# Status of Engine Rotor Burst Protection Program for Aircraft

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## Theme

ACCOMPANYING today's use of turbomachinery in aircraft is the associated danger that occasionally a high-speed rotor will fail and the fragments will damage equipment and threaten passenger safety. Such adverse effects can be reduced either by prevention of or protection against rotor bursts. A significant effort is being expended to improve methods for detecting defects during fabrication, operation, and maintenance. Despite such efforts, however, statistics continue to reflect the persistence of rotor failures. During the past 9 years, 170 uncontained failures of gas-turbine engine components were reported by U.S. commercial airlines. Accordingly, NASA has been sponsoring a research program with a view toward providing protection to the aircraft without imposing large weight penalties.

This program is directed toward the development of criteria and methods for the design of practical devices to contain rotor fragments as well as to deflect them away from the critical aircraft components. The immediate aim is to develop meaningful tests and analytical methods to evaluate possible solutions.

In order to generalize the results, experiments are closely coordinated with analytical methods. Tests, conducted in the Navy Containment Evaluation Facility,[1-4] are compared with results of calculation methods developed by the Massachusetts Institute of Technology.[5,6] Test rotors, modified to fail with predetermined sizes and shapes of fragments, are caused to impact containment/deflection devices in a spin chamber. The complex interaction between the fragments and the protective device is recorded by high-speed photography. Deformations of the containment/deflection device, measured on the photographs and related to the time reference, show the dynamic interaction. This paper highlights some of the accomplishments to date and presents future plans.

## Contents

Simple tests were run first to support analysis. A blade was modified to fail at a specified speed and impact an aluminum alloy (2024-T4) freely supported containment ring (i.e., no restraints to motion in the plane of the ring). The response is show in Fig. 1 at the three elapsed times. Ring deflections around the circumference (at the alternate black and white marks) were recorded at approximately 30-μsec intervals. Comparison of the measured and analytically predicted ring profiles after impact shows good agreement for this simple case. However, improvements in the calculation methods are being pursued to increase the accuracy of the predictions and to handle the interaction between more complex fragments and containment rings. The method of analysis also calculates the stresses that result from the ring deformation.

Investigations have been conducted to study the influence of several parameters on the interaction between the fragment and the protective device which it impacts. Some early results will be presented regarding 1) the deformation of the containment ring, 2) the number of fragments that impact the containment ring, 3) candidate ring materials, and 4) a deflection device.

Figure 2 shows the response of a freely supported ring to the impact of three fragments. Blades were removed at three places and the disk was cut radially at these locations. Note that the fragment rotates about its center of mass as well as translates tangentially. Also, that the steel ring experiences large deformations and a lobe develops for each fragment.

Post-test measurements indicate that the rings that contained the fragment attacks deform plastically only in localized areas. It was therefore concluded that any criteria for containment that are based on large failure strains throughout the ring are not well founded. One such questionable theory, which is accepted by some investigators, states that containment will be provided by a ring only if the fragment attack energy does not exceed the potential strain energy (defined as the area under the stress-strain curve multiplied by the volume of material in the ring). Results of the present investigation indicate that such a theory is not valid. Under similar attack by three fragments, rings of the same weight (3.2 kg, or 7.0 lb) provided containment at average values of attack energy equal to three times the potential strain energy for a high-strength steel (4130A) and only one-half the potential strain energy for an aluminum alloy (2024-T3). In other words, the energy ratios were 3.0 and 0.5, respectively, and not 1.0 as this theory predicts.

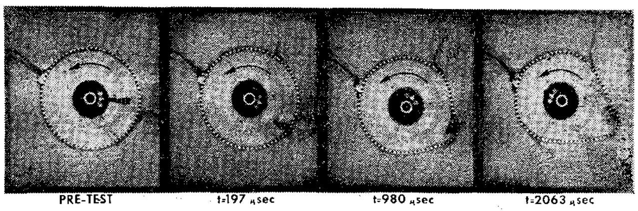


**Fig. 1 Response of free ring to single-blade impact.**

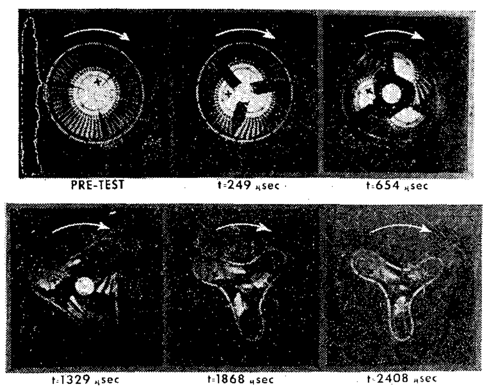


**Fig. 2 Response of free ring to attack by rotor fragments.**

Received August 26, 1971; synoptic received October 22, 1971; revision received March 10, 1972. Full paper is available from National Technical Information Service, Springfield, Va., 22151 as N71-30762, at the standard price (available upon request). The full paper also appears in *NASA Aircraft Safety and Operating Problem*, Vol. 1, NASA SP-270, proceedings of a conference held at Langley Research Center, Hampton, Va., May 4–6, 1971.

Index categories: Aircraft Subsystem Design; Structural Dynamic Analysis.

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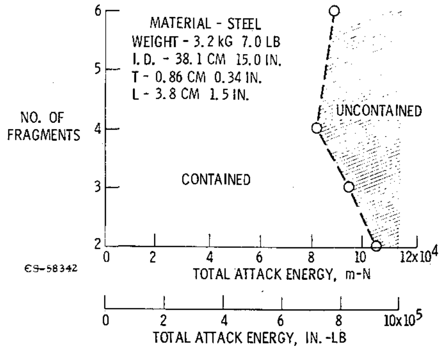


**Fig. 3 Effect of number of fragments on containment by ring.**

The extent to which a containment ring can absorb the energy of an impacting fragment depends on the restraints imposed on the ring. In an exploratory test, a ring which was restrained at three equally spaced points, failed near all three restraints; whereas the similar freely mounted containment ring (Fig. 2) did not fail under the same attack energy.

A limited number of tests were performed to determine how the response of a containment ring is influenced by the number of fragments that impact it. Similar high-strength-steel (4130A) freely supported rings [weight, 3.2 kg (7.0 lb); inside diameter, 38.1 cm, (15.0 in.); radial thickness $T$, 0.86 cm (0.34 in.); and axial length $L$, 3.8 cm (1.5 in.)] were attacked by rotors modified to generate two, three, four and six equal fragments. The results shown in Fig. 3 indicate that such a ring is least effective when attacked by the four-fragment burst. Additional tests are being performed to check this preliminary conclusion.

As an indication of the influence of the mechanical properties of candidate structural materials on their capability to protect against attack by rotor fragments, containment rings of several materials were evaluated. The materials were selected to provide a variation in strength and ductility and a range of potential strain energy of about one decade (i.e., $0.28 \times 10^5$ to $2.03 \times 10^5$ mn or $0.25 \times 10^6$ to $1.80 \times 10^6$ in.-lb). Results show that the steels (4130A and TRIP) are possible candidates for protective devices in the turbine region, and the aluminum (2024-T3) and nonmetallics (ballistic nylon or filament wound E-glass) might be used in the lower temperature compressor region or other auxiliary equipment.

Another way to protect the aircraft from the impact of rotor fragments is to use a shield in the form of a partial ring. In this way, a "window" is provided through which fragments may escape in specific directions to minimize effects of a rotor burst. Exploratory test results in Fig. 4 show a mild-steel (1025) half ring supported at two points, similar to the rear engine mount of a pod-mounted engine. The area to be protected is the shaded area shown at the top of the pretest photograph. The rotor is simulated by a flat disk which turns counterclockwise and generates three fragments. By observing the consecutive positions of the fragment marked with a cross, it is seen that the partial ring did deflect it downward and to the left. Similarly, the other two fragments were also deflected away from the protected area by this "static" shield.

The tests performed to date were directed at the study of the interaction between the fragments and the containment/deflection device which they impacted, including the effects of number of fragments, relative merits of some ring materials and simple tests to support analysis. An experimental program is being pursued to determine the ring weight required to defeat the fragments of a rotor burst at maximum operating speed. Such information will provide design guidelines for protecting an aircraft from fragments generated by a rotor of a given size and mass. Two sizes of fragment generators, 78.7-cm (31-in.) diam and 35.6-cm (14-in) diam will be used to represent turbine rotors of current airplane and helicopter engines. More realistic tests will also be performed to support the analytical procedures.

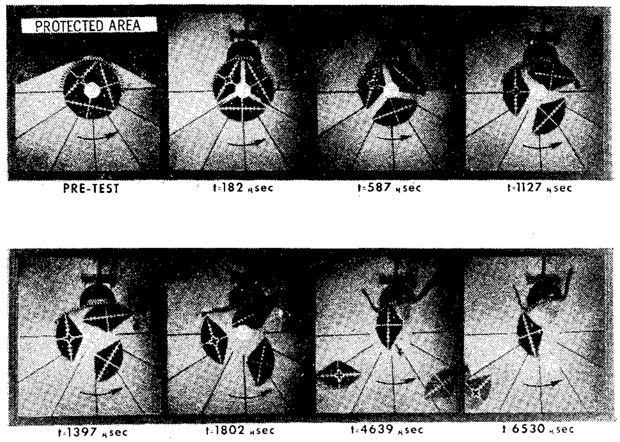


**Fig. 4 Deflection of three flat-disk fragments by static shield.**

A computer program (JET 2), developed for calculating the response of a freely supported ring to the impact forces exerted by the fragments, is valid for predicting the ring deformation and the accompanying stresses if the applied forces are known. Another program (TEJ 2) uses the measured ring deflections to calculate the applied forces which are then introduced into the JET 2 program to calculate the ring response. Both programs published in Refs. 5 and 6 are being used by engine manufacturers. Another computer program (JET 3) is under development and accounts for the effect of mode of support of complete or partial rings. Work will be continued to improve the accuracy of the results.

## References

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