Cancelled See 1;4

Federal Aviation Agency

ADVISORY CIRCULAR

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AIRCRAFT ENGINES
EFFECTIVE: 6/24/65

SUBJECT: TURBINE-ENGINE FOREIGN OBJECT INGESTION AND ROTOR BLADE CONTAINMENT TYPE CERTIFICATION PROCEDURES

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1. PURPOSE. This circular provides guidance and acceptable means, not the sole means, by which compliance may be shown with the design and construction requirements of Part 33 of the Federal Aviation Regulations.

2. REFERENCES. Federal Aviation Regulations 33.13 and 33.19.

3. BACKGROUND. Experience acquired with turbine engines has revealed that foreign object ingestion has, at times, resulted in safety hazards. Such hazards may be extreme and possibly catastrophic involving explosions, uncontrollable fires, engine disintegration, and lack of containment of broken blading. In addition, lesser but potentially severe hazards may involve airflow disruption with flameouts, lengthy or severe power losses, or momentary disruptions and possibly minor blade damage. While the magnitude of the overall hazards from foreign object ingestion are often dependent upon several factors, the nature of engine design appears to be the most important.

4. SCOPE. For the purpose of showing compliance with the reference regulations, engine type certification programs should include substantiation of engine ingestion properties and broken rotor blade damage containment. To insure the provision of a desired degree of engine tolerance to the disruptive effects of foreign object ingestion, substantiation should include an evaluation of the engine design and tests to demonstrate the ability to ingest typical foreign objects without causing a serious reduction in flight safety. The engine applicant is permitted to specify the use of protected inlets for his engine as an alternative to substantiation for airborne foreign objects.

5. ENGINE DESIGN FEATURES. The following design features have been generally favorable toward minimizing severe effects of foreign object ingestion and increasing safety:

a. Front rotor blades and stators and entry guide vanes material and design to minimize impact damage, severe deflection, tearing, and rupture.

b. Shrouds for the first several rotor and stator stages.

c. Compressors without entry guide vanes.

d. Appreciable axial clearance between the first stage compressor rotor blades entry guide vanes and between stators of the first several compressor stages, especially near the rotor blade forward tips.

e. Puncture resistant rotor housings or separate armor adequate to contain broken rotor blades and stator vanes.

f. Adequate strength of engine main structure and bearing supports to provide a strength margin for a period of shutdown and low speed windmilling when large unbalances typical of damaged rotor blading occur.

g. A generous stall margin for the engine, good combustion stability during airflow disturbances incident to foreign object ingestions, and rapid relight capability.

6. CLASSIFICATION OF TYPICAL FOREIGN OBJECTS. For the purpose of the substantiation program, the foreign objects considered typical are classified into two major groups.

a. Foreign objects in Group I are those applicable to all turbine engines and are likely to be encountered only as single occurrences affecting just one engine of any multiengine aircraft in any one flight.

Group I.

(1) A cleaning cloth of typical size.

(2) A mechanics hand tool of pocket size.

(3) A small size aircraft steel bolt and nut typical of aircraft inlet hardware.

(4) Compressor and turbine rotor blades. The most critical single blade(s) usually of the largest size with broken retention members or a significant portion of blades of integrally bladed rotors. While rotor blades are not normally to be categorized as foreign objects in their respective engines, failed blades are so considered for the purpose of this circular.

b. Foreign objects in Group II are those considered to be airborne as regards their reason for entry into engines and are likely to be ingested by more than one engine of an aircraft on any one occasion. Unless for certain foreign objects, the specific installation, inlet design, or other factors preclude the possibility of their ingestion, all of the following objects are applicable:

Group II.

(1) Water in the form of rain.

(2) Gravel of mixed sizes to one-fourth inch typical of airport surface material in quantities likely to be ingested in one flight.

(3) Sand of mixed sizes typical of airport surface material in quantities likely to be ingested in one flight.

(4) Ice of typical sizes and forms representative of inlet duct and lip formations, engine front frame and guide vane deposits, in quantities likely to be ingested during a flight.

(5) Hail stones of approximately .7 density and of one- and two-inch diameter.

(6) Birds of small sizes (two to four oz.) typical of starlings, sparrows, and larks, and of large sizes (two to four lbs.) typical of sea gulls and ducks.

7. ACCEPTABLE MEANS OF COMPLIANCE. In showing compliance with the reference regulations relative to showing freedom from hazardous or unreliable consequences of typical foreign object ingestion, and demonstrating containment of damage from broken rotor blades, it is acceptable to conduct tests of the nature indicated in paragraph 8 and 9. In lieu of planned official tests, pertinent related development experience, service experience, and analyses are usually acceptable means of compliance for engine substantiation. Engine substantiation may be based on consideration of only these foreign objects which are known to cause the more severe effects rather than on all typical foreign objects indicated herein. Special operating precautions or techniques determined from these tests, which will aid in quickly restoring engine power or preventing further adverse effects to the engine after ingestion typical of those expected to occur in service, should be incorporated in the engine manual.

8. SUBSTANTIATION TESTS.

a. Group I, Foreign Objects.

(1) Ingestion of Group I foreign objects while operating at maximum r.p.m. and output. The typical foreign objects being ingestion tested are normally introduced by dropping them into the inlet. However, as rotor blades are to be evaluated for both ingestion effects and containment, they should be released from a rotor at maximum operating r.p.m. The rotor blades evaluated normally include all those which in combination with the adjacent rotor case wall section are likely to be the most difficult to contain and may include tests of more than one blade row in an engine. In regard to broken rotor blades, both the hazards resulting from internal damage, and the containment of damage by the rotor cases are considered important. Where applicable, component tests rather than engines may be utilized for this substantiation.

b. Group II, Foreign Objects.

(1) Group II foreign objects ingestion tests while engine is operating at maximum output. Tests of engine front frames alone may be conducted, if desired, to substantiate this component for direct impact. The provision of a windtunnel facility to provide a moving airstream into the test engine is desirable, but is not essential where the injection of the foreign objects into the operating engine to simulate the effects of aircraft speed is adequate. Whenever results considered particularly critical to safety result from ingestion tests, however, it is desirable to conduct either a windtunnel test, a flight test, or a particularly accurate simulation of flight effects on the severity of ingestion effects. As an example, the minimum propeller blade pitch settings used with turbopropeller engines in flight may require special test settings under static test stand conditions to simulate flight operation characteristics of the propeller.

(2) Hail Ingestion. Hail ingestion testing with operating engines:

(a) With one-inch hailstones, ingest at the usual cruising flight speed characteristic of the applicable type aircraft.

(b) With two-inch hailstones, ingest at the typical rough air airspeed for cruise, climb and descent, whichever is the highest speed characteristic of the applicable type aircraft.

(c) The effects of ingesting hailstones in sequence should be evaluated to indicate possible critical conditions. Suggested test quantities are one two-inch stone and two one-inch stones per engine and per each 400 square inches of inlet area.

(3) Water Ingestion. Water ingestion testing is acceptable when simulating maximum rainfall and in quantities up to approximately four percent of the engine airflow.

(4) Bird Ingestion. Bird ingestion tests have been accomplished acceptably when the birds are freshly killed and injected via air tubes into the representative engine inlet at the appropirate velocities indicated in 8b.4(a) and (b). Other techniques may be substituted, including lower injection velocities, testing without the aircraft inlet, equivalent substitute materials for birds, or other means of injection provided adequate severity of the results can be assured. Since the probability of multiple bird ingestion varies with inlet cross section, the number of birds to be ingested during the test is related to inlet area in the subparagraphs below.

(a) Small birds. Ingest at typical takeoff operating flight speeds and engine output levels. Ingest one bird for each 50 square inches (or fraction thereof) of inlet area, except that, if the bird cannot pass through the inlet, no test is necessary, and the number of birds ingested in one encounter need not exceed 16.

(b) Large birds. Ingest at takeoff flight speed with takeoff engine output, and at the highest typical speed of cruise, descent, or climb, characteristic of operation through approximately 12,000 feet altitude, typical climb engine output. Ingest one bird for each 400 square inches (or fraction thereof) of inlet area, except that, if the bird cannot pass through the inlet, no test is necessary.

(c) The birds should be introduced in random sequence, simulating an encounter with a flock.

9. SUBSTANTIATION CRITERIA.

a. The engine is acceptable if, during the ingestion tests, the damage from rotor blade failures are contained by the rotor cases (as prescribed in § 33.19) and the ingestion tests are completed without extreme or catastrophic hazards occurring such as engine explosion, disintegration, or uncontrollable fire. It is acceptable that the engine may require immediate shutdown for safety reasons, but this should be readily indicated in a timely manner by excessive vibration or other direct operating evidence.

b. The engine should demonstrate the ability to minimize overall hazards and potentially serious hazards and safely continue operation for a period of at least five minutes following ingestions where there is no indication of need for immediate shutdown. Duration of the run following ingestion is intended to assure that the engine is not in a condition of imminent failure. In such cases, the engine output may often be at reduced levels. Following typical Group II ingestions, it is desirable that power recovery be accomplished readily to levels of about 50 percent or more.

c. When the use of protective inlets are elected by the applicant in lieu of ingestion testing of Group II foreign objects, it will be necessary to restrict the application of that engine to aircraft which provide acceptable inlet protection. The engine manufacturers' installation data, and, when deemed necessary, the engine type certificate data sheet should, therefore, indicate that a protective inlet is needed. The qualification of specific "protective" inlets for both normal function in the aircraft and ability to effectively exclude certain foreign objects is a part of aircraft certification.

George S. Moore
Director
Flight Standards Service