U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: DESIGN CONSIDERATIONS FOR MINIMIZING HAZARDS CAUSED BY UNCONTAINED TURBINE ENGINE AND AUXILIARY POWER UNIT ROTOR FAILURE	**Date:** 3/25/97 **Initiated by:** ANM-110	**AC No:** 20-128A **Change:**

1. PURPOSE. This advisory circular (AC) sets forth a method of compliance with the requirements of §§ 23.901(f), 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 failures. The guidance provided within this AC is harmonized with that of the European Joint Aviation Authorities (JAA) and is intended 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. CANCELLATION. Advisory Circular 20-128, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures," dated March 9, 1988, is canceled.

3. APPLICABILITY. This AC applies to part 23 and part 25 airplanes (and airplanes type-certificated under predecessor parts 3 and 4b of the Civil Air Regulations) for which a new, amended, or supplemental type certificate is requested.

4. RELATED DOCUMENTS. Sections 23.903, and 25.903 of the FAR, as amended through Amendments 23-43 and 25-73 respectively, and other sections relating to uncontained engine failures.

NOTE: APPENDIX 1 provides additional guidance for completion of the numerical analysis requested in Paragraph 10 of this AC.

a. Related Federal Aviation Regulations. Sections which prescribe requirements for the design, substantiation and certification relating to uncontained engine debris include:

§ 23.863, 25.863	Flammable fluid fire protection
§ 25.365	Pressurized compartment loads
§ 25.571	Damage-tolerance and fatigue evaluation of structure

§ 25.963	Fuel tanks: general
§ 25.1189	Shutoff means
§ 25.1461	Equipment containing high energy rotors

(Note: An APU does not have its own type certificate and has been considered "equipment" installed on an airplane. As such, the provisions of § 25.1461 have occasionally been used in the approval of APU installations regardless of protection from high energy rotor disintegration. However, the more specific requirements of § 25.903(d)(1) and associated guidance described within this AC take precedence over the requirements of § 25.1461.)

b. Advisory Circulars (AC).

AC 25-8	Auxiliary Fuel System Installations
AC 25-20	Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight Including High Altitude Operations
AC 23-10	Auxiliary Fuel System Installations
AC 20-135	Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria (or the equivalent International Standard Order (ISO) 2685)
AC 25-571-1A	Damage Tolerance and Fatigue Evaluation of Structure

Advisory Circulars can be obtained from the U.S. Department of Transportation, M-443.2, Subsequent Distribution Unit, Washington, D.C. 20590.

c. Technical Standard Orders (TSO).

TSO C77a (or JAR APU)	Gas Turbine Auxiliary Power Units

Technical Standard Orders can be obtained from the Federal Aviation Administration (FAA), Aircraft Certification Service, Aircraft Engineering Division, Technical Analysis Branch (AIR-120), 800 Independence Ave. S.W., Washington, DC, 205921.

d. Society of Automotive Engineers (SAE) Documents.

AIR1537	Report on Aircraft Engine Containment, dated October, 1977.
AIR4003	Uncontained Turbine Rotor Events Data Period 1976 through 1983.
AIR4770 (Draft)	Uncontained Turbine Rotor Events Data Period 1984 through 1989.

These documents can be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

5. BACKGROUND. Although turbine engine and APU manufacturers are making efforts to reduce the probability of uncontained rotor failures, service experience shows that uncontained compressor and turbine rotor failures continue to occur. Turbine engine failures have resulted in high velocity fragment penetration of adjacent structures, fuel tanks, fuselage, system components and other engines on the airplane. While APU uncontained rotor failures do occur, and to date the impact damage to the airplane has been minimal, some rotor failures do produce fragments that should be considered. Since it is unlikely that uncontained rotor failures can be completely eliminated, parts 23 and 25 require that airplane design precautions be taken to minimize the hazard from such events.

a. Uncontained gas turbine engine rotor failure statistics are presented in the Society of Automotive Engineers (SAE) reports covering time periods and number of uncontained events listed in the table shown below. The following statistics summarize 28 years of service experience for fixed wing airplanes and do not include data for rotorcraft and APU's:

			No. of Events	
Report No.	Period	Total	Category 3	Category 4
AIR1537	1962-75	275	44	5
AIR4003	1976-83	237	27	3
AIR4770 (Draft)	1984-89	164	22	7
TOTAL		676	93	15

The total of 676 uncontained events includes 93 events classified in Category 3 and 15 events classified in Category 4 damage to the airplane. Category 3 damage is defined as significant airplane damage with the airplane capable of continuing flight and making a safe landing. Category 4 damage is defined as severe airplane damage involving a crash landing, critical injuries, fatalities or hull loss.

During this 28 year period there were 1,089.6 million engine operating hours on commercial transports. The events were caused by a wide variety of influences classed as environmental (bird ingestion, corrosion/erosion, foreign object damage (FOD)), manufacturing and material defects, mechanical, and human factors (maintenance and overhaul, inspection error and operational procedures).

b. Uncontained APU rotor failure statistics covering 1962 through 1993 indicate that there have been several uncontained failures in at least 250 million hours of operation on transport category airplanes. No Category 3 or 4 events were reported and all failures occurred during ground operation. These events were caused by a wide variety of influences such as corrosion, ingestion of deicing fluid, manufacturing and material defects, mechanical, and human factors (maintenance and overhaul, inspection error and operational procedures).

c. The statistics in the SAE studies indicate the existence of many different causes of failures not readily apparent or predictable by failure analysis methods. Because of the variety of causes of uncontained rotor failures, it is difficult to anticipate all possible causes of failure 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 failures. These guidelines, therefore, assume a rotor failure will occur and that analysis of the effects 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.

6. DEFINITIONS.

a. Rotor. Rotor means the rotating components of the engine and APU that analysis, test, and/or experience has shown can be released during uncontained failure. The engine or APU manufacturer should define those components that constitute the rotor for each engine and APU type design. Typically rotors have included, as a minimum, disks, hubs, drums, seals, impellers, blades and spacers.

b. Blade. The airfoil sections (excluding platform and root) of the fan, compressor and turbine.

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 fragments from the engine or APU 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 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 from the same uncontained event.

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, with conditions of considerably increased flightcrew workload and degraded flight characteristics of the airplane.

f. Fragment Spread Angle. The fragment spread angle is the angle measured, fore and aft from the center of the plane of rotation of an individual rotor stage, initiating at the engine or APU shaft centerline (see Figure 1).

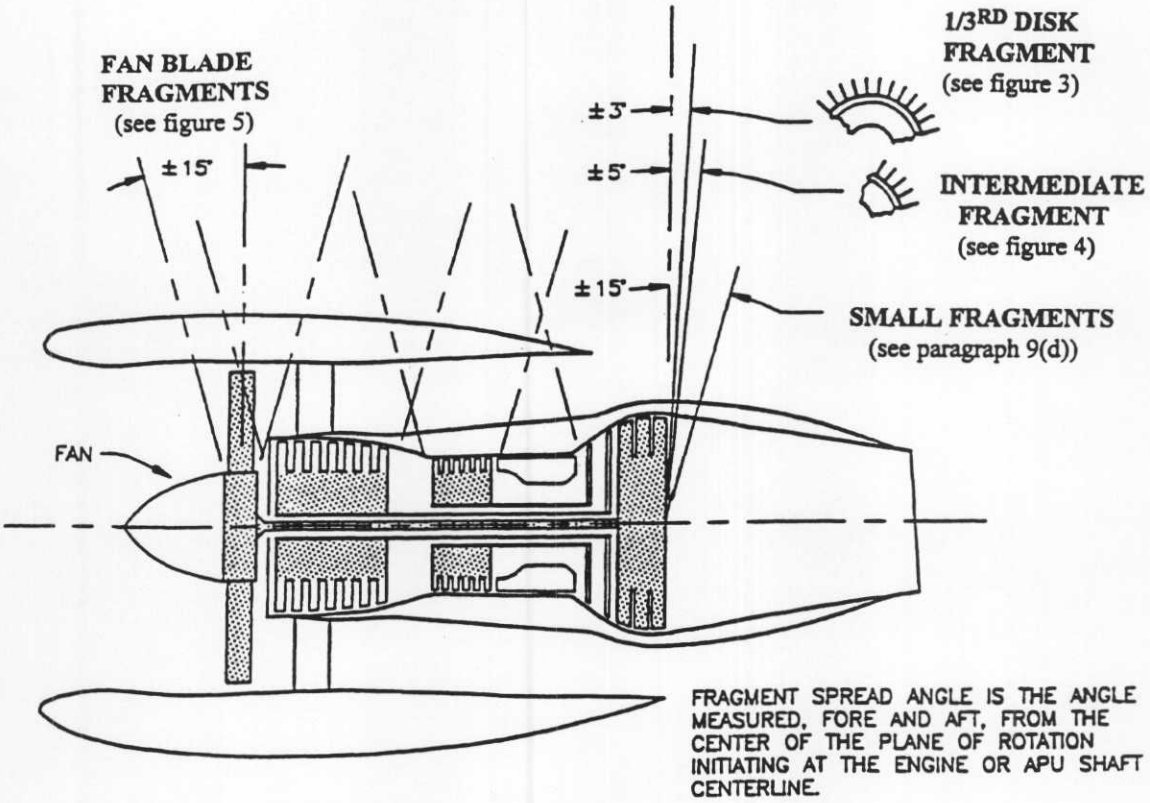


FIGURE 1 - ESTIMATED PATH OF FRAGMENTS

g. Impact Area. The impact area is that area of the airplane likely to be impacted by uncontained fragments generated during a rotor failure (see Paragraph 9).

h. Engine and APU Failure Model. A model describing the size, mass, spread angle, energy level and number of engine or APU rotor fragments to be considered when analyzing the airplane design is presented in Paragraph 9.

7. DESIGN CONSIDERATIONS. Practical design precautions should be used to minimize the damage that can be caused by uncontained engine and APU rotor fragments. The most effective methods for minimizing the hazards from uncontained rotor fragments include location of critical components outside the fragment impact areas or separation, isolation, redundancy, and shielding of critical airplane components and/or systems. The following design considerations are recommended:

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

(1) Any other engine(s) or an APU that provides an essential function;

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

(3) Pilot compartment areas;

(4) Fuel system components, piping and tanks;

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

(6) Any fire extinguisher system of a cargo compartment, an APU, or another engine including electrical wiring and fire extinguishing agent plumbing to these systems;

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

(8) Instrumentation essential for continued safe flight and landing;

(9) Thrust reverser systems where inadvertent deployment could be catastrophic; and

(10) Oxygen systems for high altitude airplanes, where these are critical due to descent time.

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 should be considered:

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

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

(3) Protection of critical systems and components can be provided by using airframe structure or supplemental shielding.

These methods have been effective in mitigating the hazards from both single and multiple small fragments within the ± 15 degree impact area. Separation of multiplicated critical systems and components by at least a distance equal to the 1/2 blade fragment dimension has been accepted for showing minimization from a single high energy small fragment when at least one of the related multiplicated critical components is shielded by significant structure such as aluminum lower wing skins, pylons, aluminum skin of the cabin pressure vessel, or equivalent structures.

Multiplicated critical systems and components positioned behind less significant structures should be separated by at least a distance equal to the 1/2 blade fragment dimension, and at least one of the multiplicated critical systems should be:

(i) Located such that equivalent protection is provided by other inherent structures such as pneumatic ducting, interiors, bulkheads, stringers, or

(ii) Protected by an additional shield such that the airframe structure and shield material provide equivalent shielding.

(4) Locate fluid shutoffs and actuation means so that flammable fluid can be isolated in the event of damage to the system.

(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 fragments.

(7) 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 or deflectors on the fluid lines, have been used to minimize the damage and hazards.

c. External Shields and Deflectors. When shields, deflection devices or airplane structure are proposed to be used to protect critical systems or components, the adequacy of the protection, including mounting points to the airframe structure, should be shown by testing or validated analyses supported by test data, using the fragment energies supplied by the engine or APU manufacturer or those defined in Paragraph 9. For protection against engine small fragments, as defined in Paragraph 9, no quantitative validation as defined in Paragraph 10 is required if equivalency to the penetration resistant structures listed (e.g. pressure cabin skins, etc.) is shown.

8. ACCEPTED DESIGN PRECAUTIONS. Design practices currently in use by the aviation industry that have been shown to reduce the overall risk, by effectively eliminating certain specific risks and reducing the remaining specific risks to a minimum level, are described within this paragraph of the AC. Airplane designs submitted for evaluation by the regulatory authorities will be evaluated against these proven design practices.

a. Uncontrolled Fire.

(1) Fire Extinguishing Systems. The engine/APU fire extinguishing systems currently in use rely on a fire zone with a fixed compartment air volume and a known air exchange rate to extinguish a fire. The effectiveness of this type of system along with firewall integrity may therefore be compromised for the torn/ruptured compartment of the failed engine/APU. Protection of the airplane following this type of failure relies on the function of the fire warning system and subsequent fire switch activation to isolate the engine/APU from airframe flammable fluid (fuel and hydraulic fluid) and external ignition sources (pneumatic and electrical). Fire extinguishing protection of such a compromised system may not be effective due to the extent of damage. Continued function of any other engine, APU or cargo compartment fire warning and extinguisher system, including electrical wiring and fire extinguishing agent plumbing, should be considered as described in Paragraph 7.

(2) Flammable Fluid Shutoff Valve. As discussed above, shutoff of flammable fluid supply to the engine may be the only effective means to extinguish a fire following an uncontained failure, therefore the engine isolation/flammable fluid shutoff function should be assured following an uncontained rotor failure. Flammable fluid shutoff valves should be located outside the uncontained rotor impact area. Shutoff actuation controls that need to be routed through the impact area should be redundant and appropriately separated in relation to the one-third disc maximum dimension.

(3) Fire Protection of Critical Functions. Flammable fluid shutoff and other critical controls should be located so that a fire (caused by an uncontained rotor event) will not prevent actuation of the shutoff function or loss of critical airplane functions. If shutoff or other critical controls are located where a fire is possible following an uncontained rotor failure (e.g. in compartments adjacent to fuel tanks) then these items should meet the applicable fire protection guidelines such as AC 20-135, "Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria" or the equivalent International Standard Order (ISO) 2685.

(4) Fuel Tanks. If fuel tanks are located in impact areas, the following precautions should be implemented:

(i) Protection from the effects of fuel leakage should be provided for any fuel tanks located above an engine or APU and within the one-third disc and intermediate fragment impact areas. Dry bays or shielding are acceptable means. The dry bay should be sized based on analysis of possible fragment trajectories through the fuel tank wall and the subsequent fuel leakage from the damaged fuel tank so that fuel will not migrate to an engine, APU or other ignition source during either in flight or ground operation. A minimum drip clearance distance of 10 inches from potential ignition sources of the engine nacelle, for static conditions, is acceptable (see Figure 2).

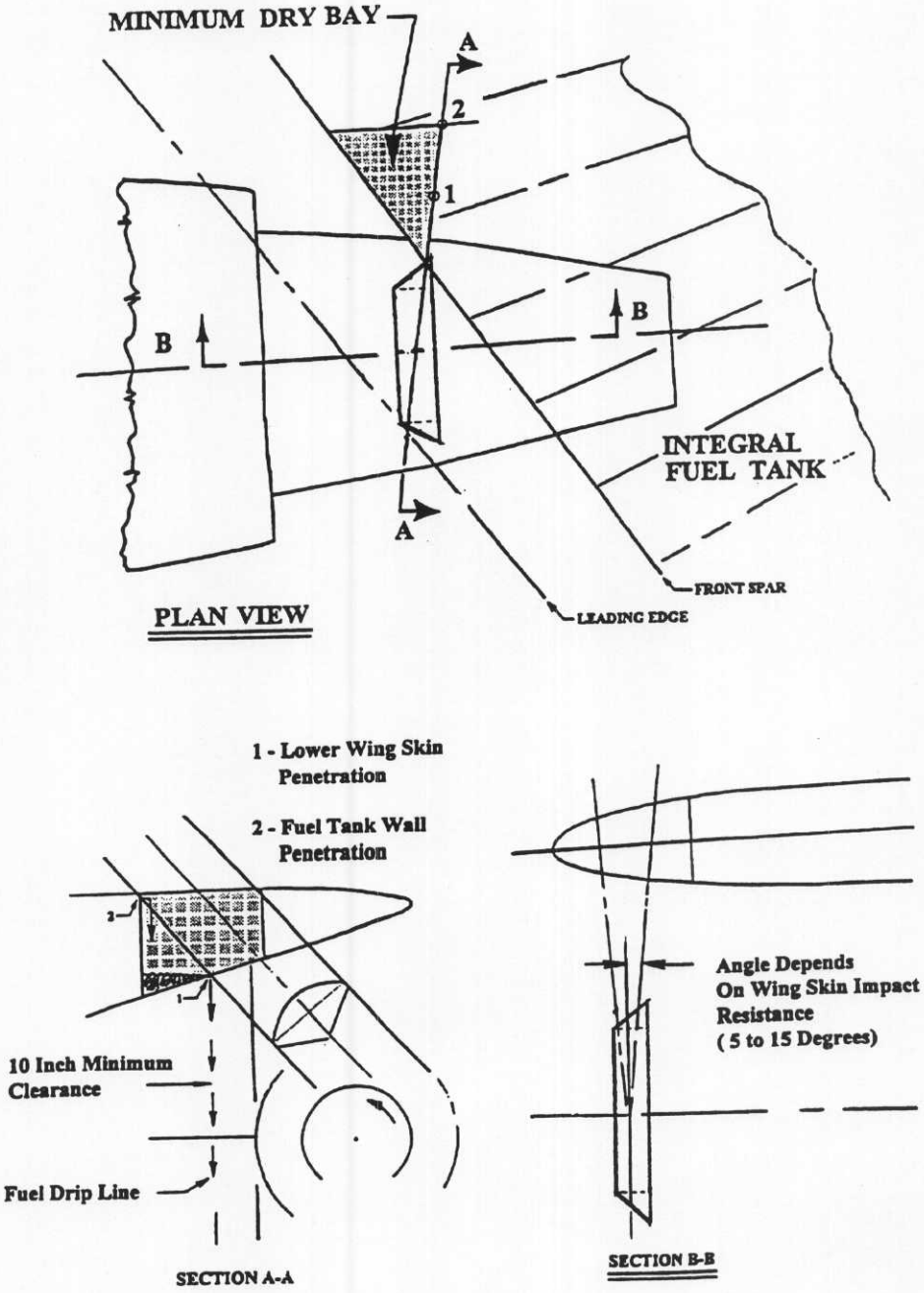


FIGURE 2- DRY BAY SIZING DETERMINATION EXAMPLE

(ii) Fuel tank penetration leak paths should be determined and evaluated for hazards during flight and ground phases of operation. If fuel spills into the airstream away from the airplane no additional protection is needed. Additional protection should be considered if fuel could spill, drain or migrate into areas housing ignition sources, such as engine or APU inlets or wheel wells. Damage to adjacent systems, wiring etc., should be evaluated regarding the potential that an uncontained fragment will create both an ignition source and fuel source. Wheel brakes may be considered as an ignition source during takeoff and initial climb. Protection of the wheel wells may be provided by airflow discharging from gaps or openings, preventing entry of fuel, a ventilation rate precluding a combustible mixture or other provisions indicated in §§ 23.863 and 25.863.

(iii) Areas of the airplane where flammable fluid migration is possible that are not drained and vented and have ignition sources or potential ignition sources should be provided with a means of fire detection and suppression and be explosion vented or equivalently protected.

b. Loss of Thrust.

(1) Fuel Reserves. The fuel reserves should be isolatable such that damage from a disc fragment will not result in loss of fuel required to complete the flight or a safe diversion. The effects of fuel loss, and the resultant shift of center of gravity or lateral imbalance on airplane controllability should also be considered.

(2) Engine Controls. Engine control cables and/or wiring for the remaining powerplants that pass through the impact area should be separated by a distance equal to the maximum dimension of a one-third disc fragment or the maximum extent possible.

(3) Other Engine Damage. Protection of any other engines from some fragments should be provided by locating critical components, such as engine accessories essential for proper engine operation (e.g., high pressure fuel lines, engine controls and wiring, etc.), in areas where inherent shielding is provided by the fuselage, engine or nacelle (including thrust reverser) structure (see Paragraph 7).

c. Loss of Airplane Control.

(1) Flight Controls. Elements of the flight control system should be adequately separated or protected so that the release of a single one-third disc fragment will not cause loss of control of the airplane in any axis. Where primary flight controls have duplicated (or multiplicated) elements, these elements should be located to prevent all elements in any axis being lost as a result of the single one-third disc fragment. Credit for maintaining control of the

airplane by the use of trim controls or other means may be obtained, providing evidence shows that these means will enable the pilot to retain control.

(2) Emergency Power. Loss of electrical power to critical functions following an uncontained rotor event should be minimized. The determination of electrical system criticality is dependent upon airplane operations. For example, airplanes approved for Extended Twin Engine Operations (ETOPS) that rely on alternate power sources such as hydraulic motor generators or APUs may be configured with the electrical wiring separated to the maximum extent possible within the one-third disc impact zone.

(3) Hydraulic Supply. Any essential hydraulic system supply that is routed within an impact area should have means to isolate the hydraulic supply required to maintain control of the airplane. The single one-third disc should not result in loss of all essential hydraulic systems or loss of all flight controls in any axis of the airplane.

(4) Thrust reverser systems. The effect of an uncontained rotor failure on inadvertent in-flight deployment of each thrust reverser and possible loss of airplane control shall be considered. The impact area for components located on the failed engine may be different from the impact area defined in Paragraph 6. If uncontained failure could cause thrust reverser deployment, the engine manufacturer should be consulted to establish the failure model to be considered. One acceptable method of minimization is to locate reverser restraints such that not all restraints can be made ineffective by the fragments of a single rotor.

d. Passenger and Crew Incapacitation.

(1) Pilot Compartment. The pilot compartment of transport category airplanes should not be located within the ±15 degree spread angle of any engine rotor stage or APU rotor stage that has not been qualified as contained, unless adequate shielding, deflectors or equivalent protection is provided for the rotor stage in accordance with Paragraph 7c. Due to design constraints inherent in smaller Par 25 airplanes it is not considered practical to locate the pilot compartment outside the ±15 degree spread angle. Therefore, for other airplanes (such as new part 23 commuter category airplanes) the pilot compartment area should not be located within the ±5 degree spread angle of any engine rotor stage or APU rotor stage unless adequate shielding, deflectors, or equivalent protection is provided for the rotor stage in accordance with Paragraph 7c of this AC, except for the following:

(i) For derivative part 23 category airplanes where the engine location has been previously established, the engine location in relation to the pilot compartment need not be changed.

(ii) For noncommuter part 23 category airplanes, satisfactory service experience relative to rotor integrity and containment in similar engine installations may be considered in assessing the acceptability of installing engines in line with the pilot compartment.

(iii) For noncommuter new part 23 category airplanes, where due to size and/or design considerations the ±5 degree spread angle cannot be adhered to, the pilot compartment/engine location should be analyzed and accepted in accordance with Paragraphs 9 and 10.

(2) Pressure Vessel. For airplanes that are certificated for operation above 41,000 feet, the engines should be located such that the pressure cabin cannot be affected by uncontained debris. Alternatively, it may be shown that rapid decompression due to the maximum hole size caused by debris and the associated cabin pressure decay rate will allow an emergency descent without incapacitation of the flightcrew or passengers. A pilot reaction time of 17 seconds for initiation of the emergency decent has been accepted. Where the pressure cabin could be affected by a one-third disc or intermediate fragments, design precautions should be taken to preclude incapacitation of crew and passengers. Examples of design precautions that have been previously accepted are:

(i) Provisions for a second pressure or bleed down bulkhead outside the impact area of a one-third or intermediate disc fragment.

(ii) The affected compartment in between the primary and secondary bulkhead was made inaccessible, by operating limitations, above the minimum altitude where incapacitation could occur due to the above hole size.

(iii) Air supply ducts running through this compartment were provided with nonreturn valves to prevent pressure cabin leakage through damaged ducts.

NOTE: If a bleed down bulkhead is used it should be shown that the rate of pressure decay and minimum achieved cabin pressure would not incapacitate the crew, and the rate of pressure decay would not preclude a safe emergency descent. Further guidance regarding compliance with the high altitude operations requirements is provided in AC 25-20, "Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight Including High Altitude Operations."

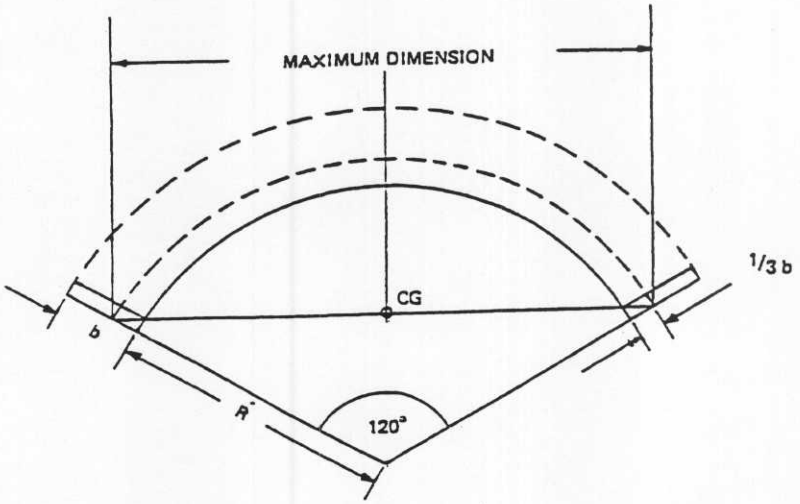
e. Structural Integrity. Installation of tear straps and shear ties within the uncontained fan blade and engine rotor debris zone to prevent catastrophic structural damage has been utilized to address this threat.

9. ENGINE AND APU FAILURE MODEL. The safety analysis recommended in Paragraph 10 should be made using the following engine and APU failure model, unless for the particular

engine/APU type concerned, relevant service experience, design data, test results or other evidence justify the use of a different model.

a. Single One-Third Disc fragment. It should be assumed that the one-third disc fragment has the maximum dimension corresponding to one-third of the disc with one-third blade height and a fragment spread angle of ± 3 degrees. Where energy considerations are relevant, the mass should be assumed to be one-third of the bladed disc mass and its energy, the translational energy (i.e., neglecting rotational energy) of the sector traveling at the speed of its c.g. location as defined in Figure 3.

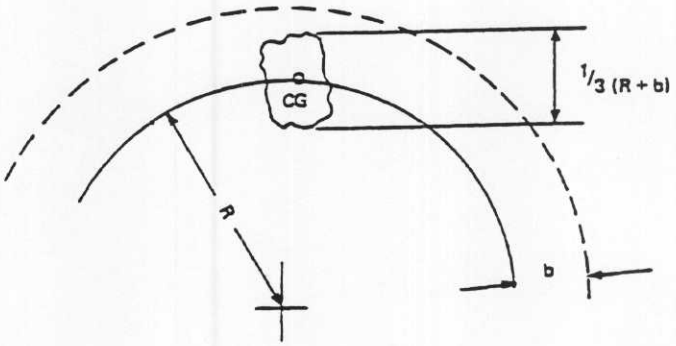
b. Intermediate Fragment. It should be assumed that the intermediate fragment has a maximum dimension corresponding to one-third of the bladed disc radius and a fragment spread angle of ± 5 degrees. Where energy considerations are relevant, the mass should be assumed to be 1/30 of the bladed disc mass and its energy the transitional energy (neglecting rotational energy) of the piece traveling at rim speed (see Figure 4).



Where R = disc radius
b = blade length

The CG is taken to lie on the maximum dimension as shown.

FIGURE 3 - SINGLE ONE-THIRD ROTOR FRAGMENT



Where R = disc radius
b = blade length

Maximum dimension = ⅓ (R + b)

Mass assumed to be 1/30th of bladed disc

CG is taken to lie on the disc rim

FIGURE 4 - INTERMEDIATE FRAGMENT

c. Alternative Engine Failure Model. For the purpose of the analysis, as an alternative to the engine failure model of Paragraphs 9a and b, the use of a single one-third piece of disc having a fragment spread angle ± 5° would be acceptable, provided the objectives of Paragraph 10a are satisfied.

d. Small Fragments. It should be assumed that small fragments (shrapnel) range in size up to a maximum dimension corresponding to the tip half of the blade airfoil (with exception of fan blades) and a fragment spread angle of ± 15 degrees. Service history has shown that aluminum lower wing skins, pylons, and pressure cabin skin and equivalent structures typically resist penetration from all but one of the most energetic of these fragments. The effects of multiple small fragments should also be considered. Penetration of less significant structures such as fairings, empennage, control surfaces and unpressurized skin has typically occurred at the rate of 2 1/2 percent of the number of blades of the failed rotor stage. Refer to paragraph 7b and 7c for methods of minimization of the hazards. Where the applicant wishes to show compliance by considering the energy required for penetration of structure (or shielding) the engine manufacturer should be consulted for guidance as to the size and energy of small fragments within the impact area.

For APUs, where energy considerations are relevant, it should be assumed that the mass will correspond to the above fragment dimensions and that it has a translational energy level of one percent of the total rotational energy of the original rotor stage.

e. Fan Blade Fragment. It should be assumed that the fan blade fragment has a maximum dimension corresponding to the blade tip with one-third the blade airfoil height and a fragment spread angle of ± 15°. Where energy considerations are relevant the mass should be assumed to be corresponding to the one-third of the airfoil including any part span shroud and the transitional energy (neglecting rotational energy) of the fragment traveling at the speed of its c.g. location as defined in Figure 5. As an alternative, the engine manufacturer may be consulted for guidance as to the size and energy of the fragment.

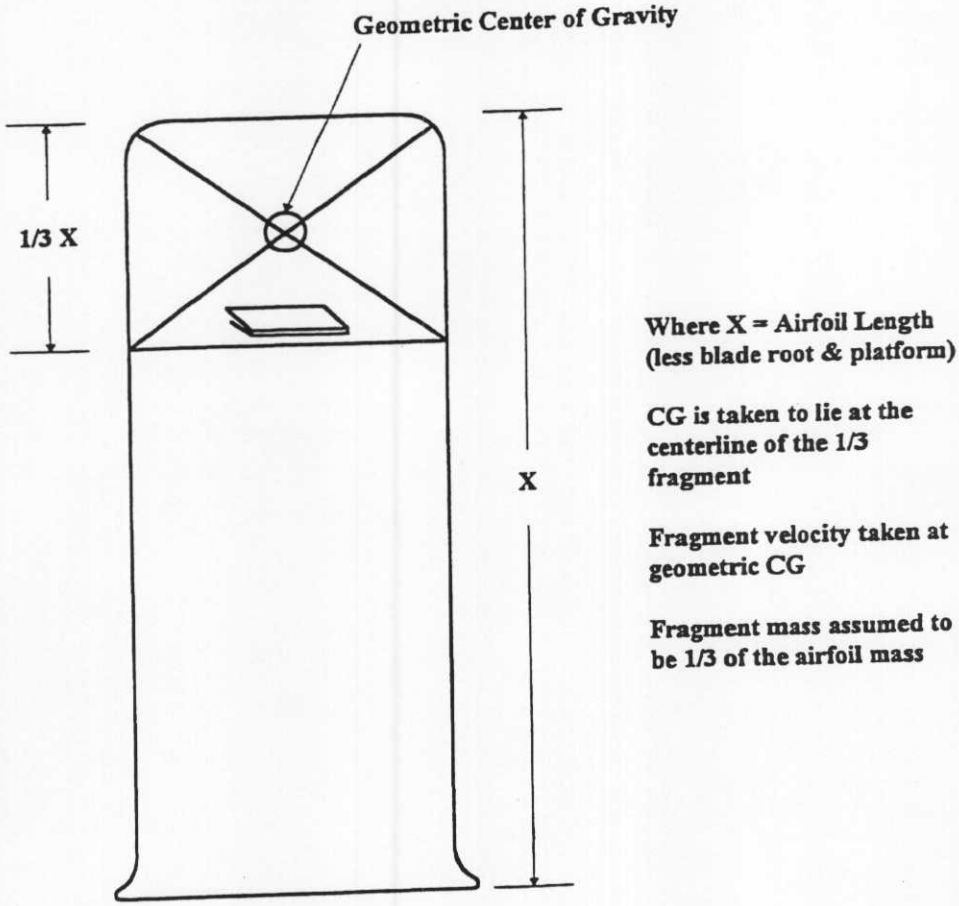


FIGURE 5 - FAN BLADE FRAGMENT DEFINITION

f. Critical Engine Speed. Where energy considerations are relevant, the uncontained rotor event should be assumed to occur at the engine or APU shaft red line speed.

g. APU Failure Model. For all APU's, the installer also needs to address any hazard to the airplane associated with APU debris (up to and including a complete rotor where applicable) exiting the tailpipe. Paragraphs 9g(1) or (2) below or applicable service history provided by the APU manufacturer may be used to define the size, mass, and energy of debris exiting that tailpipe. The APU rotor failure model applicable for a particular APU installation is dependent upon the provisions of the Technical Standard Orders (TSO) that were utilized for receiving approval:

(1) For APU's where rotor integrity has been demonstrated in accordance with TSO C77a/JAR APU, i.e. without specific containment testing, Paragraphs 9a, b, and d, or Paragraphs 9c and 9d apply.

(2) For APU rotor stages qualified as contained in accordance with the TSO, historical data shows that in-service uncontained failures have occurred. These failure modes have included bi-hub, overspeed, and fragments missing the containment ring which are not addressed by the TSO containment test. In order to address these hazards, the installer should use the APU small fragment definition of Paragraph 9d or substantiated in-service data supplied by the APU manufacturer.

10. SAFETY ANALYSIS

The numerical assessment requested in paragraph 10 (c)(3) is derived from methods previously prescribed in ACJ 25.903. The hazard ratios provided are based upon evaluation of various configurations of transport category airplanes, made over a period of time, incorporating practical methods of minimizing the hazard to the airplane from uncontained engine debris.

a. Analysis. An analysis should be made using the engine/APU model defined in Paragraph 9 to determine the critical areas of the airplane likely to be damaged by rotor debris and to evaluate the consequences of an uncontained failure. This analysis should be conducted in relation to all normal phases of flight, or portions thereof.

(1) A delay of at least 15 seconds should be assumed before start of the emergency engine shut down. The extent of the delay is dependent upon circumstances resulting from the uncontained failure including increased flightcrew workload stemming from multiplicity of warnings which require analysis by the flightcrew.

(2) Some degradation of the flight characteristics of the airplane or operation of a system is permissible, provided the airplane is capable of continued safe flight and landing.

Account should be taken of the behavior of the airplane under asymmetrical engine thrust or power conditions together with any possible damage to the flight control system, and of the predicted airplane recovery maneuver.

(3) When considering how or whether to mitigate any potential hazard identified by the model, credit may be given to flight phase, service experience, or other data, as noted in Paragraph 7.

b. Drawings. Drawings should be provided to define the uncontained rotor impact threat relative to the areas of design consideration defined in Paragraphs 7a(1) through (10) showing the trajectory paths of engine and APU debris relative to critical areas. The analysis should include at least the following:

(1) Damage to primary structure including the pressure cabin, engine/APU mountings and airframe surfaces.

NOTE: Any structural damage resulting from uncontained rotor debris should be considered catastrophic unless the residual strength and flutter criteria of AC 25.571, Paragraph 8(c), can be met without failure of any part of the structure essential for completion of the flight. In addition, the pressurized compartment loads of § 25.365(e)(1) and (g) must be met.

(2) Damage to any other engines (the consequences of subsequent uncontained debris from the other engine(s), need not be considered).

(3) Damage to services and equipment essential for safe flight and landing (including indicating and monitoring systems), particularly control systems for flight, engine power, engine fuel supply and shut-off means and fire indication and extinguishing systems.

(4) Pilot incapacitance, (see also paragraph 8 d(1)).

(5) Penetration of the fuel system, where this could result in the release of fuel into personnel compartments or an engine compartment or other regions of the airplane where this could lead to a fire or explosion.

(6) Damage to the fuel system, especially tanks, resulting in the release of a large quantity of fuel.

(7) Penetration and distortion of firewalls and cowling permitting a spread of fire.