ATTACHMENT 1

TO

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

DCA17FA021

Federal Aviation Administration

Order

8110.11

ORDER

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

8110.11

11/19/75

SUBJ: DESIGN CONSIDERATIONS FOR MINIMIZING DAMAGE CAUSED BY UNCONTAINED AIRCRAFT TURBINE ENGINE ROTOR FAILURES

1. PURPOSE. This order contains information on design considerations for minimizing damage caused by uncontained aircraft turbine engine rotor failures.

2. DISTRIBUTION. This order is distributed to all Flight Standards offices in Washington, to the branch level; to all regional Flight Standards offices to the section level; and to the Aircraft Engineering Division in the Western Region.

3. BACKGROUND. Since introduction of the turbine engine to commercial aviation in the early 1950's, uncontained rotor failures have been a significant problem. Failures have resulted in high velocity fragment penetration of fuel tanks, adjacent structures and other engines on the aircraft. Fragments have severed fuel lines, control cables, and penetrated pressurized fuselage skin and frames.

   a. Uncontained rotor failures, including fan, compressor, and turbine discs, and blades, have accounted for three-quarters of engine-caused accidents involving turbine powered aircraft, though this is often a secondary effect. Federal Aviation Administration statistics for a twelve-year period beginning in 1962 indicate 266 uncontained rotor and blade failures (Fig. 1). These statistics were compiled and analyzed by the Naval Air Propulsion Test Center, Trenton, New Jersey, under NASA contract.

   b. Although no major accidents have been attributed to rotor failures, they have been contributing factors and the record shows that several near misses have occurred. The uncontained rotor failure incident rate, while tending to level off, has not improved significantly in the last ten years. For this reason, the FAA has developed more stringent regulations for engine certification which require special testing to substantiate rotor integrity.

   c. Records of uncontained rotor failures indicate the existence of many different failure modes not readily apparent or predictable by applicable failure analyses. Part of the problem in this area results from the fact that rotor blade containment is demonstrated without aerodynamic loading of the blades. The axial component of the loaded blade plays an important part in the ultimate trajectories of the blade fragments. The situation is further complicated by the fact that, as reported by Reference 2 of Appendix 1, failure studies have shown that fragment-control system interactions differ greatly from the well-studied ballistic or hypervelocity impact phenomena; and therefore one cannot adapt these results to the design of uncontained rotor failure protection systems. Because of the random nature of uncontained rotor failures, it becomes very difficult to analyze all possible failure modes and to provide protection to all areas. In spite of this difficulty, design considerations reflected in this order provide appropriate guidelines for achieving the desired objective of protecting the aircraft from uncontained rotor failures.

d. Although engine manufacturers are making every effort to reduce the probability of uncontained rotor failures, at least for the very near future, aircraft designers will have to ensure aircraft safety by configuring the aircraft such that primary control systems, fuel systems, essential electrical systems, critical structural components, and the cabin are protected by containment shields, redundant design with sufficient physical separation of critical components or by location of essential systems and equipment outside the envelope of probable fragment trajectories.

e. FAR 25.903(d) was amended May 1970 to insure that, for turbine engine installations, design precautions are taken to minimize the hazards to the airplane in the event of an engine rotor failure. This order outlines some of the means found acceptable for minimizing effects of damage caused by uncontained rotor failures. It is important to note, however, that while the means described herein are based on experience, tests, and analyses within the current state-of-the-art, they are not necessarily the only means available to the designer.

f. For purposes of this order, the following definitions apply:

(1) Rotor. Rotors referred to herein include hubs, discs, rims, and spacers. Except for the statistical data shown in Figure 1, the term rotor failure does not include blade failures resulting from fractures within the blade, but does include blade separations resulting from failure of any of the aforementioned components.

(2) Critical Component. Any component whose failure jeopardizes the safety of the airplane is a critical component. Each component under consideration must be evaluated on an individual basis. For example, if the failure of an engine compartment fire

extinguisher component results in the inability to extinguish a fire in that compartment, then that component is critical. On the other hand, if failure of some other component results in the premature shutdown of the affected engine, then that component may not necessarily be classified as critical.

(3) Probable Impact Area. Probable impact area is that area likely to be impacted by rotor fragments contained within an imaginary ring of tapered cross section, having a 15° slope, generated around the plane of rotation of the various major rotor assemblies as shown in Figure 2. The definition is based on observations of damaged areas resulting from previous uncontained rotor failures.

4. DESIGN CONSIDERATIONS. The following design considerations provide information and guidelines and are not intended to exclude the use of other means or methods of compliance. The problem of uncontained rotor failure protection is approached by suggesting the following three basic considerations in order of assumed practicality: location of engines; location of critical systems and components; protective armor and deflection barriers.

5. LOCATION OF ENGINES. During preliminary aircraft design reviews, there should be an examination of the location of each engine from the standpoint of minimizing the effects of uncontained rotor failures. In this regard, the following observations are listed for consideration:

a. Engines should not be located in a position such that uncontained rotor failure fragments could disable the pilots.

b. Wing pylon mounted engine rotating elements should be forward of the wing leading edge, if possible.

c. Embedded engines, located within the primary airplane envelope, because of their close proximity to adjacent structure, introduce special problems which must be studied carefully for satisfactory solutions. The goal here, however, is still the same, and that is to provide protection for vital structure, primary flight controls and essential systems from uncontained rotor failures.

d. Wing mounted engines should be positioned in a manner such that the plane of rotating elements in one engine does not intersect critical portions of an adjacent wing engine.

e. Aft fuselage mounted engines should be positioned in a manner such that the plane of rotating elements does not intersect critical tail structure, essential controls and systems, or the fuselage pressure vessel. If this is not possible, other available design precautions should be taken to minimize effect on safety.

6. LOCATION OF CRITICAL SYSTEMS AND COMPONENTS. Flammable fluid system components should not be installed in probable fragment impact areas if damage to any of these components will jeopardize the safety of the airplane. Should necessity dictate the need to mount these components in vulnerable areas, then they should be protected by installing them behind massive airframe structure. Some airplane manufacturers currently employ this principle by mounting critical components behind wing spars and massive fuselage structural elements. These components should also be installed in a manner such that fragments from any one engine failure will not render the remaining engines inoperative.

a. Provisions should be incorporated to assure that flammable fluids released from damaged lines or components will not impinge on ignition sources. In this regard, electrical equipment located in areas where flammable fluids may be liberated due to line or tank puncture should be of a nonsparking type or otherwise protected and isolated.

b. One design consideration is to incorporate some degree of redundancy for critical system components located in impact zone areas. This redundancy should provide sufficient physical separation of the critical components to ensure against simultaneous damage of the redundant components following an uncontained rotor failure. For example, one airplane manufacturer of an airplane with aft fuselage mounted engines provides two separate hydraulic rudder control systems with one set of components mounted on the forward vertical stabilizer spar and the other system components are mounted on the rear spar.

c. Fuel tanks should not be located in impact zone areas. If, however, it should become absolutely necessary to locate fuel tanks in these vulnerable areas, then the following observations are pertinent:

(1) Fragment punctures of fuselage fuel tanks are unacceptable if the fuel will spill into the fuselage bays, whereas punctures of the wing fuel tanks may be acceptable if the fuel spills into the airstream away from the aircraft.

(2) Appropriate testing should be accomplished to determine the ignition potential of rotor fragments passing through or being contained within the fuel tank. Reference 7 provides details of tests conducted for this purpose. These tests consisted of the firing of an IMI "HYLITE 45" titanium projectile 8" x 2" x 5/16" (simulating a typical compressor blade), through an aluminum tank with target plates simulating the wing tanks.

The projectiles were fired end-on at velocities ranging from 550 ft./sec. to 740 ft./sec. at initial temperatures ranging from 460° F. to 700° F.

d. Large structural elements, which are depended upon to protect critical aircraft systems, components, and controls from rotor fragment impact, should be designed to deflect the fragments or otherwise attenuate their effects. Fail safe elements should provide alternate load paths in the event of fragment impact damage. The subject of fragment impact energies and protective armor effectiveness is also discussed in Paragraph 7 of this order.

e. Essential electrical system components should not be located in impact zone areas unless adequately protected from fragment impact damage. It should be noted that in addition to the loss of electrical power due to such damage, the sparking or excessive heating of damaged electrical elements can ignite flammable fluids released from punctured lines in the area.

f. Instrument system components which are critical to safe flight operation should not be located in impact zone area unless system redundancy is provided and lines are routed in a manner such that damage to both systems cannot occur.

g. One additional consideration concerns the probable extent of damage to the fuselage pressure vessel in the event of an uncontained rotor failure. This involves an analytical estimate of the location and hole sizes anticipated. Airframe engineers responsible for evaluation of pressure vessel integrity should be advised of the analytical results.

7. PROTECTIVE ARMOR AND DEFLECTORS. Protective armor is recommended where other methods of protection are impractical or impossible. The type and degree of armor protection should be based on analysis or test to determine the most probable energy and fragment trajectory. Much of this information should be furnished by the engine manufacturer. A great deal of work in this area has been accomplished by the Massachusetts Institute of Technology under a NASA contract (Reference 3).

a. In estimating the energy to be absorbed by the protective armor, the designer should consider fragment energies associated with the simultaneous failure of all blades and their included disc serrations plus the disc section in a 1/3 segment of any rotor stage when operating at the take-off power rating. Armor protection to provide containment of engine fragments has been investigated extensively by the Naval Air Propulsion Test Center in Philadelphia. Suggested design procedures based on these tests are contained in Reference 4.

b. Although it has been assumed that a trisector burst would be the most severe in terms of its potential for doing damage, it is well to note that restrained rotational energy is directly transferable into translational energy. This means a fragment whose translational velocity has been retarded by some means, such as penetration of the engine casing, may still possess sufficient rotational energy to do considerable damage. This fact has been verified by tests conducted at the Naval Air Propulsion Test Center, Philadelphia (Ref. 5). The trisector burst criterion noted herein represents a reasonable compromise and has been universally accepted as a design condition for showing containment of high energy rotors following a failure.

c. Tests have indicated that structural damage to the aircraft may be minimized by providing controlled deflection devices. The most effective device consists of a hinged partial ring designed to control the trajectory of fragments away from the protected region (Ref. 5). In tests, these partial rings proved to be the most effective means of controlling fragment trajectories for the least weight. Additionally, more recent testing by Boeing Airplane Company (Ref.6) indicates promising results with multilayered fabric containment shields. The shield material was made from Kevlar, a DuPont product, which offers a very high strength to weight ratio and excellent ballistic impact properties.

d. If armor plating or deflection devices are to be used to provide protection from uncontained rotor failures, the design rationale should consider the most probable failure modes, fragment trajectories, translational and rotational velocities, fragment temperature, and fragment energies. Design substantiation should be accomplished by appropriate testing if the analysis is not based on a background of testing.

JAMES E. PURCELL, Chief
Engineering & Manufacturing Division

APPENDIX 1. FIGURES AND REFERENCES

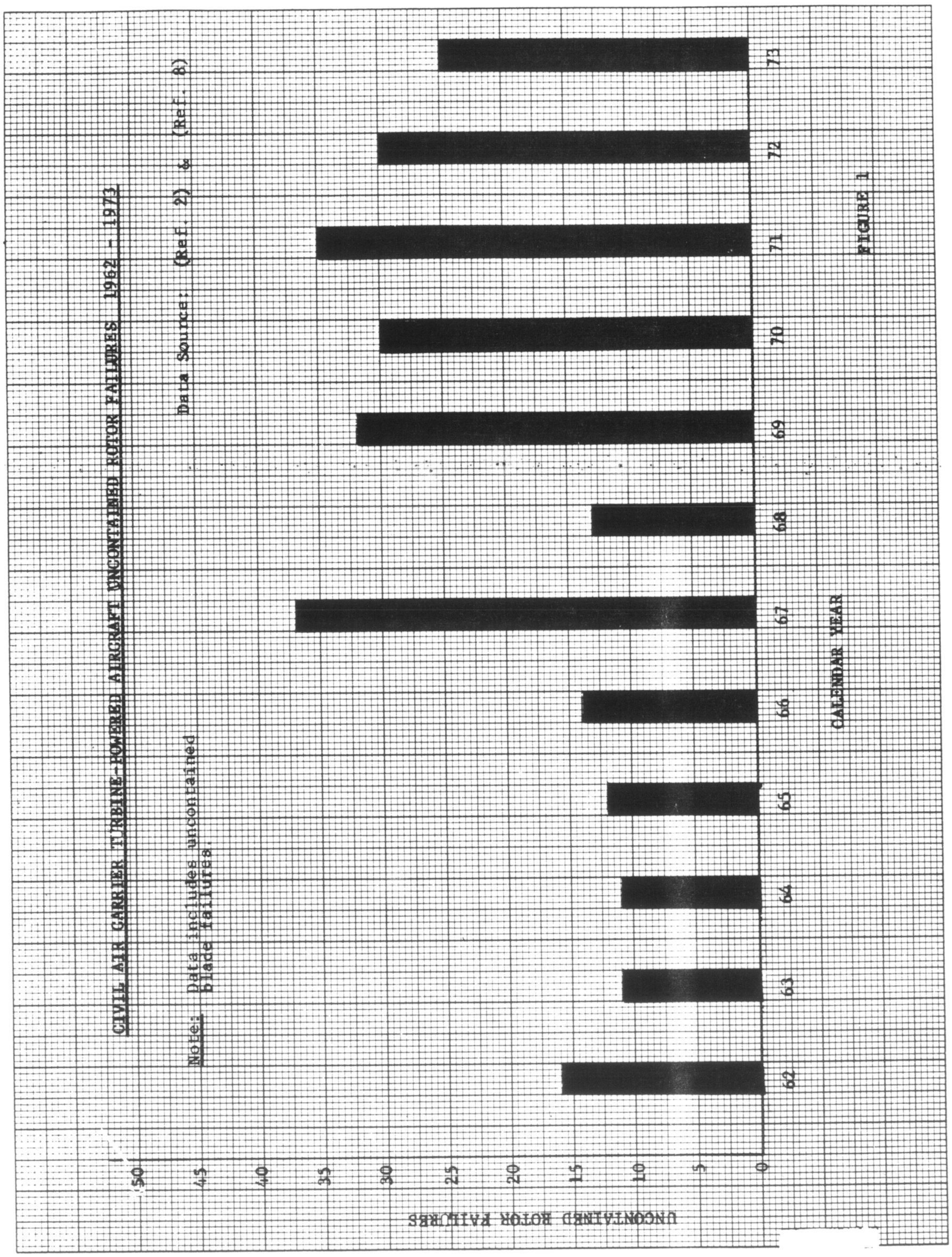

FIGURE 1

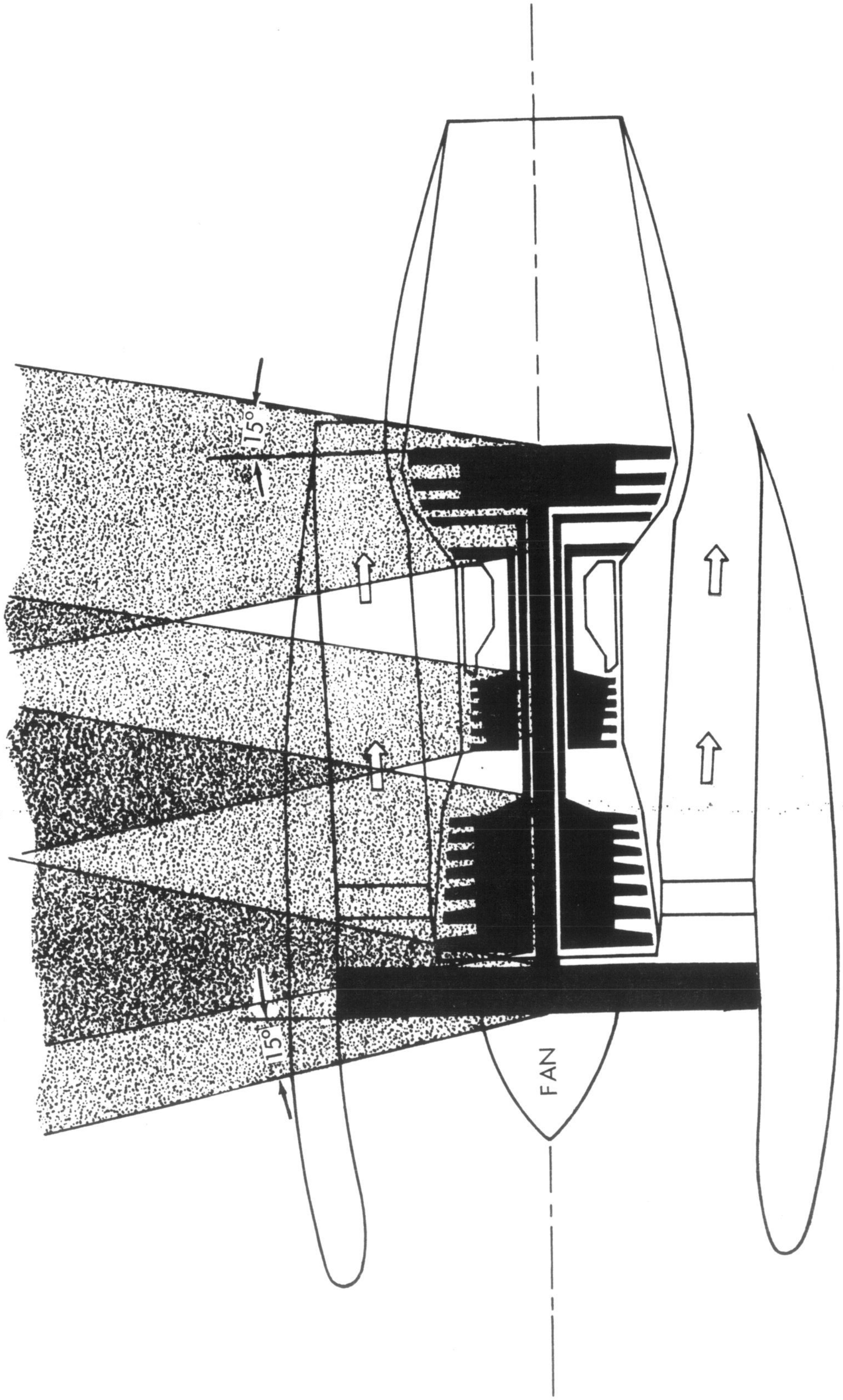

Figure 2

Estimated Path of Fragments From an Uncontained Rotor Failure

REFERENCES

1. "Noncontainment of Engine Debris," CAA Report PP/5HE/557, September 29, 1972.

2. Martino, Albert A., "Designing Rotor Burst Protection," ASME Publication No. 71-GT-70, April 1971.

3. Yeghayan, R. P..; Leech, John W.; and Witmer, Emmett, A,; "Experimental and Data Analysis Techniques for Reducing Collision Induced Forces from Photographic Histories of Engine Rotor Fragment Impact/Interaction with a Containment Ring,"NASA CR134548, ASRL-TR-154-5, Massachusetts Institute of Technology, October 1973.

4 Martino, Albert A., "Designing for Rotor Burst Protection," Naval Air Propulsion Test Center, FAUSST 8.3.2.06, Trenton, NJ

5. Martino, Albert A. and Mangano, G.J., "Rotor Burst Protection Program," Phase V - Final Report (NASA DPR R-105), NAPTC-AED-1901, May 1969.

6. Gerstle, J. H., "Analysis of Rotor Fragment Impact on Ballistic Fabric Engine Burst Containment Shields," AIAA Journal of Aircraft, Vol. 12, No 4, April 1975.

7. Madgwick,T., "Progress Report on Tests to Determine the Ignition Risk in Fuel Tanks if Penetrated by Engine Failure Debris,"British Aircraft Technical Report SST/R35/FIRE/9456/, October 4, 1972.

8. Mangano, G. J., and DeLucia, R.A., "Rotor Burst Protection Program: Statistics on Aircraft Gas Turbine Engine Rotor Failures that Occurred in U.S. Commercial Aviation During 1973," ASME Publication No. 75-GT-12, March 1975.