 10-minute periods must be at rated maximum continuous augmented thrust; and

(iv) Six periods of 1 minute at rated takeoff augmented thrust each followed by 2 minutes, including acceleration and deceleration time, at idle thrust.

(2) Simulated supersonic test. Each run of the simulated supersonic test must be preceded by changing the inlet air temperature and pressure from that attained at subsonic condition to the temperature and pressure attained at supersonic velocity, and must be followed by a return to the temperature attained at subsonic condition. Thirty runs of 4 hours each must be made, consisting of--

(i) One period of 30 minutes at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust followed by 10 minutes at the thrust obtained with the power control lever set at the position for 90 percent of rated maximum continuous augmented thrust. The end of this period in the first 5 runs must be made with the induction air temperature at the limiting condition of transient overtemperature, but need not be repeated during the periods specified in subdivisions (ii)through (iv) of this subparagraph;

(ii) One period repeating the run specified in subdivision (i) of this subparagraph, except that it must be followed by 10 minutes at the thrust obtained with the power control lever set at the position for 8 percent of rated maximum continuous augmented thrust;

(iii) One period repeating the run specified in subdivision (i) of this subparagraph, except that it must be followed by 10 minutes at the thrust obtained with the power control lever set at the position for 60 percent of rated maximum continuous augmented thrust and then 10 minutes at not more than 15 percent of rated takeoff thrust;

(iv) One period repeating the runs specified in subdivisions (i) and (ii) of this subparagraph; and

(v) One period of 30 minutes with 25 of the runs made at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust, each followed by idle thrust and with the remaining 5 runs at the thrust obtained with the power control lever set at the position for rated maximum continuous augmented thrust for 25 minutes each, followed by subsonic operation at not more than 15 percent of rated takeoff thrust and accelerated to rated takeoff thrust for 5 minutes using hot fuel.

(3) Starts. One hundred starts must be made, of which 25 starts must be preceded by an engine shutdown of at least 2 hours. There must be at least 10 false engine starts, pausing for the applicant's specified minimum fuel drainage time before attempting a normal start. At least 10 starts must be normal restarts, each made no later than 15 minutes after engine shutdown. The starts may be made at any time, including the period of endurance testing.

***

Guidance. The INTENT of this section is to demonstrate a minimum level of operability of the complete engine, within its to be approved ratings, limitations, inspection, and maintenance requirements.

Incorporations: AC 20-18A, "Qualification Testing of Turbojet Engine Thrust Reversers," dated March 16, 1966.

References: None.

a. Although endurance testing rules for propeller-driving engines do not require an intended propeller be installed, it is recommended that such test engines be so equipped, when feasible. This practice would provide additional operating data/information on which to assess engine-to-propeller compatibility.

b. Approval of transient limitations of measured gas temperature, speeds, torques, engine pressure ratios, oil temperature, etc., should be based on those transient excursions (parameter level and time) consistently demonstrated during the endurance test's acceleration runs. Being transients, such limitations should not be approved for times greater than approximately 30 seconds for transients associated with the Maximum Continuous, Takeoff, Continuous OEI, and 30-Minute OEI ratings. Transients associated with the 2-1/2-Minute OEI rating should be limited to very brief periods, on the order of 5 to 10 seconds maximum.

c. Approvals of turboprop and turboshaft engine limits of torque and output shaft speed, as with other limits, are based on those limits having been demonstrated during the engine block tests, particularly the endurance test. Further, approval of simultaneous usage of both the torque and the output shaft speed limits should be based on demonstration of simultaneous excursions of both parameters. For example, each required acceleration to the Takeoff, 30-Minute OEI, Continuous OEI, and 2-1/2 Minute OEI power ratings of the appropriate endurance test schedule should be conducted to the respective torque and output shaft speed limits (value and time) to be requested for approval.

d. In all cases, approval should be granted only to the extent demonstrated. Of principal concern is that approved individual limits of overtorque and overspeed, if applied together, could, for some engine designs, result in a shaft horsepower level which would not have been evaluated during the engine TC process and, thus, may be an unairworthy condition.

e. Under certain ambient conditions, it may not be possible to simultaneously exercise, to its respective speed limitation, each rotor of a multiple rotor engine during endurance test running. During such a case, and if approved by the cognizant FAA project manager or engineer, the required substantiation may be shown by test replication as necessary, and/or by valid analysis.

59. Section 33.88, Engine Overtemperature Test.

Section 33.88 Engine overtemperature test.

Each engine must be run for 5 minutes at maximum permissible r.p.m. and with the gas temperature at least 75 °F (42 °C) higher than the maximum operating limit. Following this run, the turbine assembly must be within serviceable limits.

***

Guidance. The INTENT of this section is to demonstrate a minimum overtemperature capability of the engine.

Incorporations: AC 33-3, Turbine and Compressor Rotors Type Certification Procedures," dated September 1968.

References: None.

a. This rule requires the test to be demonstrated on a complete engine, not a rig. The test should be set up on an engine without mismatching component flow capacities, if possible. For example, the maximum rpm and maximum gas path temperature could be set up on the engine by means of an inlet heater. Then, by modulating compressor bleed, the 75 °F (42 °C) overtemperature (above the maximum rating steady-state limit) would be obtained, under circumstances close to what could be experienced in service. Note that "maximum permissible r.p.m." means the highest rotor speed for power-on engine operation (non-windmill, non-autorotative), whether steady-state or transient, which will be specified on the engine type certificate data sheet (TCDS). Also, note that the critical parameter is turbine inlet gas temperature, not exhaust gas temperature.

b. The overtemperature test condition should be based on the engine's maximum steady-state operating temperature limit. For example, if an engine's maximum steady-state gas temperature for the takeoff rating is 850 °C, the test should be run at 892 °C; however, if this same engine also has a 2-1/2-Minute OEI rating with a steady-state temperature of 900 °C, then this test should be conducted at 942 °C.

c. Post test acceptance criteria is that the engine turbine assembly, which includes blades, discs, drums, spacers, shafts, seals, stators, nozzles, and support structure, must be within serviceable limits. Serviceable limits, including dimensional limits, are determined during the type certification process and as published per "Appendix A to Part 33 -- Instructions for Continued Airworthiness" (See Section 33.4, Instructions for Continued Airworthiness).

60. Section 33.89, Operation Test.

Section 33.89 Operation test.

(a) The operation test must include testing found necessary by the Administrator to demonstrate--

(1) Starting, idling, acceleration, overspeeding, ignition, functioning of the propeller (if the engine is designated to operate with a propeller);

(2) Compliance with the engine response requirements of Section 33.73; and

(3) The minimum power or thrust response time to 95 percent rated takeoff power or thrust, from power lever positions representative of minimum idle and of minimum flight idle, starting from stabilized idle operation, under the following engine load conditions:

(i) No bleed air and power extraction for aircraft use.

(ii) Maximum allowable bleed air and power extraction for aircraft use.

(iii) An intermediate value for bleed air and power extraction representative of that which might be used as a maximum for aircraft during approach to a landing.

(4) If testing facilities are not available, the determination of power extraction required in paragraph

(a)(3)(ii) and (iii) of this section may be accomplished through appropriate analytical means.

(b) The operation test must include all testing found necessary by the Administrator to demonstrate that the engine has safe operating characteristics throughout its specified operating envelope.

***

Guidance. The INTENT of this section is to demonstrate safe operating characteristics and a minimum standard of power/thrust response characteristics.

Incorporations: AC 33.65-1, "Surge and Stall Characteristics of Aircraft Turbine Engines," dated December 6, 1985.

References: None.

Note: Although the incorporation applies to large high bypass ratio turbofan engines, the guidance material therein may also be useful for other engine applications.

a. This section addresses the block test requirements covering surge and stall characteristics. The correlating design and construction requirements are addressed in Section 33.65, "Surge and stall characteristics."

b. Engine transient characteristics at altitude should be defined by testing. However, steady state testing in an altitude test facility, in addition to component and engine analysis, is acceptable, when facility limitations preclude altitude transient testing, if accomplished as follows:

(1) Qualitatively determine, by sea level testing, the transient operating characteristics, including acceleration, deceleration, surge, stall, and flameout.

(2) Considering the limitations of the available altitude test facility, perform a quantitative analysis of the operating characteristics, identified by the above testing, over the complete operating range of the engine.

(3) Select, on the basis of the analysis, those critical conditions which may provide a problem in projected aircraft usage; and demonstrate quantitatively, on a quasi-steady basis, the validity of the analysis in the altitude test facility. "Quasi-steady" means that disturbances of short duration will be applied to the engine when operating on the steady-state operating line, such that the effect of the transient on the engine is determined before the test facility conditions are disturbed.

(4) As a part of the sea level demonstration, the ability of the engine to withstand takeoff surge, without damage, should be shown.

(5) The testing and analysis should show that margins are adequate to tolerate likely variations in fuel schedule, variable geometry schedule, anticipated installations and environmental (temperature, pressure, humidity) effects.

C. The operation test should also include:

(1) Low temperature and high temperature tests (fluids and carcass) for starting and operating the engine.

(2) Substantiation of the ignition system design duty cycle.

(3) Substantiation of the propeller parking brake, if the engine is so equipped.

(4) Substantiation of the engine ground and, where feasible, the in-flight starting envelopes. This substantiation should address all possible combinations of ignition system operation and power sources to be approved, and should result in defined acceptable start times, from initiation of the starting sequence to stabilized idle conditions.

(5) Substantiation of the propeller parking brake, if the engine is so equipped.

(6) Substantiation of all engine operating attitudes, and additionally, for powered-lift engines rotationally displaceable along their longitudinal axis, slue angles, and rates.

61. Section 33.90, Initial Maintenance Inspection.

Section 33.90 Initial maintenance inspection.

Each engine, except engines being type certificated through amendment of an existing type certificate or through supplemental type certification procedures, must undergo an approved test run that simulates the conditions in which the engine is expected to operate in service, including start-stop cycles, to establish when the initial maintenance inspection is required. The test run must be accomplished on an engine which substantially conforms to the final type design.

***

Guidance. The INTENT of this section is to demonstrate the ability of new type certificate engines to operate in a simulation of expected service conditions, for a specified number of cycles and/or hours before requiring maintenance inspection.

Incorporations: None.

References: None.

The requirements of this section are separate and distinct from those of Section 33.14, "Start-stop cyclic stress."

a. The use of an abbreviated flight cycle could satisfy Section 33.90, when supported by analytical data and/or supplemental test data. Applicants may submit existing data, such as from development tests and service experience where applicable and when creditable. The following information should be supplied to permit assessment of the inspection/overhaul period in support of the abbreviated flight cycle:

(1) The design flight cycle for the engine should identify the time history of engine power, or thrust usage including reverse thrust, if applicable, from engine start-up through shutdown, during a typical flight of a representative aircraft which uses the engine.

(2) The design analysis should identify those features of the engine for which initial life limitations will be established, or which will require threshold maintenance inspection; and whether a limitation is based on low cycle fatigue (cycles) or total engine or part-time (hours).

(3) A substantiation of the validity of the limitations and the acceptability of the test procedure as a valid representation of the design flight cycle, with regard to stress, temperature, and vibration (simulating the maximum rotor imbalances to be approved for production acceptance).

b. The initial maintenance inspection test run of engines designed to drive a propeller should be equipped with a propeller representative of the intended application, and include propeller parking brake usage and APU-mode operations, if so equipped.

62. Section 33.91, Engine Component Tests.

Section 33.91 Engine component tests.

(a) For those systems that cannot be adequately substantiated by endurance testing in accordance with the provisions of Section 33.87, additional tests must be made to establish that components are able to function reliably in all normally anticipated flight and atmospheric conditions.

(b) Temperature limits must be established for those components that require temperature controlling provisions in the aircraft installation to assure satisfactory functioning, reliability, and durability.

(c) Each unpressurized hydraulic fluid tank may not fail or leak when subjected to maximum operating temperature and an internal pressure of 5 p.s.i., and each pressurized hydraulic fluid tank may not fail or leak when subjected to maximum operating temperature and an internal pressure not less than 5 p.s.i. plus the maximum operating pressure of the tank.

(d) For an engine type certificated for use in supersonic aircraft, the systems, safety devices, and external components that may fail because of operation at maximum and minimum operating temperatures must be identified and tested at maximum and minimum operating temperatures and while temperature and other operating conditions are cycled between maximum and minimum operating values.

***

<u>Guidance</u>. The INTENT of this section is to assure test substantiation of all engine components, functions, and features which would not otherwise have been evaluated by endurance or other testing.

<u>Incorporations</u>: None.

<u>References</u>: None.

Engine component tests may include, but are not limited to, the following:

a. Fire proof/resistance tests of flammable fluid carrying or holding components.

b. Sea level and altitude pressure conditions testing/calibration of electronic control, fuel, lube, pneumatic, and starting systems.

c. Cold and hot ambient temperature conditions testing/calibration of fuel, lube, pneumatic, and starting systems.

d. Other environmental testing, such as salt spray, humidity, fungus, explosive atmosphere, etc.

e. Electromagnetic compatibility (EMC/HERF) testing.

f. Testing of engine electronic control lightning tolerance, as discussed under Section 33.7 of this AC.

g. Engine thrust reverser systems tests.

h. Engine mount structure loads tests.

i. Engine ignition systems (duty cycles) tests.

j. Compressor mapping tests.

k. Engine control and monitoring systems software validations; and

l. Tests of electronic control integrity, while operating with various combinations of intended dispatchable control subsystem failures.

63. Section 33.92, Windmilling Tests.

Section 33.92 Windmilling tests.

(a) For engines to be used in supersonic aircraft, unless means are incorporated in the engine to stop rotation of the engine rotors when the engine is shut down in flight, each engine rotor must either seize or be capable of rotation for 3 hours at the limiting windmilling rotational r.p.m. with no oil in the engine system, without the engine--

(1) Catching fire;

(2) Bursting (releasing hazardous uncontained fragments); or

(3) Generating loads greater than those ultimate loads specified in Section 33.23(a).

(b) A turbojet or turbofan engine incorporating means to stop rotation of the engine rotors when the engine is shut down in flight must be subjected to 25 operations under the following conditions:

(1) Each engine must be shut down while operating at rated maximum continuous thrust.

(2) For engines certificated for use on supersonic aircraft, the temperature of the induction air and the external surfaces of the engine must be held at the maximum limit during the tests required by this paragraph.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

The FAA dropped the pre-Amendment 10 requirement for windmilling tests of subsonic turbine engines, on the basis that it imposed an unnecessary burden on the engine manufacturer, and that service experience showed no reported incidents involving windmilling hazards resulting from loss of engine oil.

64. Section 33.93, Teardown Inspection.

Section 33.93 Teardown inspection.

After completing the endurance test, each engine must be completely disassembled, and--

(a) Each component having an adjustment setting and a functioning characteristic that can be established independent of installation on the engine must retain each setting and functioning characteristic within the limits that were established and recorded at the beginning of the test; and

(b) Each engine part must conform to the type design and be eligible for incorporation into an engine for continued operation, in accordance with information submitted in compliance with Section 33.4.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

65. Section 33.94, Blade Containment and Rotor Unbalance Tests.

Section 33.94 Blade containment and rotor unbalance tests.

(a) Except as provided in paragraph (b) of this section, it must be demonstrated by engine tests that the engine is capable of containing damage without catching fire and without failure of its mounting attachments when operated for at least 15 seconds, unless the resulting engine damage induces a self shutdown, after each of the following events:

(1) Failure of the most critical compressor or fan blade while operating at maximum permissible r.p.m. The blade failure must occur at the outermost retention groove or, for integrally-bladed rotor discs, at least 80 percent of the blade must fail.

(2) Failure of the most critical turbine blade while operating at maximum permissible r.p.m. The blade failure must occur at the outermost retention groove or, for integrally-bladed rotor discs, at least 80 percent of the blade must fail. The most critical turbine blade must be

determined by considering turbine blade weight and the strength of the adjacent turbine case at case temperatures and pressures associated with operation at maximum permissible r.p.m.

(b) Analysis based on rig testing, component testing, or service experience may be substituted for one of the engine tests prescribed in paragraphs (a)(1) and (a)(2) of this section if--

(1) That test, of the two prescribed, produces the least rotor unbalance; and

(2) The analysis is shown to be equivalent to the test.

***

Guidance. The INTENT of this section is to demonstrate engine blade containment by test, or by test and, in part, by proven analytical methodology.

Incorporations: AC 33-5, "Turbine Engine Rotor Blade Containment Durability," dated November 7, 1989.

References: None.

66. Section 33.95, Engine-propeller Systems Tests.

Section 33.95 Engine-propeller systems tests.

If the engine is designed to operate with a propeller, the following tests must be made with a representative propeller installed by either including the tests in the endurance run or otherwise performing them in a manner acceptable to the Administrator:

(a) Feathering operation: 25 cycles.

(b) Negative torque and thrust system operation: 25 cycles from rated maximum continuous power.

(c) Automatic decoupler operation: 25 cycles from rated maximum continuous power (if repeated decoupling and recoupling in service is the intended function of the device).

(d) Reverse thrust operation: 175 cycles from the flight idle position to full reverse and 25 cycles at rated maximum continuous power from full forward to full reverse thrust. At the end of each cycle the propeller must be operated in reverse pitch for a period of 30 seconds at the maximum rotational speed and power specified by the applicant for reverse pitch operation.

***

Guidance. The INTENT of this section is to assure that the engine, if designed to operate with a propeller, has been minimally tested with a representative propeller installed.

Incorporations: None.

References: None.

67. Section 33.96, Engine Tests in Auxiliary Power Unit (APU) Mode.

Section 33.96 Engine tests in auxiliary power unit (APU) mode.

If the engine is designed with a propeller brake which will allow the propeller to be brought to a stop while the gas generator portion of the engine remains in operation, and remain stopped during operation of the engine as an auxiliary power unit ("APU mode"), in addition to the requirements of Section 33.87, the applicant must conduct the following tests:

(a) Ground locking: A total of 45 hours with the propeller brake engaged in a manner which clearly demonstrates its ability to function without adverse effects on the complete engine while the engine is operating in the APU mode under the maximum conditions of engine speed, torque, temperature, air bleed, and power extraction as specified by the applicant.

(b) Dynamic braking: A total of 400 application-release cycles of brake engagements must be made in a manner which clearly demonstrates its ability to function without adverse effects on the complete engine under the maximum conditions of engine acceleration/deceleration rate, speed, torque, and temperature as specified by the applicant. The propeller must be stopped prior to brake release.

(c) One hundred engine starts and stops with the propeller brake engaged.

(d) The tests required by paragraphs (a), (b), and (c) of this section must be performed on the same engine used for the tests required by Section 33.87.

(e) The tests required by paragraphs (a), (b), and (c) of this section must be followed by engine disassembly to the extent necessary to show compliance with the requirements of Section 33.93(a) and Section 33.93(b).

***

Guidance. The INTENT of this section is to assure that turboprop engines incorporating propeller brake (APU-mode) features are tested to ensure compatibility of those features with the rest of the engine.

Incorporations: None.

References: None.

a. These tests are intended to provide for the assessment of:

(1) Hot section tolerance for locked rotor operations effects on combustor stability/coking, turbine nozzle integrity, turbine blade integrity, vibration, etc.; and

(2) Engine drive system stability/response, including the power turbine rotors, shafting, bearings and supports, reduction and accessory gear trains, and rotor brake components.

b. These propeller brake tests may be conducted in conjunction with the required tests of Section 33.87, where conditions permit, and if found appropriate by the Administrator.

c. The existing airworthiness standards concerning engine installations in FAR Parts 23 and 25, are considered adequate to assure a minimum level of airworthiness for certification installations of engines designed with propeller brakes for APU mode operations.

(1) In this case, the engine manufacturer will be required to perform a safety analysis, in accordance with the existing requirements of Section 33.75, which addresses APU mode operations.

(2) It is intended that the results of this analysis be applied, as necessary, to the installed engine safety analysis, at the airframe level by the airframe manufacturer, to demonstrate compliance with Sections 23.1309 or 25.1309, as appropriate.

68. Section 33.97, Thrust Reversers.

Section 33.97 Thrust reversers.

(a) If the engine incorporates a reverser, the endurance, calibration, operation, and vibration tests prescribed in this subpart must be run with the reverser installed. In complying with this section, the power control lever must be moved from one extreme position to the other in not more than 1 second except, if regimes of control operations are incorporated necessitating scheduling of the power-control lever motion in going from one extreme position to the other, a longer period of time is acceptable but not more than 3 seconds. In addition, the test prescribed in paragraph (b) must be made. This test may be scheduled as part of the endurance run.

(b) One hundred seventy-five reversals must be made from flight-idle forward thrust to maximum reverse thrust and 25 reversals must be made from rated takeoff thrust to maximum reverse thrust. After each reversal, the reverser must be operated at full reverse thrust for a period of 1 minute, except, that, in the case of a reverser intended for use only as a braking means on the ground, the reverser need only be operated at full reverse thrust for 30 seconds.

***

Guidance. The INTENT of this section is to assure that engines incorporating thrust reversers are tested to ensure reverser airworthiness and compatibility with the rest of the engine.

Incorporations: AC 20-18A "Qualification Testing of Turbojet Engine Thrust Reversers," dated March 16, 1966.

References: None.

Note that the published volume of the Code of Federal Regulations, Aeronautics and Space Title 14, Parts 1 to 59, has an omission in Section 33.97. This publication omits the comma in Section 33.97(a) following "endurance". Thus, some interpretations have been made that an endurance test with the reverser installed is not required; but rather a calibration test as that associated with pre- and post-endurance testing is the requirement (in addition to operation and vibration tests). The point of clarification herein is that an endurance test, a calibration test, an operation test, and a vibration test are all required to evaluate thrust reversers.

69. Section 33.99, General Conduct of Block Tests.

Section 33.99 General conduct of block tests.

(a) Each applicant may, in making a block test, use separate engines of identical design and construction in the vibration, calibration, endurance, and operation tests, except that, if a separate engine is used for the endurance test it must be subjected to a calibration check before starting the endurance test.

(b) Each applicant may service and make minor repairs to the engine during the block tests in accordance with the service and maintenance instructions submitted in compliance with Section 33.4. If the frequency of the service is excessive, or the number of stops due to enngine malfunction is excessive, or a major repair, or replaccemennof a part is found necessary during the block tests or as the result of findings from the teardown inspection, the engine or its parts must be subjected to any additional tests the Administrator finds necessary.

(c) Each applicant must furnish all testing facilities, including equipment and competent personnel, to conduct the block tests.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

70. Section 33.13, Design Features.

Section 33.13 Design features.

The engine may not have design features that experience has shown to be hazardous or unreliable. The suitability of each questionable design detail or part must be established by tests.

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Guidance. The INTENT of this section is self-evident.

Incorporations: None.

References: None.

This rule applies to engines having a type certification basis of FAR Part 33, Amendment 5, or earlier. This rule was deleted by Amendment 6 on the basis that the regulations contain adequate and appropriate safety standards for aircraft engines. The preamble for the deletion further stated that testing of questionable design features may be required under the provisions of Section 21.33 and special conditions may be prescribed under Section 21.16 for novel or unusual design features.