# ROTOR BURST PROTECTION CRITERIA AND IMPLICATIONS

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## - ABSTRACT -

Due to the high energy content of the rotating compressor and the turbine assemblies in a turbine engine, the possibility of an engine burst was recognized as a potential hazard from the earliest development days. Recognition of the potential for engine burst has led to definitive FAA certification regulations and specific considerations in the design of current aircraft. This design philosophy is continued today and historically proved very effective. However, rotor burst protection must be considered an important element of overall aircraft safety and continued effort to reduce the frequency and minimize the consequence of non-contained rotor failures is justified. This paper reviews current aircraft design practices to minimize the hazard from rotor bursts, and discusses the consequences of non-contained engine failures and the impact of rotor burst protection systems on aircraft design.

## INTRODUCTION

The high energy content of the rotating compressor and the turbine assemblies in a turbine engine and the possibility of an engine burst was recognized as a potential hazard to turbine powered aircraft from the earliest development days. For this reason, the FAA has developed stringent regulations for engine certification which requires special testing to substantiate rotor integrity. Recognition of this potential for engine burst has also led to definitive FAA certification regulations and specific considerations in the design of current aircraft.

This design philosophy is continued today and historically has proved very effective. The U. S. commercial air carrier record of one fatality attributed to non-contained rotor fragments in over 400 million turbine engine hours of flying shows that engine rotor failure is, in fact, statistically a very small hazard to the welfare and safety of commercial aircraft passengers.

However, to further improve flight safety, it is necessary to continually look for means of eliminating or reducing the potential for accidents, including the non-containment of turbine engine fragments. Consideration of the potential hazard of an engine rotor burst is an important factor in overall aircraft safety and continued efforts to reduce the potential hazard is warranted.

## CURRENT DESIGN PRACTICES

Although considerable effort is being expended by engine manufacturers to reduce the number of engine rotor failures, it is believed that the rate will not be reduced to zero. Rotor failures may continue to occur at a rate near the current level of approximately one non-contained failure per million engine hours. Therefore, continued effort to minimize the hazard to the aircraft of non-contained engine fragments is required.

Current design practices to minimize this hazard include configuring the aircraft to reduce the risk of: (1) loss of additional thrust, (2) fuel fed fires, (3) loss of critical systems, and (4) loss of structural integrity. These objectives are accomplished by: (1) controlling the relative location and spacing of engines and critical systems, (2) use of redundant systems, (3) use of dual load path structure, and (4) use of fire protection systems. In addition, where configuration peculiarity indicates, consideration is given to special shielding of critical components. The application of these concepts is of course very dependent upon the basic airplane configuration. The success of this design approach is a matter of record.

## CONSEQUENCE OF AN ENGINE BURST

Boeing has recently completed a study to identify the consequence of engine non-contained failures and to determine if there is a correlation between damage severity and fragment type. Information on aircraft damage resulting from non-contained engine fragments was obtained from FAA, NTSB, and CAA reports (References 1 through 5). All current Boeing aircraft models were included in the study as well as available data on DC-8, DC-9, DC-10, CV880, CV990, and L-1011 aircraft. Damage data were collected on 366 jet engine non-containments that occurred between January 1964 and February 1976.

For this study, "non-containment" was defined as the release of internal parts of an engine with sufficient force to puncture or split the engine outer case with or without fragments passing through the case. Generally, non-containments that involve fragments that exit the nacelle with the potential to damage aircraft structure other than the affected nacelle are of primary concern. However, the broad definition of non-containment used in this study was selected to give consideration to all non-contained occurrences.

Various other studies (References 6 and 7) have examined non-contained engine failures from the standpoint of the cause of failure. The Boeing study was an attempt to analyze the consequence of non-contained failures with respect to the hazard to the aircraft and its passengers. Since all commercial aircraft certified under FAR Part 25 are capable of continued safe operation after the loss of thrust from one engine during any phase of flight, this study was concerned with damage to the aircraft other than the affected nacelle.

A method was developed which attempted to relate the aircraft damage caused by an engine non-containment to the potential hazard to the aircraft resulting from that damage and to the class of fragment causing the damage. The method generated a "relative damage severity rating" for each occurrence. This rating was in the form of a number by which the hazard associated with one occurrence could be compared to that of another occurrence. The rating has no absolute meaning. It was offered only as an aid in relating occurrences to each other.

The relative damage severity rating is a subjective measure of what could have happened in a particular occurrence, given the actual damage caused by the engine non-containment. Thus, it is a means of identifying the potential hazard. Since it is subjective, each occurrence could be rated differently by different analysts. However, it was felt that by applying the same criteria by the same analyst to all occurrences, a reasonable picture of the criticality could be obtained. After the numerical values for the relative damage severity were determined for each occurrence, the data were divided into four general categories shown in Table 1. It is apparent that Categories 1 and 2 damage severity presents no hazard to the welfare and safety of the commercial airline passenger. It is also apparent that if a meaningful reduction in the hazard to the aircraft from non-contained rotor failure is to be achieved, Categories 3 and 4 type damage must be significantly reduced.

It should be recognized that Boeing has no first hand knowledge of the vast majority of these occurrences and while for purposes of this study the information reported and the conclusions reached by the investigating authority or operator involved are assumed to be correct, they may not be so.

The results of the study are summarized in Figure 1. Of the 366 non-contained occurrences classified, 283 were judged to have caused minor damage severity, 53 moderate damage severity, 19 significant damage severity, and 11 extreme damage severity. These data indicate that a relatively small percentage of engine non-contained failures result in significant or extreme damage severity. Only limited data was available covering the number of blades released, the size of the rim or disk segment or how many pieces were involved in a failure. For this reason only general categories of fragment size were used in plotting the data. The fragment categories used are: single blade, multiple blades, rim segments, and disk segments. Only occurrences where measurable aircraft damage occurred and where the fragment class was known are plotted. The figure shows that the majority of non-contained occurrences with high damage severity ratings (significant or extreme) involved large fragments with high energy levels (rim or disk segments) while very few smaller fragments (blades) were involved in significant or extreme damage severity. Thus to measurably reduce the hazard of non-contained rotor failures by the use of containment would require containment of the majority of the large high energy fragments.

These analyses indicated that the majority of non-contained engine bursts released fragments with relatively low energy levels. Although the installation of increased containment capability could significantly reduce the number of non-contained engine bursts to which the aircraft structure and system are exposed, reducing the number of non-contained burst does not directly imply an equivalent reduction in hazard to the aircraft. The hazard to the aircraft is a function of fragment size and energy. Containment of only the low energy fragments would not significantly reduce the hazard to the aircraft and could result in a significant weight penalty.

## IMPACT OF ENGINE BURST PROTECTION

Substantial design effort has been expended by aircraft companies to retain a high degree of flight safety and at the same time minimize the penalties to the aircraft due to current design practices for engine burst protection. Any consideration of changes to the current design practices, such as increasing the containment capability must be evaluated on the basis of overall improvement in flight safety. The impact on air carrier operating cost must also be determined.

Improving the engine fragment containment capability or providing deflection capability in order to further protect vital aircraft areas impacts almost all aspects of aircraft design. The impact could include: nacelle weight, airframe weight, nacelle performance, nacelle and engine thermal balance, engine maintainability, aircraft weight and balance and aircraft structure including flutter. The amount of impact is dependent upon the configuration and the design of the specific aircraft being considered.

Increasing the containment capability presents an additional problem. Containing fragments within the engine case can cause increased damage to the rotor system and cause the release of more and larger fragments. This in turn could result in a greater hazard to the aircraft than the release of the initial fragment.

## CONCLUSIONS

The Boeing study of non-contained turbine engine rotor failures resulted in the following conclusions:

1. Current design practices to: (1) reduce the number of turbine engine rotor failures, and (2) to minimize the hazard of a rotor failure to the aircraft has resulted in an outstanding safety record.

2. There was significant or extreme damage severity to individual aircraft in a relatively small percentage of engine non-containments.

3. The majority of non-contained occurrences with high damage severity ratings (significant or extreme) involved large fragments (rim or disk segments) with high energy levels. Containment of only low energy fragments (blades) would not have significantly reduced the hazard to the aircraft.

4. Any measure to reduce the hazard of non-contained engine fragments must be evaluated in terms of overall aircraft safety. In addition, economic effects must be evaluated.

## REFERENCES

1. National Transportation Safety Board Report Number NTSB-AAS-74-4 Volume II, December 18, 1974: Turbine Engine Rotor Disk Failure Case History.

2. National Transportation Safety Board Report: Fan/Compressor/Turbine Disk Failure, 1963-1967.

3. National Transportation Safety Board: Briefs of Accidents/Incidents, All Turbine Engines Selected Cause/Factor, U. S. Civil Aviation 1964-1974.

4. Federal Aviation Administration AFS-140 January 1, 1974, Tabulation of Uncontained Rotor Disk Failure Cause in Civil Engines.

5. Civil Aviation Authority (United Kingdom): January 10, 1975: Tabulation of U. S. Uncontained Engine Failures, 1963 through September 1974.

6. National Transportation Safety Board Report Number NTSB-AAS-74-4, Volume I; December 18, 1974: Special Study - Turbine Engine Rotor Disk Failures.

7. Naval Air Propulsion Test Center Report NAPTC-PE-67, NASA/CR-134855, Rotor Burst Protection Program: Statistics on Aircraft Gas Turbine Engine Rotor Failures that Occurred in U. S. Commercial Aviation during 1974, September 1975.

## TABLE 1. - DAMAGE SEVERITY.

- AIRCRAFT DAMAGE CLASSIFIED BY RELATIVE DAMAGE SEVERITY

1. MINOR - DAMAGE TO AFFECTED NACELLE, NICKS AND DENTS IN AIRCRAFT STRUCTURE
2. MODERATE - DAMAGE TO SECONDARY STRUCTURE AND SYSTEMS
3. SIGNIFICANT - DAMAGE TO AIRCRAFT PRIMARY STRUCTURE AND SYSTEMS, MINOR INJURIES
4. EXTREME - HULL LOSS, FATALITIES

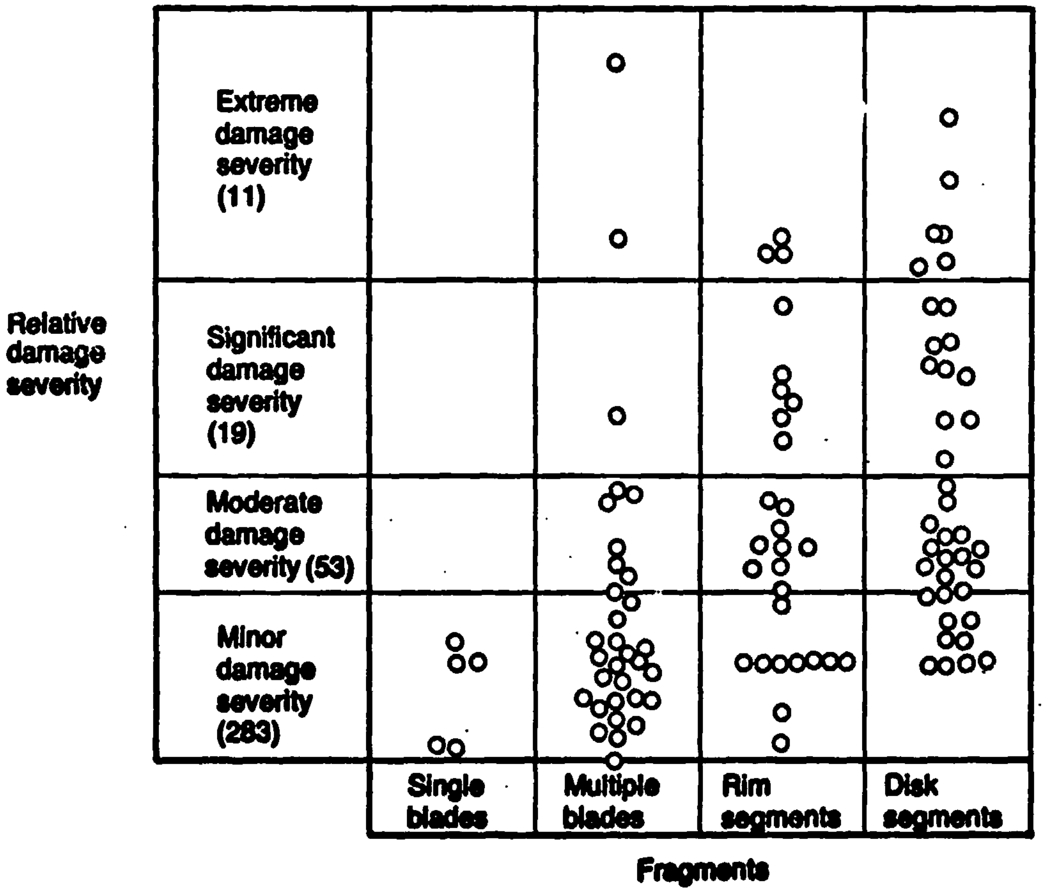

Figure 1. - Relative Damage Severity Versus Fragment Size.

## DISCUSSION

E. Witmer, MIT-ASRL

Ralph, you talked about the occurrence of secondary damage that might develop as the result of primary fragment release. Are you suggesting that perhaps the use of deflectors rather than containers might be a preferable alternative?

R. McCormick, Boeing

I didn't mean to imply that. I suppose that may be a consideration. I intended to suggest that perhaps small fragments would do less damage by exiting out than if we contained them in the engine.

Unknown Questioner

Are you in a position to do more of a systems study of the effect of containment on these items that you talked about: flutter, increased weight, fuel consumption, those sorts of things?

R. McCormick, Boeing

We haven't done that type of study because we haven't looked at a containment system installation in an aircraft and we have no immediate plans to do so.