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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 A, effective June 19, 1968, is canceled.

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

   a. Broken rotor blade containment testing has been modified to emphasize testing with a complete engine with a special consideration for fan rotors and observing a delay period when shutting down after ingestion. With these changes the tests will more closely compare with actual operating conditions.

   b. Impact testing the engine nose fairing and all critical frontal areas of engines is indicated for hail and birds to cover realistic possibilities.

   c. A paragraph on ice ingestion testing is included for the first time.

   d. Tire tread is included as a Group I foreign object.

   e. Water ingestion testing is clarified to indicate a 3-minute ingestion period.

   f. Medium and large bird ingestion testing is stipulated to be conducted at takeoff engine output at initial climb speeds to simulate the most typical encounters.

   g. The medium bird ingestion rate is revised from 1/150 to 1/300 with a decreasing rate for more than 10 birds to correlate better with both large and small engines.

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h. Large bird ingestion is decreased to one bird as multiple ingestions are believed to be unlikely. An increased number of medium birds is substituted for multiple large bird testing in large engines. Freedom from catastrophic effects from 4-lb. bird ingestion is stressed without any reference to power recovery ability.

i. Rotor blade containment acceptance criteria now preclude expulsion of blades through the engine case or shield to reduce the possibility of secondary hazards to the aircraft.

j. The engine acceptability basis is clarified with a separate treatment of Group I versus Group II foreign object ingestion test results; attention is directed to possible hazards from water ingestion testing, and a statement is included to clarify acceptable results of hail and ice ingestion tests.

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. Front stage compressors (or fans) without entry guide vanes.

d. Blades which effectively mince birds upon contact.

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

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

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

h. 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) A piece of aircraft tire tread of length equal to the tread width of a representative size tire.

(5) Compressor and turbine rotor blades. The most critical single blade(s), usually of the largest size, with failure assumed in or adjacent to the outermost retention member. 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.

(6) Birds of 4 lbs. and over (geese, buzzards, largest gulls and ducks).

b. Foreign objects in Group II are those considered to be generally 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 and snow.

(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 several flights.

(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 follow:

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

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

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 tests, pertinent related development experience, service experience, and analyses are usually acceptable means of compliance for engine substantiation. Any special engine 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 ingestions 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, the objective is to demonstrate both single blade containment and that the probability of secondary internal failures penetrating the engine cases is minimized. Unacceptable consequences have occurred from the secondary balling-up action of internal engine debris when pieces were released with considerable energy. Some demonstration of blade containment should be accomplished with a complete engine to evaluate secondary effects of blade loss such as severe unbalance, balling-up of blade debris, and to determine blade fragment trajectories. In fan engines, the fan assembly may be tested separately for blade containment if it is agreed that fan blade or vane debris would not enter the compressor after a fan blade failure. Component tests with complete compressors or turbine sections are acceptable as backup tests. Substantiation should cover the effects on containment with rotor cases at the maximum temperatures reached in service.

10. SUBSTANTIATION TESTS.

a. Group I. Foreign Objects.

(1) Ingestion of Group I foreign objects except rotor blades and large birds while operating at maximum output. The typical objects being ingestion tested are normally introduced by dropping them into the inlet. It is desired that engine operation after ingestion be continued to determine whether

the engine is in a condition of imminent failure, particularly when some unbalance is present.

(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. excluding transient overspeeds. 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. If the engine continues to operate, observe a representative delay of about 15 seconds in initiating engine shutdown after the first indication of a fault from engine instruments following blade ingestion, to simulate crew reaction time and determine the short term effects of operation with this unbalance. Longer post-ingestion operation should be accomplished to determine the effects of questionable internal damage which may not be readily indicated by engine instruments.

(3) Ingestion of a 4-lb. bird. Ingest one large bird of at least 4 lbs. weight if it can enter the inlet and reach the engine face. Ingest at typical maximum climb speed with takeoff power output. Refer to paragraph 10b(5) for other details of bird test techniques.

b. Group II, Foreign Objects.

(1) General.

(a) The engine front face including the nose cone area should be tested to substantiate direct impact effects. This may be accomplished as component tests.

(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 characteristics.

(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. Ingestion testing the large bird is aimed primarily at substantiating direct impact effects. Ingestion testing of the smaller birds is aimed at substantiating the effects of bird masses. 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 including the nose fairing.

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

(c) With single two-inch hailstones, ingest at climb (or rough air) speed for up to 15,000 feet altitude, whichever is the highest speed with maximum continuous engine output. The tests with two-inch hailstones may be omitted if the kinetic energy developed with the one-inch hail tests is as high.

(d) For multiple hailstone testing, ingest the following test quantities sequenced at close intervals to simulate random encounters at climb (or rough air) speed and with maximum continuous power level. Test quantities suggested for

each 150 square inches or less of inlet area are either one 1-inch and one 2-inch hailstone or, if 1-inch hail is used in accordance with foregoing paragraph (c), use two 1-inch hailstones. For engines of 100 square inches inlet area or less, only one 1-inch hailstone is applicable.

(3) Ice Ingestion. Ice should be introduced into an engine operating at cruise conditions to simulate typical ice shedding from inlets and the engine front face because of possible delays in operating ice protection systems. Engine flameout tendencies, reignition, and power recovery capability should be evaluated.

(4) 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 stabilized cruise and sea level takeoff power levels for at least 3 minutes.

(5) 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, include all frontal areas considered to be critical and appropriate bird velocities indicated in the following paragraphs should be attained at the inlet. Other ingestion effects such as compressor stall or blowout 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 number of small birds to be ingested as a group need not exceed 16. Small bird testing may be omitted for large engines when it is agreed that medium birds will pass into the engine blading passages and result in a test of at least equal severity.

(b) Medium Birds. Ingest at typical initial climb speed with takeoff engine output. When medium birds can enter the inlet and reach the engine intake section, ingest one

bird for each 300 square inches (or fraction thereof) of intake area up to 3000 square inches, with additional medium birds at 1/3 of this rate for larger engines.

(c) Small and medium birds should be ingested in random sequence, dispersed over the inlet area, to simulate an encounter with a flock.

11. SUBSTANTIATION CRITERIA.

a. Rotor Blade Containment. The engine is acceptable if, during the tests, the damage from rotor blade failures is contained by the engine, e.g., without causing significant rupture or hazardous distortion of the engine casing and the expulsion of blades through or beyond the edge of the engine case or shield.

b. Ingestion Hazards.

(1) Group I Objects. The engine is acceptable if ingestion tests demonstrate freedom from engine explosion, disintegration, or uncontrollable fire. It is acceptable that the engine may require shutdown, but this should be indicated by excessive vibration or other direct operating evidence in a timely manner which would permit a safe shutdown.

(2) Group II Objects. The engine is acceptable if tests demonstrate freedom from the foregoing hazards and the ability to minimize overall hazards and potentially serious conditions, with the quantities and conditions indicated, 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 prompt engine recovery should be obtained. There should be no flameouts or significant sustained power loss from ice, hail, or water ingestion or hazardous effects from case contraction 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.

c. Limitations. If an engine has not met the criteria in b. above or when the use of protective inlets is elected by the applicant in lieu of ingestion testing Group II foreign objects, the engine should be used only with acceptable inlet protection. The engine manufacturers' installation data and the engine type certificate sheet should, therefore, indicate that a protective inlet is needed when none is incorporated in the engine. The qualification

of specific "protective" inlets for both normal function in the aircraft and ability to effectively exclude specified foreign objects is normally a part of aircraft certification.

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