

Task Assignment

Aviation Rulemaking Advisory Committee; Transport Airplane and Engine Subcommittee; Installation Harmonization Working Group

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of establishment of installation harmonization working group.

SUMMARY: Notice is given of the establishment of the Installation Harmonization Working Group of the Transport Airplane and Engine Subcommittee. This notice informs the public of the activities of the Transport Airplane and Engine Subcommittee of the Aviation Rulemaking Advisory Committee.

FOR FURTHER INFORMATION CONTACT: Mr. William J. (Joe) Sullivan, Executive Director, Transport Airplane and Engine Subcommittee, Aircraft Certification Service (AIR-3), 800 Independence Avenue SW., Washington, DC 20591, Telephone: (202) 267-9554; FAX: (202) 267-5364.

SUPPLEMENTARY INFORMATION: The Federal Aviation Administration (FAA) established an Aviation Rulemaking Advisory Committee (56 FR 2190, January 22, 1991) which held its first meeting on May 23, 1991 (56 FR 20492, May 3, 1991). The Transport Airplane and Engine Subcommittee was established at that meeting to provide advice and recommendations to the Director, Aircraft Certification Service, FAA regarding the airworthiness standards for transport airplanes, engines and propellers in parts 25, 33, and 35 of the Federal Aviation Regulations (14 CFR parts 25, 23 and 35).

The FAA announced at the Joint Aviation Authorities (JAA)-Federal Aviation Administration (FAA) Harmonization Conference in Toronto, Ontario, Canada, (June 2-5, 1992) that it would consolidate within the Aviation Rulemaking Advisory Committee structure an ongoing objective to "harmonize" the Joint Aviation Requirements (JAR) and the Federal Aviation Regulations (FAR). Coincident with that announcement, the FAA assigned to the Transport Airplane and Engine Subcommittee those projects related to JAR/FAR 25, 33 and 35 harmonization which were then in the process of being coordinated between the JAA and the FAA. The harmonization process included the intention to present the results of JAA/FAA coordination to the public in the form of either a Notice of Proposed Rulemaking or an advisory circular—an

objective comparable to and compatible with the assigned to the Aviation Rulemaking Advisory Committee. The Transport Airplane and Engine Subcommittee, consequently, established the Installation Harmonization Working Group.

Specifically, the Working Group's tasks are the following:

The Installation Harmonization Working Group is charged with making recommendations to the Transport Airplane and Engine Subcommittee concerning the FAA disposition of the following subjects recently coordinated between the JAA and FAA:

Task 1—Installations (Engines): Develop recommendations concerning new or revised requirements for the installation of engines on transport category airplanes and determine the relationship, if any, of the requirements of FAR 25.1309 to these engine installations (FAR 25.901).

Task 2—Windmilling Without Oil: Determine the need for requirements for turbine engine windmilling without oil (FAR 25.903).

Task 3—Non-contained Failures: Revise advisory material on non-contained engine failure requirements (FAR 25.903 and related provisions of FAR Parts 23, 27, 29, 33, and 35, as appropriate; AC 20-128). The working group should draw members for this task from the interests represented by the General Aviation and Business Airplane, and Rotorcraft Subcommittees.

Task 4—Thrust Reversing Systems: Develop recommendations concerning new or revised requirements and guidance material for turbojet engine thrust reversing systems (FAR 25.933).

Reports:

A. Recommend time line(s) for completion of each task, including rationale, for Subcommittee consideration at the meeting of the subcommittee held following publication of this notice.

B. Give a detailed conceptual presentation on each task to the Subcommittee before proceeding with the work stated under items C and D, below. If tasks 1, 2, and 4 require the development of more than one Notice of Proposed Rulemaking, identify what proposed amendments will be included in each notice.

C. Draft a Notice of Proposed Rulemaking for tasks 1, 2 and 4 proposing new or revised requirements, a supporting economic analysis, and other required analysis, with any other collateral documents (such as Advisory Circulars) the Working Group determines to be needed.

D. Draft a change to Advisory Circular 120-128 for task 3 providing appropriate advisory material for each task. When the detailed briefing under item B, above, and this report are presented to the subcommittee, the Subcommittee and Working Group Chairs should arrange for a joint meeting with the General Aviation and Business Airplane and Rotorcraft Subcommittees to consider and join in the consensus on the results of those reports.

E. Give a status report on each task at each meeting of the Subcommittee.

The Installation Harmonization Working Group will be comprised of experts from those organizations having an interest in the tasks assigned. A Working Group member need not necessarily be a representative of one of the organizations of the parent Transport Airplane and Engine Subcommittee or of the full Aviation Rulemaking Advisory Committee. An individual who has expertise in the subject matter and wishes to become a member of the Working Group should write the person listed under the caption **FOR FURTHER INFORMATION CONTACT** expressing that desire, describing his or her interest in the task, and the expertise he or she would bring to the Working Group. The request will be reviewed with the Subcommittee and Working Group Chairs and the individual will be advised whether or not the request can be accommodated.

The Secretary of Transportation has determined that the information and use of the Aviation Rulemaking Advisory Committee and its subcommittees are necessary in the public interest in connection with the performance of duties of the FAA by law. Meetings of the full Committee and any subcommittees will be open to the public except as authorized by section 10(d) of the Federal Advisory Committee Act. Meetings of the Installation Harmonization Working Group will not be open to the public except to the extent that individuals with an interest and expertise are selected to participate. No public announcement of Working Group meetings will be made.

Issued in Washington, DC, on December 4, 1992.

William J. Sullivan,
Executive Director, Transport Airplane and Engine Subcommittee, Aviation Rulemaking Advisory Committee.

[FR Doc. 92-30118 Filed 12-10-92; 8:45 am]

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Recommendation Letter

August 8, 1995
B-T000-ARAC-95-006

Gerald R. Mack
Director
Certification &
Government Requirements

Boeing Commercial Airplane Group
P.O. Box 3707, MS 67-UM
Seattle, WA 98124-2207

Mr. Anthony J. Broderick
Associate Administrator for Regulations and Certification, (AVR-1)
Department of Transportation
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington DC 20591
Tele: (202) 267-3131
Fax: (202) 267-5364

Dear Mr. Broderick:

On behalf of the Aviation Rulemaking Advisory Committee, I am pleased to submit the enclosed recommendations for publication on the following subjects:

AC 20.128A Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure

AC 29.2A Advisory Material for Compliance with Rotor Burst Rule

The enclosed packages are in the form of final draft ACs. The packages were developed by the Powerplant Installation Harmonization Working Group chaired by Bruce Honsberger of Boeing and Wim Overmars of Fokker. The membership of the group is a good balance of interested parties in the U.S. and Europe. This group can be made available if needed for docket review.

The members of ARAC appreciate the opportunity to participate in the FAA rulemaking process and fully endorse these recommendations.

Sincerely,



Gerald R. Mack
Assistant Chairman
Transport Airplane & Engine Issues Group
Aviation Rulemaking Advisory Committee
Tele: (206) 234-9570, Fax: 237-0192, Mailstop: 67-UM

Enclosure

cc: M. Borfitz (617) 238-7199
B. Honsberger 67-UW
S. Miller (206) 227-1100
W. Overmars 31-206052895

BOEING

Acknowledgement Letter



U.S. Department
of Transportation
**Federal Aviation
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800 Independence Ave., S.W.
Washington, D.C. 20591

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SEP 18 1995

Mr. Gerald R. Mack
Aviation Rulemaking Advisory Committee
Boeing Commercial Airplane Group
P.O. Box 3707, M/S 67-UM
Seattle, WA 98124-2207

Dear Mr. Mack:

Thank you for your August 8 letter forwarding the Aviation Rulemaking Advisory Committee's (ARAC) recommendations in the form of two advisory circulars: Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure; and Advisory Material for Compliance with Rotor Burst Rule.

I want to thank the aviation community for its commitment to ARAC and its expenditure of resources to develop the recommendations. We in the Federal Aviation Administration pledge to process the documents expeditiously as high-priority actions.

Again, let me thank ARAC, and particularly the Powerplant Installation Harmonization Working Group, for its dedicated efforts in completing this task.

Sincerely,

Anthony J. Broderick
Associate Administrator for
Regulation and Certification

MAR 15 2000 *

Mr. Craig Bolt
Assistant Chair, Transport Airplanes
and Engines Issues Group
400 Main Street
East Hartford, CT 06108

Dear Mr. Bolt:

This letter acknowledges receipt of the following working group technical reports that you have submitted on behalf of the Aviation Rulemaking Advisory Committee (ARAC) on Transport Airplane and Engine Issues (TAE):

Date of Letter	Task No.	Description of Recommendation	Working Group
12/14/00	1, 2, 3	Fast track reports addressing §§ 25.703(a) thru (c) (takeoff warning system); 25.1333(b) (instrument systems; and 25.1423(b) (public address system)	ASHWG ✓
12/17/00	5	Fast track reports addressing §§ 25.111(c)(4), 25.147, controllability in 1-engine inoperative condition; 25.161 (c) (2) and (4), and (e) (longitudinal trim and airplanes with 4 or more engines) 25.175(d) (static longitudinal stability; 25.177(a)(b) (static lateral-directional stability); 25.253(a)(3) (high speed characteristics); 25.1323(c) (airspeed indicating system); 25.1516 (landing gear speeds); 25.1527 (maximum operating altitude); 25.1583(c) and (f) operating limitations) 25.1585 (operating procedures); and 25.1587 (performance information)	FTHWG ✓
12/17/00	7	Fast track report addressing § 25.903(e) (inflight engine failures)	PPIHWG ✓

12/20/00	5	Fast track reports addressing §§ 25.1103 (auxiliary power units); 25.933(a) (thrust reversers); 25.1189 (shutoff means); 25.1141 (powerplant controls); 25.1093 (air intake/induction systems); 25.1091 (air intake system icing protection); 25.943 (thrust reverser system tests); 25.934 (negative acceleration); 25.905(d) (propeller blade debris); 25.903(d)(1) (engine case burn-through); 25.901(d) (auxiliary power unit installation); and 1.1 (general definitions)	✓ PPIHWG ✓
12/20/00	4	Fast track report, category 2 format--NRRM addressing § 25.302 and appendix K (interaction of systems and structures)	✓ LDHWG ✓
12/20/00	2	Fast track report—(in NPRM/AC format) addressing §§ 25.361 and 25.362 (engine and auxiliary power unit load conditions)	✓ LDHWG ✓
12/20/00	1	Fast track report addressing § 25.1438 (pressurization and low pressure pneumatic systems)	✓ MSHWG ✓

The above listed reports will be forwarded to the Transport Airplane Directorate for review. The Federal Aviation Administration's (FAA) progress will be reported at the TAE meetings.

This letter also acknowledges receipt of your July 28, 1999, submittal which included proposed notices and advisory material addressing lightning protection. We apologize for the delay. Although the lightning protection task is not covered under the fast track proposal, the FAA recognizes that technical agreement has been reached and we will process the package accordingly. The package has been sent to Aircraft Certification for review; the working group will be kept informed of its progress through the FAA representative assigned to the group.

Lastly, at the December 8 - 9, 1999, TAE meeting, Mr. Phil Salee of the Powerplant Installation Harmonization Working Group indicated that the working group members agreed that § 25.1103 was sufficiently harmonized and that any further action was beyond the scope of task 8 assigned. We agreed with the TAE membership to close the task. This letter confirms the FAA's action to close the task to harmonize § 25.1103.

I would like to thank the ARAC, particularly those members associated with TAE for its cooperation in using the fast track process and completing the working group reports in a timely manner.

Sincerely,

**ORIGINAL SIGNED BY
ANTHONY F. FAZIO**

Tony F. Fazio
Director, Office of Rulemaking

ARM-209:EUpshaw:fs:6/27/00:PCDOCS #12756v1
cc: ARM-1/20/200/209; APO-300/320, ANM-114
File #1340.12

File #ANM-98-182-A (landing gear shock absorption test requirements) and
ANM-94-461-A (Taxi, takeoff, and landing roll design loads)



**U.S. Department
of Transportation**

**Federal Aviation
Administration**

**Transport Airplane Directorate
Aircraft Certification Service**
Boeing Certificate Management Office
2500 East Valley Road, Suite C2
Renton, Washington 98055

Mr. Craig R. Bolt
Assistant Chair, Transport Airplane Engine Issues Group
Pratt & Whitney
400 Main Street
East Hartford, CT 06108

Dear Mr. Bolt,

This letter is to inform you of the Federal Aviation Administration's (FAA) decision with respect to instituting a moratorium on certain Aviation Rulemaking Advisory Committee (ARAC), Transport Airplane and Engine Issues Group (TAEIG) taskings. During the November 2002 Harmonization Management Team Meeting, industry requested that the FAA consider placing a moratorium on certain lower priority ARAC taskings while the FAA, Joint Aviation Authorities (JAA) and Transport Canada (TCCA), worked to develop a joint rulemaking priority list. Industry requested this moratorium to conserve resources until a final rulemaking priority list could be implemented.

The FAA agreed with industry's request and has worked with the JAA and TCCA to identify appropriate ARAC TAEIG tasks to be placed under a moratorium. The taskings were identified based on the relative priority of these projects within the FAA, JAA and TCCA as well as the maturity of the project. Also, the FAA considered that addressing working groups as a whole, rather than just specific taskings, would best address industry's concern with respect to resource conservation. The working groups and taskings that have been identified for the moratorium are the following:

- General Structures Harmonization Working Group
 - 25.365(d) High Altitude Flight
 - 25.631, 25.571, 25.775 Bird Strike
 - 25.571 Fatigue and Damage Tolerance
 - 25.683 Operational Tests
 - 25.603 Material Properties
- Power plant Installations Harmonization Working Group
 - 25.903(d) Rotorburst
 - 25.975 Fuel Tank Vent Fire Protection

The FAA requests that these two working groups hold one more meeting to document the discussions, agreements, and outstanding issues or actions for each of their taskings. This information should be documented using the attached working group report format,

which is typically used by working groups to document completed TAEIG harmonization recommendations for submittal to the FAA. When the reports have been completed, they should be forwarded to the TAEIG for transmittal to the FAA.

The FAA also requests that these two working groups identify the date of their last meeting, as well as a schedule for submitting their working group report to the TAEIG and FAA.

It should be noted that this moratorium only suspends the schedules and activities associated with the working groups and taskings listed above. It does not serve to disband the working groups or revoke the related taskings. Once the joint rulemaking prioritization list is finalized and implemented, the FAA will advise TAEIG as to any further action with respect to all harmonization-working groups and their respective tasks.

Any questions regarding this issue can be directed to Mr. Mike Kaszycki at 425-227-2137 or Mike.Kaszycki@faa.gov or Ms. Dionne Krebs at 425-227-2250 or Dionne.Krebs@faa.gov.

Michael Kaszycki
Manager

cc: ARM (Tony Fazio, Florence Hamn, and Effie Upshaw)

Recommendation

16 August 1999

PPIHWG – Draft Harmonization Report

Harmonization Proposal for FAR/JAR 25 Appendix I

Harmonization Proposal for 25.901(d) and JAR-J (Gas Turbine Auxiliary Power Unit Installation).

1. What is the underlying safety issue addressed by FAR/JAR? [Explain the underlying safety rationale for the requirement. Why does the requirement exist?]

The installation of an APU is functionally intended to free the airplane from the need for ground-based power and thereby permit more flexible aircraft operations. The APU installation may be designed to supply pneumatic power for aircraft air conditioning (environmental control), main engine starting, and electrical power for operation of aircraft systems while the airplane is on the ground only. This type of APU is classified as non-essential as it is installed as a matter of convenience as it may be non-operational without jeopardizing safe airplane operations. An APU installation may also be designed to be utilized in flight to supply electrical and/or pneumatic power to support aircraft system requirements related to redundancy and/or engine inflight starting. This type of APU installation is considered essential at dispatch of the airplane or for continued safe flight. The APU installation and operation are intended to perform their intended function(s) without producing an unsafe condition. The installation requirements proposed herewith are intended to ensure that the functional and specific failure conditions on an Auxiliary Power Unit installation are appropriately addressed by the design.

This proposed regulatory action is prompted by a review of previously certified APU installations which has revealed that, in some cases, part 25 APU certification requirements have not been applied consistently to transport category airplanes. Further, this action is intended to harmonize APU installation requirements with standards utilized by the European Joint Aviation Requirements. APU technology has advanced and new functional capabilities are being provided. These new functions are regulated under the proposed requirement.

2. What are the current FAR and JAR standards? [Reproduce the FAR and JAR rules text as indicated below.]

See current JAR-J and FAR 25. Reproducing a large number of pages of text in this report would not serve a useful purpose.

3. What are the differences in the standards and what do these differences result in? [Explain the differences in the standards, and what the differences result in relative to (as applicable) design features/capability, safety margins, cost, stringency, etc.]

The current FAR standards for APU installations are numerous and embedded in various sections of Part 25, while the JAR requirements are all presented in a separate Subpart J to JAR-25. The Tasking and Work Plan directed that the most appropriate requirement from either FAR or JAR be assembled into a single harmonized set of requirements to be presented as an Appendix.

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4. **What, if any, are the differences in the means of compliance?** *[Provide a brief explanation of any differences in the compliance criteria or methodology, including any differences in either criteria, methodology, or application that result in a difference in stringency between the standards.]*

No significant difference in means of compliance from current policy is intended. The proposed requirements clarify the various APU installation categories and the specific regulations applicable to each.

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5. **What is the proposed action?** *[Is the proposed action to harmonize on one of the two standards, a mixture of the two standards, propose a new standard, or to take some other action? Explain what action is being proposed (not the regulatory text, but the underlying rationale) and why that direction was chosen.]*

The NPRM package attached hereto contains the unanimously agreed harmonized APU requirements sent to FAA for preliminary legal and economic review.

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6. **What should the harmonized standard be?** *[Insert the proposed Text of the harmonized standard here.]*

See attachment.

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7. **How does this proposed standard address the underlying safety issues (identified under #1)?** *[Explain how the proposed standard ensures that the underlying safety issue is taken care of.]*

Given that the most appropriate requirement from either FAR or JAR has been utilized in the proposal, adequate coverage of all safety concerns is provided. Further, no significant safety shortfall, attributed the APU Installation Requirements, has been identified by operational experience.

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8. **Relative to the current FAR, does the proposal increase, decrease or maintain the same level of safety? Explain.** *[Explain how each element of the proposed change to the standard affects the level of safety relative to the FAR. It is possible that some portions of the proposal may reduce the level of safety even though the proposal as a whole may increase the level of safety.]*

The same level or slightly higher level of safety has been provided by selection of the most appropriate requirement from either standard.

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9. **Relative to current industry practice, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.** *[Since industry practice may be different than what is required by the FAR (e.g., general industry practice may be more restrictive), explain how each element of the proposed change to the standards affects the level of safety relative to current industry practice. Explain whether current industry practice is in compliance with the proposed standard.]*

Same level of safety.

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- 10. What other options have been considered and why were they not selected?** *[Explain what other options were considered and why they were not selected (e.g., cost/benefit, unacceptable decrease in the level of safety, lack of consensus, etc.)]*

No other options have been considered to be more appropriate or necessary based on current experience.

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- 11. Who would be affected by the proposed change?** *[Identify the parties that would be materially affected by the rule change – airplane manufacturers, airplane operators, etc.]*

Airframe and APU⁷ manufacturers, and STC APU installers.

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- 12. To ensure harmonization, what current advisory material (e.g., ACJ, AMJ, AC, policy letters) needs to be included in the rule text or preamble?** *[Does the existing advisory material include substantive requirements that should be contained in the regulation? This may occur because the regulation itself is vague, or if the advisory material is interpreted as providing the only acceptable means of compliance.]*

There are ACJ's to Subpart J related to

- 25A901(b)(2),
- 25A901(b)(4),
- + 25A901(d),
- + 25B903(e)(2),
- 25A939(a),
- 25A943,
- 25A953(b),
- 25B961(a)(5),
- 25B991,
- 25B1093(b)(2),
- 25a1195(b).

A review of the ACJ for JAR-25 Subpart J has led to the deletion of two current ACJ's: 25B903(e)(2) and 25A939(a). The remaining ACJ's are considered not to add new requirements.

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- 13. Is the existing FAA advisory material adequate? If not, what advisory material should be adopted?** *[Indicate whether the existing advisory material (if any) is adequate. If the current advisory material is not adequate, indicate whether the existing material should be revised, or new material provided. Also, either insert the text of the proposed advisory material here, or summarize the information it will contain, and indicate what form it will be in (e.g., Advisory Circular, policy, Order, etc.)]*

FAA advisory material was not addressed by the HWG.

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- 14. How does the proposed standard compare to current ICAO standard?** *[Indicate whether the proposed standard complies with or does not comply with the applicable ICAO standards (if any).]*

There are no known ICAO requirements for APU's - Airworthiness or Environmental.

15. Does the proposed standard affect other HWG's? *[Indicate whether the proposed standard should be reviewed by other harmonization working groups and why.]*

No.

16. What is the cost impact of complying with the proposed standard? *[Is the overall cost impact likely to be significant, and will the cost be higher or lower? Include any cost savings that would result from complying with one harmonized rule instead of the two existing standards. Explain what items affect the cost of complying with the proposed standard relative to the cost of complying with the current standard.]*

Applicants in past airplane programs have met the requirements of both FAA and JAA. No cost increase or change is judged to be significant. Some minor cost saving are possible, but could not be reliably determined.

17. Does the HWG want to review the draft NPRM at "Phase 4" prior to publication in the Federal Register?

Yes

18. In light of the information provided in this report, does the HWG consider that the "Fast Track" process is appropriate for this rule making project, or is the project too complex or controversial for the Fast Track Process. Explain? Explain. *[A negative answer to this question will prompt the FAA to pull the project out of the Fast Track Process and forward the issues to the FAA's Rulemaking Management Council for consideration as a "significant" project.]*

Yes

Draft Advisory Circular



U.S. Department
of Transportation
Federal Aviation
Administration

Subject: **DESIGN CONSIDERATIONS FOR
MINIMIZING HAZARDS CAUSED BY
UNCONTAINED TURBINE ENGINE AND
AUXILIARY POWER UNIT ROTOR FAILURE** Date: **July 18, 1995** AC No. **20-128A**
Initiated by: ANM-110

THIS DOCUMENT IS A WORKING DRAFT AND IS NOT FOR PUBLIC RELEASE

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 was harmonized as of the issuance date 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 3, 1988, is cancelled.
3. **APPLICABILITY.** This advisory circular applies to Part 23 and Part 25 airplanes 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 Amendment 25-tbd and 23-tbd (**FAA to insert appropriate Amendment levels prior to publication**) respectively, and other sections relating to uncontained engine failures.
 - 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
§ 25.365 (e)(1)

Flammable Fluid Fire Protection
Pressurized Compartment Loads

§ 25.571 (a), (e)(2)(3)(4)	Damage Tolerance and Fatigue evaluation of structure.
§ 25.963 (e)	Equipment, systems and installations
§ 25.1189	Shutoff means.

b. Advisory Circulars (AC's) and Users Manual.

AC 25-8	Auxiliary Fuel System Installations
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 2685)
AC 25-571	Damage Tolerance and Fatigue Evaluation of Structure
Users Manual	Users Manual for AC20-128A, "Uncontained Engine Failure Risk Analysis Methodology", dated tbd.

Advisory Circulars and the Users Manual 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's).

TSO C77a (or JAR APU)	Gas Turbine Auxiliary Power Units
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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 of 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 the service experience for fixed wing airplanes and do not include data for rotorcraft and APU's:

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

The total of 676 uncontained events includes 93 events in the Category 3 and 15 events in Category 4 damage to the airplane. Category 3 damage is defined as significant airplane damage with the airplane 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 flight crew 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).

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 area;
- (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 multiplied 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 multiplied critical components is shielded by significant structure such as aluminum lower wing skins, pylons, pressure cabin skins 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 multiplied 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 aircraft 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 standards such as AC 20-135, "Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria" or the equivalent ISO 2685.

(4) **Fuel Tanks.** If fuel tanks are located in impact areas, then 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, has been acceptable (see Figure 5).

(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. Where primary flight controls have duplicated (or multiplicated) elements, these elements should be located to prevent all elements 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) operations 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.

(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 7 (c). 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 41000 ft. the engines should be located such that the pressure cabin cannot be affected by an uncontained one-third or intermediate disc fragment. Alternatively, it may be shown that rapid decompression due to the maximum hole size caused by these fragments 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 descent 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 the use of 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.

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 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 2.

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 th of the bladed disc mass and its energy the translational energy (neglecting rotational energy) of the piece traveling at rim speed (see Figure 3).

c. Alternative Engine Failure Model. For the purpose of the analysis, as an alternative to the engine failure model of Paragraphs 9(a) and (b), the use of a single one-third piece of disc

having a fragment spread angle $\pm 5^\circ$ would be acceptable, provided that the objectives of Paragraph 10(a) 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 7(b) and 7(c) 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 $\pm 15^\circ$. 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 energy the translational energy (neglecting rotational energy) of the fragment traveling at the speed of its c.g. location as defined in Figure 4. As an alternative, the engine manufacturer may be consulted for guidance as to the size and energy of the fragment.

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. Subparagraph (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 Order (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 9(a), (b), and (d), or Paragraphs 9(c) and 9(d) 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.

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 for the emergency engine shut down drill. The extent of the delay is dependent upon circumstances resulting from the uncontained failure including increased flight crew workload stemming from multiplicity of warnings which require analysis by the flight crew.

(2) Some degradation of the flight characteristics of the airplane or operation of a system may be permissible, if the ability to complete continued safe flight and landing is provided. 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), and ACJ 25.571 (a) subparagraph 2.7.2 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) (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.

(8) Damage to or inadvertent movement of aerodynamic surfaces (e.g.. flaps, slats, stabilizers, ailerons, spoilers, thrust reversers, elevators, rudders, strakes, winglets, etc.) and the resultant effect on safe flight and landing.

c. Safety Analysis Objectives. It is considered that the objective of minimizing hazards will have been met if:

(1) The practical design considerations and precautions of Paragraphs 7 and 8 have been taken;

(2) The safety analysis has been completed using the engine/APU model defined in paragraph 9;

(3) For Part 25 transport and Part 23 commuter category airplanes, the following hazard ratio guidelines have been achieved:

(i) Single One-Third Disc Fragment. There is not more than a 1 in 20 chance of catastrophe resulting from the release of a single one-third disc fragment as defined in Paragraph 9a.

(ii) Intermediate Fragment. There is not more than a 1 in 40 chance of catastrophe resulting from the release of a piece of debris as defined in Paragraph 9.

(iii) Multiple Disc Fragments. (Only applicable to any duplicated or multiplied system where all of the system channels contributing to its function have some part which is within a distance equal to the diameter of the largest bladed rotor, measured from the engine centerline). There is not more than 1 in 10 chance of catastrophe resulting from the release in three random directions of three one-third fragments of a disc each having a uniform probability of ejection over the 360° (assuming an angular spread of $\pm 3^\circ$ relative to the plane of the disc) causing coincidental damage to systems which are duplicated or multiplied.

NOTE: Where dissimilar systems can be used to carry out the same function (e.g. elevator control and pitch trim), they should be regarded as duplicated (or

Multiplicated) systems for the purpose of this subparagraph provided control can be maintained .

NOTE: The numerical assessments described above may be used to judge the relative values of minimization. The degree of minimization that is feasible may vary depending upon airplane size and configuration and this variation may prevent the specific hazard ratio from being achieved. These levels are design goals and should not be treated as absolute targets. It is possible that any one of these levels may not be practical to achieve.

(4) For new non-commuter Part 23 airplanes the chance of catastrophe is not more than twice that of 10 (c)(3)(i), (ii) and (iii) for each of these fragment types.

(5) A numerical risk assessment is not requested for the single fan blade fragment, small fragments, and APU and engine rotor stages which are qualified as contained.

d. **APU Analysis** For APU's that are located where no hazardous consequences would result from an uncontained failure, a limited qualitative assessment showing the relative location of critical systems/components and APU impact areas is all that is needed. If critical systems/components are located within the impact area, more extensive analysis is needed. For APU's which have demonstrated rotor integrity only, the failure model outlined in Paragraph 9g(1) should be considered as a basis for this safety assessment. For APU rotor stages qualified as contained per the TSO, the airplane safety analysis may be limited to an assessment of the effects of the failure model outlined in Paragraph 9g(2).

e. **Specific Risk** The airplane risk levels specified in Paragraph 10c, resulting from the release of rotor fragments, are the mean values obtained by averaging those for all rotor on all engines of the airplane, assuming a typical flight. Individual rotors or engines need not meet these risk levels nor need these risk levels be met for each phase of flight if either--

(1) No rotor stage shows a higher level of risk averaged throughout the flight greater than twice those stated in Paragraph 10c.

NOTE: The purpose of this Paragraph is to ensure that a fault which results in repeated failures of any particular rotor stage design, would have only a limited effect on airplane safety.

(2) Where failures would be catastrophic in particular portions of flight, allowance is made for this on the basis of conservative assumptions as to the proportion of failures likely to occur in these phases. A greater level of risk could be accepted if the exposure exists only during a particular phase of flight e.g., during takeoff. The proportional risk of engine failure during the particular phases of flight is given in SAE Papers referenced in paragraph 4 (d). See also data contained in the CAA paper "Engine Non-Containments - The CAA View", which includes Figure 6. This paper is published in NASA Report CP-2017, "An Assessment of Technology for Turbo-jet Engine Rotor Failures", dated August 1977.

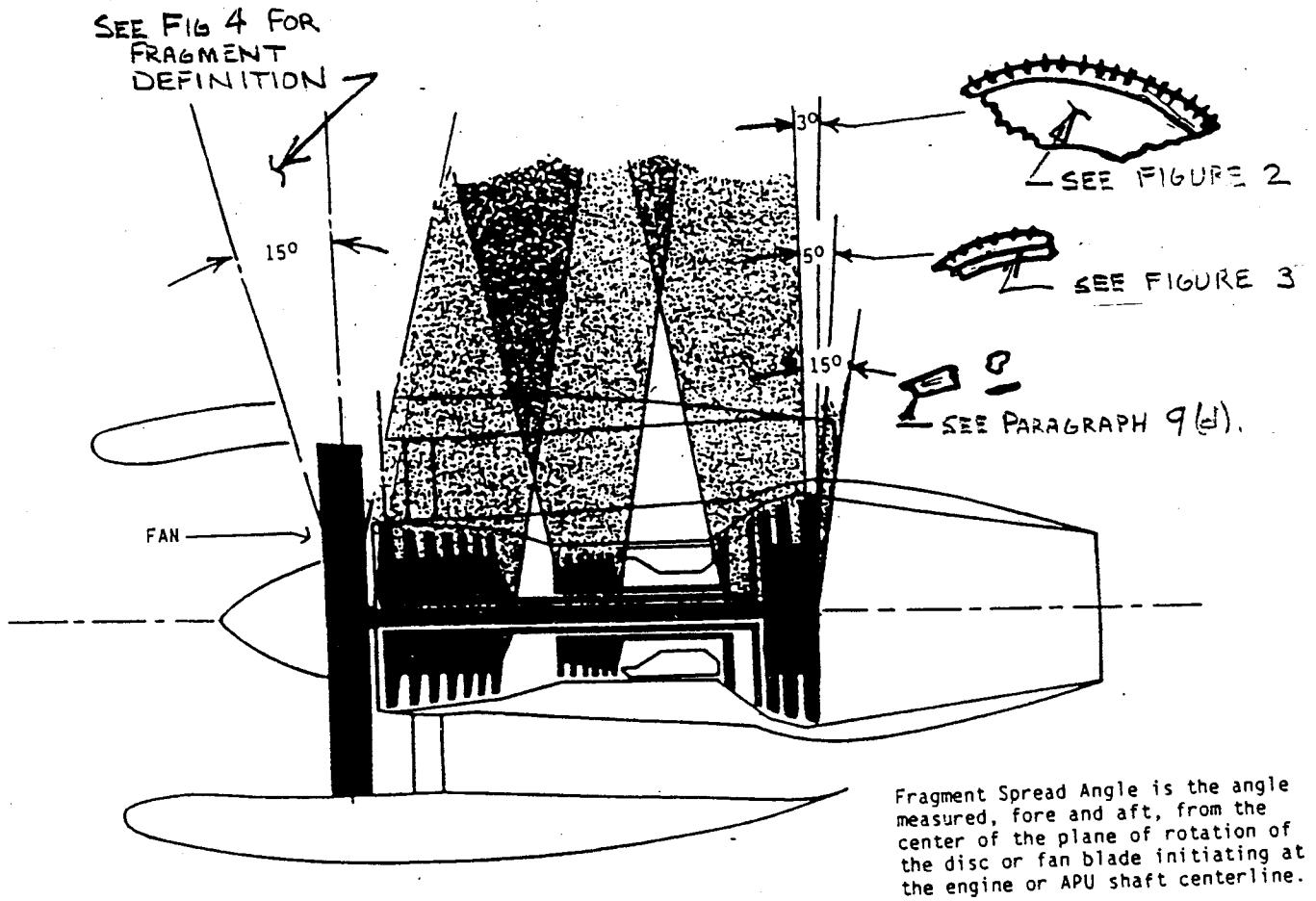
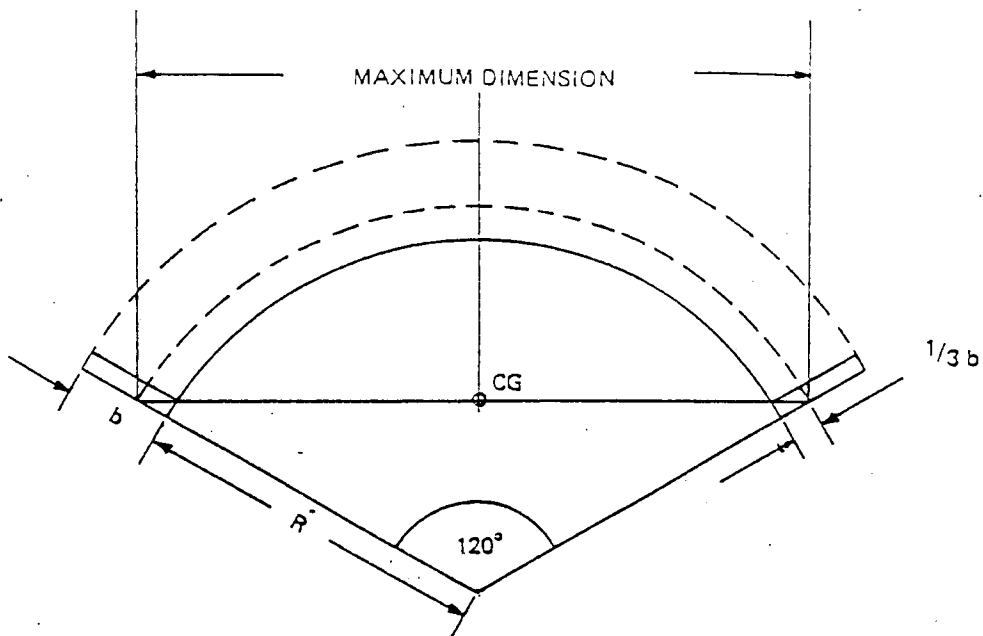


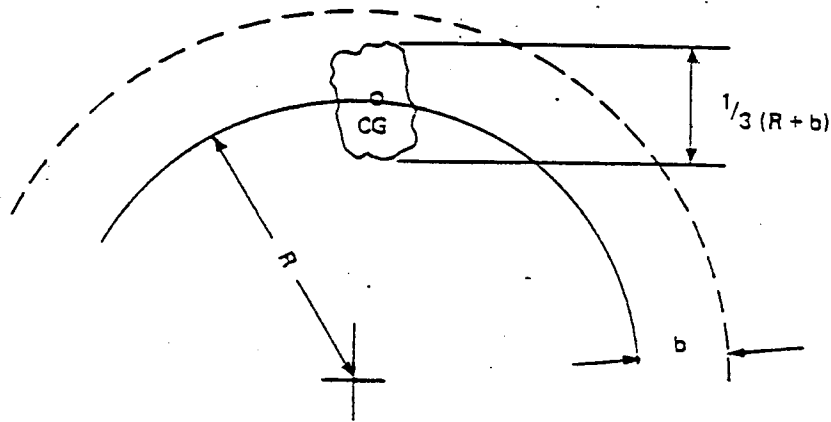
FIGURE 1
ESTIMATED PATH OF FRAGMENTS



Where R = disc radius
 b = blade length

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

FIGURE 2 - SINGLE ONE-THIRD ROTOR FRAGMENT



Where R = disc radius
 b = blade length

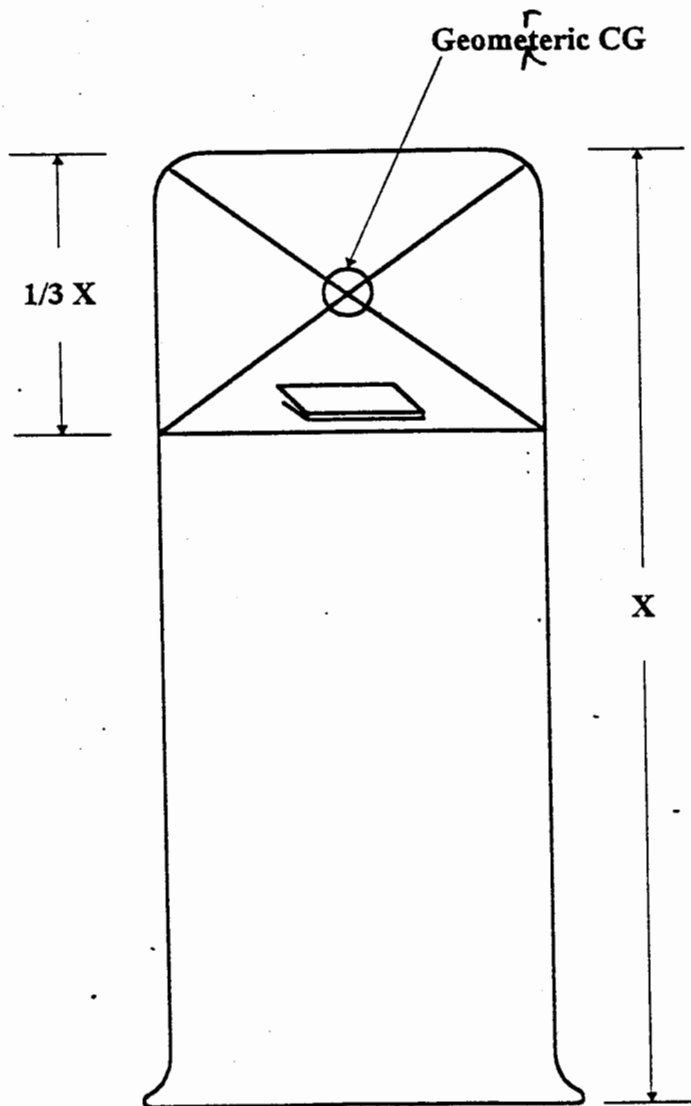
Maximum dimension = $\frac{1}{3} (R + b)$

Mass assumed to be $\frac{1}{30}$ th of bladed disc

CG is taken to lie on the disc rim

FIGURE 3 - INTERMEDIATE FRAGMENT

FIGURE 4 FAN BLADE FRAGMENT DEFINITION



Where X = Airfoil Length
(less blade root & platform)

CG is taken to lie at the
centerline of the $1/3$
fragment

Fragment velocity taken at
geometric CG

Fragment mass assumed to
be $1/3$ of the airfoil mass

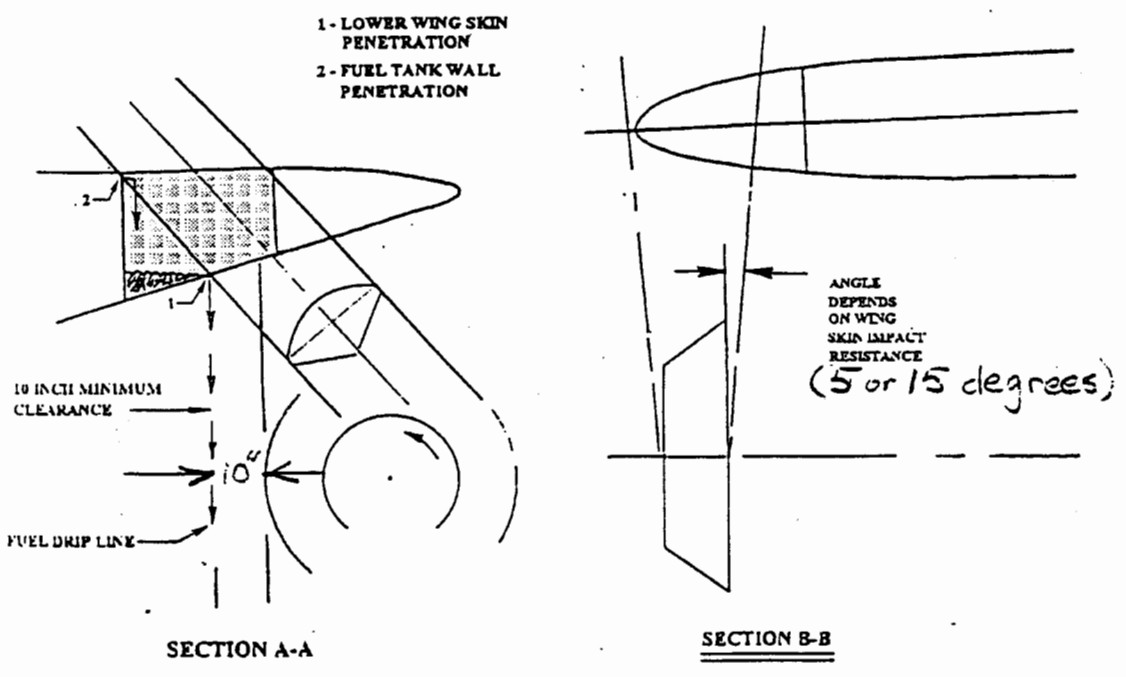
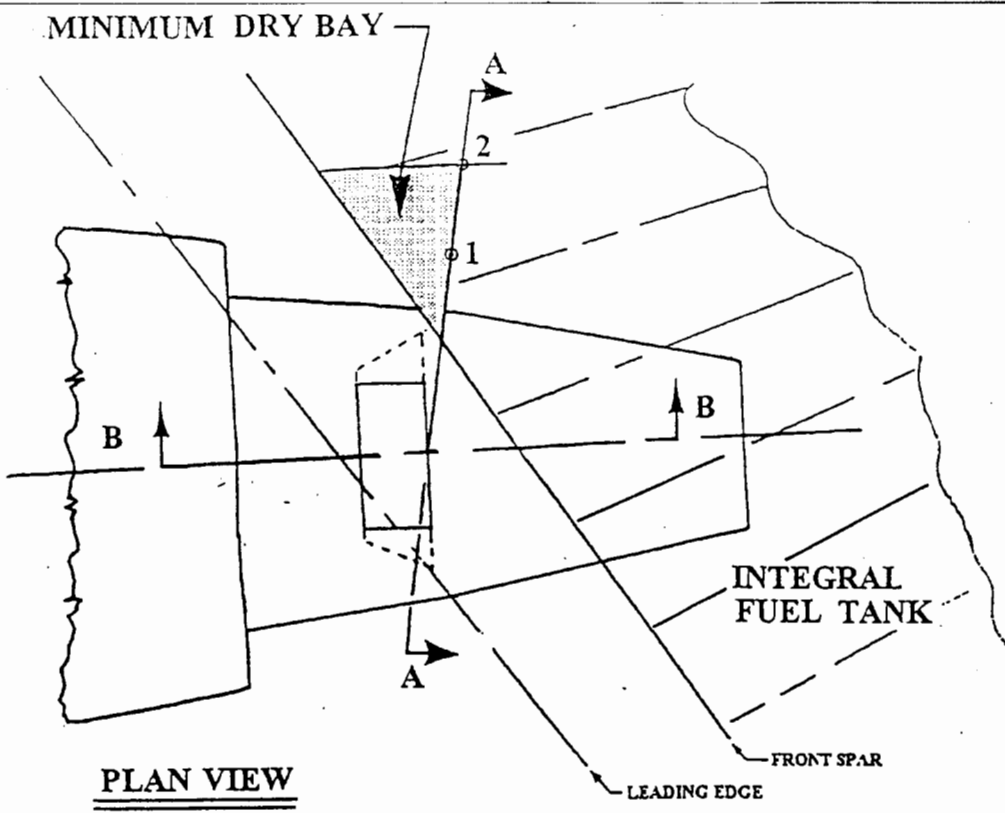
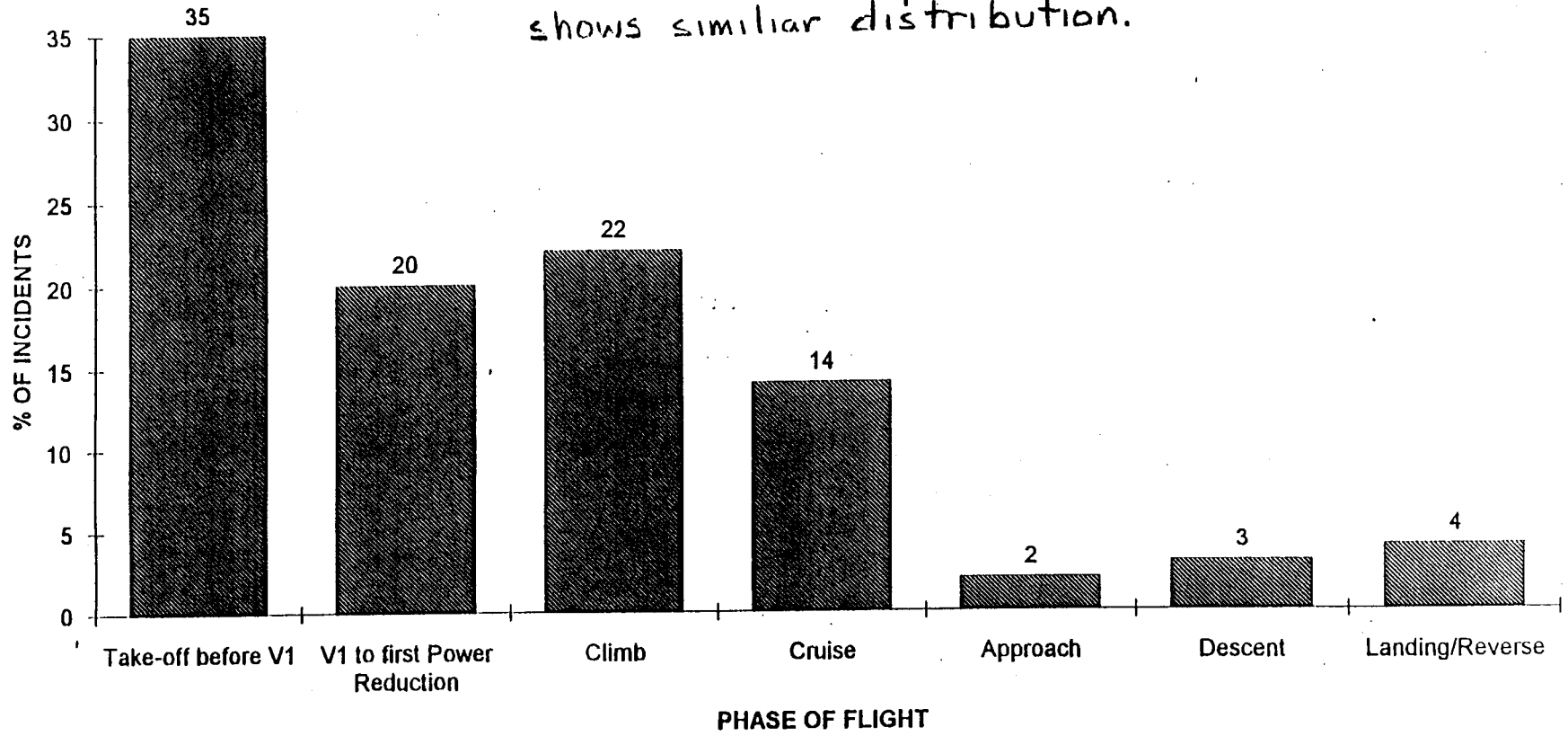


FIGURE 5- DRY BAY SIZING DETERMINATION EXAMPLE

Average of UK and US Data (1966-76)*
SAE data for the period 1962 to 1989
shows similar distribution.



61

FIGURE 6 - ALL NON-CONTAINMENTS BY PHASE OF FLIGHT

Draft no. 3

April 18, 1995

Advisory Material for Compliance
with Rotor Burst Rule
(Appendix to AC 29-2A)

DRAFT

NOT FOR PUBLICATION

Appendix to AC 29-2A

29.901 & 29.903

1. PURPOSE. This advisory material sets forth a method of compliance with the requirements of 29.901, 29.903(b)(1), and 29.903(d)(1) of the Federal Aviation Regulations (FAR) pertaining to design precautions taken to minimize the hazards to rotorcraft in the event of uncontained engine rotor (compressor and turbine) failure. 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/JAR SECTIONS. Sections 29.901(c) and 29.903(d)(1) of the FAR/JAR.

3. BACKGROUND. Although turbine engine manufacturers are making efforts to reduce the probability of uncontained rotor failures, service experience shows that such 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 rotorcraft. Since it is unlikely that uncontained rotor failures can be completely eliminated, rotorcraft design precautions should be taken to minimize the hazard from such

events. These design precautions should recognize rotorcraft design features that may differ significantly from that of an airplane, particularly regarding an engine location and its proximity to another engine, systems and components.

A. Uncontained gas turbine engine rotor failure

statistics for rotorcraft are presented in the Society of Automotive Engineers (SAE) Reports no. AIR 4003 (period 1976-83) and AIR 4770 (period 1984-89).

B. The statistics in the SAE studies indicate the

existence of some failure modes not readily apparent or predictable by failure analysis methods. Because of the variety of uncontained rotor 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 rotorcraft from uncontained rotor failures. These guidelines, therefore, assume a rotor 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. Minimize Means to reduce to a minimum, decrease to the least possible amount, that can be shown to be both technically feasible and economically justifiable to the certification authority.

B. Separation. Positioning of redundant critical structure, systems, or system components within the impact area such that the distance between the components minimizes the potential impact hazard. Redundant critical components should be separated within the spread angles of a rotor by a distance at least equal to either a 1/2 unbladed disk (hub, impeller) sector, or a 1/3 bladed disk (hub, impeller) sector with 1/3 blade height, with each rotating about its c.g., whichever is greater (see Figure 6).

C. Isolation. A means to limit system damage so as to maintain partial or full system function after the system has been damaged by fragments. Limiting the loss of hydraulic fluid by the use of check valves to retain the capability to operate flight controls is an example of "isolation." System damage is confined allowing the retention of critical system functions.



D. 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 with sufficient energy to hazard the rotorcraft.

The engine or APU manufacturer should define those components that constitute the rotor for each engine and APU type design. Typical rotors have included, as a minimum, disks, hubs, drums, seals, impellers, and spacers.

E. Uncontained Engine or APU Failure (or Rotorburst).

For the purposes of rotorcraft 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 create a hazard to the rotorcraft. Rotor failures which are of concern are those where released fragments have sufficient energy to create a hazard to the rotorcraft.

Uncontained failures of APU's which are "ground operable only" are not considered hazardous to the rotorcraft.

F. Critical Component (System). A critical component is any component or system whose failure or malfunction would contribute to or cause a failure condition that

would prevent the continued safe flight and landing of the rotorcraft. These components (systems) should be considered on an individual basis and in relation to other components (systems) that could be degraded or rendered inoperative by the same fragment or by other fragments during any uncontained failure event.

G. Fragment Spread Angle. The fragment spread angle is the angle measured, fore and aft, from the center of the plane of rotation of the disk (hub, impeller) or other rotor component initiating at the engine or APU shaft centerline or axis of rotation (see figure 1). The width of the fragment should be considered in defining the path of the fragment envelope's maximum dimension.

H. Ignition Source. Any component that could precipitate a fire or explosion. This includes existing ignition sources and potential ignition sources due to damage or fault from an uncontained rotor failure. Potential ignition sources include hot fragments, damage or faults that produce sparking, arcing, or overheating above the auto-ignition temperature of the fuel. Existing ignition sources include items such as unprotected engine or APU surfaces with temperature greater than the auto-ignition temperature of the fuel or any other flammable fluid.

5. SAFETY ASSESSMENT

A. Procedure - Assess the potential hazard to the rotorcraft using the following procedure:

(1) Minimizing Rotor Burst Hazard. The rotorburst hazard should be reduced to the lowest level that can be shown to be both technically feasible and economically justifiable. The extent of minimization that is possible will vary from new or amended certification projects and from design to design. Thus the effort to minimize must be determined uniquely for each certification project.

Design precautions and techniques such as location, separation, isolation, redundancy, shielding, containment and/or other appropriate considerations should be employed, documented, agreed to by the certifying authority, and placed in the type data file. A discussion of these methods and techniques follows.

(2) Geometric Layout and Safety Analysis. The applicant should prepare a preliminary geometric layout and safety analysis for a minimum rotorburst

hazard configuration determination early in the design process and present the results to the certification authority no later than when the initial design is complete. Early contact and coordination with the certifying authority will minimize the need for design modification later in the certification process. The hazard analysis should follow the guidelines indicated in paragraph 397c(2) of AC 29-2A and 5.F. of this document. Geometric layouts and analysis should be used to evaluate and identify engine rotorburst hazards to critical systems, powerplants, and structural components from uncontained rotor fragments, and to determine any actions which may be necessary to further minimize the hazard. Calculated geometric risk quantities may be used in accordance with paragraph D following, to define the rotorcraft configuration with the minimum physical rotorburst hazard.

B. Engine and APU Failure Model. The safety analysis 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. In particular, a suitable failure

model may be provided by the engine/APU manufacturer. This may show that one or more of the considerations below do not need to be addressed.

(1) 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 $\pm 3^\circ$. Where energy considerations are relevant, the mass should be assumed to be one-third the bladed disc mass and its energy—the translational energy (i.e. neglecting rotational energy) of the sector (see Figure 2).

(2) Intermediate Fragments. It should be assumed that the intermediate fragment has a maximum dimension corresponding to one-third of the disc radius with one-third blade height and a fragment spread angle of $\pm 5^\circ$. Where energy considerations are relevant, the mass should be assumed to be 1/30th of the bladed disc mass and its energy the translational energy (neglecting rotational energy) of the piece traveling at rim speed (see Figure 3).

(3) Alternative Engine Failure Model. For the purpose of the analysis, as an alternative to the

engine failure model of section (1) and (2) above, the use of a single one-third piece of disc having a fragment spread angle of $\pm 5^\circ$ would be acceptable, provided that the objectives of the analysis are satisfied.

(4) Small Fragments. It should be assumed that small fragments have a maximum dimension corresponding to the tip half of the blade airfoil and a fragment spread angle of $\pm 15^\circ$. Where energy considerations are relevant the mass should be assumed to be corresponding to the above fragment dimensions and the energy is the translational energy (neglecting rotational energy) of the fragment travelling at the speed of its c.g. location. The effects of multiple small fragments should be considered during this assessment.

(5) Critical Engine Speed. Where energy considerations are relevant the uncontained rotor event should be assumed to occur at the engine shaft speed for the maximum rating appropriate to the flight phase (exclusive of OEI ratings), unless the most probable mode of failure would be expected to result in the engine rotor reaching a red line speed or a design burst speed. For APU's,

use the maximum rating appropriate to the flight phase or the speed resulting from a failure of any one of the normal engine control systems.

(6) APU Failure Model: Service experience has shown that some APU rotor failures produced fragments having significant energy have been expelled through the APU tailpipe. For the analysis, the applicable APU service history and test results should be considered in addition to the failure model as discussed in paragraph 5 (b) above for certification of APU installations near critical items. In addition, the APU installer needs to address the rotorcraft hazard associated with APU debris exiting the tailpipe. Applicable service history or test results provided by the APU manufacturer may be used to define the tailpipe debris size, mass, and energy. The uncontained APU rotor failure model is dependent upon the design/analysis, test and service experience.

(a) For APU's where rotor containment has been demonstrated in accordance with TSO C77a/JAR APU, i.e. without specific containment testing. Paragraphs 5.(2)(1), 5.(B)(2) and 5.(B)(4) or Paragraph 5.(B)(3) and 5.(B)(4) apply. If shielding of critical airframe components is

proposed, the energy level that should be considered is that of the tri-hub failure released at the critical speed as defined in Paragraph 5.(B)(5). The shield and airframe mounting point(s) should be shown to be effective at containing both primary and secondary debris at angles specified by the failure model.

(b) For APU rotor stages qualified as contained in accordance with the TSO, an objective review of the APU location should be made to ensure the hazard is minimized in the event of an uncontained APU rotor failure. Historical data shows that in-service uncontained failures have occurred on APU rotor stages qualified as contained per the TSO. These failure modes have included bi-hub and overspeed failure resulting in some fragments missing the containment ring. In order to address these hazards, the installer should use the small fragment failure model, or substantiated in-service data supplied by the APU manufacture. Analytical substantiation for the shielding system if proposed is acceptable for showing compliance.

C. Engine/APU Rotorburst Data. The engine or APU manufacturer should provide the required engine data to

accomplish the evaluation and analysis necessary to minimize the rotorburst hazard such as:

1. engine failure model (range of fragment sizes, spread angles and energy)
2. engine rotorburst probability assessment
- 3 list of components constituting the rotors

D. Fragment Impact Risks. FAA research and development studies have shown that, for rotorcraft conventional configurations (one main rotor and one tail rotor), the main and tail rotorblades have minimal risks from a rotorburst, and thus, they require no special protection. However, unique main and tail rotor blade configurations should be carefully reviewed. Certain zones of the tail rotor drive shaft and other critical parts which may be necessary for continued safe flight and landing may not have natural, minimal risk from uncontained rotor fragments.

E. Engine Service History/Design. For the purpose of a gross assessment of the vulnerability of the rotorcraft to an uncontained rotor burst, it must be taken that an uncontained engine rotor failure (burst) will occur. However, in determining the overall risk to the rotorcraft, engine service history and engine design

features should be included in showing compliance with 29.903 to minimize the hazard from uncontained rotor failures. This is extremely important since the engine design and/or the service history may provide valuable information in assessing the potential for a rotor burst occurring and this should be considered in the overall safety analysis.

Information contained in the recent SAE studies (see paragraph 3.A.) should be considered in this evaluation.

F. Certification Data File. A report, including all geometric layouts, that details all the aspects of minimizing the engine rotorburst hazards to the rotorcraft should be prepared by the applicant and submitted to the certification authority. Items which should be included in this report are the identification of all hazardous failures that could result from engine rotor failure strikes and their consequences (i.e., an FMEA or equivalent analysis) and the design precautions and features taken to minimize the identified hazards that could result from rotor failure fragment strikes. Thus an analysis that lists all the critical components; quantifies and ranks their associated rotorburst hazard; and clearly show the minimization of that quantified, ranked hazard to the "maximum practicable extent" should

be generated and agreed upon during certification. Critical components should all be identified and their rotorburst hazard quantified, ranked, and minimized where necessary. Design features in which the design precautions of this guidance material are not accomplished should be identified along with the alternate means used to minimize the hazard. To adequately address minimizing the hazards, all rotorcraft design disciplines should be involved in the applicant's compliance efforts and report preparation.

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

A. Consider the location of the engine and APU rotors relative to critical components, or areas of the rotorcraft such as:

(1) Opposite Engine - Protection of the opposite engine from damage from 1/3 disc rotor fragments may not be feasible. Protection of the opposite engine from other fragments may 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 other structure.

(2) **Engine Controls** - Controls for the remaining engine(s) that pass through the uncontained engine failure zone should be separated/protected to the maximum extent practicable.

(3) **Primary structure of the fuselage**

(4) **Flight crew** - The flight crew is considered a critical component.

(5) **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.)

(6) **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

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

(8) Instrumentation necessary for continued safe flight and landing

(9) Transmission and rotor drive shafts

B. Location of Critical Systems and Components.

The following design practices have been used to minimize hazards to critical components:

(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 or outside debris impact 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 fragments.

(7) Consider the likely damage caused by multiple fragments.

(8) Fuel tanks should not be located in impact areas. However, if necessitated by the basic configuration requirements of the rotorcraft type to locate fuel tanks in impact areas, then the engine rotorburst hazard should be minimized by use of design features such as minimization of hazardous fuel spillage (that could contact an ignition source by drainage or migration); by



drainage of leaked fuel quickly and safely into the airstream; by proper ventilation of potential spillage areas; by use of shielding; by use of explosion suppression devices (i.e., explosion resistant foam or inert gases); and by minimization of potential fuel ignition sources or by other methods to reduce the hazard.

(9) The rotor integrity or containment capability demonstrated during APU evaluation to TSO-C77a, or JAR-APU should be considered for installation certification.

(10) The flight data recorder, cockpit voice recorder and emergency locator transmitter, if required, should be located outside the impact zone when practical.

(11) Items such as human factors, pilot reaction time, and correct critical system status indication in the pilot compartment after an uncontained engine failure has occurred should be considered in design to permit continued safe flight and landing.

C. Rotorcraft Modifications. Modifications made to rotorcraft certified to this rule should be assessed

with the considerations of this AC. These modifications include but are not limited to re-engining installations (including conversion from reciprocating to turbine powered), APU installations, fuselage stretch, and auxiliary fuel tank installations. Auxiliary fuel tank(s) should be located as much as practical so as to minimize the risk that this tank(s) will be hit by rotor failure fragments. The need to remain within the approved C.G. limits of the aircraft will of necessity limit the degree to which the risk may be minimized.

7. PROTECTIVE MEASURES. The following list is provided for consideration as some measures which may be used to minimize effects of a rotor burst:

A. Powerplant Containment

(1) Engine Rotor Fragment Containment. It should be clearly understood that containment of rotor fragments is not a requirement. However, it is one of many options which may be used to minimize the hazards of an engine rotor burst. Containment structures (either around the engine, or APU, or on the rotorcraft) that have been demonstrated to provide containment should be accepted as minimizing the hazard defined by the rotor

failure model for that particular rotor component. Contained rotor in-service failures may be used to augment any design or test data. Containment material stretch and geometric deformation should be considered in conjunction with fragment energies and trajectories in defining the hazards to adjacent critical components such as structures, system components, fluid lines, and control systems. Data obtained during containment system testing along with analytical data and service experience should be used for this evaluation.

(2) APU Containment

Rotor integrity or containment capability demonstrated during APU TSO evaluation should be considered for installation certification. If rotor containment option was shown by analysis or rig test, an objective review of the APU location should be made to ensure the hazard is minimized in the event of an uncontained APU rotor failure.

B. Shields and Deflectors. When shields, deflection devices, or intervening rotorcraft structure are used to protect critical systems or components, the adequacy of the protection should be shown by testing or analysis supported by test data, using the impact area, fragment mass, and fragment energies based on the definitions

stated herein. Analytical methods used to compute protective armor or shielding thicknesses and energy absorption requirements should reflect established methods, acceptable to the certifying authority, that are supported by adequate test evidence. Protective armor, shielding, or deflectors that stop, slow down, or redirect uncontained fragments redistribute absorbed energy into the airframe. The resulting loads are significant for large fragments and should be considered as basic load cases for structural analysis purposes (reference paragraph 29.301). These structural loads should be defined and approved as ultimate loads acting alone. The protective devices and their supporting airframe structures should be able to absorb or deflect the fragment energies defined herein and still continue safe flight and landing. If hazardous, the deflected fragment trajectories and residual energies should also be considered.

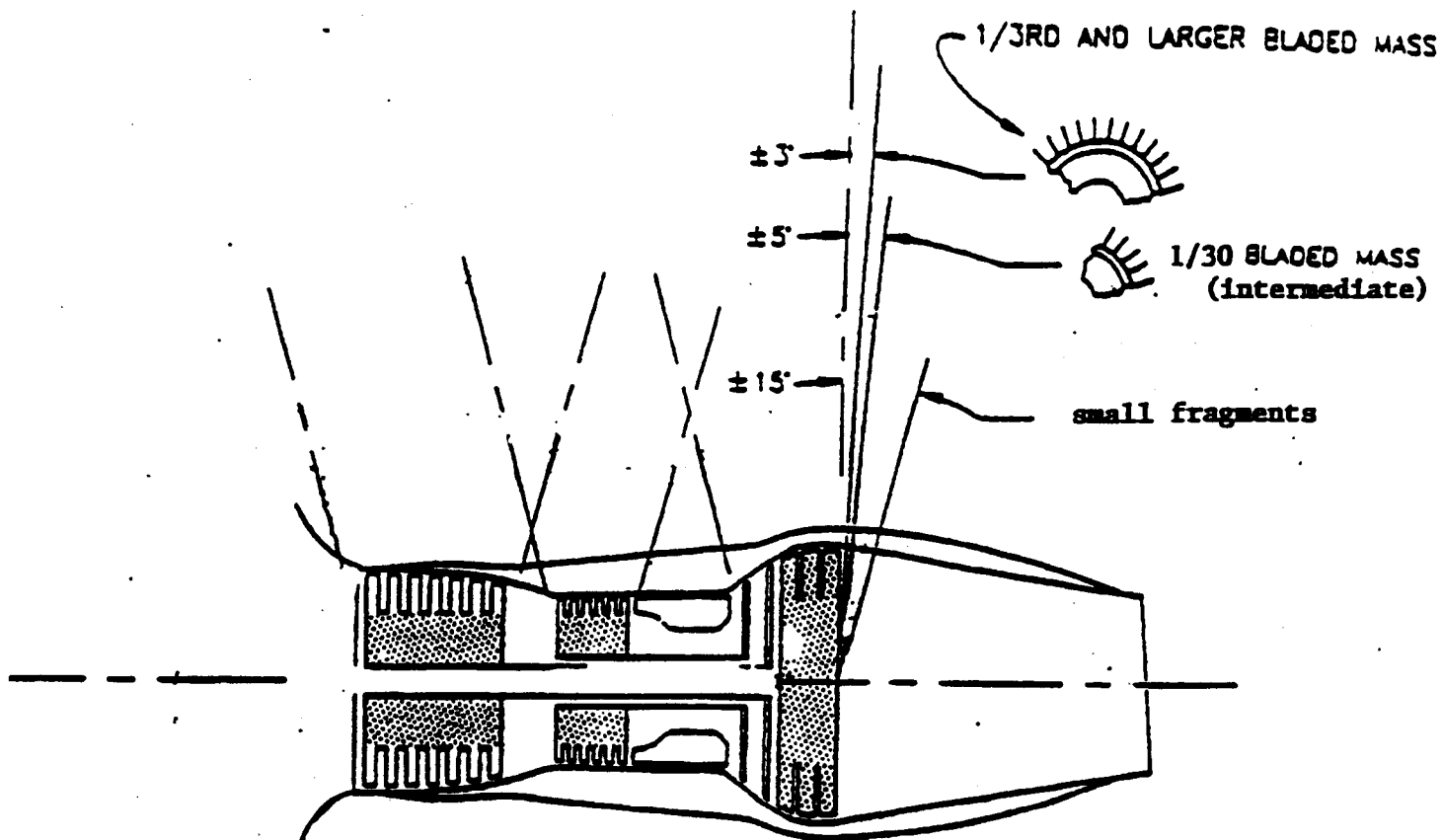
C. Isolation or Redundancy.

(1) Other Engines - Although other engines may be considered critical, engine isolation from rotorburst on multi-engine rotorcraft is not mandatory. Other methods of minimizing the risk to the engine(s) may be acceptable.

(2) Other Critical Components - Isolation or redundancy of other critical components, the failure of which would not allow continued safe flight and landing should be evaluated relative to the risk of occurrence and where the risk is deemed unacceptable isolation or shielding or other means of reducing the risk should be incorporated.

D. Composite Materials. If containment devices, shields or deflectors are chosen by the applicant to be wholly or partially made from composites; they should comply with the structural requirements of AC 20-107A, "Composite Aircraft Structure", and AC 29-2A, Paragraph 788, "Substantiation of Composite Rotorcraft Structure", (which includes glass transition temperature considerations). Glass transition temperature considerations are critical for proper certification of composite or composite hybrid structures used in temperature zones that reach or exceed 200° to 250°F (93° to 121°C) for significant time periods. Hot fragment containment is typically accommodated in such protective devices by use of metal-composite hybrid designs that use the metal component's properties to absorb the fragment heat load after the entire hybrid structure has absorbed the fragment's impact load. These devices

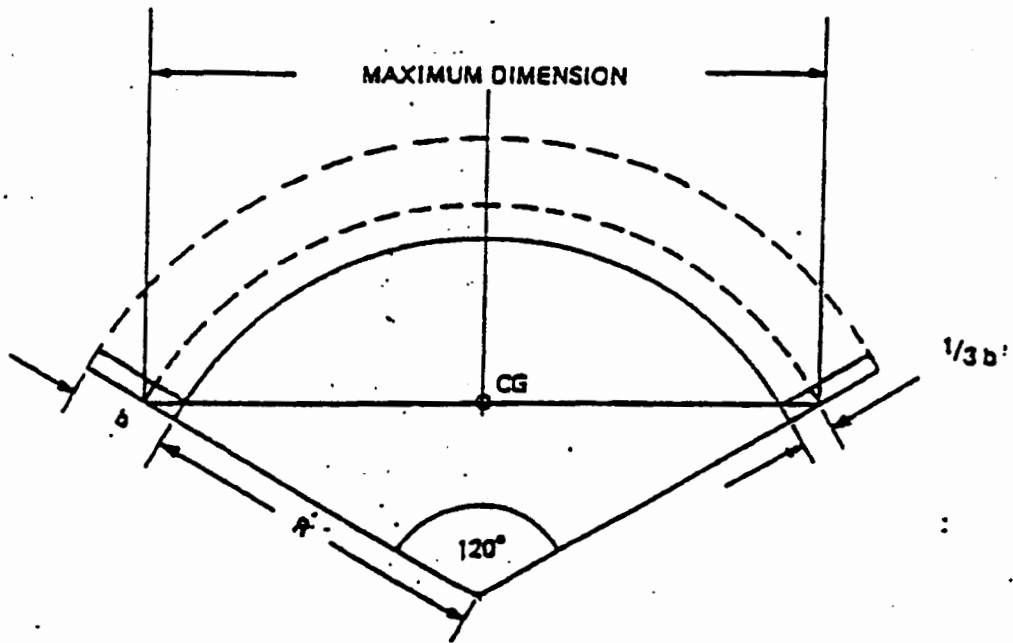
should comply with paragraphs 29.609 and 29.1529 to ensure continued airworthiness.



FRAGMENT SPREAD ANGLE IS THE ANGLE MEASURED, FORE AND AFT, FROM THE CENTER OF THE PLANE OF ROTATION INITIATING AT THE ENGINE OR APU SHAFT CENTERLINE.

- NOTE: 1) THE POSSIBILITY OF TURBINE MOVEMENT SHOULD BE CONSIDERED.
- 2) ALL ROTORS ARE CONSIDERED TO BE FULLY BLOADED FOR CALCULATING MASS.
- 3) FAILURE OF EACH ROTOR STAGE SHOULD BE CONSIDERED.

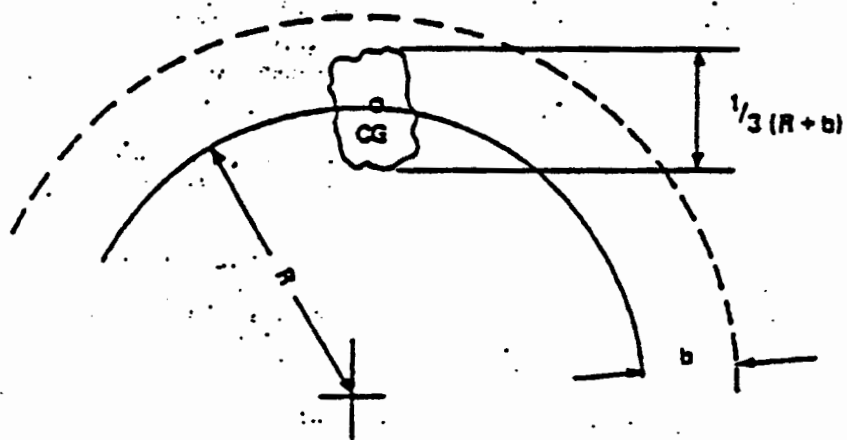
Figure 1 - Estimated Path of Fragments



Where R = disc radius
 b = blade length

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

FIGURE 2.— SINGLE ONE-THIRD DISC FRAGMENT



Where R = disc radius
 b = blade length

Maximum dimension = $\frac{1}{3} (R + b)$

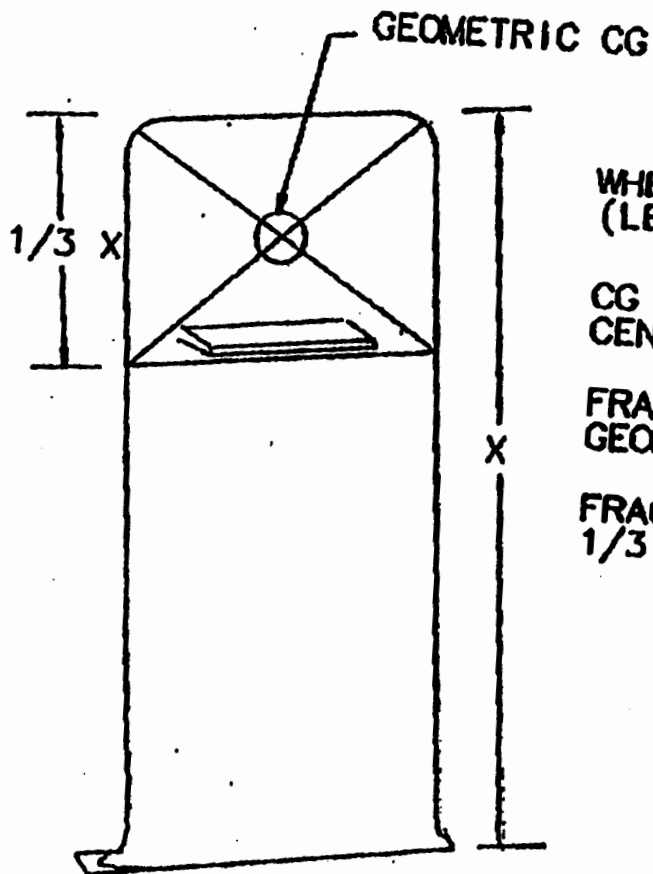
Mass assumed to be $\frac{1}{30}$ th of bladed disc

CG is taken to lie on the disc rim

INTERMEDIATE 8
 FIGURE 3.— SMALL PIECE OF DEBRIS

Fig 4

BLADE FRAGMENT DEFINITION



WHERE X = AIRFOIL LENGTH
(LESS BLADE ROOT & PLATFORM)

CG IS TAKEN TO LIE AT THE
CENTERLINE OF THE $1/3$ FRAGMENT

FRAGMENT VELOCITY TAKEN AT
GEOMETRIC CG

FRAGMENT MASS ASSUMED TO BE
 $1/3$ OF THE AIRFOIL MASS

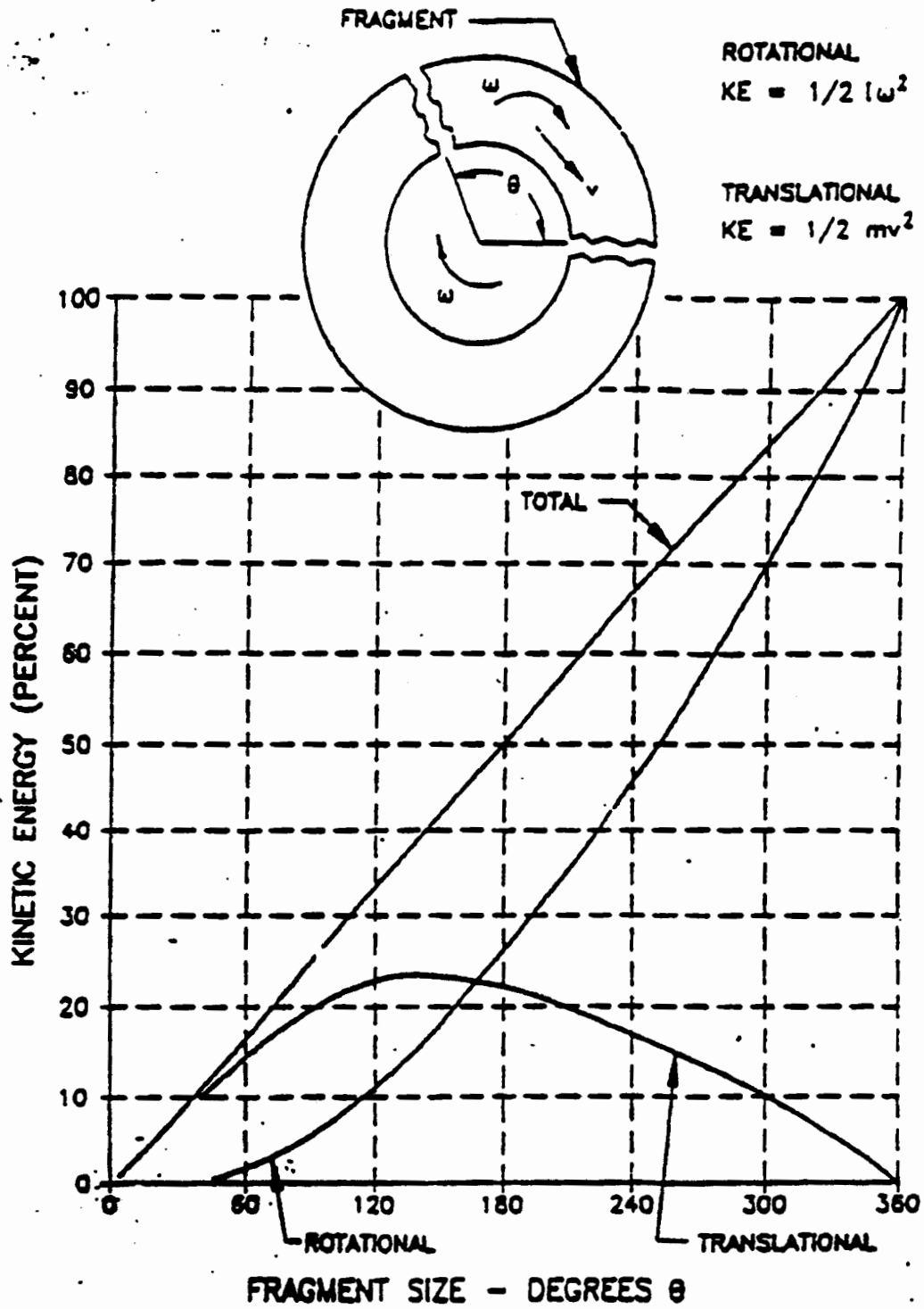
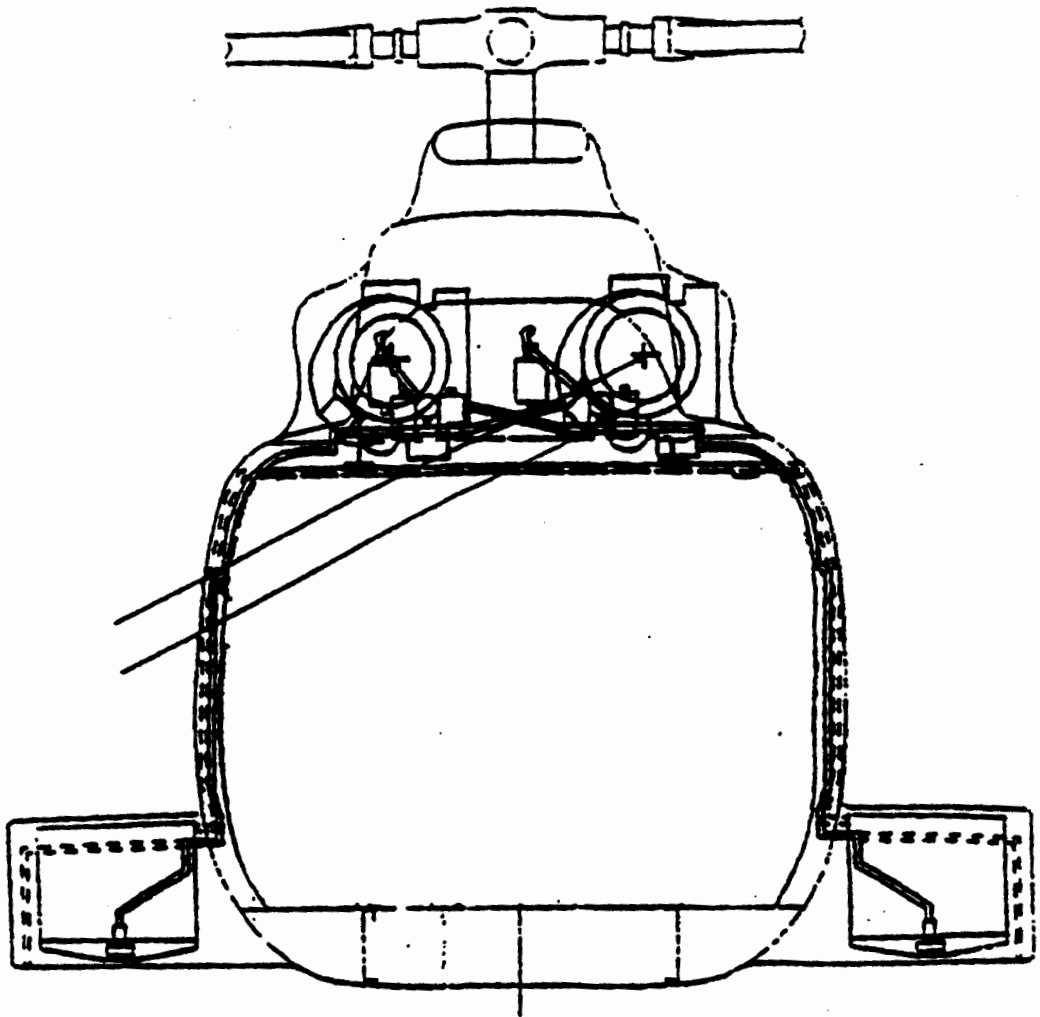


Figure 5 - Distribution of Translational and Rotational Kinetic Energy of Rotor-Component Fragments as a Function of Fragment Size θ



C.G. OF FRAGMENT
BECOMES CENTER OF ROTATION
OF FRAGMENT

FOR
SEPARATION
DISTANCE
CALCULATIONS - 1/3RD ROTOR
WITH 1/3RD BLADE HEIGHT



Figure 6 - Cross Section Through Rotorcraft at Plane
of Rotation of the Engine Disk Fragment

FAA Action – Not Available