OBS

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ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

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

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. CANCELLATION. AC No. 33-1, effective June 24, 1965, is canceled.

3. CHANGES. Principal changes introduced in this revision are as follow:

   a. Hailstone specific gravity is now .8 to .9 which better represents natural hail. One-inch hail may be substituted for two-inch hail under certain test circumstances. Hail test quantities have been increased to more closely simulate hail encounters.

   b. Bird categories now include a medium weight bird of one to two pounds. Test quantities of medium and large birds have been revised to be more consistent with ingestion experience. Precautions are included if prefrozen birds are used for tests. An explanation of bird size and test quantities versus inlet sizes and bird flocking characteristics is included.

   c. Blade containment testing now includes consideration of cases at operating temperatures as pertinent to supersonic engines. Either complete engines or complete major engine components should be used in tests to insure realistic tests. A crew reaction time delay is specified if engine shutdown is necessary in tests. Blade containment criteria now includes consideration of hazardous case distortion and blade expulsion hazard to aircraft as being more realistic with actual experience.

   d. Water ingestion testing now includes tests at both cruise and take-off to cover possible critical points, and substantiation criteria of no flameouts is included as clarifying the intent.

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e. Substantiation criteria for power recovery levels after ingestion of airborne foreign objects is increased to 75 percent, except for four-pound birds, to be more consistent with ingestion experience and desired power levels after flock strikes.

4. REFERENCES. Federal Aviation Regulations 33.13 and 33.19.

5. 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 more than one factor, engine design appears to be the most important.

6. 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.

*7. DESIRABLE ENGINE DESIGN FEATURES. Experience has indicated that the following design features have generally minimized severe effects of foreign object ingestion and effectively increased safety: *

a. Front rotor blades, inlet and stator vanes material and design which minimize impact damage, severe deflections, tearing, and rupture.

b. Shrouded tips 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 and tear 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.

8. CLASSIFICATION OF TYPICAL FOREIGN OBJECTS. For the engine 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 failure * assumed in the retention member or in adjacent base sections if considered more likely to fail in service. While the majority of failures are expected to occur in the blade airfoil section, failures in or near the retention sections of the blade are also anticipated and are more difficult to contain in the engine. For integrally bladed rotors, failure of a significant portion * of a blade should be assumed. 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 may be ingested * by more than one engine of an aircraft on any one occasion. Since all engines of an aircraft, whether single or multiengine, may be affected by ingestions in the same flight, power recovery level is covered herein. Unless the specific installation, inlet design, or * other factors preclude the possibility of the ingestion of particular foreign objects, all of the following objects are applicable:

Group II.

(1) Water in the form of rain.

(2) Gravel of mixed sizes up 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 .8 to .9 specific gravity and of * one- and two-inch diameter.

(6) Birds in weight categories as follows:

(a) Small birds of two to four ounces (starlings).

* (b) Medium birds of one to two pounds (the common gulls, small * ducks, and pigeons).

* (c) Large birds of three to five pounds (geese, buzzards, and * largest gulls and ducks).

9. ACCEPTABLE MEANS OF COMPLIANCE.

a. In complying 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 10 to meet all of the substantiation criteria in paragraph 11. In lieu of planned official test, pertinent related development experience, service experience, and analyses are usually acceptable means of compliance for engine substantiation. Any 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.

b. Engine substantiation may be based on consideration of only those foreign objects which are known to cause the more severe effects rather than on all typical foreign objects indicated herein.

* c. Engines having closely spaced inlet guide vanes or air passage screens which can trap ingested debris may incur excessive gas temperature rises after ingestions, resulting in low power recovery. Whether power losses are caused by ingestion damage, or by air blockage from trapped birds or other debris, is immaterial as these conditions are undesirable, whatever the reason. *

* d. When demonstrating blade containment, substantiation should cover the effects on containment with rotor cases at the maximum temperatures reached in service. The objective is to demonstrate both single blade containment and that the possibility of secondary internal failures penetrating the engine cases is minimized. Lack of containment has occurred from the secondary balling-up action of internal engine debris. It is desired that demonstration of blade containment be accomplished with a complete engine but, when component testing is chosen, complete compressor and turbine rotor section assemblies should be used. *

10. SUBSTANTIATION TESTS.

a. Group I, Foreign Objects.

(1) Ingestion of Group I foreign objects except rotor blades while operating at maximum output. The typical objects being ingestion tested are normally introduced by dropping them into the inlet.

(2) Ingestion of broken rotor blades. Rotor blades are to be evaluated for both ingestion effects and containment, and 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. A representative delay in initiating engine shutdown is recommended after the first indication of a fault from engine instruments, following blade ingestion, to simulate crew reaction time.

b. Group II, Foreign Objects.

(1) General.

(a) Tests of engine front frames alone may be conducted, if desired, to substantiate this component for direct impact effects.

* (b) Damage resulting from ingesting airborne foreign objects could cause blade damage or failures and tolerance to this should be evaluated with an operating engine. *

(c) 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 characterisitics.

* (d) Bird sizes, weights, and quantities indicated for test purposes are based on ingestion experience. There are numerous instances reported of small bird and medium bird ingestions, both singly and in multiples. Large birds have been encountered singly in all but a very few instances. As bird flocks can be expected to include a range of bird sizes and weights, only a few of the heaviest of a given bird specie may be in any flock, lessening the probability of multiple large bird ingestions. It is anticipated, however, that engines with extremely large inlet areas (e.g., over 2,000 square inches) may more often encounter multiple ingestions of large birds. Both inlet opening width and overall area have a bearing on the probability of ingestion of given size birds and these factors, along with bird flocking density, were considered in selecting bird sizes and quantities. *

* (e) Duration of the engine running following ingestion of any Group II objects should be at least five 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. *

* (2) Hail Ingestion.

(a) Hail ingestion should be tested with operating engines. To simulate the effects of random strikes on different portions of the engine face, hailstones should be aimed at areas which could be the most critical for hail impact. The tests with two-inch hailstones may be omitted if the kinetic energy is as high for the one-inch hail stones tested. *

(b) With one-inch hailstones, ingest at the maximum cruising flight speed representative of the applicable type aircraft.

(c) With two-inch hailstones, ingest at the rough airspeed for cruise, climb, and descent for 15,000 feet altitude or lower, whichever is the highest speed representative of the applicable type aircraft. *

(d) Ingest the following test quantities sequenced at close intervals to simulate actual encounters. Test quantities suggested are either one 1-inch and one 2-inch hailstones for each 150 square inches or less of inlet area or, if only 1-inch hail is tested per paragraph (a) above, use two 1-inch hailstones. For engines of 100 square inches inlet area or less, only one 1-inch hailstone is applicable. *

(3) Water Ingestion. An acceptable water ingestion testing method simulates maximum rainfall in quantities up to approximately four percent of the engine weight airflow with engine operating at cruise and takeoff power levels. *

(4) Bird Ingestion. Bird ingestion tests using freshly killed birds and gun injection are preferable as actual strikes are closely simulated. Other acceptable techniques have been used which utilize previously frozen birds and injection means other than guns. If previously frozen birds are used, they should be completely thawed for the tests, and have normal moisture content. If frozen for appreciable periods, moisture content may be reduced below normal levels. Use of synthetic "birds" has been proposed and will be acceptable if the results of ingestion can be shown to be equivalent to ingesting actual birds. For testing impact effects, appropriate bird velocities indicated in the following paragraphs should be attained at the inlet while other ingestion effects may be sufficiently severe at somewhat lower bird velocities. *

(a) Small Birds. Ingest at typical takeoff flight speeds and engine output levels. Ingest one small bird for each 50 square inches of inlet area (or fraction thereof) if it can enter the inlet and reach the engine face. The maximum of birds to be ingested as a group need not exceed 16.

(b) Medium and Large Birds. Ingest at typical maximum climb speed and maximum continuous engine operating conditions for operation up to 8,000 feet altitude.

1. Ingest one medium bird of nominally 1½ pounds weight for each 150 square inches of inlet area (or fraction thereof) if it can enter the inlet and reach the engine face. The maximum number of birds to be ingested as a group need not exceed 10.

2. Ingest one large bird of nominally four pounds weight with one for each 2,000 square inches of inlet area (or fraction thereof) if it can enter the inlet and reach the engine face. *

(c) Birds should be introduced in random sequence, to simulate an encounter with a flock.

11. SUBSTANTIATION CRITERIA.

a. Rotor Blade Containment. The engine is acceptable if, during the ingestion tests, the damage from rotor blade failures is contained * by the engine, e.g., without causing (1) extreme hazards (2) significant case rupture or hazardous distortion of the engine casing and the expulsion of blades through and beyond the engine case in a manner which could cause hazard to the aircraft. *

b. Ingestion Hazards.

* (1) The engine is acceptable if ingestion tests of Group I and II objects are completed without extreme or catastrophic hazards occurring such as engine explosion, disintegration, or uncontrollable fire. It is acceptable that the engine may require * shutdown for safety reasons, but this should be readily indicated in a timely manner by excessive vibration or other direct operating evidence.

(2) The engine is acceptable if it demonstrates the ability to minimize overall hazards and potentially serious conditions resulting from ingestion of Group II (airborne) foreign objects, by * 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, and rapid engine recovery should be obtained. There should be no steady power loss or blowouts from the water ingestion test. Power recovery to stabilized operation following other Group II ingestions may be at reduced levels and the desired minimum level is 75 percent except for four-pound birds. For the four-pound birds, no specific power recovery level is established, although a useful power is desired.

* c. Limitations. If an engine cannot meet the criteria in b. above or when the use of protective inlets are elected by the applicant in lieu of ingestion testing Group II foreign objects, the engine should be used only in aircraft which provide acceptable inlet protection. The engine manufacturers' installation data and the engine type certificate 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 specified foreign objects is a part of aircraft certification. *

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