U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Obsolete

Subject: DESIGN CONSIDERATIONS FOR MINIMIZING HAZARDS CAUSED BY UNCONTAINED TURBINE ENGINE AND AUXILIARY POWER UNIT ROTOR AND FAN BLADE FAILURES

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Change:

1. PURPOSE. This advisory circular (AC) sets forth a method of compliance with the requirements of §§ 23.903(b)(1), 25.901(d) and 25.903(d)(1) of the Federal Aviation Regulations (FAR) pertaining to design precautions taken to minimize the hazards to an airplane in the event of uncontained engine or auxiliary power unit (APU) rotor (compressor and turbine) failure and engine fan blade failures. It is for guidance and to provide a method of compliance that has been found acceptable. As with all AC material, it is not mandatory and does not constitute a regulation.

2. RELATED FAR SECTIONS. Sections 23.903(b)(1), 25.365(e)(1), 25.571(e)(2), (3), (4), 25.901(d) and 25.903(d)(1) of the FAR.

3. BACKGROUND. Although turbine engine and APU manufacturers are making efforts to reduce the probability of uncontained rotor and fan blade failures, service experience shows that uncontained compressor and turbine rotor and fan blade failures continue to occur. Failures have resulted in high velocity fragment penetration of fuel tanks, adjacent structures, fuselage, system components and other engines of the airplane. Since it is unlikely that uncontained rotor and fan blade failures can be completely eliminated, Parts 23 and 25 require that airplane design precautions be taken to protect the airplane from such events.

a. Uncontained gas turbine engine rotor failure statistics presented in Society of Automotive Engineers (SAE) Reports AIR 1537 and AIR 4003, "Report on Aircraft Engine Containment", cover two study periods, 1962 to 1975, and 1976 to 1983, respectively. During this time period (21 years total) there were 478 incidents of noncontained engine rotor failures reported for 768.2 million engine operating hours on commercial transport airplanes. The failures were due to high cycle fatigue, low cycle fatigue, material and manufacturing defects, rubbing against static parts and foreign object damage (FOD). The major cause of FOD was bird strikes which principally affected the fan sections of the high bypass ratio engines. It is noted that since 1975 the use of this engine type has increased from about 5 percent of the fleet hours to 23 percent of the total hours.

b. The statistics in the SAE studies indicate the existence of many different failure modes not readily apparent or predictable by failure analysis methods. Because of the variety of uncontained rotor and fan blade failures, it is difficult to analyze all possible failure modes and to provide protection to all areas. However, design considerations outlined in this AC provide guidelines for achieving the desired objective of minimizing the hazard to an airplane from uncontained rotor and fan blade failures. These guidelines, therefore, assume a rotor or fan blade failure will occur and that analysis of the effects or evaluation of this failure is necessary. These guidelines are based on service experience and tests but are not necessarily the only means available to the designer.

4. DEFINITIONS.

a. Rotor. Rotors include hubs, discs, rims, drums, seals, and spacers. Rotor failure does not include blade failures resulting from fractures within the blade, but does include blade separations resulting from failure of any of the aforementioned components.

b. Blade. Blades include fan, compressor and turbine blades.

c. Uncontained Failure. For the purpose of airplane evaluations in accordance with this AC, uncontained failure of a turbine engine is any failure which results in the escape of rotor or blade fragments from the engine that could result in a hazard. Rotor failures which are of concern are those where released fragments have sufficient energy to create a hazard to the airplane.

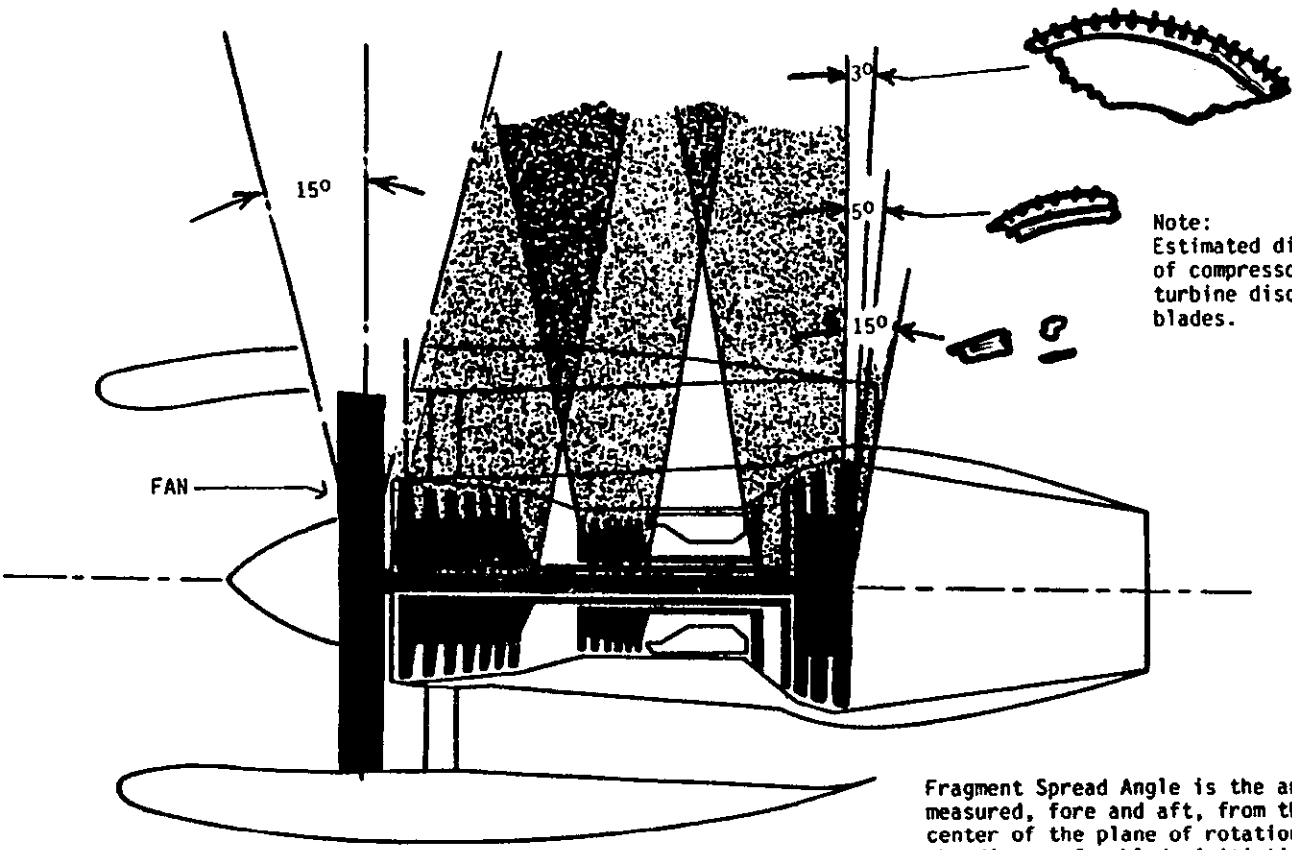
d. Critical Component. A critical component is any component (or system) whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the airplane. These components should be considered on an individual basis and in relation to other components which could be damaged by the same fragment or by other fragments at the same time.

e. Continued Safe Flight and Landing. Continued safe flight and landing means that the airplane is capable of continued controlled flight and landing, possibly using emergency procedures and without exceptional pilot skill or strength, after any failure which has not been shown to be extremely remote.

f. Fragment Spread Angle. The fragment spread angle is the angle measured, fore and aft from the center of the plane of rotation of the disc or fan blade, initiating at the engine or APU shaft centerline. (Refer to Figure 1)

FIGURE 1

ESTIMATED PATH OF FRAGMENTS



Note:
Estimated dispersion of compressor and turbine discs and blades.

Fragment Spread Angle is the angle measured, fore and aft, from the center of the plane of rotation of the disc or fan blade initiating at the engine or APU shaft centerline.

g. Impact Area.

(1) Rotor Failures. The impact area is that area likely to be impacted by uncontained rotor or disc rim segment fragments. Recorded observations of impact areas resulting from uncontained engine rotor failures show that heavy fragments tend to remain within a spread angle of ±3 degrees. Smaller fragments have been deflected at spread angles as much as ±15 degrees. Spread angles which should be considered in designs to minimize the hazards of uncontained rotor failures are ±3 degrees for the 1/3 disc sector with 1/3 of the blade length above the rim intact; ±5 degrees for other large fragments (3 bladed rim sector with blade root serrations); and ± 15 degrees for the smaller fragments (shrapnel).

(2) Fan Blade Failures. Service experience has shown that fan blade fragments have been contained initially by the engine but have been expelled from the plane of rotation of the fan in both the forward and aft directions. In forward trajectory failures, blade tip fragments have been expelled forward of the engine front flange and lodged in or penetrated the nacelle inlet or departed without contacting the nacelle inlet. In one aft trajectory failure incident, blade fragments lodged in the fan case wall, shearing a hydraulic line and impacting a main fuel line. The design impact area for fan blade fragments is within a spread angle of ±15 degrees.

(3) Auxiliary Power Unit. If an APU is installed which has not been shown to have rotor containment, the impact areas and spread angles identified above, along with the energy level of the uncontained fragments specified by the manufacturer, should be used. Even though rotor containment may have been demonstrated, a subjective review of the APU location and rotor failure consequences should be made to assure that the hazardous condition would not be created in the unlikely event of an uncontained APU rotor failure.

5. DESIGN CONSIDERATIONS. Practical design precautions should be used to minimize the damage that can be caused by uncontained engine and APU rotor and fan blade debris. The following design considerations are recommended:

a. Consider the location of the engine rotors and fan blades relative to critical components, APU systems or areas of the airplane such as:

(1) The other engine(s) on the same and/or opposite wing and engine(s) mounted on the aft fuselage and in the empennage;

(2) Pressurized sections of the fuselage and other primary structure of the fuselage, wings and empennage;

(3) Pilot compartment area (NOTE: Normally engine rotors and fans are not in line with the pilot compartment area. However, for turbine engine installations on Part 23 airplanes, satisfactory service experience relative to rotor and fan blade integrity and containment in similar engine installations can be considered in assessing the acceptability of installing engines in line with the pilot compartment area.);

(4) Fuel system components, piping and tanks including fuel tank access panels (NOTE: Spilled fuel into the engine or APU compartments, on engine cases or on other critical components or areas could create a fire hazard.);

(5) Essential or critical control systems, such as primary and secondary flight controls, electrical power cables, systems and wiring, hydraulic systems, engines control systems, flammable fluid shut-off valves, and the associated actuation wiring or cables;

(6) Engine and APU fire extinguisher systems including electrical wiring and fire extinguishing agent plumbing to engine compartments;

(7) Engine air inlet attachments and effects of engine case deformations caused by fan blade debris resulting in attachment bolt failures.

(8) Instrumentations essential for continued safe flight and landing.

b. Location of Critical Systems and Components. Critical airplane flight and engine control cables, wiring, flammable fluid carrying components and lines (including vent lines), hydraulic fluid lines and components, and pneumatic ducts should be located to minimize hazards caused by uncontained rotors and fan blade debris. The following design practices have been used:

(1) Locate, if possible, critical components or systems outside the likely debris impact areas.

(2) Duplicate and separate critical components or systems if located in debris impact areas or provide suitable protection.

(3) Protection of critical systems and components can be provided by using airframe structure where shown to be suitable.

(4) Locate fluid shutoffs so that flammable fluids can be isolated in the event of damage to the system. Design and locate the shut-off actuation means in protected areas.

(5) Minimize the flammable fluid spillage which could contact an ignition source.

(6) For airframe structural elements, provide redundant designs or crack stoppers to limit the subsequent tearing which could be caused by uncontained rotor or fan blade fragments.

(7) Consider the likely damage extent caused by multiple fragments (smaller fragments or shrapnel in the ±15 degree spread angle areas).

(8) Locate fuel tanks and other flammable fluid systems and route lines (including vent lines) behind airplane structure to reduce the hazards from spilled fuel or from tank penetrations. Fuel tank explosion-suppression materials, protective shields, as deflectors on the fluid lines have been used to minimize the likely damage and hazards.

c. External Shield and Deflectors. When shields, deflection devices or airplane structure are proposed to be used to protect systems or components, the adequacy of the protection should be shown by testing or analysis supported by test data, using the fragment energies suggested in paragraph 6.

d. Airplane Modifications. Modifications made to current certificated airplanes should not compromise the original airplane safety level relative to uncontained engine or APU rotor or fan blade failures. Examples are reengining installations, APU installations and auxiliary fuel tank installations.

6. FRAGMENT ENERGIES.

a. The energy level the designer needs to consider is that associated with the total mass in the 1/3 sector of a disk identified in paragraph 4g(1), at the critical rotating speed and translational velocity. This energy level would be the most severe in terms of catastrophic damage. Damage caused by these fragments can be minimized by the design considerations outlined in this AC.

b. Service experience primarily on high bypass engines without inlet guide vanes has shown that the engine can eject blade fragments beyond the engine case (forward and aft) even with a containment ring that remains intact. Some of the most severe incidents involved large blade tip fragments (up to 3 pounds) which spiral forward of the engine front flange. These fragments have velocities up to 900 feet per second. Another type of fragment is one that may be reingested and rebounds forward. These fragments shear and puncture at the point of impact. The fragments can weigh as much as 0.6 pounds and have velocities up to 400 feet per second. As previously noted, some occurrences have resulted in engine case penetration of basically full-sized fan blades aft of the engine containment ring.

c. The size and trajectory of the fragments vary with each particular engine design. The use of soft case containment systems, such as Kevlar, has changed the failure dynamics relative to fan blade failure events. Therefore, the engine installer should consider the engine manufacturer's data on fragment energies and trajectories in relation to the engine installation for the particular location on the airplane.

William J. Sullivan

Deputy Director of Airworthiness

U.S. Department
of Transportation

**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

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