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Aviation Research Division
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Large Engine Uncontained Debris Analysis—High-Bypass Ratio Engine Update

April 2019

Final Report

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16. Abstract

Under contract to the FAA William J. Hughes Technical Center, the Naval Air Warfare Center has conducted an analysis to update the characteristics of large commercial transport turbine engine uncontained debris. This work was initiated after the 2010 uncontained failure of a third generation high-bypass engine on an A380. The objective of the analysis was to define the debris size, weight, exit velocity, and trajectory that can be used to update Advisory Circular (AC) 20-128A. The effort was conducted by gathering historical data from uncontained engine failures. These data included, when available, phase of flight, engine operating condition, the failed engine component, aircraft damage location, and damage size. With this basic information, debris size was correlated to damage size. A methodology was developed to estimate debris exit velocity. Representative engine cases and cowls were defined, and existing ballistic penetration equations were used to calculate debris exit velocity. This analysis was conducted for disk and blade failures on fan, compressor, and turbine components.

From 1994 until 2003, the Aviation Rulemaking Advisory Committee, Transport Airplane Engine Installation Group, and Power Plant Installation Harmonization Working Group developed guidance for Title 14 Code of Federal Regulations 25.903(d)(1). The Task Group produced an update to the engine uncontained fragment hazard model as defined in AC 20-128A in 1997. Additional work was underway to update the model as AC 20-128B when the group was placed in moratorium. The original Large Engine Analysis report DOT/FAA/AR-99/11 has been updated in this report to include more recent events. The analysis defined herein is a significant part of that effort because it provides a methodology to define fragment energies, and it defines a generic engine fragment model. Additionally, some preliminary modeling of ballistic penetration of aircraft structures and potential barrier materials are presented.

Results of the analysis provided some interesting insight to these events. With respect to the debris trajectories, the analysis shows that the trajectories defined in AC 20-128A are too narrow and should be expanded significantly. Also, the analysis highlights the fact that during an uncontained event, the aircraft is subjected to multiple “small” fragment impacts, not just a single impact. The Australian Transportation Safety Board report stated “damage to VH-OQA exceeded the parameters of the model provided in the advisory material (AC20-128) for predicting the likely damage from a Uncontained Engine Rotor Failure.”

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Advisory Circular
AIA	Aerospace Industries Association
AIR	Aerospace Information Reports
ARAC	Aviation Rulemaking Advisory Committee
ATSB	Australian Transportation Safety board
FPE	FAA Penetration Equations
HBPR	High Bypass Ratio (engine)
HPT	High-pressure turbine
LPT	Low-pressure turbine
NTSB	National Transportation Safety Board

EXECUTIVE SUMMARY

Under contract to the FAA William J. Hughes Technical Center, the Naval Air Warfare Center has conducted an analysis to update the characteristics of large commercial transport turbine engine uncontained debris. This work was initiated after the 2010 uncontained disk failure of a third-generation, high-bypass engine on an A380. The objective of the analysis was to define the debris size, weight, exit velocity, and trajectory that can be used to update Advisory Circular (AC) 20-128A. The effort was conducted by gathering historical data from uncontained engine failures. These data included, when available, phase of flight, engine operating condition, the failed engine component, aircraft damage location, and damage size. With this basic information, debris size was correlated to damage size. A methodology was developed to estimate debris exit velocity. Representative engine cases and cowls were defined, and existing ballistic penetration equations were used to calculate debris exit velocity. This analysis was conducted for disk and blade failures on fan, compressor, and turbine components.

From 1994 until 2003, the Aviation Rulemaking Advisory Committee (ARAC), Transport Airplane Engine Installation Group, and Power Plant Installation Harmonization Working Group developed guidance for Title 14 Code of Federal Regulations 25.903(d)(1). The Task Group produced an update to the engine uncontained fragment hazard model as defined in AC 20-128A in 1997. Additional work was underway to update the model as AC 20-128B when the group was placed in moratorium. The original Large Engine Analysis report DOT/FAA/AR-99/11 was generated from data provided by engine manufacturers that were members of the ARAC group. The original report has been updated in this revision to include more recent events. The analysis defined herein is a significant part of that effort because it provides a methodology to define fragment energies and defines a generic engine fragment model. Additionally, some preliminary modeling of ballistic penetration of aircraft structures and potential barrier materials is presented.

Results of the analysis provided some interesting insight into these events. With respect to the debris trajectories, the analysis shows that the fore and aft fragment trajectories defined in AC 20-128A do not accurately reflect the debris patterns from in-service events. The AC 20-128A debris model results in trajectories that are too narrow, and adequate minimization may not be provided without expanding the model to accurately reflect in-service event data. Also, the analysis highlights the fact that during an uncontained event the aircraft is subjected to multiple “small” fragment impacts, not just a single impact. It is the combined effects of the disk fragments and the multiple small fragments that can disable redundant systems in the aircraft.

From a fragment-energy perspective, this report defines the characteristics of the high-energy fragments that exit the engine cowling. In an uncontained event, there are generally several high-energy disk or rim fragments and many lower-energy fragments that impact the aircraft.

1. INTRODUCTION

From 1994 until 2003, the Aviation Rulemaking Advisory Committee (ARAC), Transport Airplane Engine Installation Group, and Power Plant Installation Harmonization Working Group developed guidance for Title 14 Code of Federal Regulations 25.903(d)(1). The Task Group produced an update to the engine uncontained fragment hazard model, as defined in AC 20-128A in 1997. Additional work was underway to update the model as AC 20-128B when the group was placed in moratorium in 2003. In 2010, an Airbus A380 third-generation[1] high-bypass engine failed and disabled the redundant control systems of the outboard engine. The Australian Transportation safety board recommended the FAA:

"13.130 ATSB AO-2010-089-SR-040

> The Australian Transport Safety Bureau recommends that the US Federal Aviation Administration, in cooperation with the European Aviation Safety Agency, review the damage sustained by Airbus A380-842, VH-OQA following the uncontained engine rotor failure overhead Batam Island, Indonesia, to incorporate any lessons learned from this accident into the advisory material."

The accident report provides the damage to the aircraft and the loss of system control to the outboard engine [1]. This revised report is in response to the Australian Transport Safety Bureau recommendation and was conducted under the FAA's Aircraft Catastrophic Failure Prevention Program.

Uncontained engine events continue to be a significant hazard to commercial aircraft (figure 1). To better understand the threat and provide information that can be used to minimize the hazard to the aircraft, the uncontained debris characteristics must be accurately defined. Debris characterization includes defining debris size, mass, velocity, trajectory angles, and the number of fragments per event type. This report brings the necessary information together to define these characteristics for high-bypass ratio engine types and various component failure modes. The previous report on this topic, DOT/FAA/AR-99/11 [2], included low-bypass ratio engine information as well. High-bypass ratio (HBPR) engines went into service in 1968 on the Boeing 747 with Pratt Whitney JT-9D first-generation high-bypass engines; they provided lower noise levels and more fuel efficiency than low-bypass engines, which were important for the new large airplane. Fuel costs through the 1980s and early 1990s kept a portion of the low-bypass equipped airplanes in service, but today there are no low-bypass engines being installed on new subsonic commercial aircraft. Therefore, new low-bypass engine information and analysis were excluded from this report.

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[1] The AIA has classified engines as first, second or third generation engines in report "AIA Report On High Bypass Ratio Turbine Engine Uncontained Rotor Events And Small Fragment Threat Characterization" .Per AIA, "Third generation engines include the GE90, CFM56-7, CF34-10, PW4000 100" and 112" fan, PW6000, Trent and BR715".

Figure 1. Uncontained turbine disk event

During the previous work, ARAC engine specialists assisted with project direction and reviewed the initial results to develop the methodology that was used for this report. Specific recommendations for data analysis and component failure mechanisms from the specialists have been incorporated.

Work to characterize large-engine debris began in FY-96 with the collection of data from uncontained engine events. A database was developed that included details of 65 large-engine uncontained events. Ten more-recent events have been incorporated into the database, bringing the total to 75 events. For the purpose of this report, large engines are defined as those engines that power narrow and wide-body commercial transport aircraft (commuter and business jet engines are considered small engines). The database spans from November 1961 to the present. Not all events are included in the database because of the lack of availability and completeness of data. The primary sources of information were private-sector engine companies, airframe companies, and the National Transportation Safety Board (NTSB). Appendix A is an example of the sanitized event data provided for the analysis. Because of the proprietary nature of some of the data involved, the FAA agreed under ARAC to publish only sanitized data in a generic form to define the threat. A debris database was established and used to capture event data that can be used to characterize typical debris sizes and trajectory angles for specific component failures. Two groups of debris data were analyzed: 1) small fragments (blades) that may be mitigated through use of shielding provided by airplane structures and components, including fuselage and wing skins with appropriate skin thickness and 2) large debris (uncontained fan blade fragments and disk segments) that may only be mitigated with redundancy and separation, or dedicated shielding.

By categorizing failure types and normalizing the damage to the engine components, a generic (non-engine-specific) debris fragment model was developed to estimate debris kinetic energy as a function of trajectory angle. The presented results are generic in nature to provide an overview of uncontained debris characteristics. For various safety analyses, the debris model can be applied to a specific engine to develop an engine-specific debris model to assess a specific aircraft configuration. The basic assumptions and procedures used to collect the data are presented in the next sections, followed by an overview of results from the Debris Data Base. A detailed breakdown follows based on engine type and component failure modes to categorize specific debris characteristics.

1.1 DEFINITION OF TERMS

Debris Database—Database used to collect and sort event data.

Generic Engine Model—Generic engine characteristics (e.g., blade length and disk diameter) used to normalize damage and to determine representative fragment size for the Generic Debris Model.

Generic Debris Model—Uncontained debris characteristics to include trajectory, size, mass, and velocity.

High-Bypass Turbofan Engine: High-bypass ratio engines achieve a significant amount of thrust from the bypass duct. Title 14 Code of Federal Regulations Part 36.7 (1) says "*Airplanes with high bypass ratio jet engines.* For an airplane that has jet engines with a bypass ratio of 2 or more before a change in type design."

Low-Bypass Turbofan Engine: A low-bypass ratio engine has a bypass ratio below 2.

1.2 UNCONTAINED EVENT HISTORY

To get a better understanding of the uncontained engine failure history, a review of two SAE Aerospace Information Reports (AIR) was conducted. These documents, AIR 4003 and AIR 4770 [3, 4], categorize uncontained turbine rotor events from 1976–1983 and 1984–1989, respectively. These data provide a historical picture of past-uncontained engine failures (table 1). The data are presented as the number of events by engine component (fan, compressor, and turbine) and failure type (blade and disk) for large engines. These data provide insight to the components with the most failures and provide a check against recently developed database to ensure that emphasis is placed in the right areas.

Table 1. Transport aircraft engine uncontained history

	AIR 4003	AIR 4770	Total
Fan Disk	5	9	14
Fan Blade	74	53	127
Fan Other	9	0	9
Compressor Disk	25	10	35
Compressor Blade	4	0	4
Compressor Other	11	2	13
Turbine Disk	22	17	39
Turbine Blade	44	39	83
Turbine Other	8	10	18
Totals	203*	143*	346*

*(1 Unknown in 4003 and 3 unknowns in 4770)

Most of the events in the "Other" category were the result of component spacer/seal failures.

1.3 ADVISORY CIRCULAR 20-128A (DESIGN CONSIDERATIONS FOR MINIMIZING HAZARDS CAUSED BY UNCONTAINED TURBINE ENGINE AND AUXILIARY POWER UNIT ROTOR FAILURE)

AC 20-128A [5] provides a definition of single-fragment characteristics intended to assess aircraft hazard levels (table 2 and figure 2). It discusses the potential of multiple small-fragment impacts to the aircraft, the generalized definition of the number of fragments, and mitigations provided by aircraft features (in paragraph d of table 2).

Table 2. Excerpt from AC 20-128A [5] describing fragment characteristics

a	Single One-Third Disk fragment. It should be assumed that the one-third disk fragment has the maximum dimension corresponding to one-third of the disk with one-third blade height and a fragment spread angle of + 3 degrees.
b	Intermediate Fragment. It should be assumed that the intermediate fragment has a maximum dimension corresponding to one-third of the bladed disk radius and a fragment spread angle of ± 5 degrees. Where energy considerations are relevant, the mass should be assumed to be 1/30 of the bladed disk mass and its energy the translational energy (neglecting rotational energy) of the piece traveling at rim speed (see figure 4).
c	Alternative Engine Failure Model. For the purpose of the analysis, as an alternative to the engine failure model of paragraphs 9a and b, the use of a single one-third piece of disk having a fragment spread angle +5° would be acceptable, provided the objectives of paragraph 10a are satisfied.
d	Small Fragments. It should be assumed that small fragments (shrapnel) range in size up to a maximum dimension corresponding to the tip half of the blade airfoil (with the 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, have typically occurred at the rate of 2 1/2 percent of the number of blades of the failed rotor stage. Refer to paragraphs 7b and 7c for methods of minimization of the hazards. Where the applicant wishes to show compliance by considering the energy required for penetration of structure (or shielding), the engine manufacturer should be consulted for guidance as to the size and energy of small fragments within the impact area.
e	Fan Blade Fragment. It should be assumed that the fan blade fragment has a maximum dimension corresponding to the blade tip with one-third the blade airfoil height and a fragment spread angle of +15°. Where energy considerations are relevant, the mass should be assumed to be corresponding to the one-third of the airfoil including any part span shroud and the transitional energy (neglecting rotational energy) of the fragment traveling at the speed of its C.G. location, as defined in figure 5. As an alternative, the engine manufacturer may be consulted for guidance as to the size and energy of the fragment.

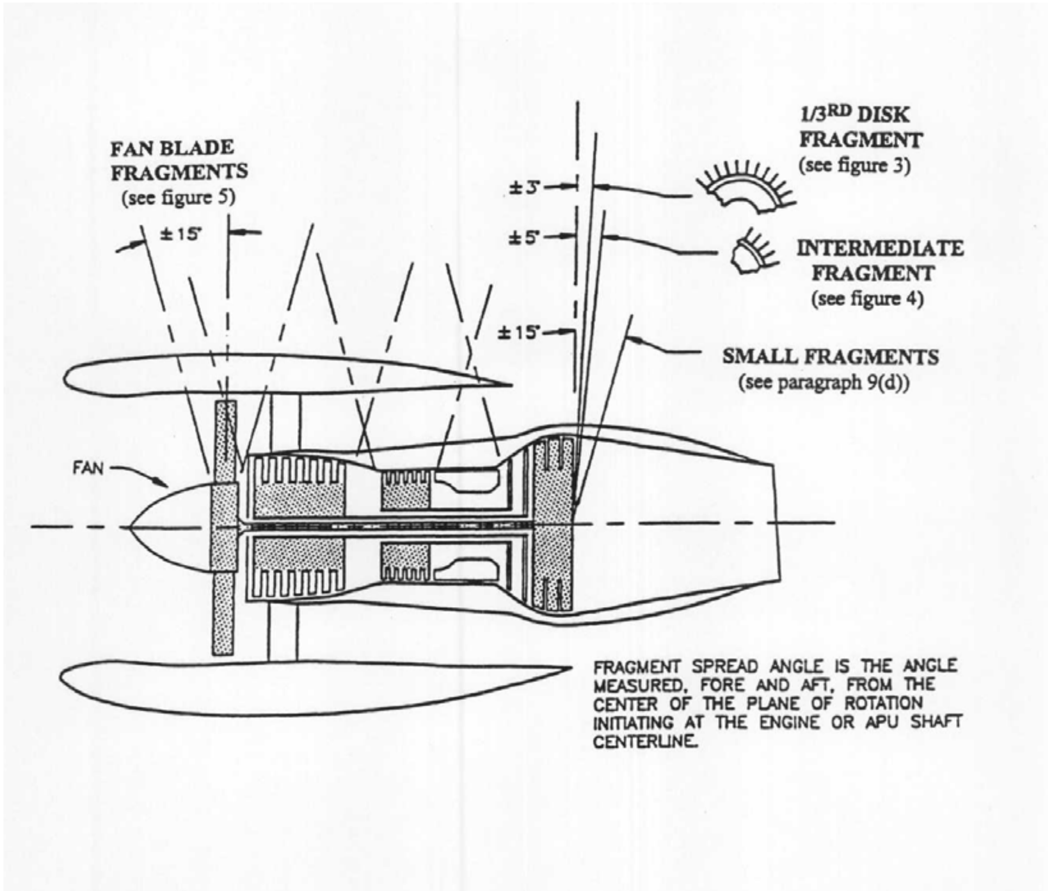


Figure 2. Estimated path of fragment

Paragraph d (9d in the AC) makes reference to the potential of multiple small fragment impacts to the aircraft and refers the reader to the engine manufacturer to obtain fragment mass and velocity when shielding is considered for a particular installation. The analysis described herein reviews the historic data and provides a generic definition of the multiple fragment threat.

2. GENERIC MULTI-FRAGMENT MODEL DEVELOPMENT

2.1 DEBRIS DATABASE

2.1.1 Overview

The large engine debris database in this report utilizes data from in-service uncontained engine events where released engine debris impacted the airplane and caused penetration of the airplane surfaces. The size, velocity and dispersion angles of the uncontained engine debris were determined from in-service events for which sufficient detailed records were available. A thorough search was conducted for data to be included in the analysis. Despite the relatively small number of data-rich incidents used in the analysis, hundreds of events were reviewed with the support of engine and airframe manufacturers. Additionally, the NTSB was very cooperative, allowing detailed data to be collected on-site for several of the events that took place during the course of this effort. The 75 events in the combined database are not merely a representative selection of the data, but the only events with sufficient information to conduct the type of analysis described herein. Many of the uncontained event records reviewed had details of the component failures, but were lacking aircraft damage details. There are many additional fan blade and turbine disk events that are not in the database because of a lack of detailed damage data. For the most part, the lack of such detailed event information is felt to be due to either the lack of aircraft damage being present or the damage being of such a minor nature that on-site repairs were conducted, and the aircraft returned to service in less than 24 hours. Specific parameters needed in the analysis include: aircraft type, engine model, failed component, engine position, engine component dimensions (disk diameter and blade length), damage location (defined by xyz coordinates relative to the failed component, or aircraft station number), size of the damage (length and width), and any subsequent damage to aircraft structure or subsystems. If the debris that caused the aircraft damage was found, the size and mass of the fragment was included.

This update adds new high-bypass-ratio events to the existing database of low- and high-bypass engine events on narrow and wide-body commercial transport aircraft. Aircraft include: Boeing 707, 720, 727, 737, 747, 767; Douglas DC-8, DC-9, MD-80, MD-88, DC-10; Lockheed L1011; Airbus A300 and A380. Engines include Pratt and Whitney JT3D, JT4A, JT8D, JT9D, TF33; General Electric CF6-50 and CF6-80A; Rolls Royce RB211, Conway 508, and Trent 972-84. The inclusion of an engine type does not imply that this engine type is any more susceptible to an uncontained failure than any other engine, but that data from such an event were available and complete for the purpose of this study. Likewise, the exclusion of an engine type does not imply that the engine type has not had an uncontained failure or is less likely to fail.

The focus of the analysis presented in this report is on high-bypass ratio engines only. No additional low-bypass events were added to the database. The low-bypass and turboprop fragment model is the same as the original report. Therefore, data for this analysis include only the high-bypass events. The post-event analysis defines debris trajectories and debris size. When actual debris is not recovered, the damage length was divided by the component length (blade length) to estimate debris size. The process used in the original report was followed for these new events. A total of 34 events was used to establish the large high-bypass ratio engine debris model provided in this report. Data were normalized and then sorted by component and failure mode (e.g., fan blade failure and fan disk failure), damage source (e.g., blade debris, disk debris, and rim debris…), and engine mounting (wing or fuselage). The data were then plotted versus trajectory angle. Key plots are presented in conjunction with the debris energy estimations in section 4.

The normalized debris analysis does provide clear trends. Table 3 lists the different event types with the number of events, average number of aircraft damages per event, maximum number of damages, and minimum number of damages in a single event. A review of table 3 shows fan disk events and turbine disk events to generate the largest amount of aircraft damaging debris. For fan failure events, the maximum number of damages is approximately three times the average number for other disk failures. For the high turbine, the maximum number of damages is approximately two times the average, and low turbine damages are slightly less than two times the average. These variations provide some insight into the sensitivity of the release point relative to the aircraft. For some events, the random primary release angle is away from the aircraft, creating little or no damage to the aircraft. Other events have release angles toward the aircraft, creating many damage locations.

Table 3. High Bypass Ratio event type summary

Event Type	Number of Events	Average Number of Damages per Event	Max Number of Damages in a Single Event	Min Number of Damages in a Single Event
Fan Disk	3*	28.3	73*	2
Fan Blade	12	6.8	24	2
Compressor Disk	2	5	7	3
Compressor Rim	-	-	-	-
HPT Turbine Disk	5	15.0	21	10
HPT Turbine Rim	3	11.7	28	3
HPT Turbine Blade	-	-	-	-
LPT Turbine Disk	3	8.0	13	5
LPT Turbine Rim	2	5.5	7	4
LPT Turbine Blade	4	9.0	12	3

*In later analysis, one of the three fan disk events was separated into three events because this event had a large witness shield.

A tabulation was also conducted to define the number of times aircraft systems (systems other than the failed engine) were damaged during an uncontained event (table 4). Other typical system damage includes failure modes like fuel tank penetrations, severed fuel lines, severed electrical wiring, severed hydraulics, or a punctured pressurized cabin. This has provided additional insight into the number of fragments exiting the engine and impacting the aircraft with a "high" energy level. It appears that, overall, 7.3% of the fragments that exit engine cases do so with sufficient energy to penetrate the aircraft (wing or fuselage) and cause damage to other systems. Disk and rim failures have a higher percentage of system damage than blade failures. System damage occurs when the fragment trajectory intercepts the component and the fragment energy is sufficient to penetrate into the aircraft and strike the component.

Table 4. Percent of damages causing system damage

Event Type	Number of Damages	Number of Damages to Systems	Percent of Damages With Systems Damaged
Fan Disk	85	7	8.2%
Fan Blade	81	4	4.9%
Compressor Disk	10	2	20.0%
Compressor Rim	19	0	0%
HPT Disk	110	10	9.1%
HPT Rim	35	3	8.6%
HPT Blade	-	-	-
LPT Disk	24	2	8.3%
LPT Rim	11	1	9.1%
LPT Blade	36	1	2.8%
TOTAL	411	30	7.3%

The following sections describe the methodology used to define the fragments that have sufficient energy to penetrate the aircraft fuselage or wing skin and cause damage to other structures or systems. The methodology used provides a conservative yet realistic estimate of the debris energy (resulting in higher fragment velocities); however, the energy estimates are not the most conservative estimate.

2.1.2 Debris Trajectory

The aircraft damage location was collected as part of the incident report and captured in the database. The damage location relative to the failed component plane of rotation was used to define the trajectory of the debris that caused the damage.

Incident reports often provide detailed aircraft damage descriptions, but the details of the actual debris that caused the damage is often unknown. For each damage location, hole size (length and width) was collected in the debris database.

To get an indication of the debris scatter, damage hole length is plotted against fore and aft trajectory angle. Fan failure events are provided as an example (figure 3). It is clear that the trajectory spread is generally centered around zero and that there are some very significant hole lengths. Looking at the trajectories of disk fragments, they fall within the AC20-128A guidelines of +/- 3 degrees, and blade-fragment trajectories fall well outside the AC 20-128A guidelines of +/- 15 degrees.

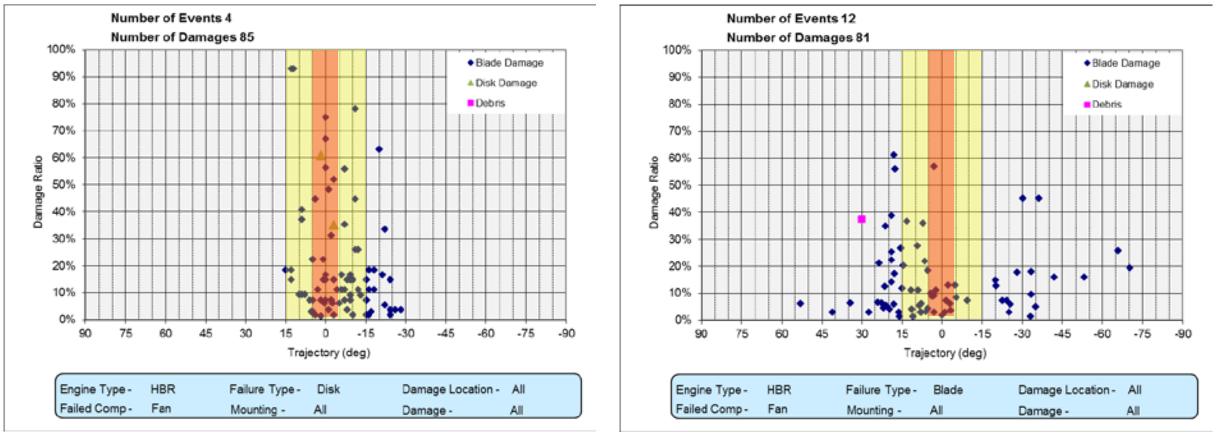


Figure 3. Damage hole length vs. trajectory angle (fan disk and fan blade events)

2.1.3 Debris Characterization

To obtain an understanding of the potential size of fragments that generated the holes in the aircraft, the aircraft damage length was normalized to the engine component size. For blade-related damage, the damage length was normalized to the blade airfoil length; for disk-related damage, length was normalized to disk diameter. The normalized damage size is referred to as damage ratio within this document. Estimated fragment size is presented in terms of damage ratio and plotted against trajectory angle. As an example, fan failure events are plotted in figure 4. For most component blade characterizations, a single fragment size is selected to represent a more significant threat. The size selected is not the largest or smallest, but a reasonable representation of the fragment, and, in most cases, the small change in fragment weight does not result in a significant change in fragment energy level. Fan blade fragments are the exception and will be discussed later in section 4.1.2.

Definition of the fragment trajectory is also needed to characterize the uncontained fragments. The damage ratio charts consist of the red max and min (largest aft trajectory), the blue 85% inclusion boundary, and the yellow characterization limits based on including a significant majority of the damage locations. The yellow characterization limits for each failure and fragment type are used in the debris characterization table.

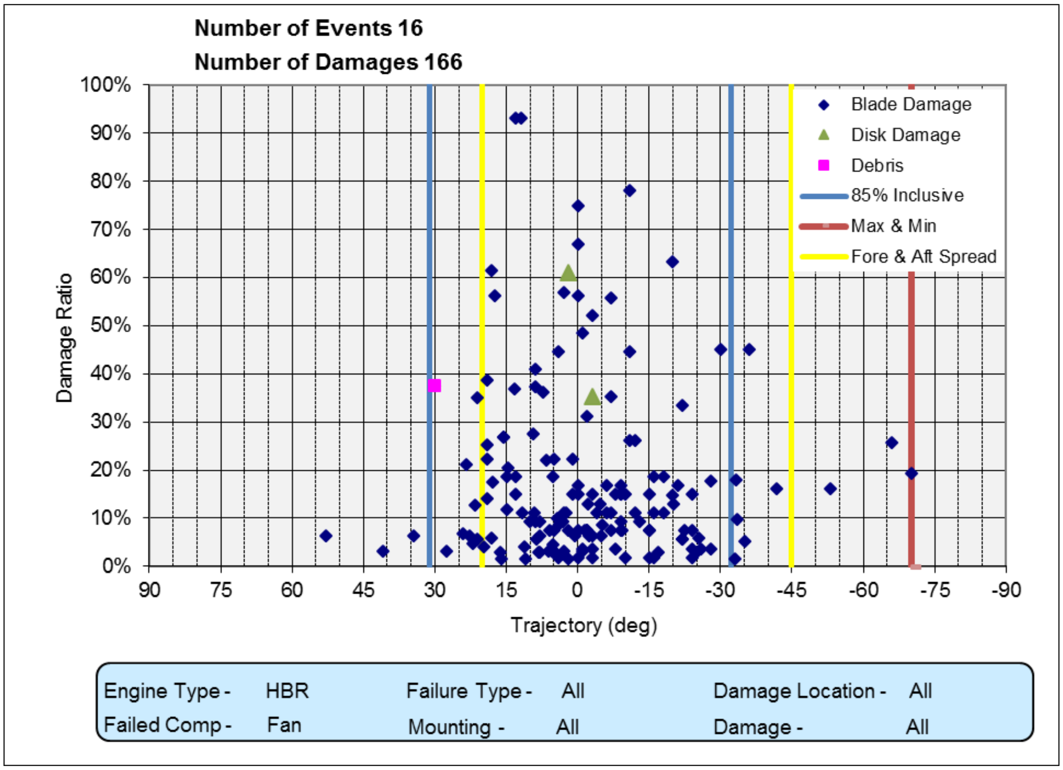


Figure 4. Example fan damage ratio vs. trajectory

2.2 FRAGMENT ANALYSIS METHODOLOGY

2.2.1 Assumptions

To provide a working model for characterizing engine debris, certain assumptions in analyzing the debris database and in estimating debris energy levels were used. The assumptions are defined in this section, followed by a discussion of the analytical procedure.

2.2.1.1 Debris Size Assumptions

Incident reports often provide detailed aircraft damage descriptions, but the details of the actual debris that caused the damage are often unknown. To provide an estimate of the debris size, the damage holes in the aircraft were normalized to the engine component size. For blade-related damage, the normalization factor was maximum blade airfoil length; for disk-related damage, the normalization factor was disk diameter. The normalized damage size is referred to as damage ratio within this document.

2.2.1.2 Generic Engine Model

The generic engine model (table 5) defines the physical description of the generic engine. The normalized damage ratio is applied to the generic engine to define debris fragment size, which can then be used in the penetration analysis to determine fragment exit velocity from the cowl.

Table 5. High-Bypass ratio generic engine model

Component	Blade Length (in.)	Blade Width (in.)	Full Blade* Weight (lbf)	Disk Diameter (in.)	Disk Bore Diameter (in.)	Disk Weight (lbf)	Rotor Speed (RPM)
Fan	32	8	12.5	30	25	136.4	3600
Compressor	4	2	0.25	20	6	30.0	10000
HP Turbine	4	2	0.3	27	19	125.0	10000
LP Turbine	8	2	0.68	30	26	120.0	3600

*Airfoil only

2.2.1.3 Engine Cowlings

A generic set of engine cowlings was used in this analysis to provide a representative structure to produce representative fragment exit velocities. The values selected were average value, based on cowling data provided by engine and airframe manufacturers (figure 5). The cowlings for fan, compressor, and turbine analyses are defined in figure 6.

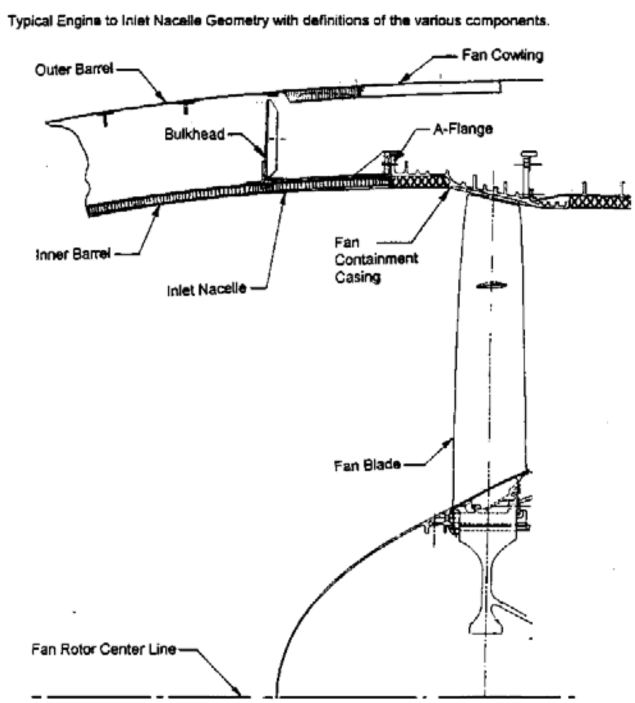
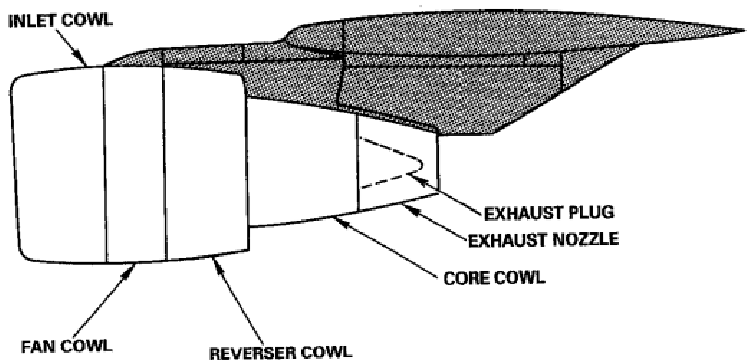


Figure 5. Typical inlet – Fan cowl configuration



Skin Thickness (in)

Fan / Inlet Cowl	Compressor Cowl	Core / Turbine Cowl
0.025 Al	0.040 Al	0.040 Al
0.025 Al		None
0.040 Al		

Note:
1. Thrust reverser was not modeled because most of the data was for engines without a fan reverser.

Figure 6. General engine cowling layout

2.2.1.4 Debris and Engine Case Interaction

When evaluating blade debris energy from a disk event, energy loss from penetrating the engine case is not estimated. The assumption is that most of the debris will exit through an existing hole in the engine case caused by a disk segment. Disk segments generally stay within the plane of rotation, whereas smaller pieces, such as blade debris, get deflected to the larger trajectory angles. As the blades continue on their trajectory, the blade debris must still penetrate the engine cowling.

2.2.1.5 Debris Velocity Analysis Assumptions

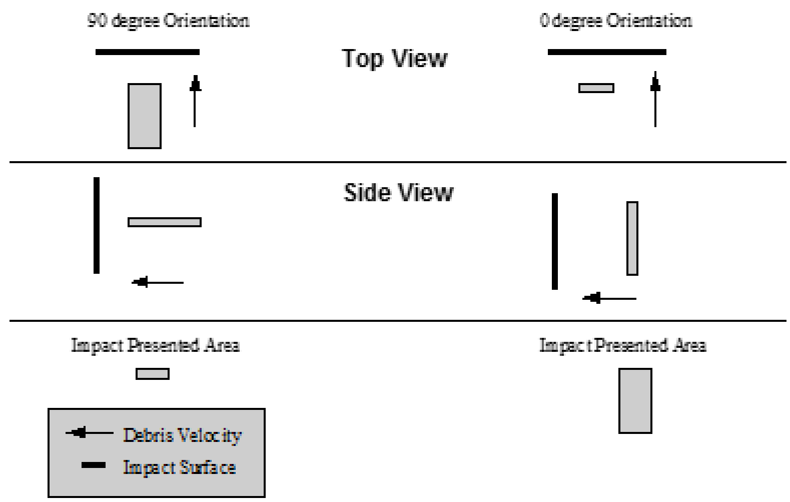
A significant effort was placed on estimating blade debris residual velocity or energy level as it exits the engine cowling. Initial velocity can be calculated based on the component rotational speed and centroid radius. Assumptions were made in calculating the energy lost as the debris penetrates through engine casings and cowl skins. Two failure modes are addressed: blade debris from disk events and blade debris from blade events. Details of the analysis for each of these failure modes are defined below. A significant factor in each of these failure modes is external aerodynamic drag effects.

2.2.2 Debris Exit Velocity Analysis Methodology

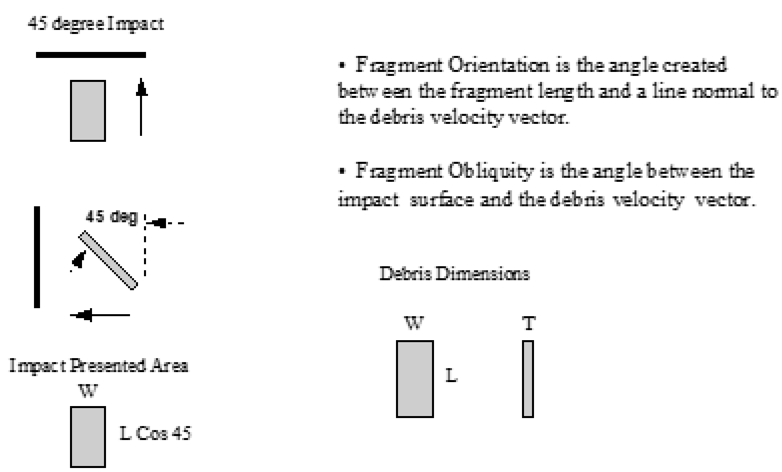
2.2.2.1 Fragment Penetration Analysis

The estimated energy loss from exiting the engine case and penetrating the cowl is provided by estimating the energy lost in the process of exiting the engine case and using the FAA Penetration

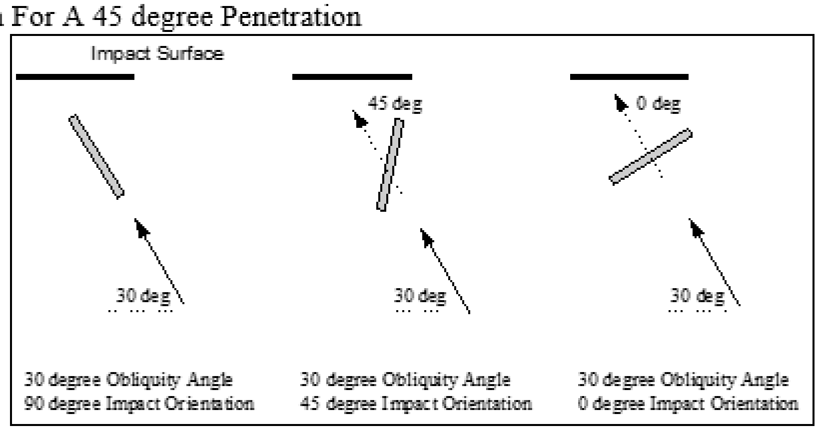
Equations (FPE)[6] to calculate the cowl exit velocity. The FPEs are empirically based for fragment-aircraft structure penetration analysis. Figure 7 summarizes the basic engine case and cowl model used for analyzing blade-fragment penetration from a disk event. Initial debris velocity ($V_{initial}$) is the tangential velocity based on the centroid location (r_{cg}). When released from within the engine, debris will initially travel tangentially in the plane of rotation impacting the case. High-speed movie documentation of fan-blade release confirmed that sliding frictional effects of released blade fragments against engine case structure as the fragment traveled in a forward helical trajectory would reduce their velocities to approximately 75% of the original blade-tip velocity. This 75% rule was also applied to blade particles in events initiated by disk failure to account for blade breakage prior to exiting the case as well as blade particle friction. Additional impacts to near-field structure or components deflect the debris as they exit the engine cowl. Energy is lost during this deflection process. A conservative model assumes the debris velocity is proportional to the cosine of the trajectory angle ($V_{debris} = V_{initial} \cos \theta$), as shown in figure 8.



a) Impact Orientation and Presented Area



b) Debris Orientation For A 45 degree Penetration



c) Fragment Obliquity

Figure 7. Fragment orientation and obliquity

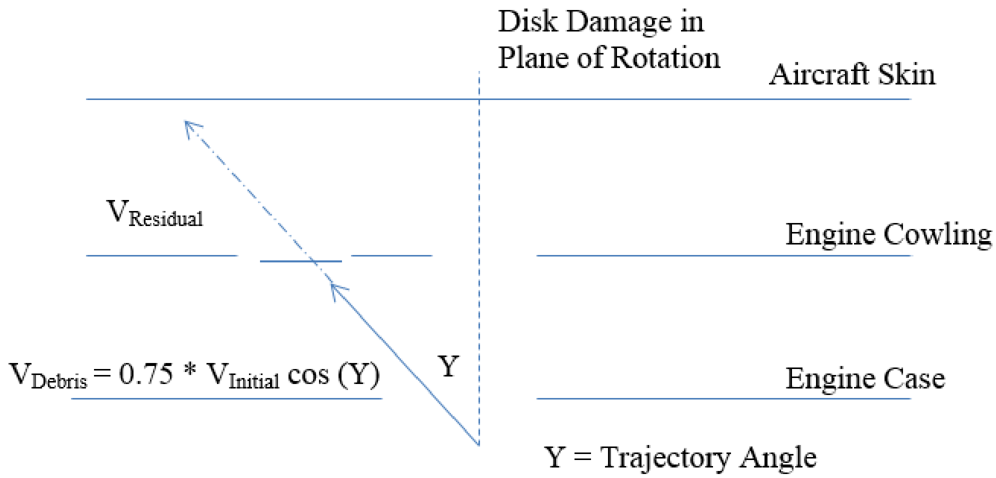


Figure 8. Blade debris penetration model for disk events

The estimated energy loss from penetrating the cowl is calculated by the FPE. The required fragment obliquity and orientation parameters for FPE are defined in figure 7a. It is important to understand the difference between obliquity angle and orientation angle. The obliquity angle refers to the angle between the debris velocity vector and the surface of the plate into which the debris is impacting. The fragment orientation angle is defined as the angle created between the fragment length and a line normal to the debris velocity vector (figure 7b). FPE calculates fragment presented area by width * length * cosine (orientation angle). The obliquity angle is used in FPE to calculate the relative thickness of the plate that the debris is impacting (figuref 7c).

2.2.2.2 Blade Debris From Uncontained Blade Failures

For fan, compressor, and turbine-blade failures, blade debris energy loss from penetrating the engine case should be considered, except in the two special cases to be discussed. For blade debris that penetrates the engine case and the engine cowl, an edgewise penetration (debris orientation of 80 degrees) through the engine case is assumed, followed by a tumbling penetration (debris orientation of 45 degrees) through the cowl (refer to figure 9). For compressor and turbine blade failure events, the engine case is represented by 0.25" of hardened steel.

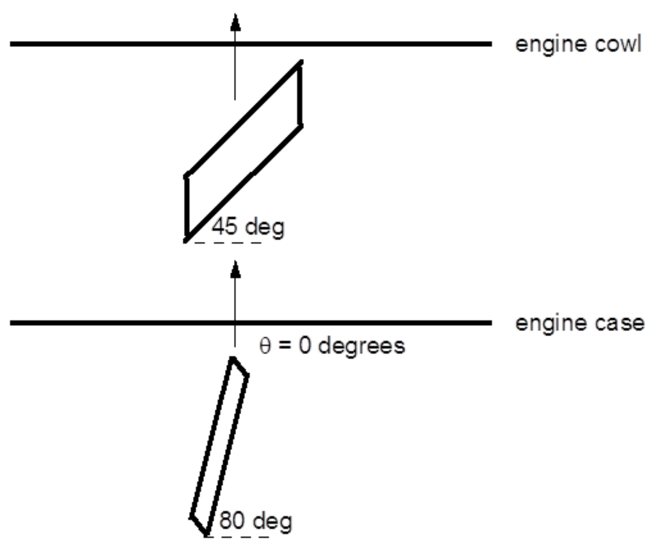


Figure 9. Blade-debris penetration model for blade events

There are two fan-blade failure scenarios for which the debris does not penetrate the engine case. In the first scenario, during a fan-blade failure, a blade-tip fragment is liberated as the blade buckles against the containment ring. The tip fragment travels forward of the containment ring into the inlet in a helical motion. Estimated debris velocity is 75% of the tip velocity. Eventually, a fragment edge ‘catches’ the soft inner inlet wall and penetrates edgewise (debris orientation of 80 degrees). After this initial penetration, the fragment is assumed to be tumbling (debris orientation of 45 degrees). The FPE’s are used to estimate the energy loss from penetrating the inlet cowl.

The second scenario involves fan debris that is re-ingested into the engine and then ‘kicked’ forward by the fan rotor. Reference [7] provides a method for estimating the debris mass and velocity as a function of trajectory angle for this process. FPE’s are then used to estimate the energy loss from penetrating the inlet cowl. It is assumed the debris is tumbling freely during this time (orientation angle of 45 degrees).

There is also a special turbine blade scenario in which the blade fragments do not penetrate the engine case or cowl. This scenario pertains to the last stage turbine blade events, for which the blade fragments exit the engine out the tailpipe but are initially traveling in a helical trajectory, similar to the fan-blade scenario. For this case, the blade fragment is assumed to lose 25% of its initial velocity because of fictional effects prior to exiting the tailpipe (figure 10). The initial helical path is influenced by the presence of struts and mixers. Additional discussion about this special case is shown in section 3.1.2

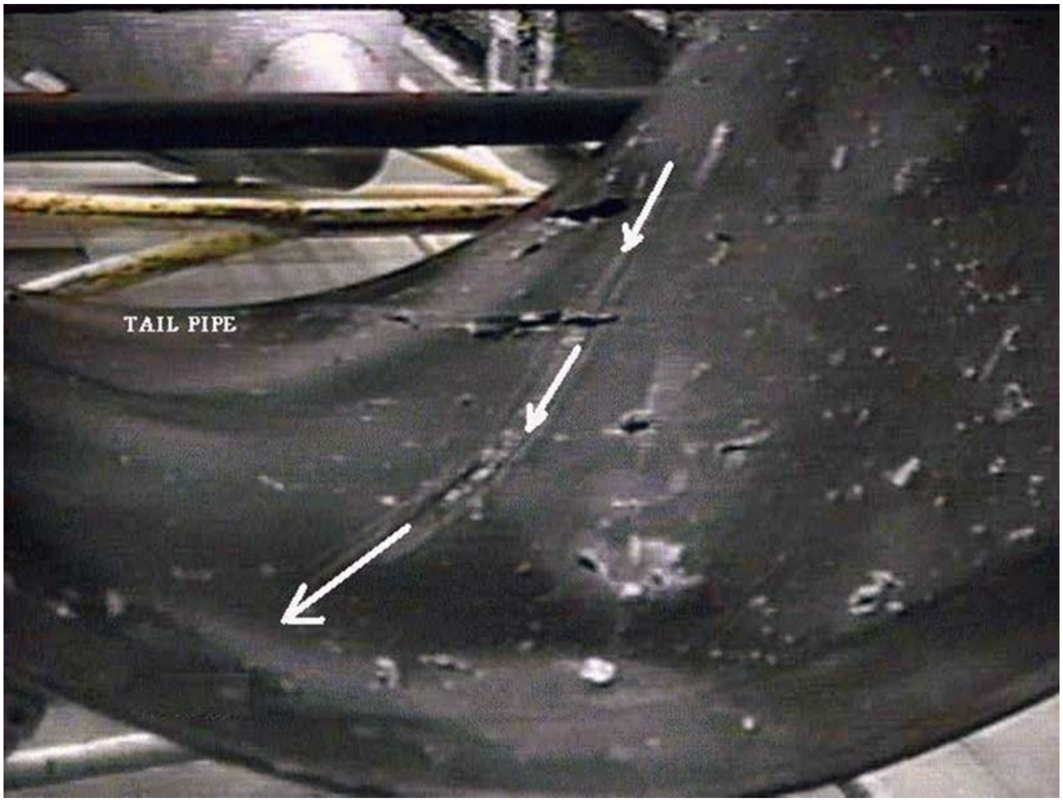


Figure 10. Turbine tail pipe showing helical exit trajectory

2.2.3 Other Considerations

2.2.3.1 Aerodynamic Effects on Blade Debris

Once the debris exits the engine, it is subjected to aerodynamic drag. Debris liberated from a wing-mounted engine may experience a significant reduction in kinetic energy before it reaches the aircraft fuselage (far-field effects). According to reference [8], an appropriate drag coefficient for blade debris in three-dimensional flow is 1.17. A 45-degree orientation is also used to represent the average presented area. Standard equations of motion are used. The analysis provided in section 2.2.3.2 was conducted at a flight condition of 35,000 feet Mach 0.85. The debris is assumed to travel 30 ft from the engine to the impact point. Specific details are shown in appendix A.

2.2.3.2 Aerodynamic Effects on Disk Debris

Aerodynamic effects on disk debris were estimated using the same routine described in reference [8]. To model a disk fragment, a different set of assumptions was used to determine the effect drag has on the debris. The blade debris aerodynamic analysis assumed a purely tumbling fragment. To model a disk fragment, rotation was assumed in the disk plane of rotation, and the debris was modeled as a flat plate relative to the free-stream velocity (figure 11). Therefore, the reference area is a planform of the debris arc segment. A drag coefficient (cd = 2.0) was used on the fragments.

The analysis was conducted at a flight condition of 35,000 feet Mach 0.85. This flight condition was chosen to provide an upper limit of trajectory shift that can be expected because of aerodynamic drag. The initial trajectory angle is 0 degrees. Disk fragment characteristics (length, width, weight, and initial velocity) are based on the most common fragment size for the given engine type. For blade fragments associated with a disk event, the final velocity is reduced to 70%–71% by this analysis.

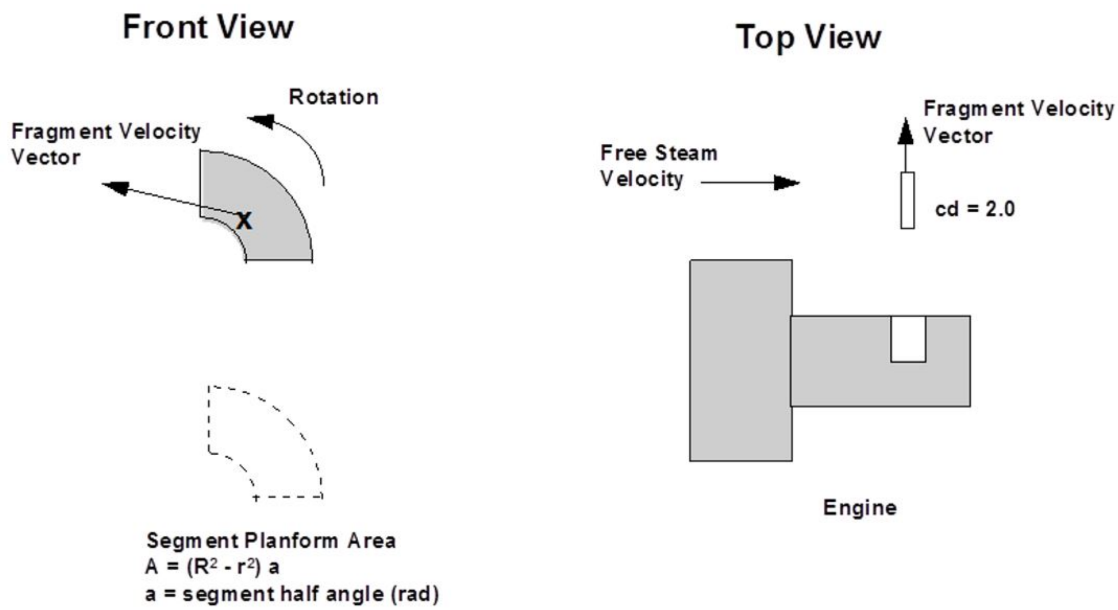


Figure 11. Disk aerodynamic assumptions

3. Aircraft Exposure

Aircraft exposure to uncontained engine debris was investigated for several aircraft configurations. For this analysis, aircraft exposure is defined as the arc defined by the two circumferential trajectories that first and last encounter the aircraft. This study looked at wing- and fuselage-mounted engine configurations. For aircraft configurations with wing-mounted engines, the analysis was conducted for turbine and fan sections because their relative position to the wing has a significant impact on aircraft exposure angles. For aircraft configurations with fuselage-mounted engines, fan and turbine exposure was considered similar.

Five aircraft with wing-mounted engines were studied to determine their exposure to uncontained engine failure (figures 12 and 13). For aircraft with twin-engine wing-mounted configurations, the fan-exposure spread was between 36 and 43 degrees, giving an average exposure near 40 degrees. The turbine exposure was also estimated, giving an exposure of near 70 degrees—almost twice that of the fan because of the relative position to the wing.

Three aircraft with fuselage-mounted engines were studied. For a wide-body center-engine configuration, the exposure is 150 degrees (figure 14). For the narrow-body twin-engine configurations, the fan and turbine have generally the same exposure at 80 degrees (figures 15 and 16). Given the close proximity of the engine to the fuselage in these configurations, it is not surprising to see an increase in exposure angle.

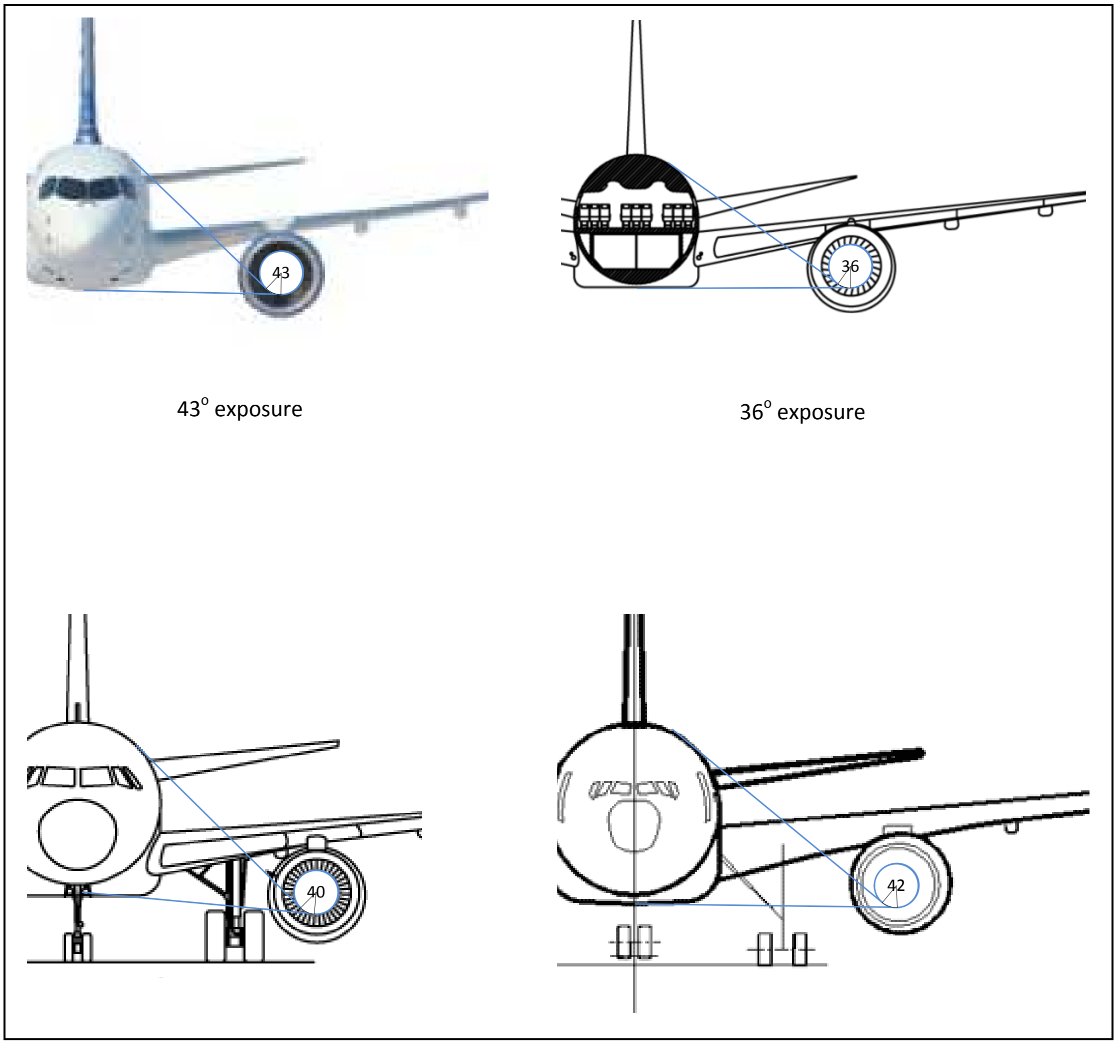


Figure 12. Aircraft exposure for wing-mounted engine configurations, fan failure

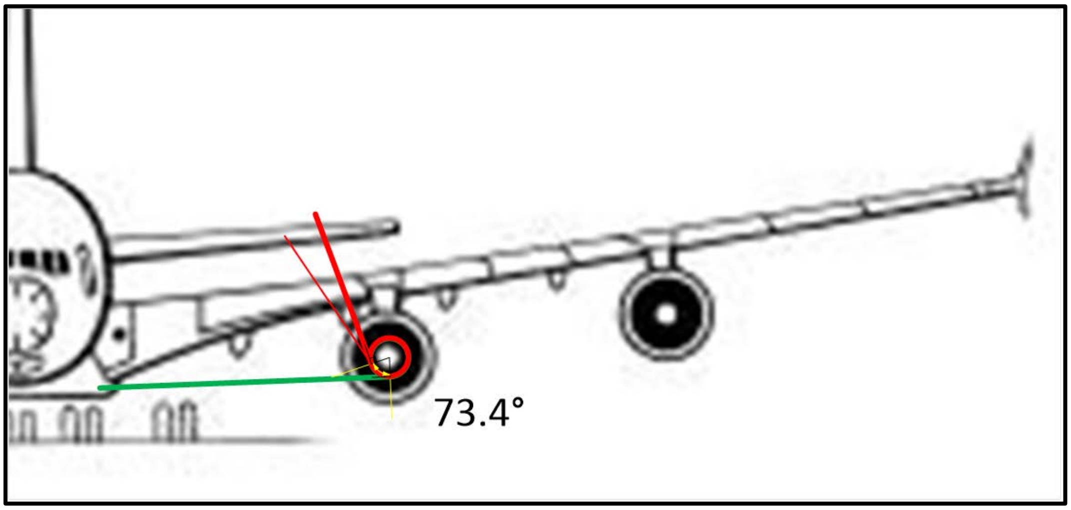


Figure 13. Aircraft exposure for wing-mounted engine, turbine failure

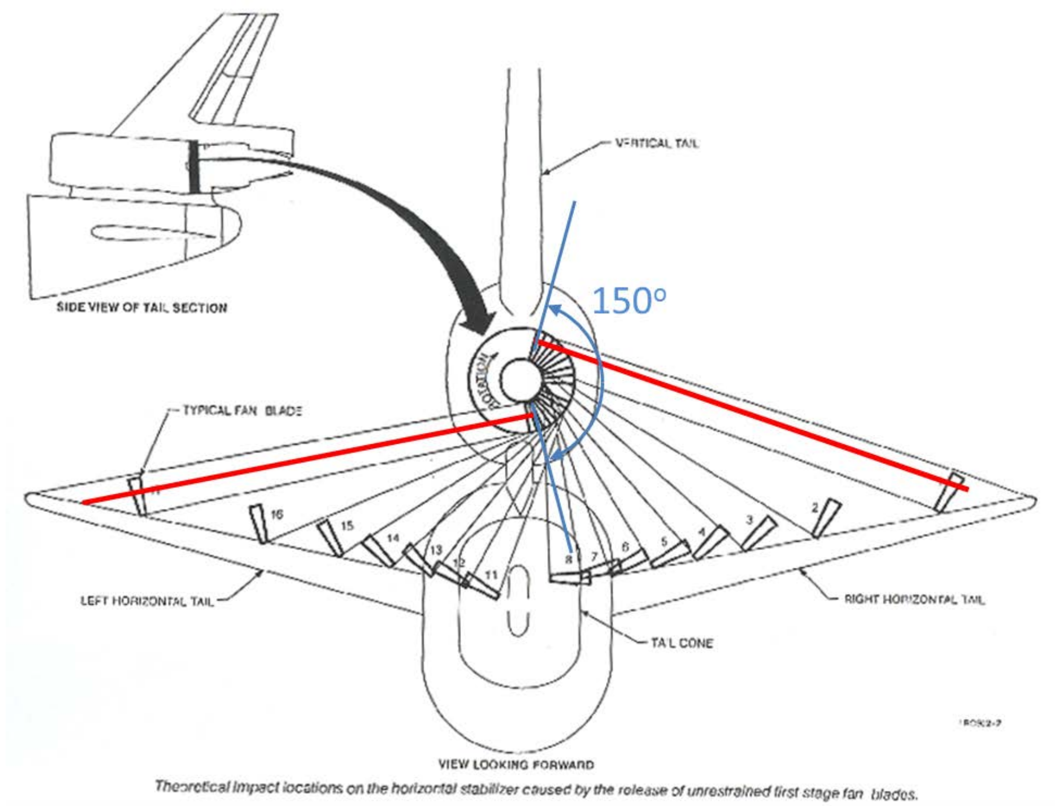


Figure 14. Aircraft exposure for engine mounted in vertical stabilizer [9]

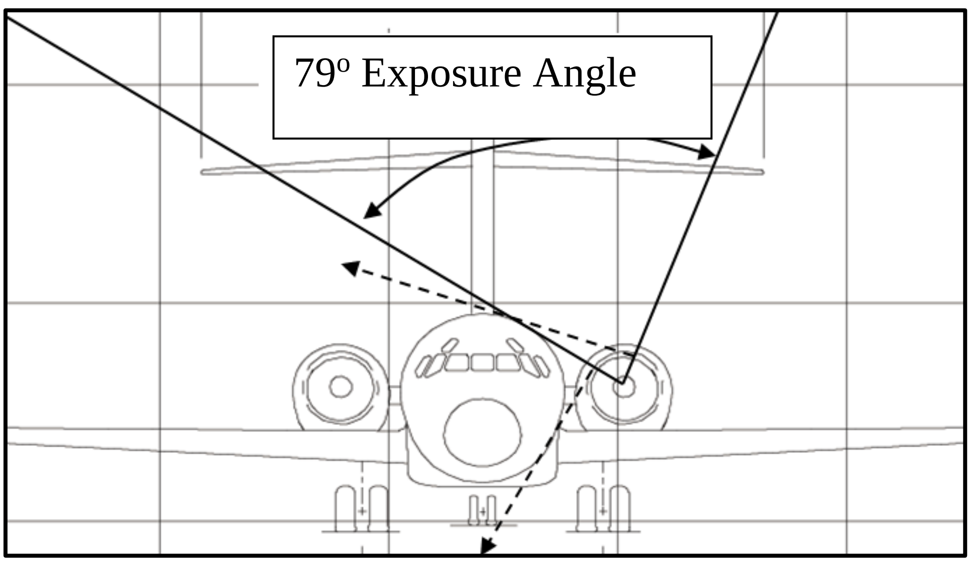


Figure 15. Example 1, Aircraft exposure for fuselage-mounted engine

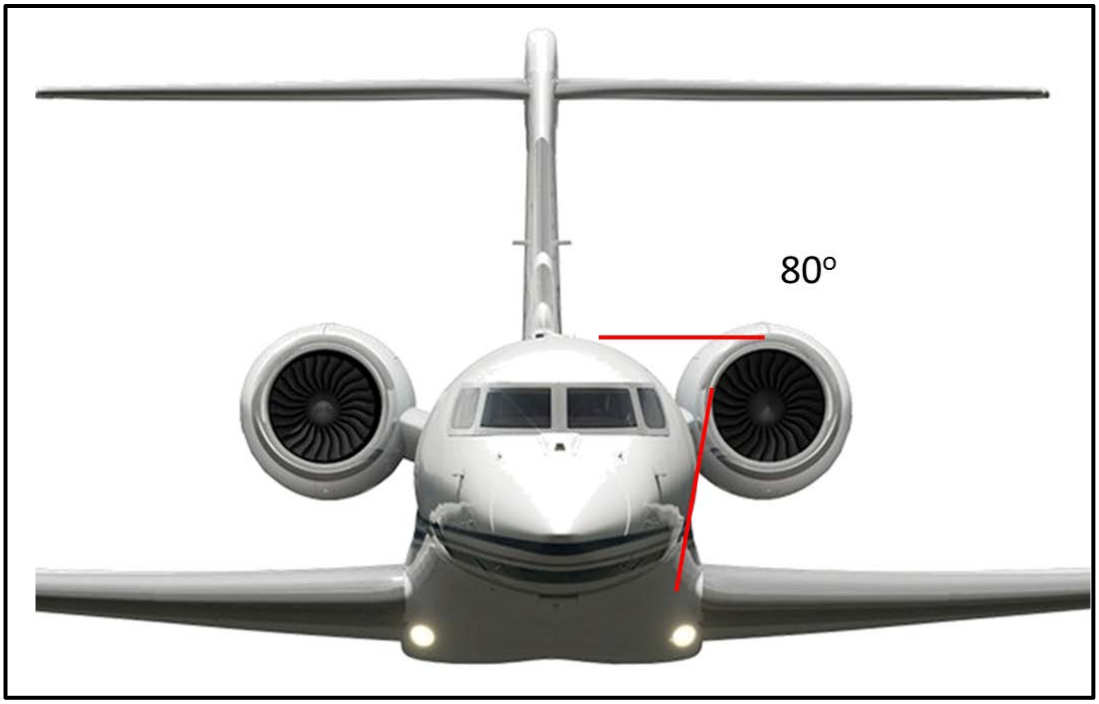


Figure 16. Example 2, Aircraft exposure for fuselage mounted engine

A summary of aircraft exposure for the airframe configuration and engine component is shown in table 6.

Table 6. Aircraft Exposure

Component	Wing-Mounted Engine	Fuselage-Mounted Engine
Fan	40 degrees	80 degrees
Compressor	40 degrees	80 degrees
Turbine	70 degrees	80 degrees

4. High-Bypass Ratio Engine Debris Characterization

From the large engine debris database described in section 2.1, high-bypass ratio engine data were extracted to develop debris characteristics for the various component failure modes. A fragment energy analysis was conducted to define fragment release velocity (energy) for the various engine components and failure types. This analysis was conducted using the generic engine model defined in section 2.2.1.2 and the cowl configuration defined in figure 5. Component analysis (fan, compressor, and turbine) includes fragment energy analysis for each failure mode, such as disk failure and blade failure. The analysis process is the same as defined in section 2 of this report. Fragment size was determined to include the majority of fragment sizes but not the worst case (largest) fragments. As discussed in section 3, only 10 percent of the fragments that penetrate the aircraft also damage aircraft structure or subsystems. Thus, this analysis characterizes the fragments most capable of causing damage to the aircraft structure or subsystems.

4.1 FAN

This section analyzes the fan disk failure and fan blade failure events. The database information is sorted to present the characteristics of each debris type. Penetration analysis is conducted to estimate fragment velocity exiting the cowl.

For the fan blade characterization, the fragment sizes were divided into multiple bins (as opposed to the single 90th percentile fragment) to account for the significant difference in energy levels from the smaller fragments to the large fragments. The generic engine model is used to define the debris sizes and initial debris velocities used in the energy analysis. Most of the fragments liberated will be smaller, have less energy, and pose a lesser threat to the aircraft than those defined. They create nicks, dings, and gouges that this report excludes.

4.1.1 Fan Disk Event

For a disk failure, the aircraft is subject to disk fragments and high-energy blade fragments (figure 17). The blade fragments do not always penetrate the containment structure on their way out of the engine. The fan disk failure analysis defines both the fan blade fragments as well as the disk fragments from this type of event.

(a)

(b)

Figure 17. (a) Uncontained fan disk debris and (b) complete fan disk failure

4.1.1.1 Fan-Blade Damage From A Disk Failure[2]

Aircraft damage generated from a fan blade liberated from a fan disk event is shown in figure 18. As previously noted, there were three fan disk events recorded in the high-bypass database. One event was separated into three events for the debris fragment characterization effort because it was a fuselage mounted engine with aircraft structure on either side of the engine. This resulted in an exposure angle of 150 degrees (roughly three times that of a typical wing mounted engine) and a corresponding high number of damages on the aircraft (73 damage locations).

The fan-blade damage from a fan disk event chart shows a majority of the damage lengths to be less than 5 inches. The associated trajectory angles range from +15 degrees to -30 degrees.

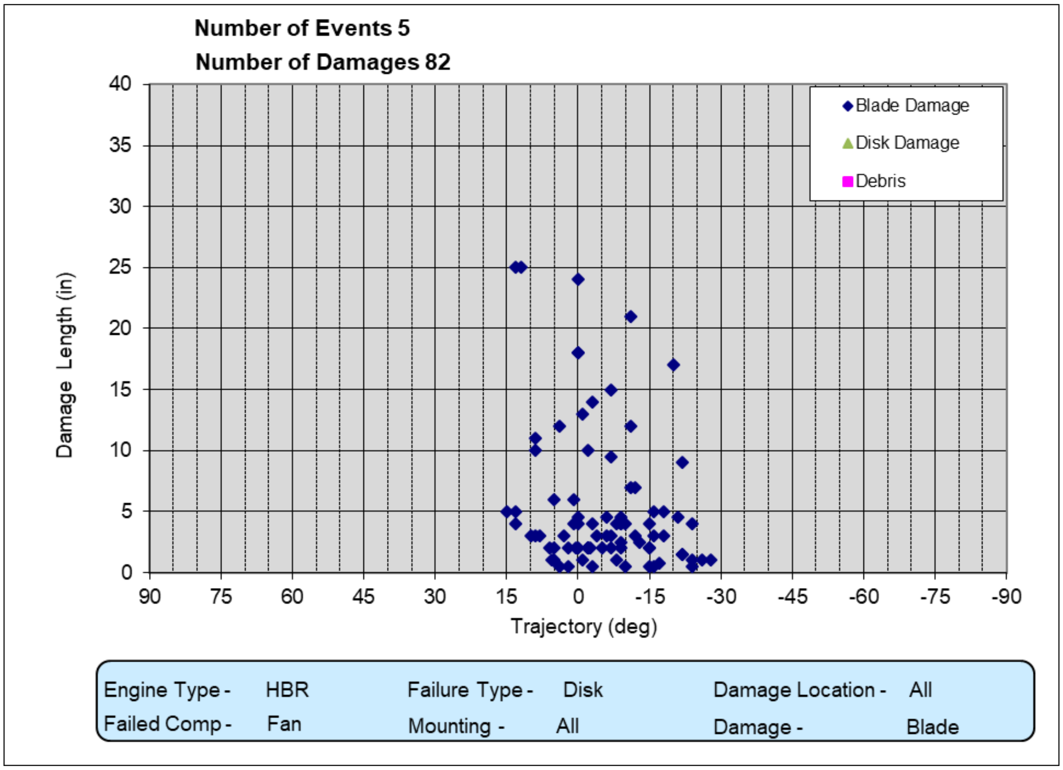


Figure 18. Blade damage, fan disk event

Dividing the damage length by the blade length yields the damage ratio. The fan blade damage ratio from a fan disk event chart (figure 19) shows a majority of the estimated debris sizes (damage ratio) to be under 25% blade length.

The data also indicate that there is a significant number of larger damages ranging to nearly 95% of a blade length. Because of the significant difference in fragment energy between a small fan blade fragment and a large fan blade fragment, the fan-blade damages were subdivided into six

[2] The majority of the data in this report is based on designs using solid metallic fan blades. Some newer technology engines use composite fan blades or hollow metal blades with significantly different debris characteristics.The debris model for fan disks with composite blades or hollow metal fan blades should be established with consultation from the engine manufacturer.

bin sizes for characterization analysis: 10%, 20%, 30%, 50%, 70%, and 100% representing the percent of blade length. Fore and aft trajectory spread angles were also determined for each of the fragment-size bins. Using the generic engine model defined in section 3.2, blade fragment physical characteristics were used to conduct penetration analysis to determine fragment velocity exiting the cowl.

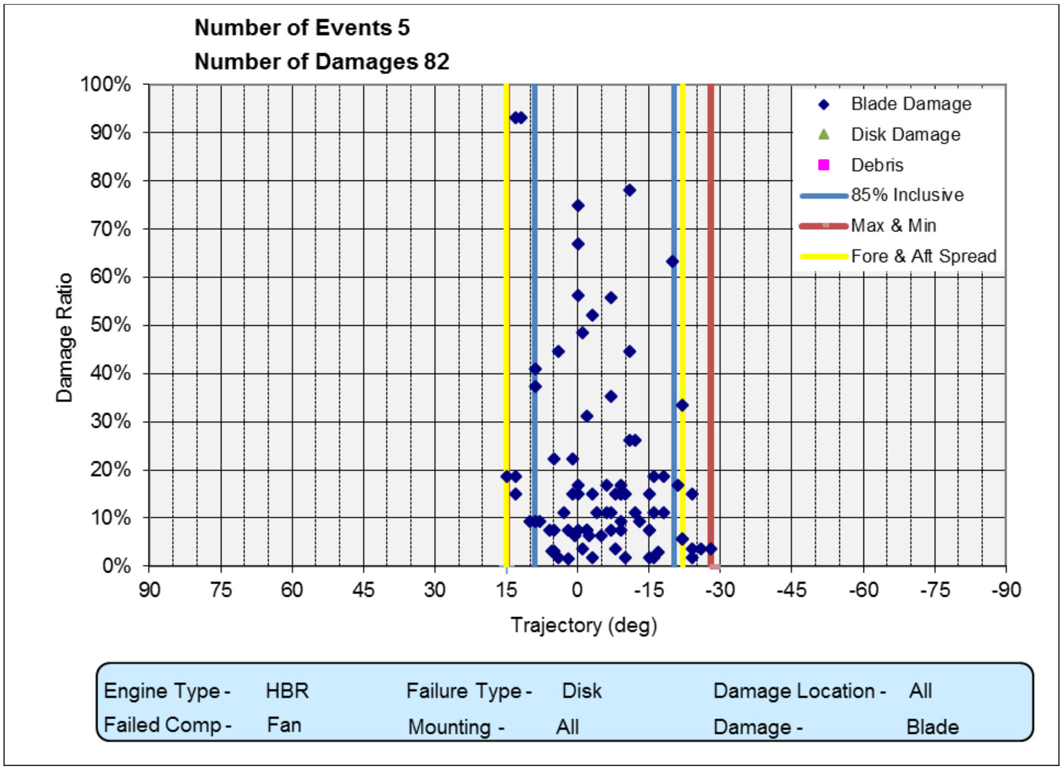


Figure 19. Fan-blade damage ratio, fan disk event

Based on the 5 fan disk events and 82 damage locations, the average number of damages per event is 16. Separating the number of damages into the defined bins provides a picture of the average number of fragments per bin for a fan disk event. A histogram provides the number of fragments within a given size bin (figure 20).

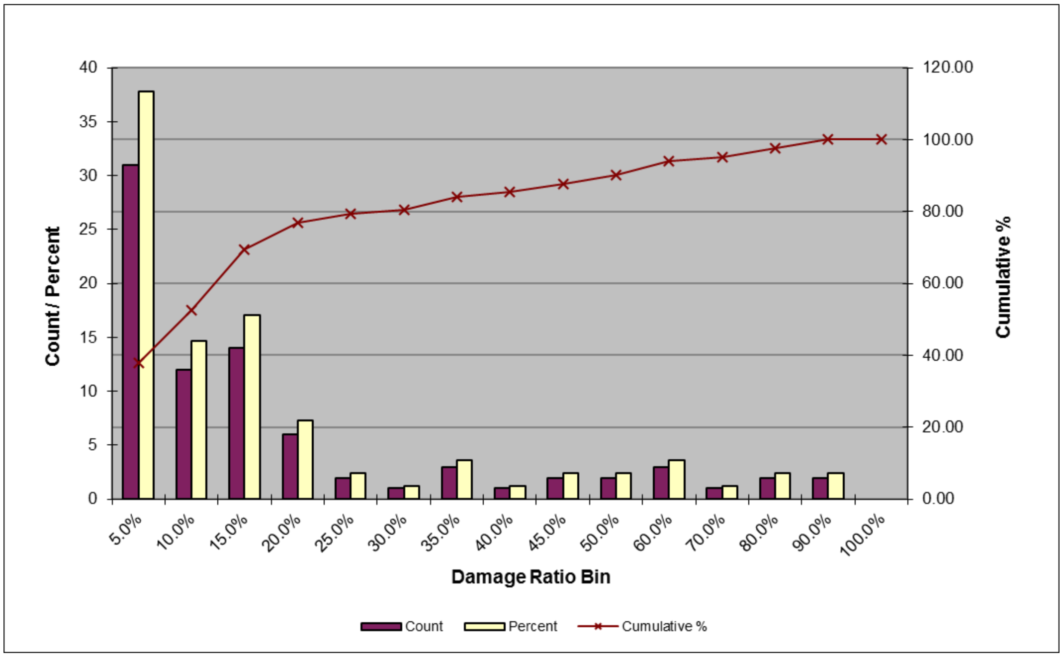


Figure 20. Histogram of blade damage, fan disk events

The bins in figure 20 were further grouped into six bins from 10% to 100% blade normalized size. Based on the average number of fragments and the percentage of fragments in each of the six bins, a fragment distribution can be obtained (table 7). This distribution defines the number of fragments that would be expected in each bin based on a fan disk event with 16 blade fragments impacting the aircraft.

Table 7. Fan blade fragment distribution, fan disk event

Average/Event	16
Normalized Size	Number of Fragments
10.00%	8
20.00%	4
30.00%	1
50.00%	2
70.00%	1
100.00%	1

To estimate debris cowl exit velocities, the methodology defined in section 2.2.2.1 was employed. As defined above, the fan-blade debris was separated into normalized size bins. For each size bin, the generic engine model (table 5) was used to define fragment size, mass, and initial velocity. The fan cowl used in this analysis was a 0.040-inch aluminum plate (figure 21). The engine-containment structure was assumed to have been compromised by the disk fragment and, therefore, was not modeled in the analysis. The resulting cowl exit velocity and energy level is shown in figure 22. Peak velocity at 0 degrees is 1005 feet per second, and peak energy is 19,624 ft-lbf.

Aerodynamic effects were considered to assess the fragment velocity and energy at the aircraft skin (figure 23). It was assumed that the fragment travels 30 feet and that the aircraft is flying at 35,000 feet 0.85 Mach. Required skin thickness to defeat the fragment is shown in figure 24.

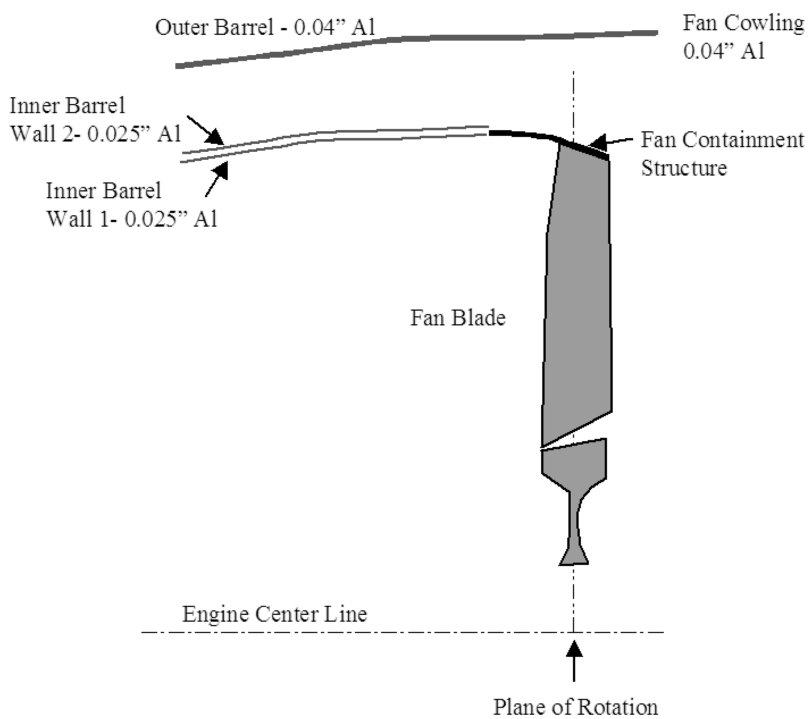


Figure 21. Fan cowl model for fan disk events

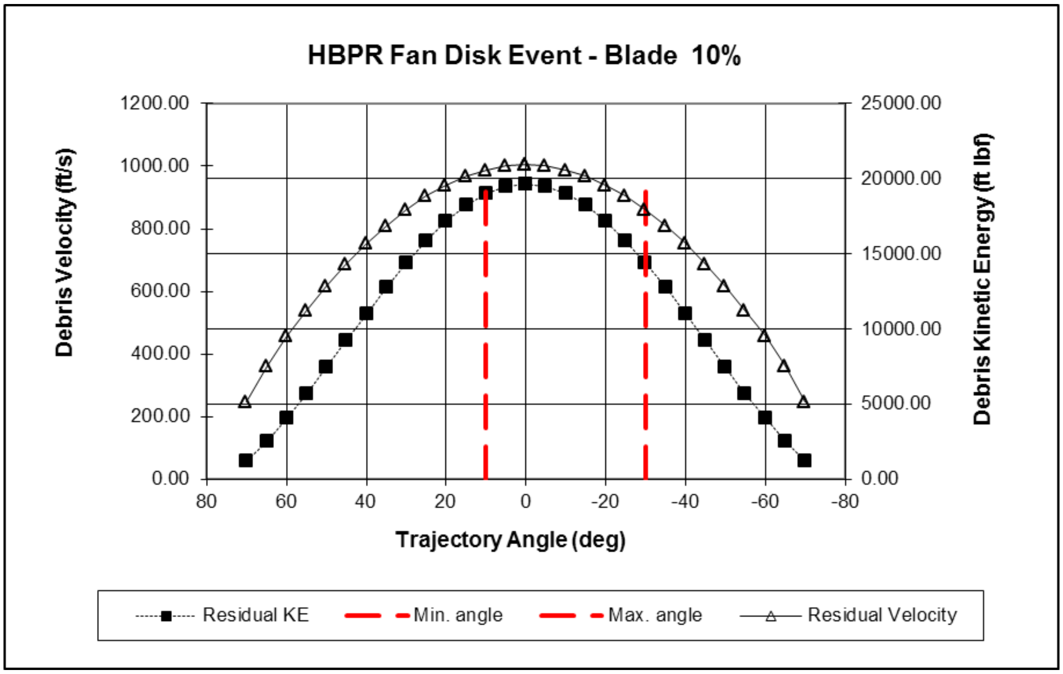


Figure 22. Fan disk event, 10% blade velocity and energy

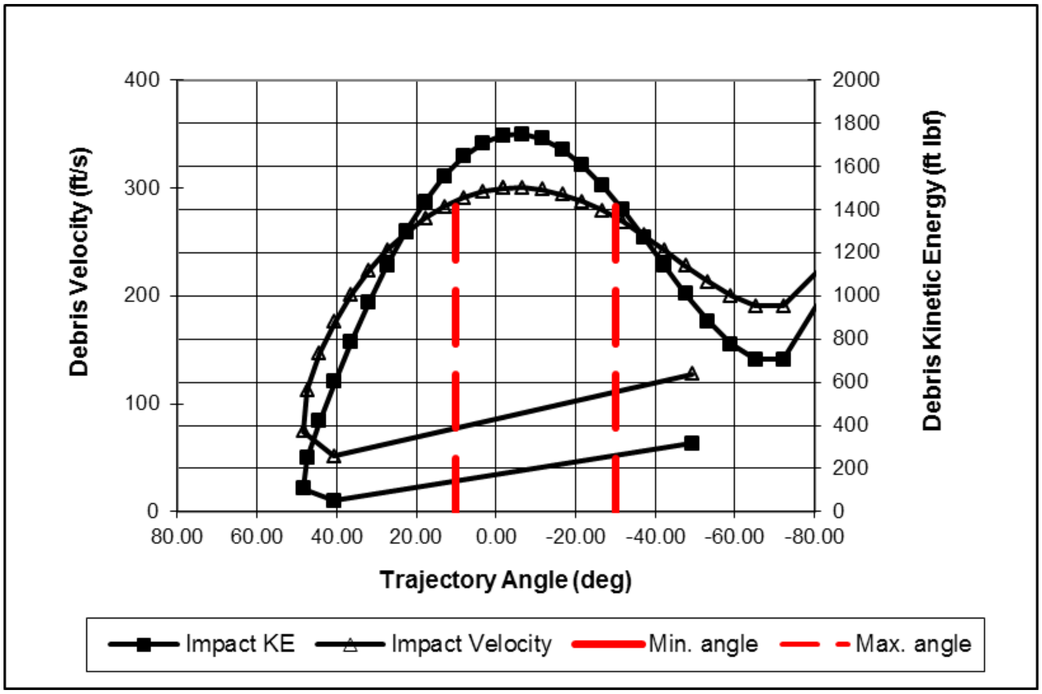


Figure 23. Aerodynamic effects 10% blade velocity and energy, fan disk event

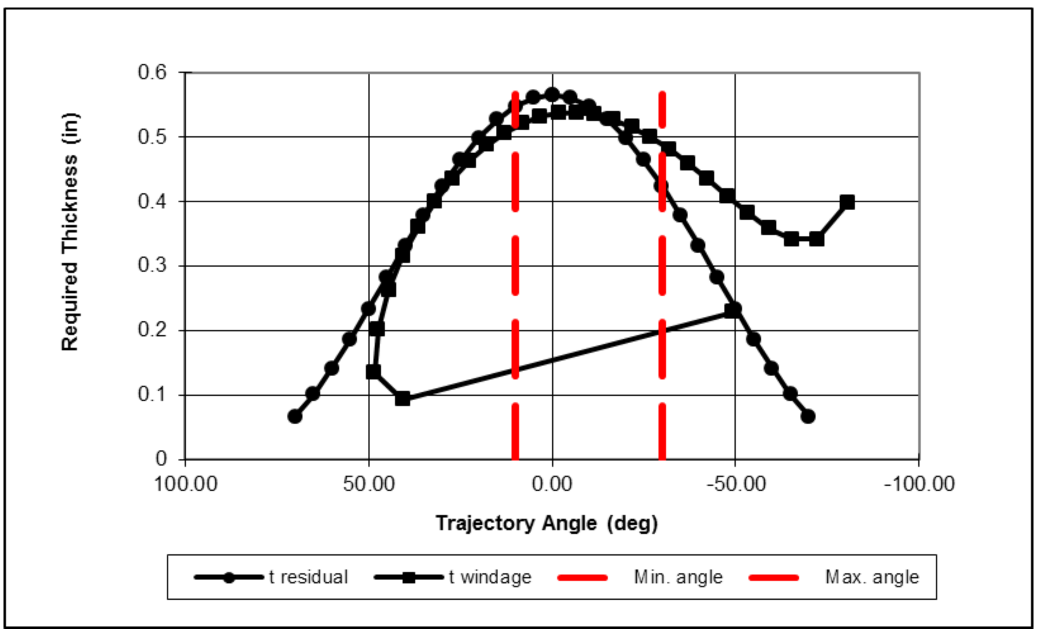


Figure 24. Aluminum skin thickness to defeat a 10% High Bypass Ratio solid metallic fan blade

This methodology was conducted for each of the fan-blade size bins. The culmination of this analysis methodology (table 8) provides a complete picture of fan-blade-fragment characteristics from a fan disk failure event. The average number of fragments per event and per size bin are defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles vary slightly across the fragment sizes.

Table 8. Fan-blade characterization, fan disk event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Disk Event	5					
Blades		16				
		8	10.00%	0.33 (3%)	0.70 (1005)	+15 to –22
		4	20.00%	2.0 (16%)	0.71 (971)	+15 to –22
		1	30.00%	3.75 (30%)	0.71 (937)	+15 to –22
		2	50.00%	6.24 (50%)	0.71 (866)	+15 to –22
		1	70.00%	8.61 (70%)	0.71 (795)	+15 to –22
		1	100.00%	12.5 (100%)	0.71 (688)	+15 to –22

4.1.1.2 Fan Disk Damage

For fan disk damage from a disk failure, figure 25 shows the basic trajectory angles to range from +2 and -3 degrees. A bladed 1/3 disk fragment is used to model fan disk debris. Release velocity and energy levels are estimated at 304 fps and 69,664 ft-lbf, respectively.

Figure 25. Fan disk event

Aircraft damage generated from fan disk fragments liberated from a fan disk event is shown in figure 26. The fan disk damage chart shows a majority of the damage lengths up to 32 inches. The associated trajectory angles range from +2 degrees to -3 degrees. The damage ratio is shown in figure 27. Fan disk velocity and energy are shown in figure 28.

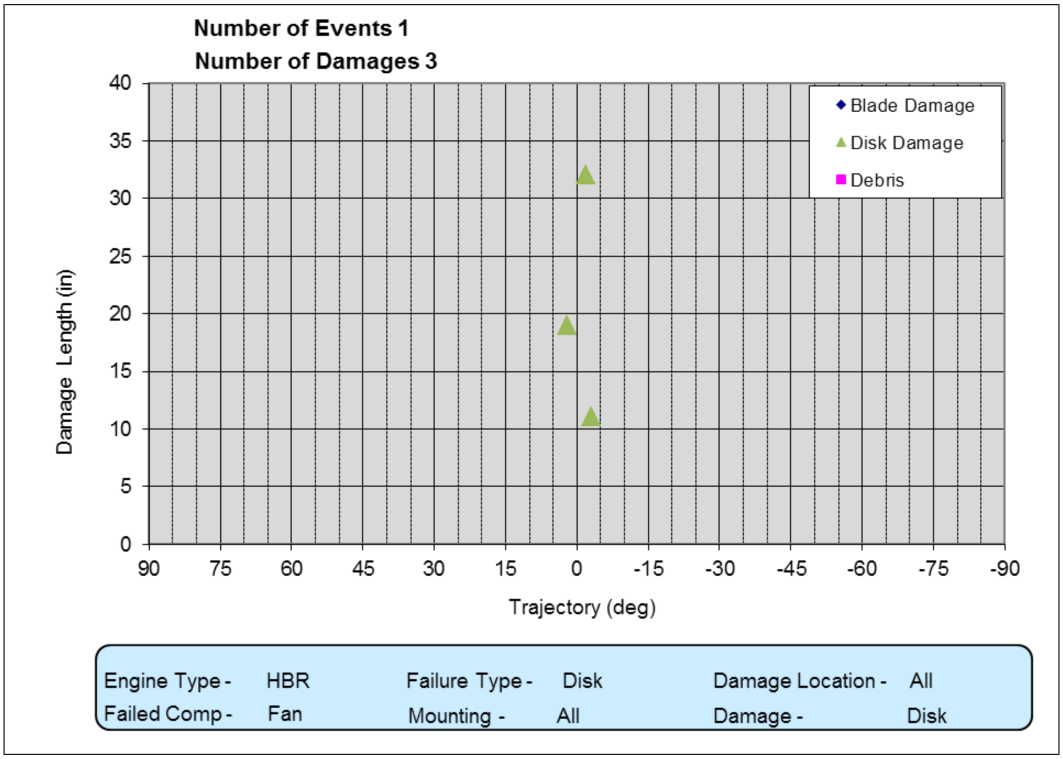


Figure 26. Fan disk damage

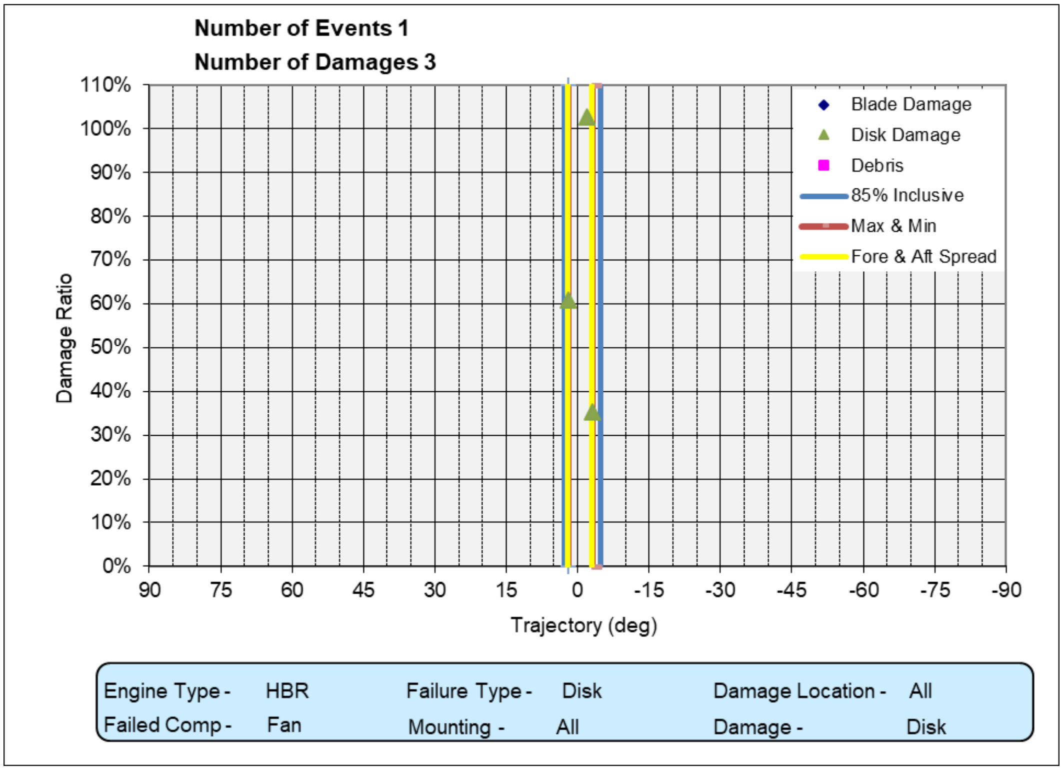


Figure 27. Fan disk damage ratio

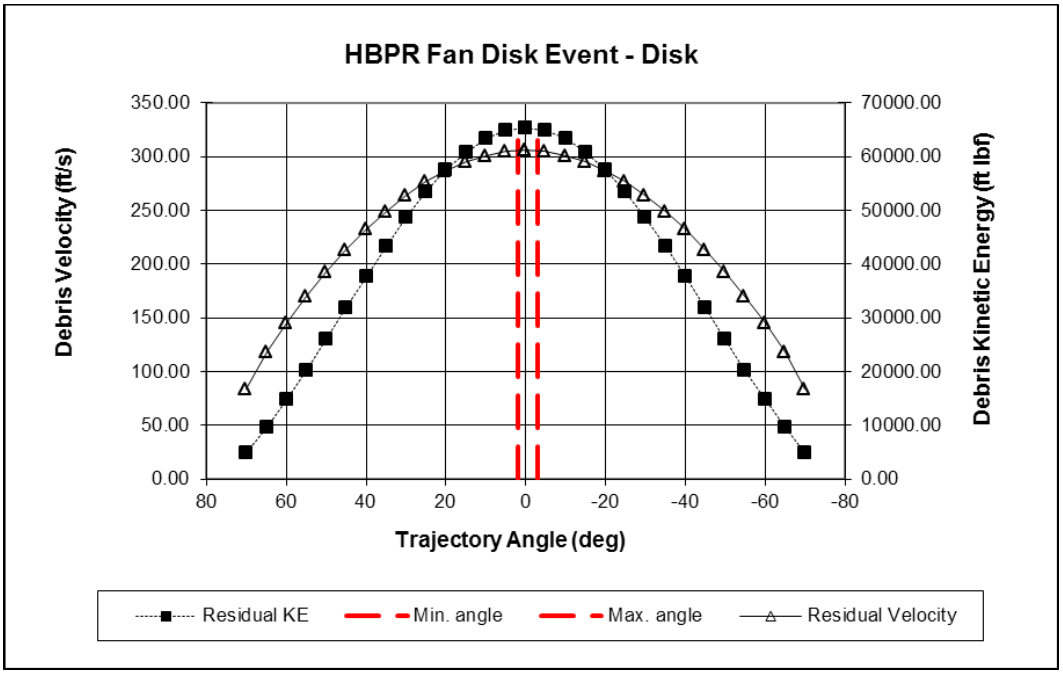


Figure 28. Fan disk velocity and energy

Fan disk characterization is shown in table 9. The normalized size is 90% of the disk diameter, which equates to a 1/3 disk section.

Table 9. Fan disk characterization

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Disks	1	3	90%	48.6 (38%)	0.74 (304)	+2 to –3

4.1.2 Fan-Blade Event

There are several scenarios that occur, resulting in an uncontained fan-blade event. Two primary failure modes to consider are: 1) helical motion of a blade tip upon fracturing against the containment ring (figure 29), and 2) particles that are re-ingested and then 'kicked' forward after impacting the fan rotor. The primary mode addressed in this analysis is the helical-motion model. The re-ingested model is assumed to produce lesser fragment energies than the helical model.

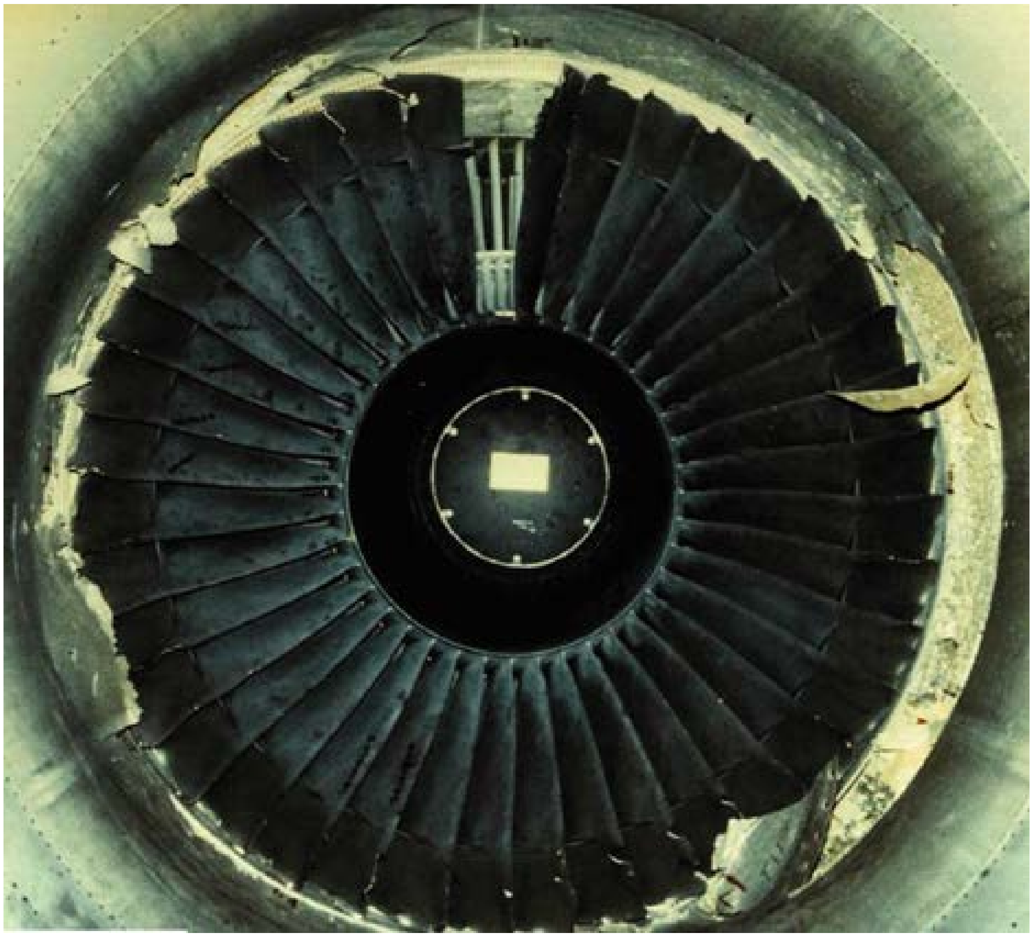


Figure 29. Fan-blade event

Aircraft damage generated from a fan-blade event is shown in figure 30. Twelve fan-blade failure events and 81 damage locations were recorded in the database. The average number of damage locations per event was 6.75 (7). The fan blade damage from a fan blade event chart shows a majority of the damage lengths to be less than 5 inches. The debris trajectories range from +53 to -70 degrees. For characterization purposes, the trajectory range is from +35 to -35 degrees. The debris damage ratio is shown in figure 31. Maximum debris damage ratio is 61%, much less than the blade-damage ratio from a fan disk event.

Separating the number of damages into the defined bins provides a picture of the average number of fragments per bin for a fan-blade event (table 10). A histogram provides the number of fragments within a given size bin (figure 32).

Table 10. Fan blade fragment distribution, fan-blade event

Average/Event	7
Normalized Size	Number of Fragments
10.00%	3
20.00%	2
30.00%	1
50.00%	1
70.00%	-
100.00%	-

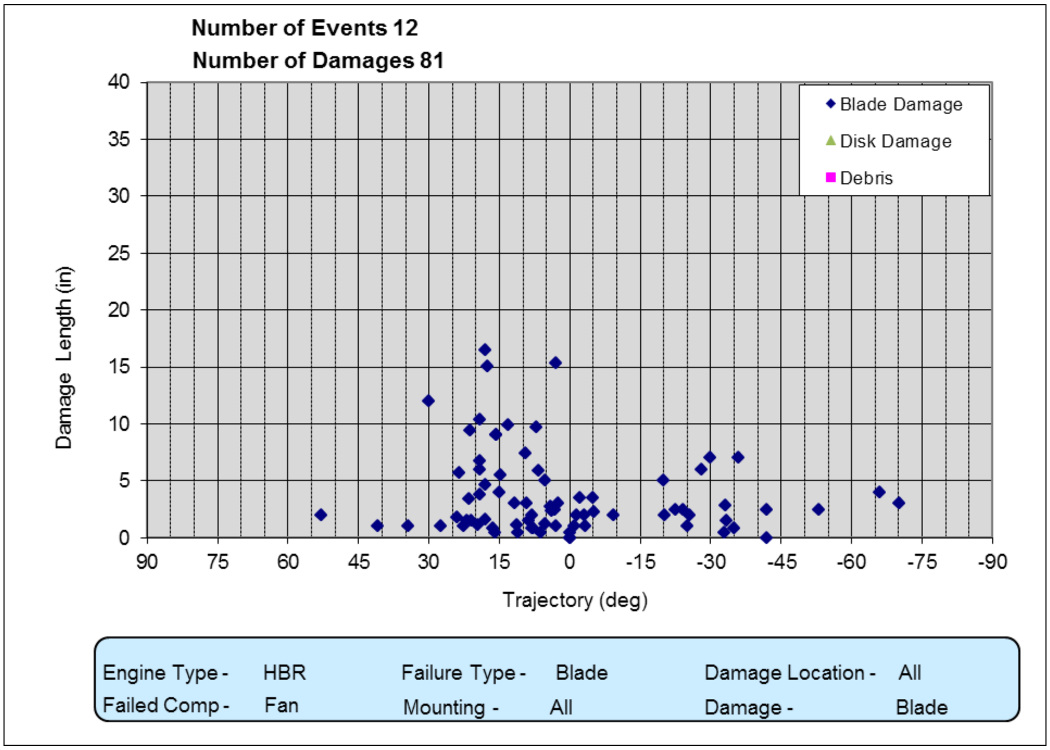


Figure 30. Blade damage, fan-blade event

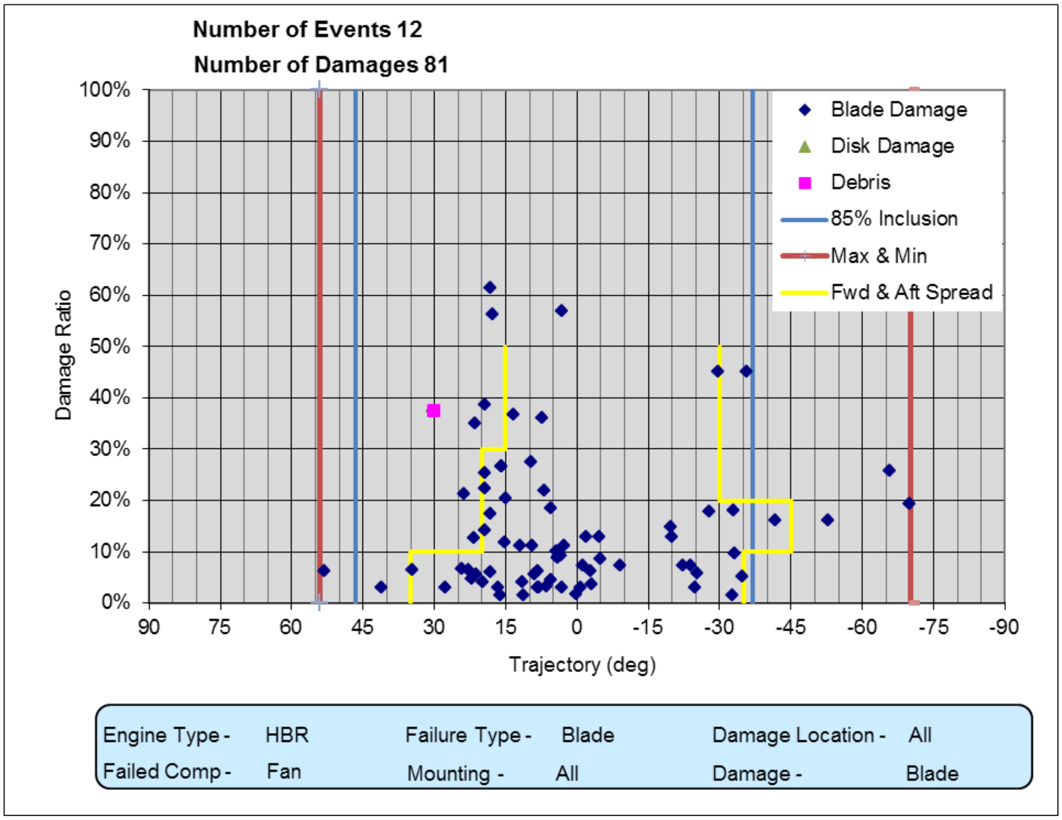


Figure 31. Blade damage ratio, fan-blade event

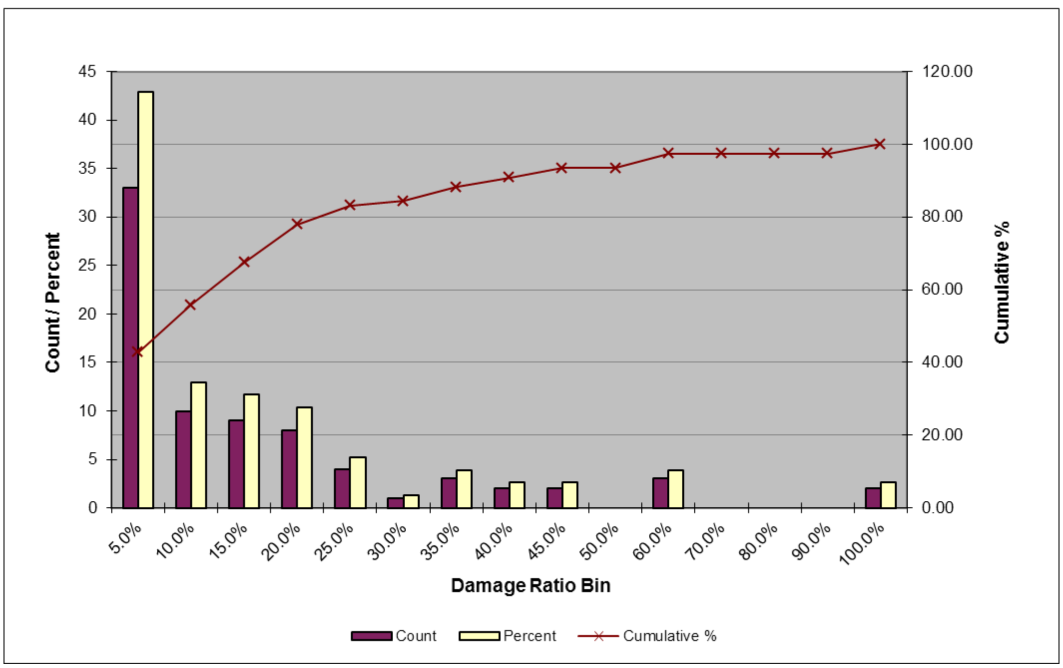


Figure 32. Histogram of blade damage, fan-blade event

To estimate the exit velocity of the fan-blade debris generated in a blade event, the assumptions defined in section 2.1.2 and the procedure in section 2.2.1 were used. These assumptions reduce the initial fragment velocity by 25%, and blade fragments pass forward of the fan containment through the inlet inner barrel, outer barrel, and cowl. The velocity was also reduced by the cosine of the fragment fore or aft trajectory angle. The FPE's were used to calculate the residual velocity exiting the fan cowl. For each size bin, the generic engine model (table 5) was used to define fragment size, mass, and initial velocity. The fan cowl used in this analysis is described in table 11. The resulting cowl exit velocity and energy level is shown in figure 33. Peak velocity at 0 degrees is 954 feet per second and peak energy is 17,690 ft-lbf.

Table 11. Fan-blade inlet—cowl configuration

Inner barrel—inlet nacelle wall 1	0.025″	Al – 2024
Inner barrel—inlet nacelle wall 2	0.025″	Al – 2024
Outer barrel—fan cowling	0.040″	Al – 2024

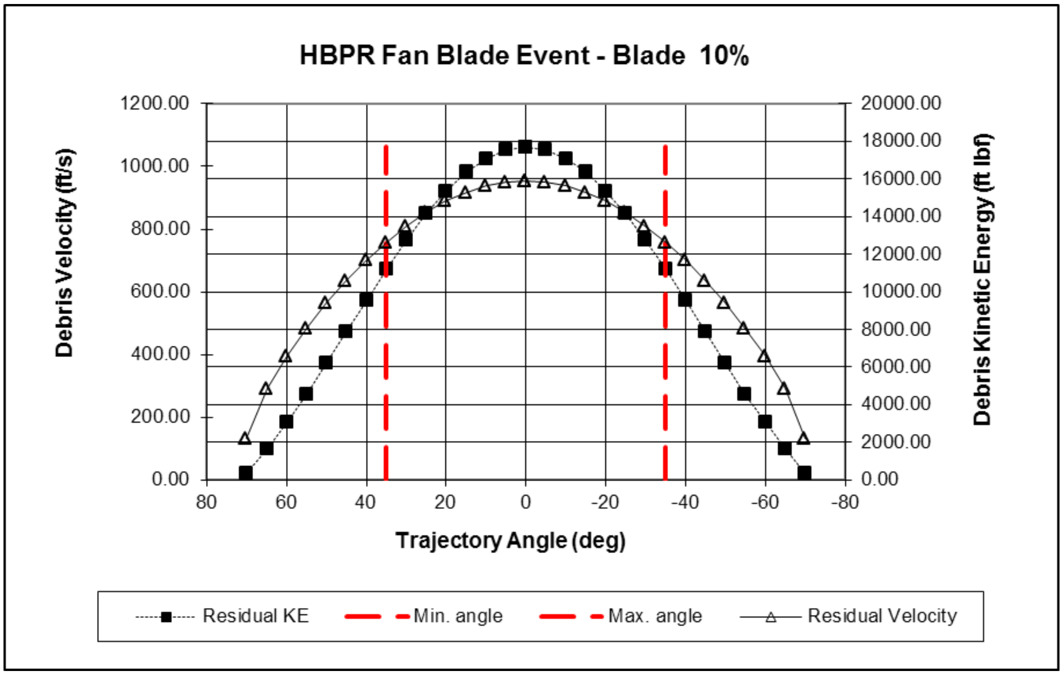


Figure 33. Fan-blade velocity and energy, fan-blade event

Aerodynamic effects were considered to assess the fragment velocity and energy at the aircraft skin (figure 34). It was assumed that the fragment travels 30 feet, and the aircraft is flying at 35,000 feet 0.85 Mach. Required skin thickness to defeat the fragment is shown in figure 35.

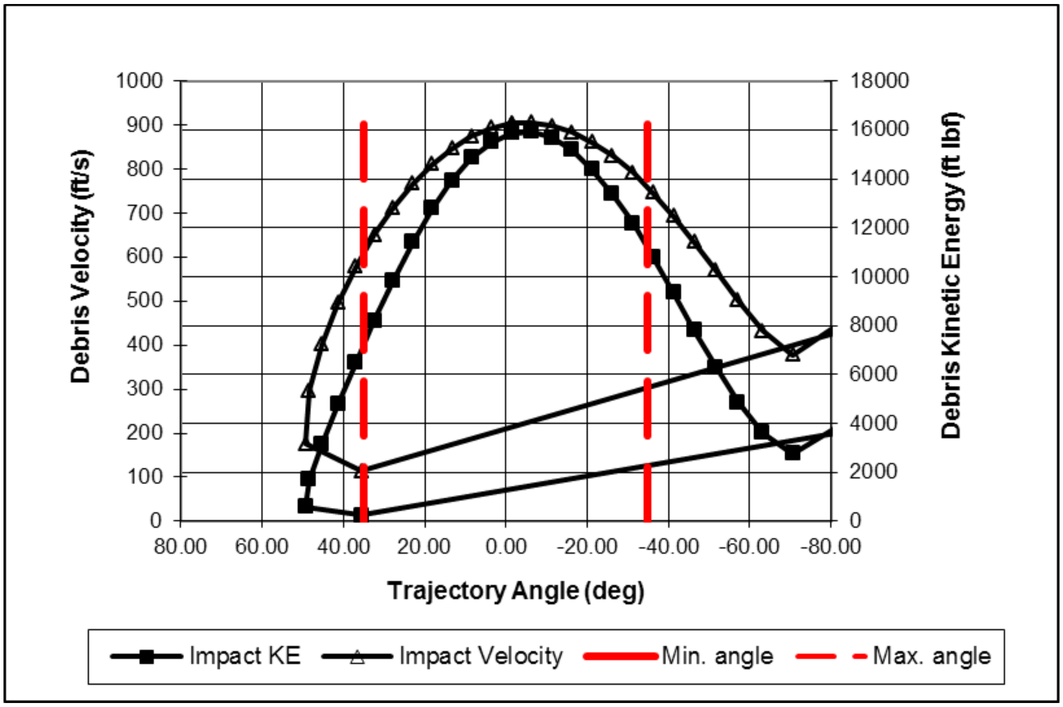


Figure 34. 10% blade velocity and energy, aerodynamic effects

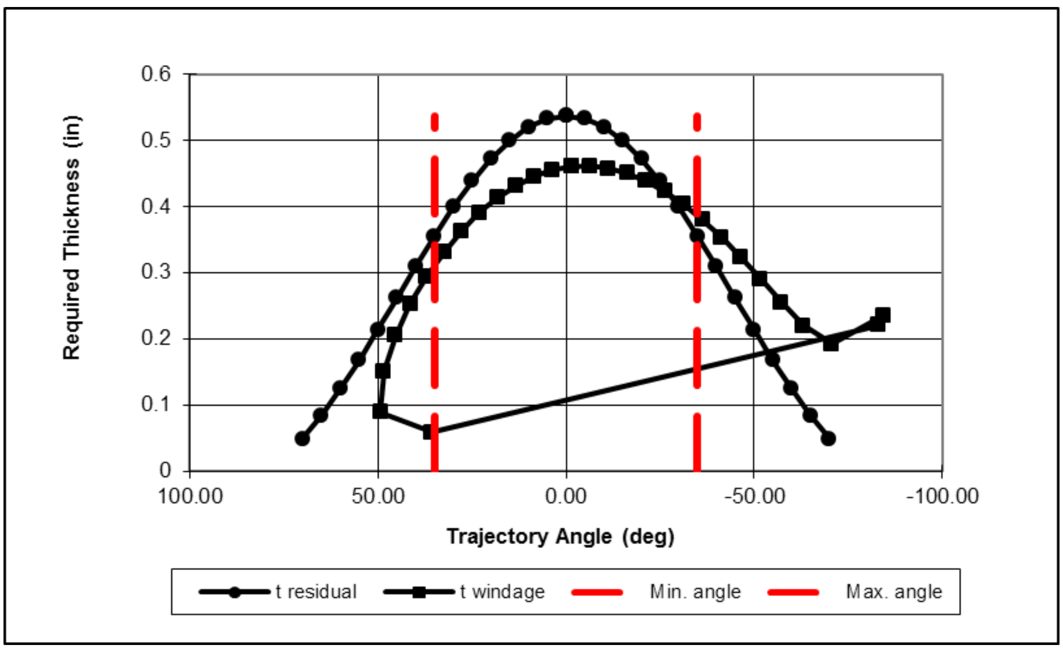


Figure 35. Aluminum skin thickness to defeat a 10% fan blade fragment

This methodology was conducted for each of the fan blade size bins. The culmination of this analysis methodology (table 12) provides a complete picture of fan blade fragment characteristics from a fan blade failure event. The average number of fragments per event and number of fragments per size bin are defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles vary slightly across the fragment sizes.

Table 12. Fan blade characterization, fan blade event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Blade Event	12					
Blades		7				
		3	10%	0.33 (3%)	0.67 (954)	+35 to -35
		2	20%	2.0 (16%)	0.67 (925)	+20 to - 45
		1	30%	3.75 (30%)	0.67 (893)	+20 to –30
		1	50%	6.24 (50%)	0.68 (827)	+15 to - 30
		-	70%	-	-	-
		-	100%	-	-	-

4.2 COMPRESSOR

Compressor events were categorized by blade, rim, and disk events. For High Bypass Ratio engines, there were no uncontained compressor blade events captured in the database; therefore, there is no characterization for compressor blade failure events. There was one compressor rim failure event, and there were two disk-failure events. Each of these event types are characterized in sections 4.2.1.1 through 4.2.2.2.

In compressor events, the thrust reverser barrel was initially included in the penetration analysis as recommended by the ARAC Group. This approach was eventually changed to not include the reverser barrel for three reasons: 1) only one incident in the debris database had the reverser barrel over the compressor, 2) by eliminating the barrel, there was a better match between the predicted debris trajectory angles and the empirical trajectory angles from the debris database, and 3) estimated energy levels are more conservative. This does not suggest that a thrust reverser should not be modeled when it is present on an installed engine configuration. In fact, the thrust reverser has been proven to be a good energy absorber, significantly reducing the hazard of uncontained compressor failures. The thrust reverser was not modeled in this analysis because the majority of the data were from engines by which the fan duct thrust reverser was not impacted.

4.2.1 Compressor Disk Event

4.2.1.1 Compressor Blade Damage From a Disk Event

Compressor blade damage from a disk event is shown in figure 36. Compressor blade trajectory angle ranges from +5 to -44.5 degrees. Maximum damage length is 12 inches. The calculated damage ratio is shown in figure 37. The 90th percentile damage ratio is a 50% blade fragment with a trajectory spread angle of +5 to -25 degrees.

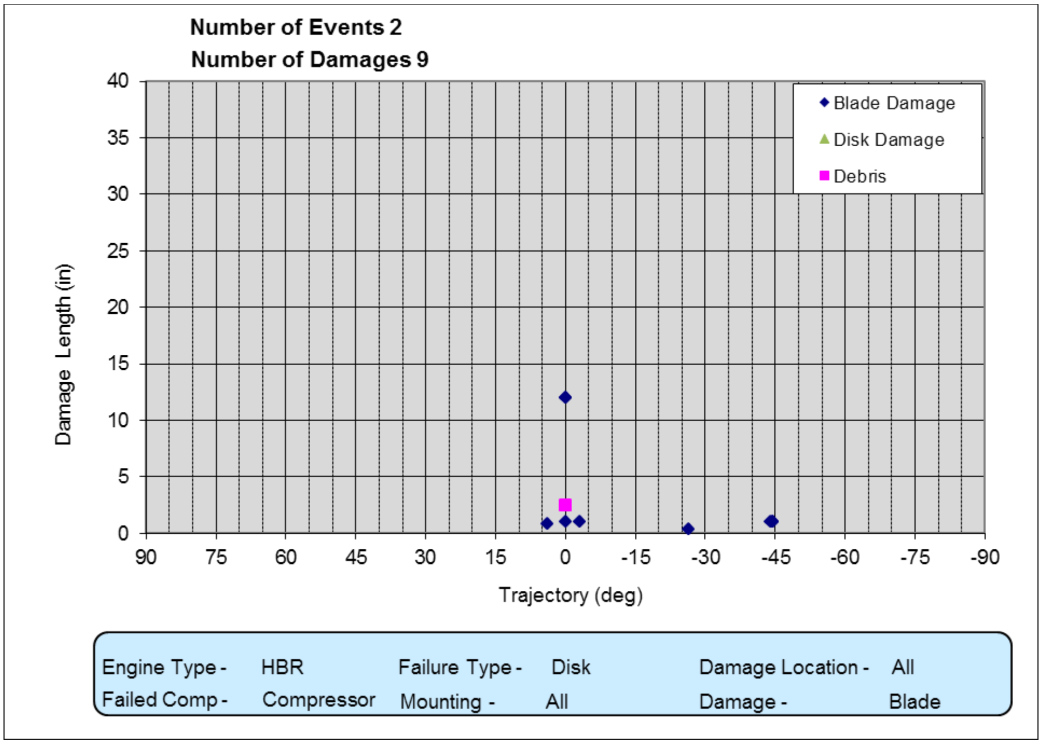


Figure 36. Blade damage, compressor disk events

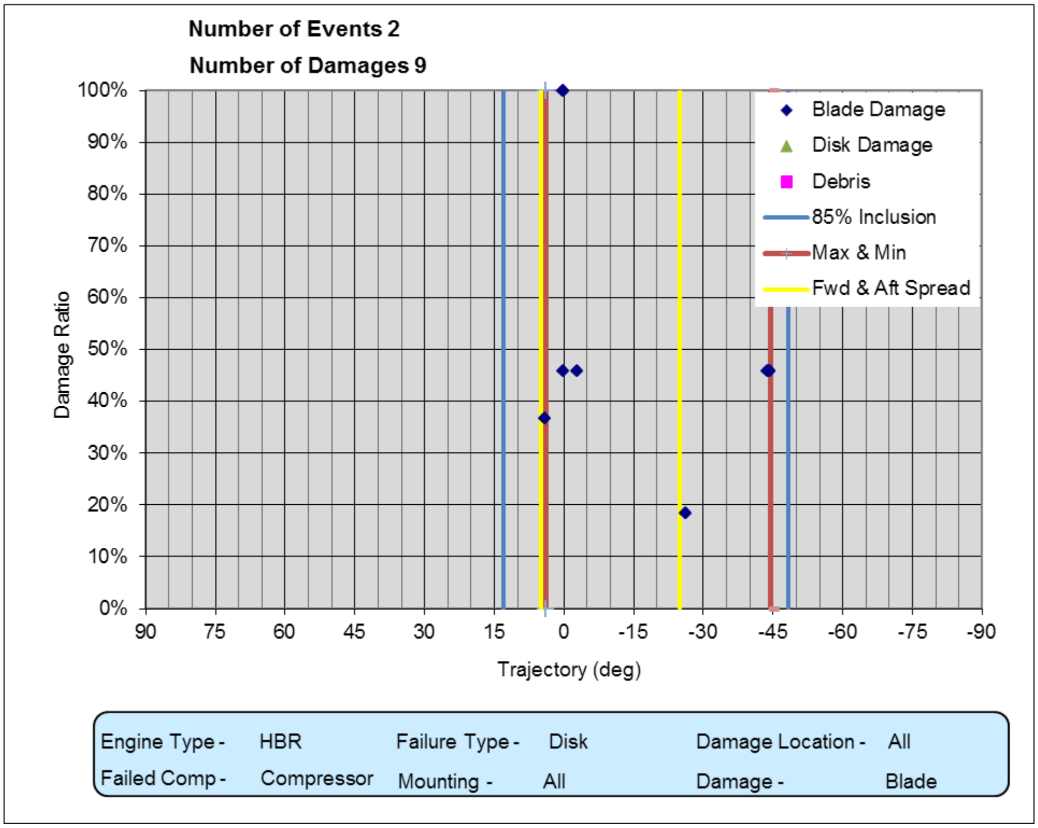


Figure 37. Blade damage ratio, compressor disk event

For uncontained compressor events, the defined cowling arrangement is shown in table 13.

Table 13. Compressor blade—Cowl configuration

Core cowl	0.040″	2024 - Al.

To calculate cowl exit velocity, the same assumptions were used to define the velocity loss due to case interaction (25% of the initial velocity). Figure 38 plots debris residual velocity and residual energy upon exiting the cowl. Maximum velocity is 764 feet per second. Aerodynamic effects are included in figure 39. Required skin thickness to defeat the fragment is shown in figure 40.

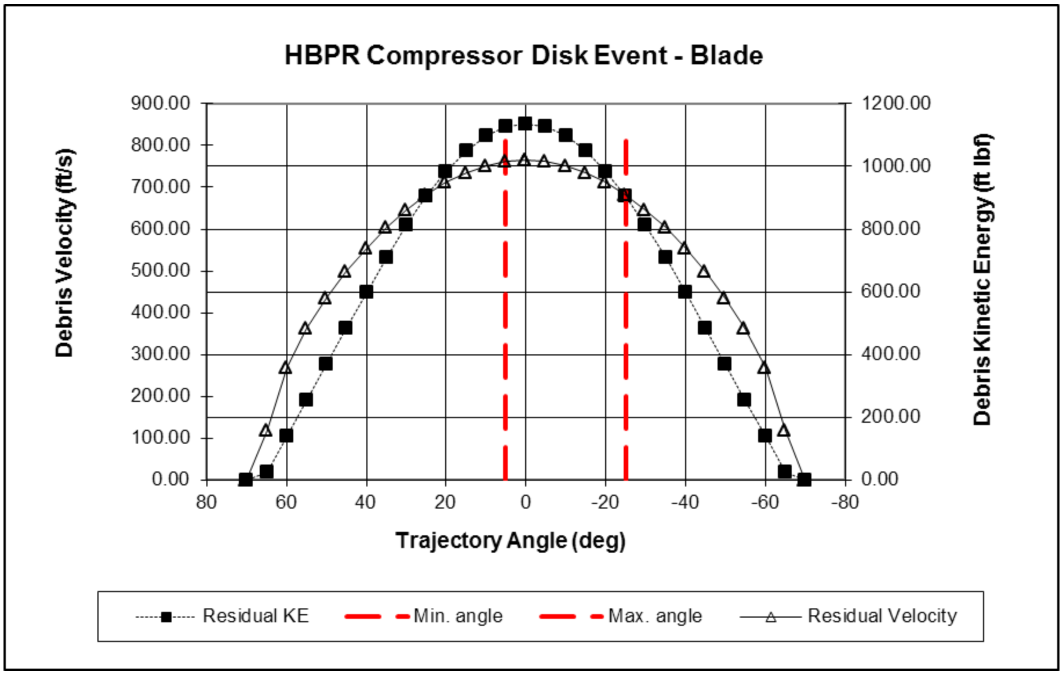


Figure 38. Blade velocity and energy, compressor disk event

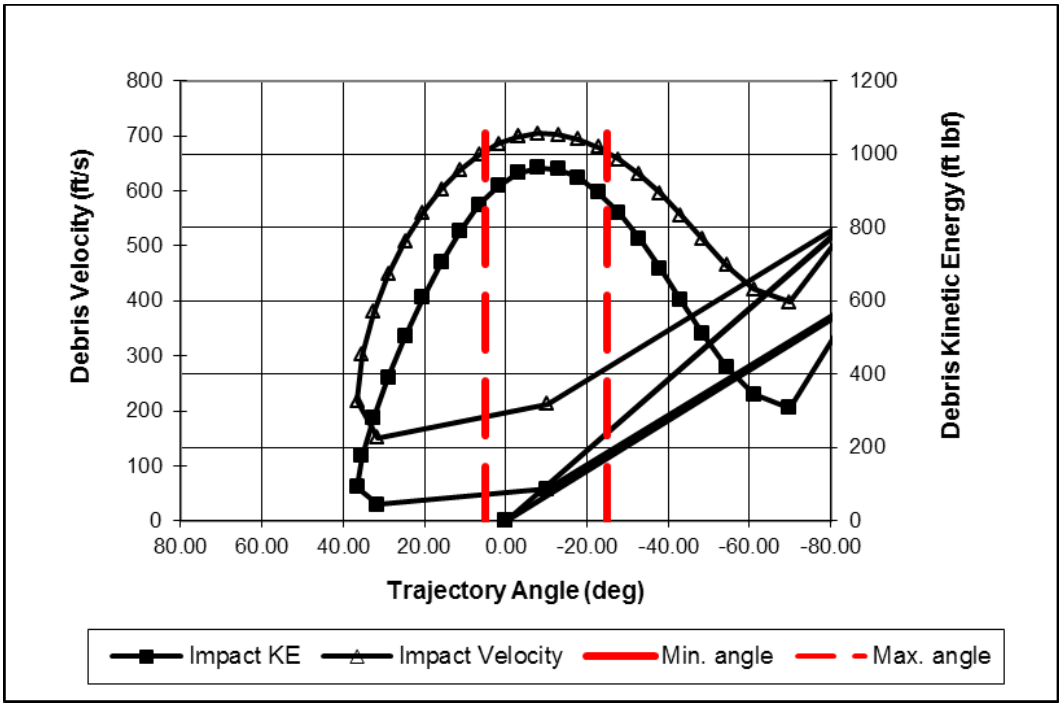


Figure 39. Aerodynamic effects 50% compressor blade, disk event

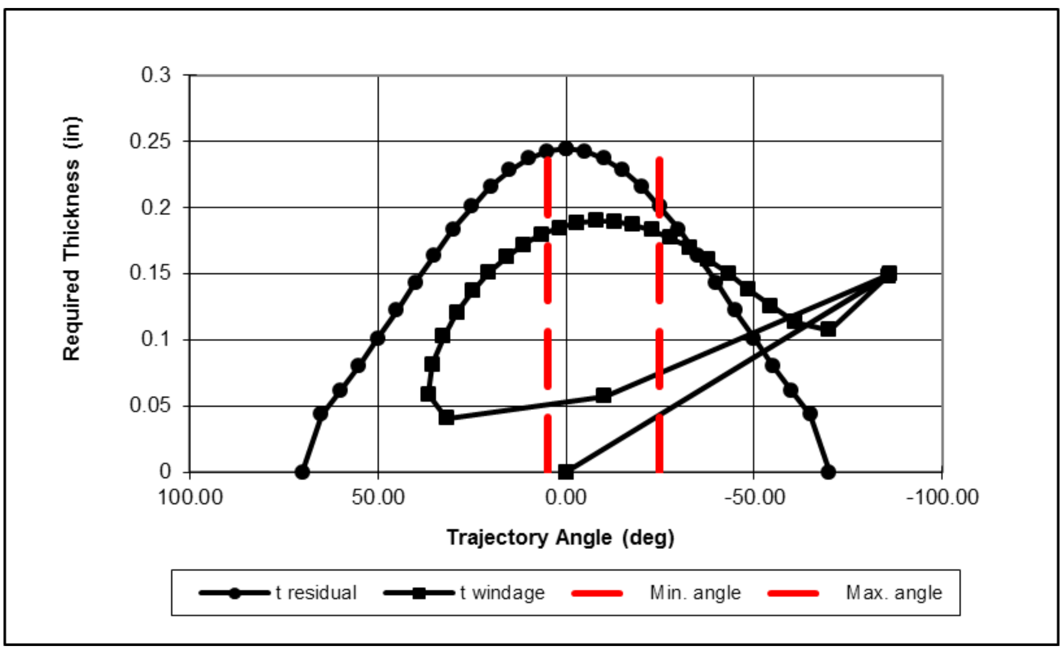


Figure 40. Aluminum skin thickness to defeat a 50% compressor blade fragment

This methodology was conducted for the 50% compressor blade size. The culmination of this analysis methodology (table 14) provides a complete picture of compressor blade fragment characteristics from a compressor rim failure event. The average number of fragments per event is defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles define the fragment trajectory.

Table 14. Blade characterization, compressor disk event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Disk Event	2					
Blades		5	50%	0.13 (50%)	0.67 (764)	+5 to –25

4.2.1.2 Compressor Disk Damage

Compressor disks exit the engine casing and cowling at relative high velocities and energy levels, which can pass completely through fuselage structure (figure 41). Figure 42 shows a single-disk impact at a 0 degrees trajectory. The damage ratio for this single fragment is 60% of the disk diameter (figure 43). Initial energy levels are near 19,403 ft-lbf at 453 feet per second (figure 44). Compressor disk characterization is shown in table 14.

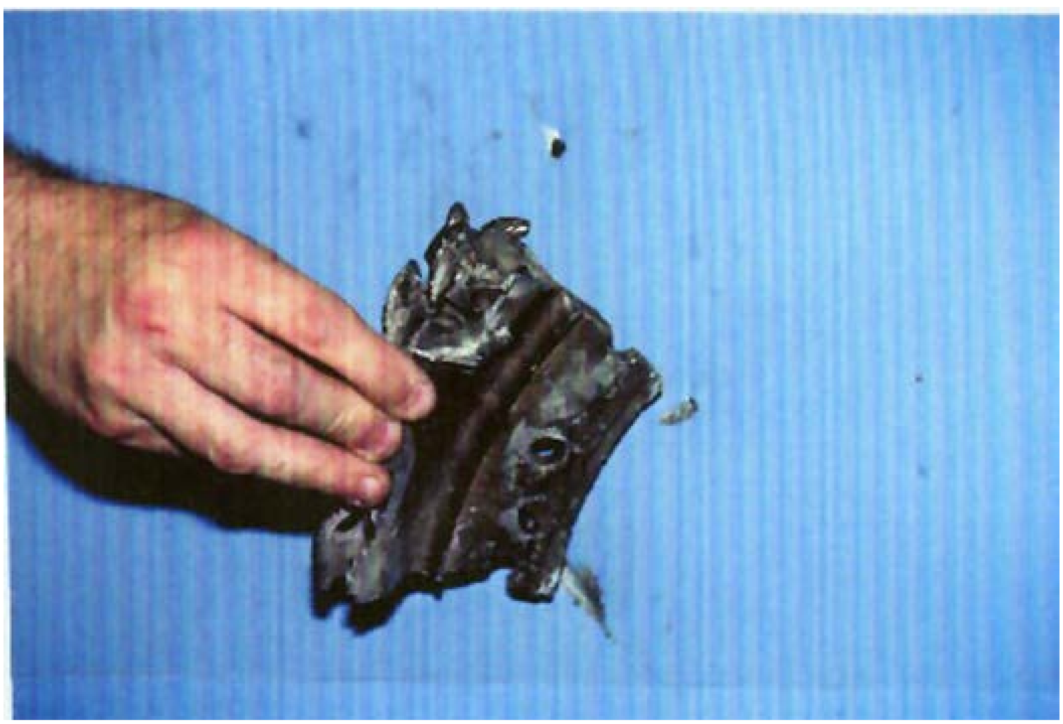


Figure 41. Compressor disk fragment impact on opposite engine nacelle after passing through the fuselage

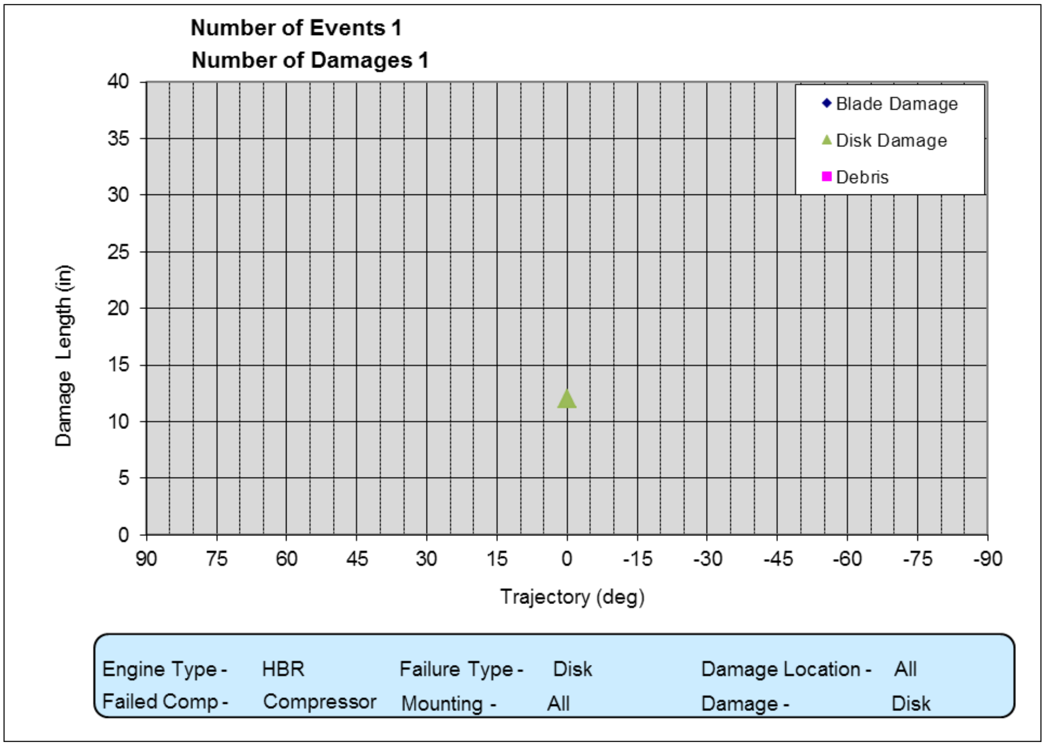


Figure 42. Compressor disk damage

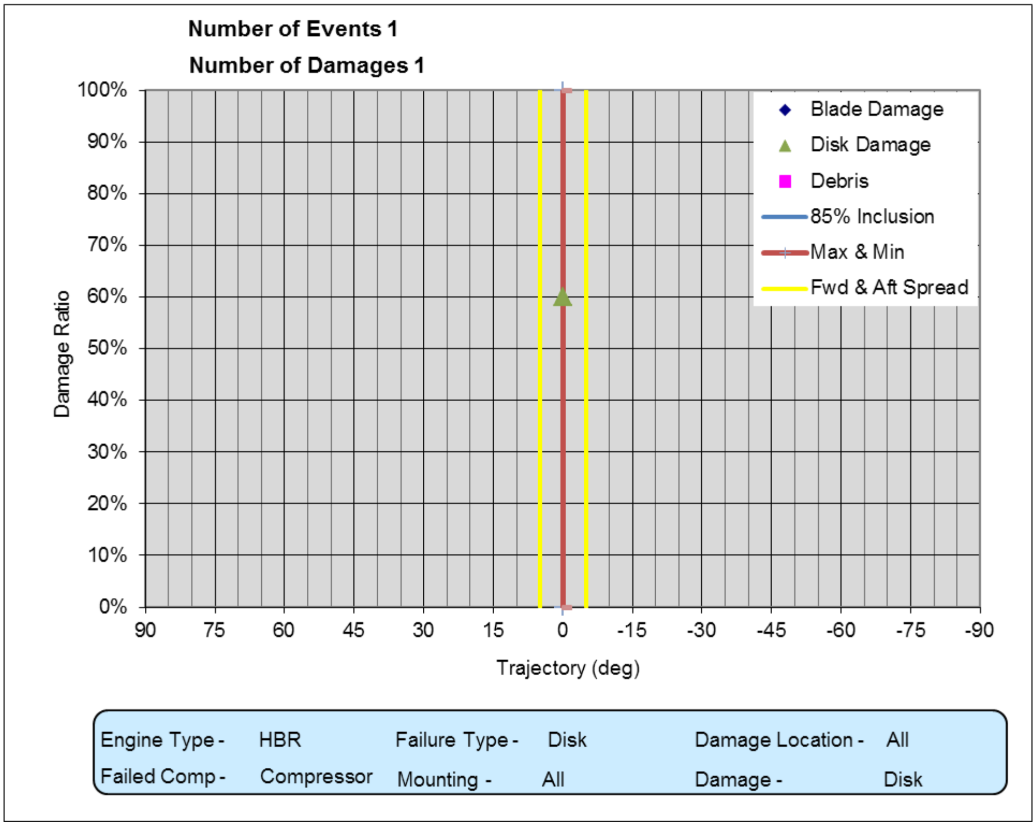


Figure 43. Compressor disk damage ratio

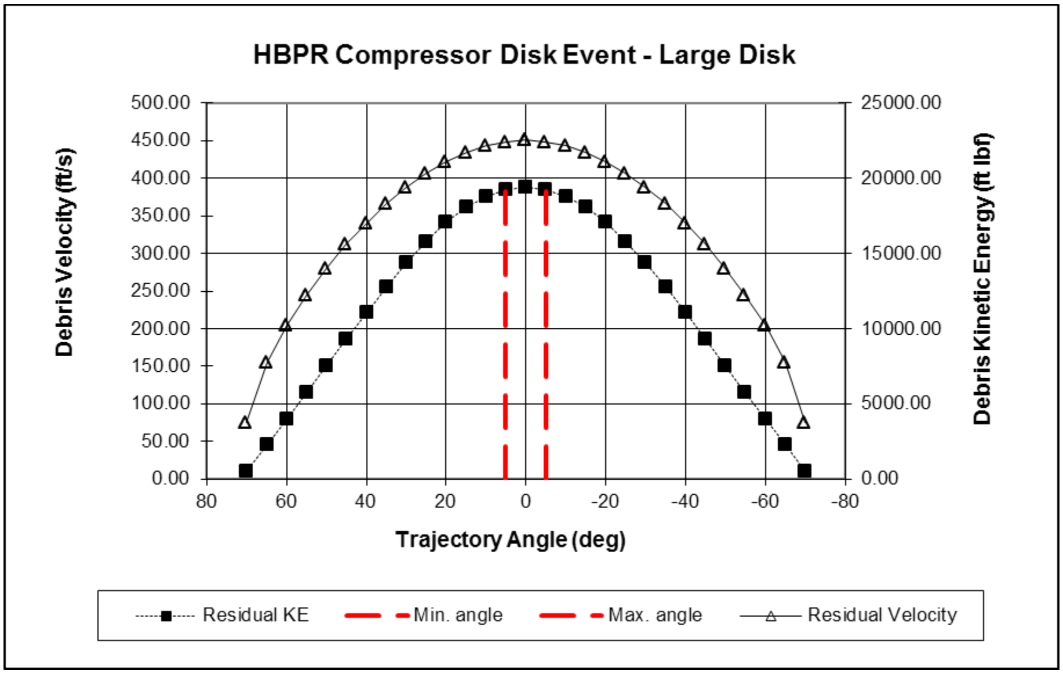


Figure 44. Compressor disk velocity and energy

This methodology was conducted for the 60% compressor disk size. The culmination of this analysis methodology (table 15) provides a complete picture of compressor disk fragment characteristics from a compressor disk failure event. The average number of fragments per event is defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles vary slightly across the fragment sizes.

Table 15. Compressor disk characterization

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Disks		1	60%	6.1 (20%)	0.74 (453)	+5 to –5

4.2.2 Compressor Rim Event

To characterize compressor rim failure events, data were pulled from the low-bypass ratio engine data. There are no HBPR compressor rim failure events recorded in the database.

4.2.2.1 Compressor Blade Damage From a Rim Event

Three compressor rim events are recorded in the event database; blade damage is shown in figure 45. Compressor blade trajectory angle ranges from +16.5 to -1.5 degrees. Maximum damage length (a tear in the vertical tail) is 36 inches. The calculated damage ratio is shown in figure 46. The blade-fragment characterization is a full-blade (100%) fragment with a trajectory spread angle of +15 to -3 degrees.

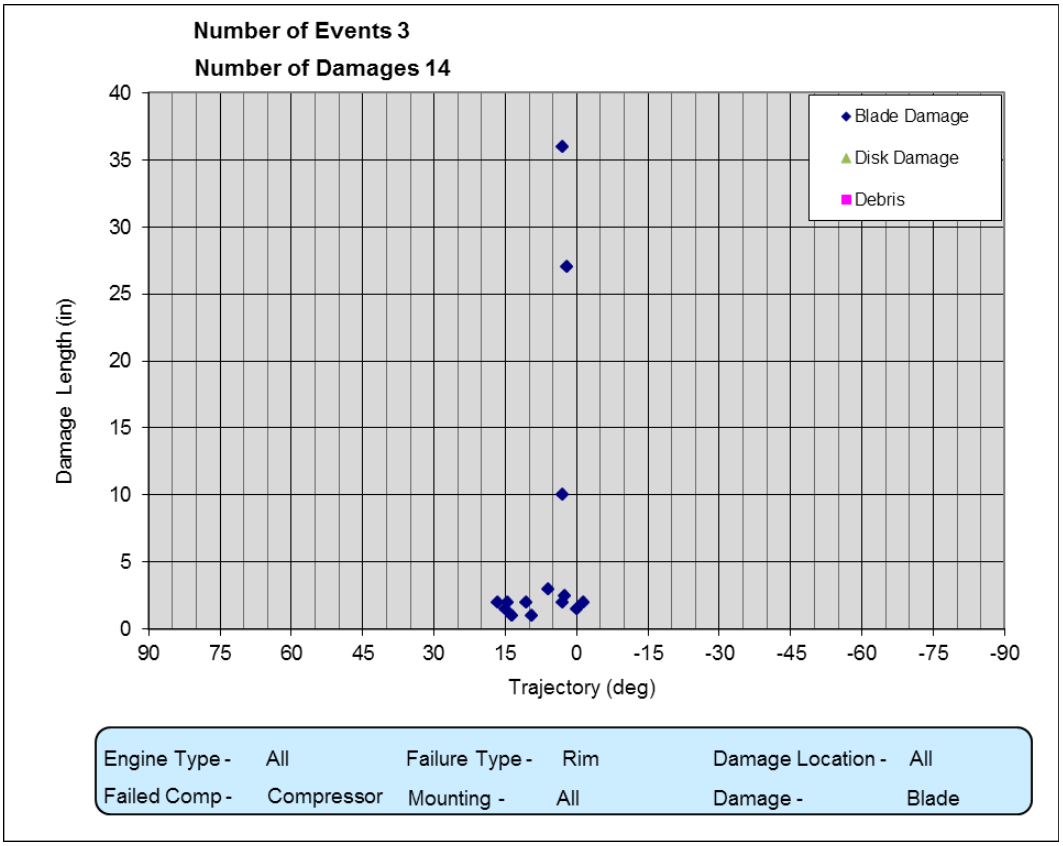


Figure 45. Blade damage, compressor-rim events

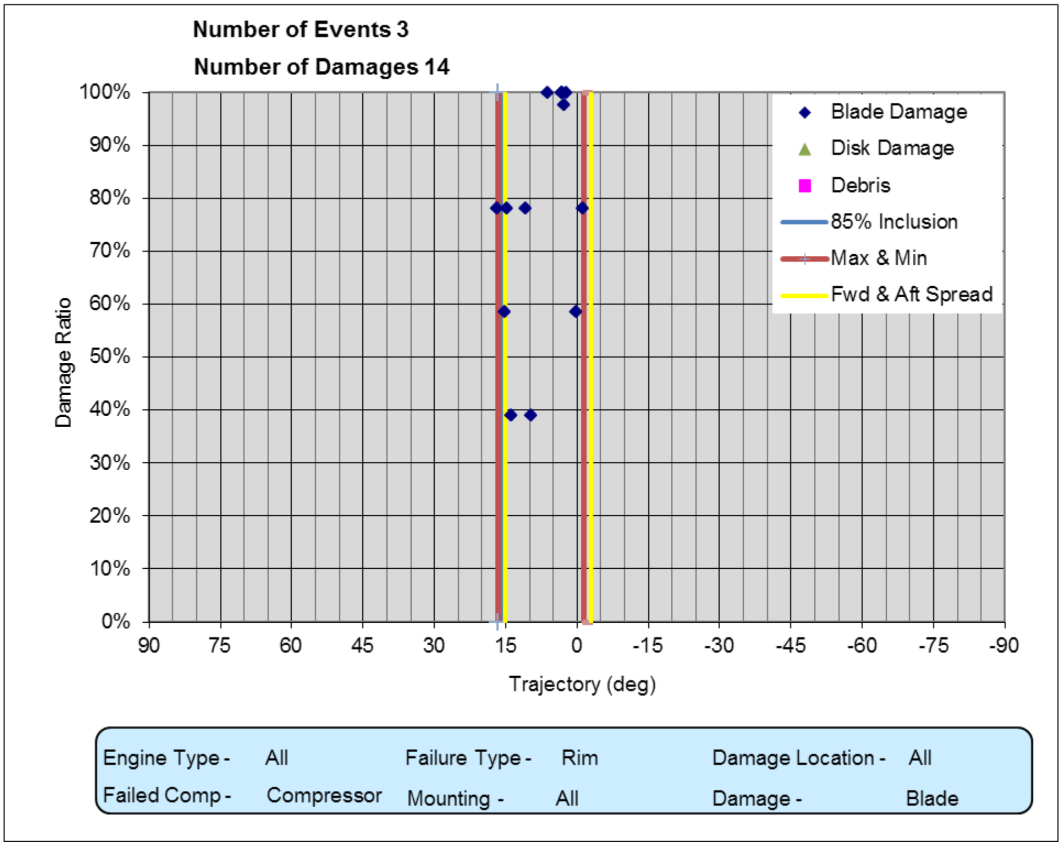


Figure 46. Blade damage ratio, compressor-rim events

To calculate cowl exit velocity, the same assumptions were used to define the velocity loss due to case interaction (25% of the initial velocity). Figure 47 plots debris residual velocity and residual energy upon exiting the cowl. Maximum velocity is 709 feet per second. Aerodynamic effects are included in figure 48. The required skin thickness to defeat the fragment is shown in figure 49.

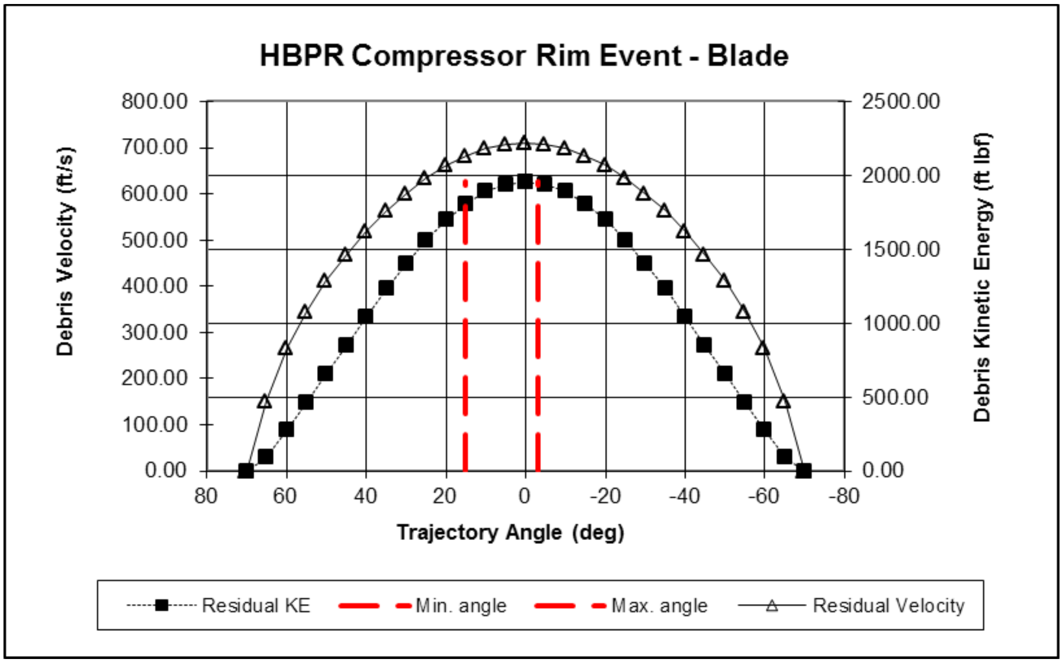


Figure 47. Compressor-blade velocity and energy, rim event

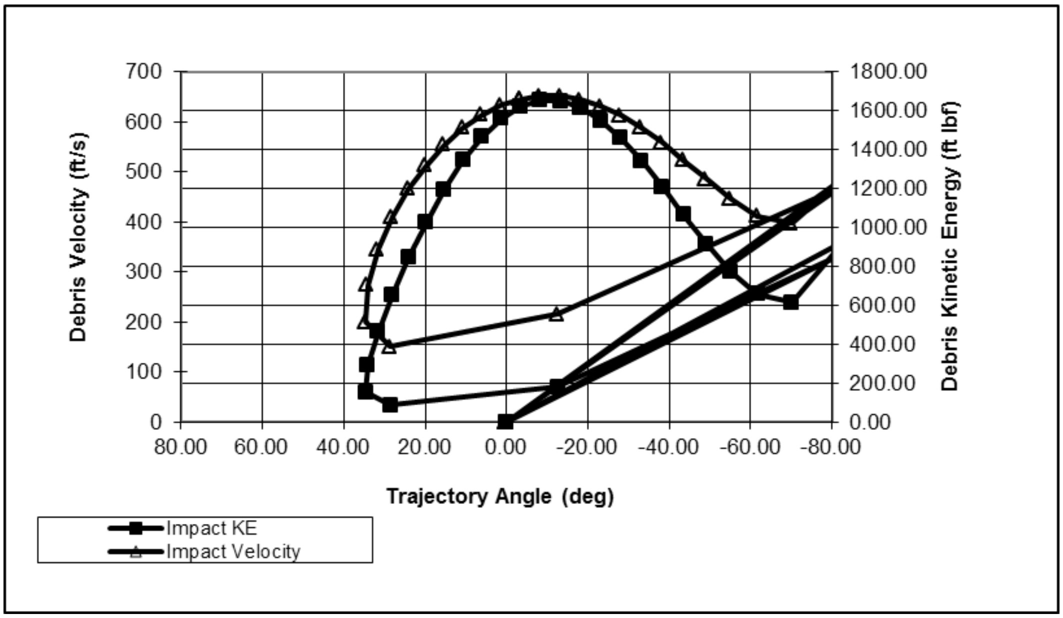


Figure 48. Aerodynamic effects compressor blade, rim event

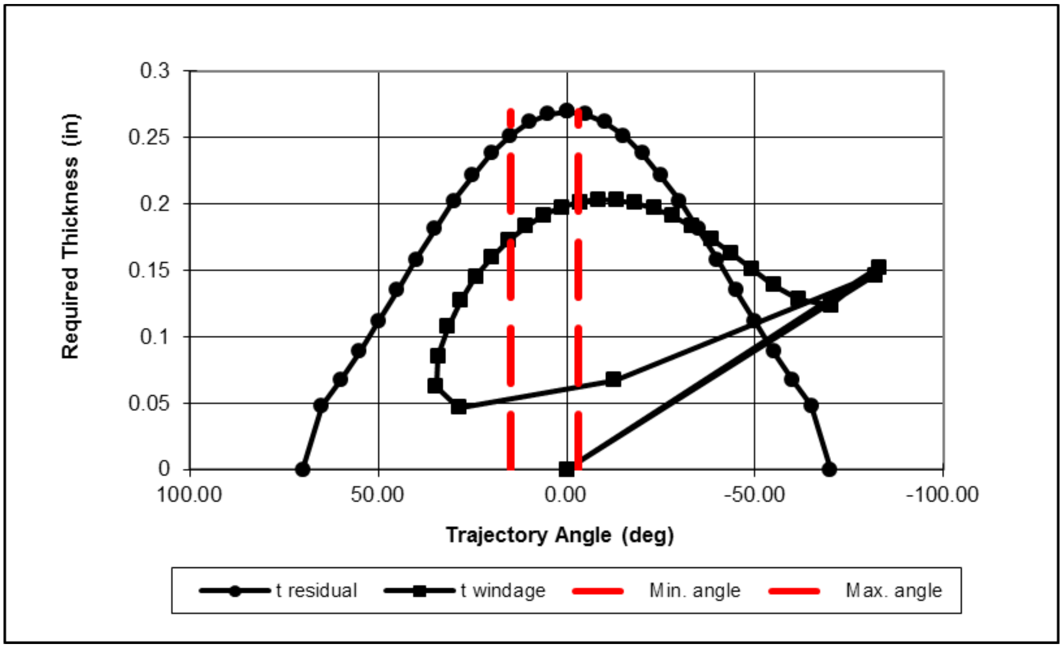


Figure 49. Aluminum skin thickness to defeat a 100% compressor-blade fragment

This methodology was conducted for the 100% compressor blade size. The culmination of this analysis methodology (table 16) provides a complete picture of compressor-blade fragment characteristics from a compressor-rim failure event. The average number of fragments per event is defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles vary slightly across the fragment sizes.

Table 16. Blade characterization, compressor rim event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Rim Event	3					
Blades		5	100%	0.25 (100%)	0.68 (709)	+15 to –3

4.2.2.2 Compressor Rim Damage From a Rim Event

Three compressor rim events are recorded in the event database. Rim damage is shown in figure 50. Compressor rim trajectory angle ranges from +16.5 to 0 degrees. Maximum damage length is 20 inches. The calculated damage ratio is shown in figure 51. The rim-fragment characterization is a 90% disk-diameter fragment with a trajectory spread angle of +15 to 0 degrees.

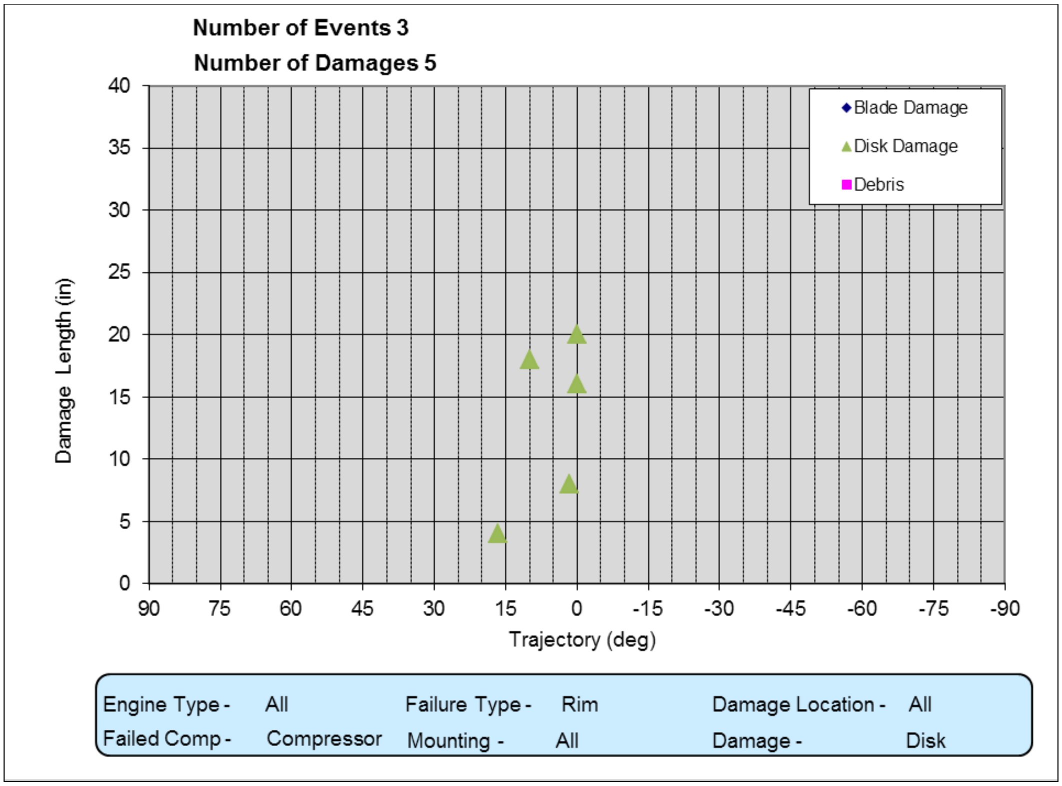


Figure 50. Rim damage, compressor rim events

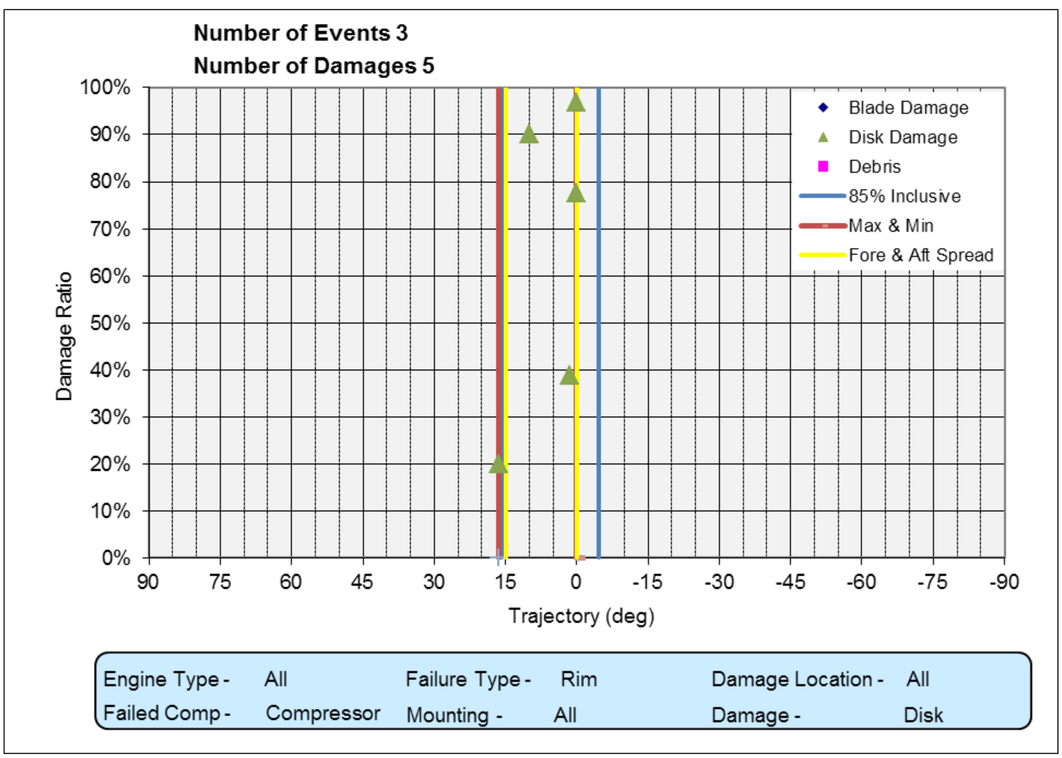


Figure 51. Rim-damage ratio, compressor rim events

To calculate cowl exit velocity, the same assumptions were used to define the velocity loss due to case interaction (25% of the initial velocity). Figure 52 plots debris residual velocity and residual energy upon exiting the cowl. Maximum velocity is 553 feet per second. Aerodynamic effects are included in figure 53. Required skin thickness to defeat the fragment is shown in figure 54.

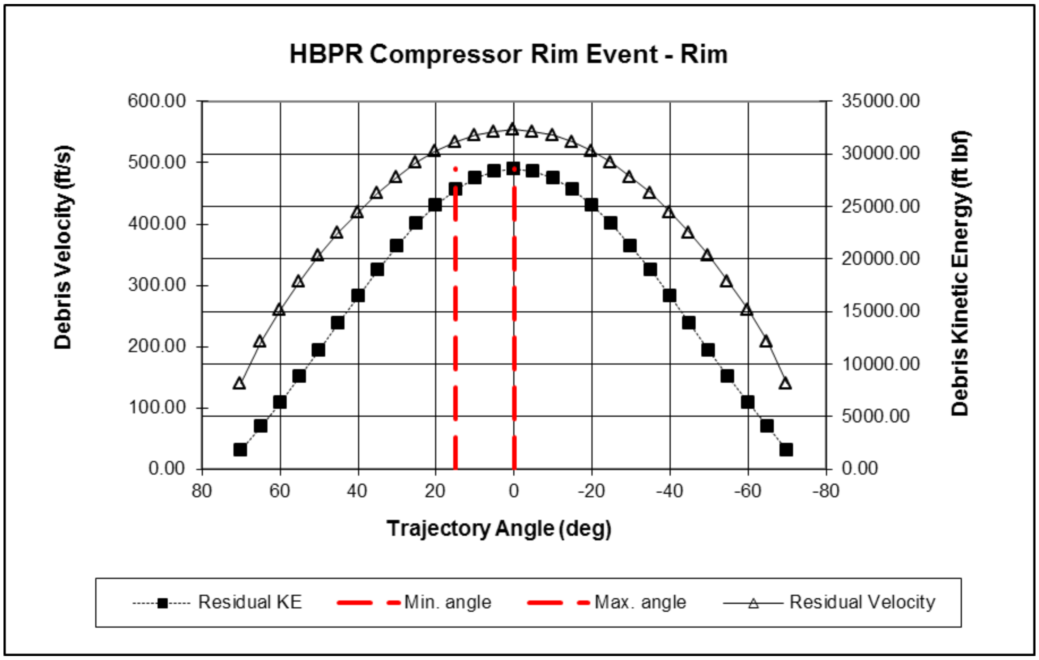


Figure 52. Compressor rim velocity and energy, rim event

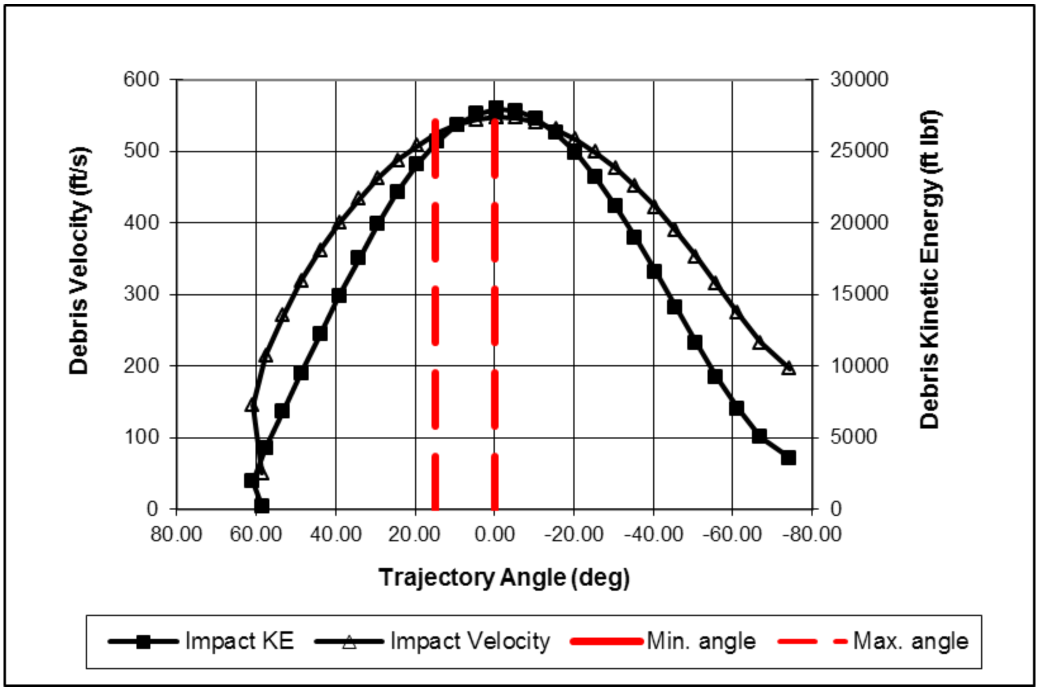


Figure 53. Aerodynamic effects compressor rim, rim event

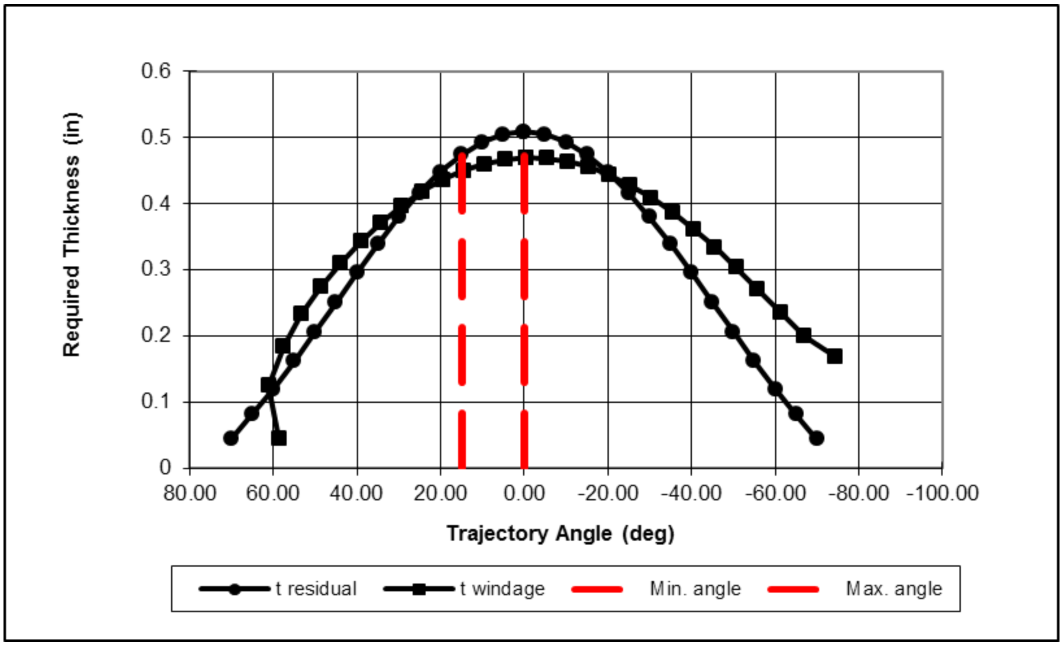


Figure 54. Aluminum skin thickness to defeat 90% compressor rim fragment

This methodology was conducted for the 90% compressor-rim size. The culmination of this analysis (table 17) provides a complete picture of compressor-rim fragment characteristics from a compressor-rim failure event. The average number of fragments per event is defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angle is provided.

Table 17. Rim characterization, compressor rim event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Rim Event	3					
Rim		2	90%	6.0 (30%)	0.74 (553)	+15 to 0

4.3 HIGH-PRESSURE TURBINE

Turbine analysis was divided into High-Pressure Turbine (HPT) and Low-Pressure Turbine categories. HPT events are a serious risk to the aircraft because of the high rotational speed, heavy weight, and larger exposure under the wing (figure 55). Representative damage from disk segments penetrating the wing are shown in figure 56. Turbine events were categorized by blade, rim, and disk failure events. There were eight HPT events, five HPT Disk events, three HPT Rim events, and no HPT Blade events (previous characterization was from LBPR engines). Each of these failure modes is characterized in sections 4.3.1.1–4.3.2.2 .

Figure 55. Turbine disk failure

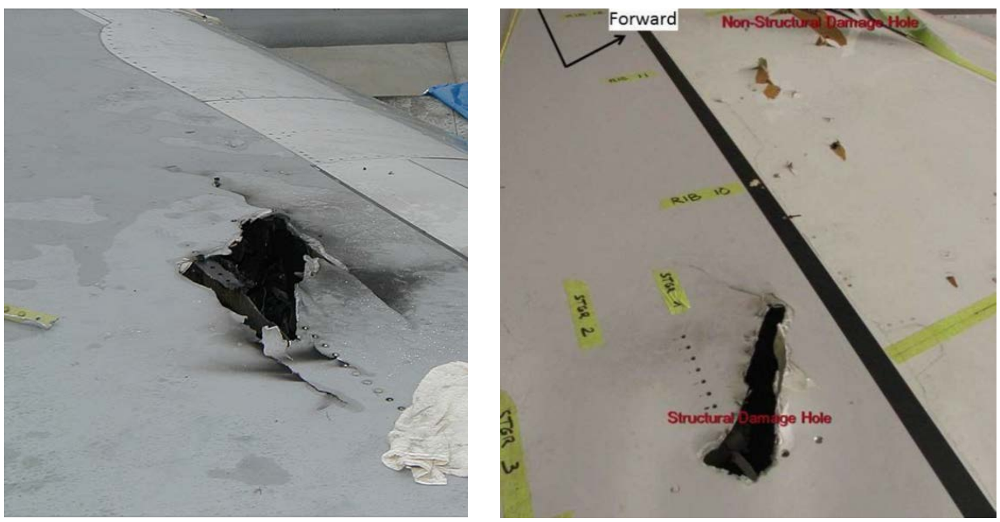


Figure 56. Upper-wing skin damage, HPT disk event

4.3.1 HPT Disk Failure

4.3.1.1 Turbine Blade Damage From an HPT Disk Event

Aircraft damage resulting from an HPT blade impact is shown in figure 57. The damage ratio is shown in figure 58. The representative turbine blade debris size for characterization is 70% blade length. The 5 disk events produced 68 damage locations, resulting in an average of 13.6 (14) blade fragments per event. The trajectory angles range between 15 degrees and -60 degrees. For characterization, the trajectory spread angle ranges from +15 to -45 degrees. Peak cowl exit velocity for a 70% blade fragment is 968 feet per second with energy of 3063 ft-lbf (figure 59).

The aerodynamic effects are shown in figure 60. The required skin thickness to defeat the fragment is shown in figure 61.

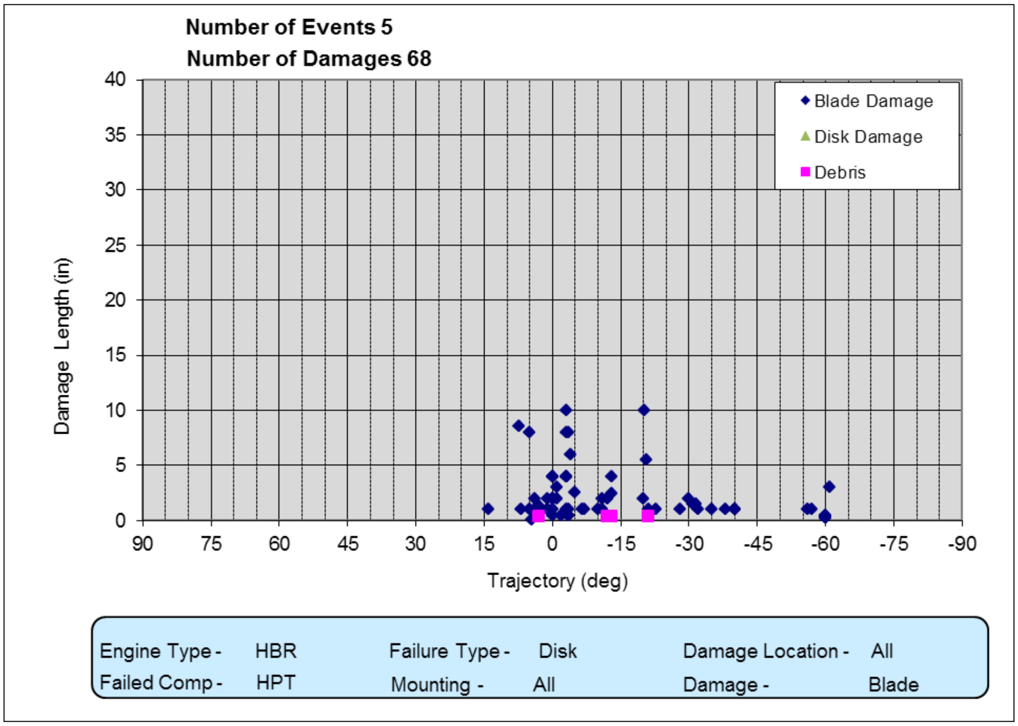


Figure 57. Blade damage, HPT disk event

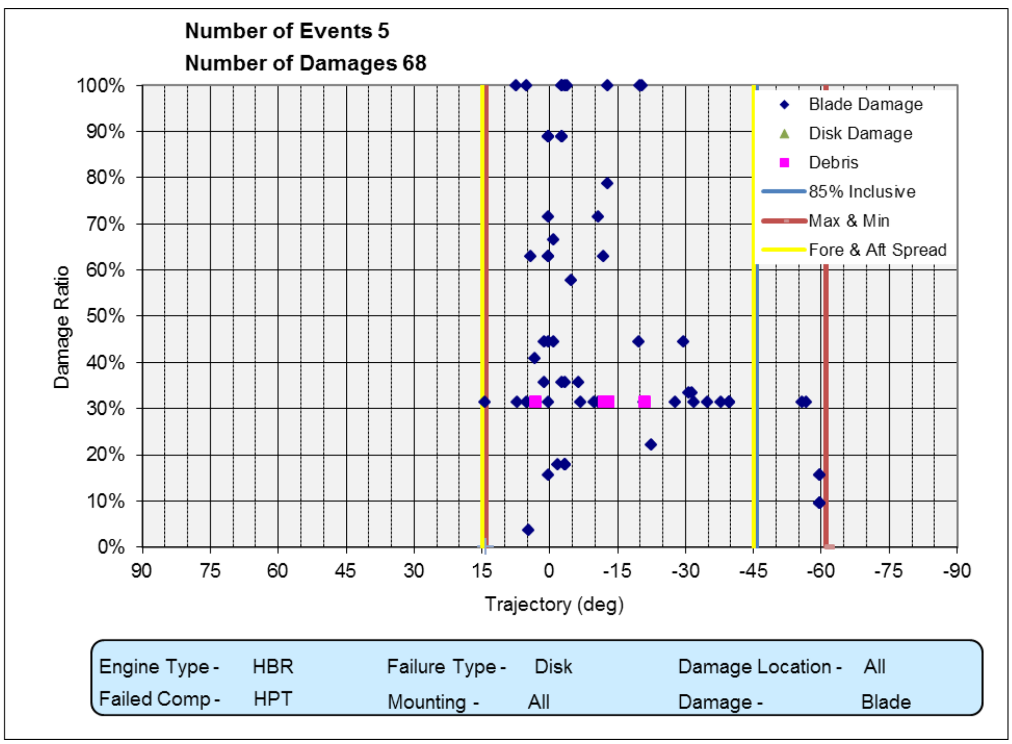


Figure 58. Blade damage ratio, HPT disk event

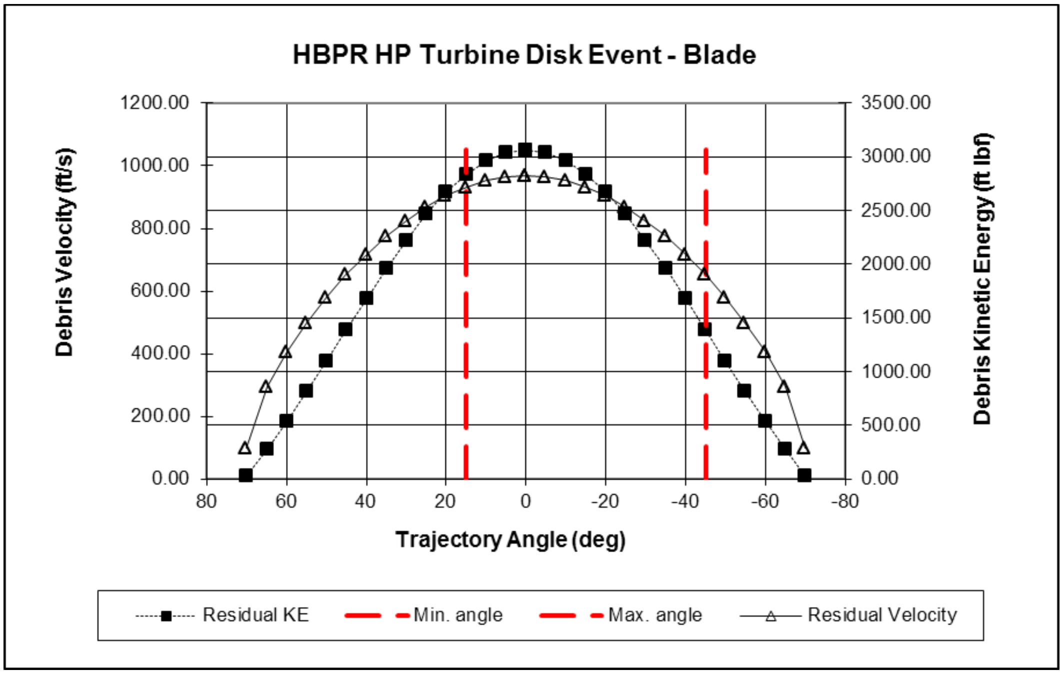


Figure 59. HPT blade velocity and energy, disk event

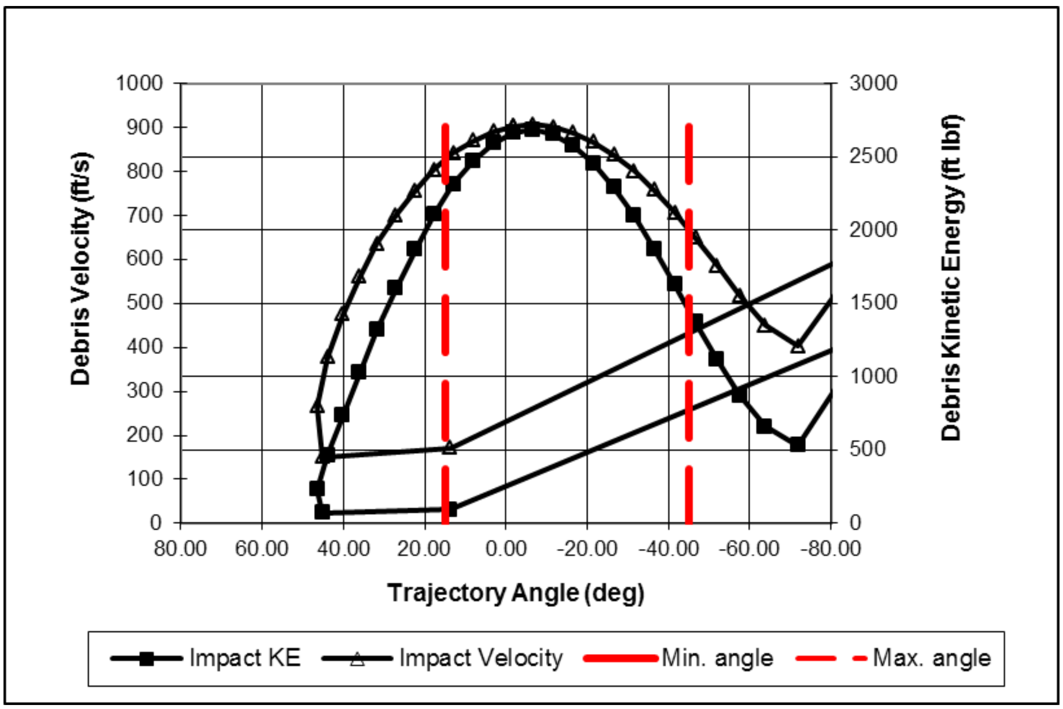


Figure 60. Aerodynamic effects HPT blade, disk event

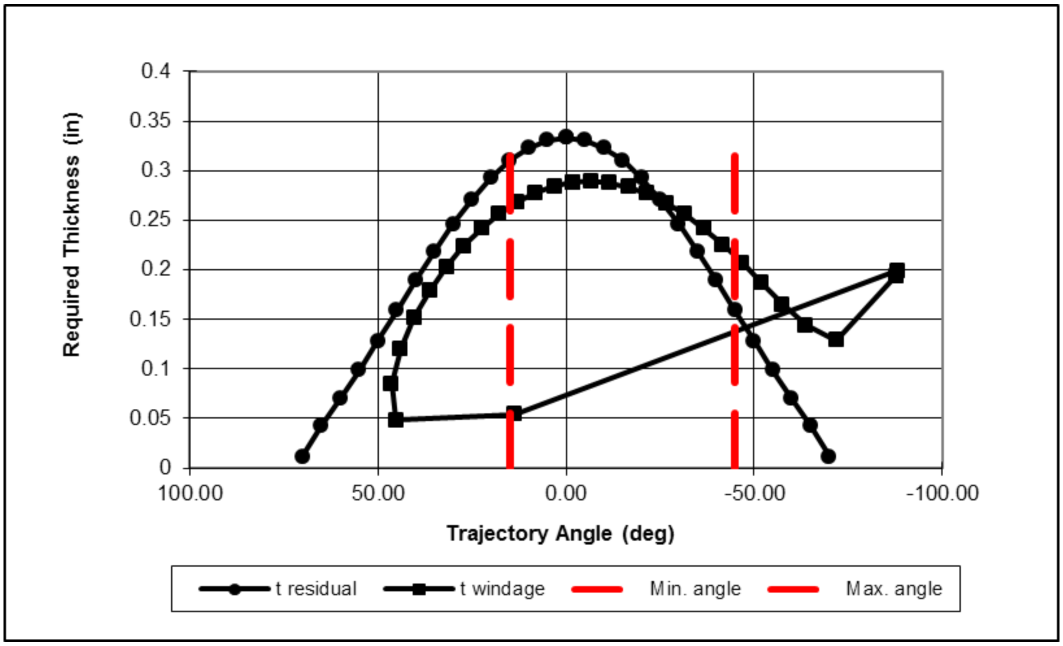


Figure 61. Aluminum skin thickness to defeat a 70% HPT blade fragment

This methodology was conducted for the 70% HPT blade size. The culmination of this analysis methodology (table 18) provides a complete picture of HPT blade-fragment characteristics from a turbine disk-failure event. The average number of fragments per event is defined. Fragment weight is defined based on the generic engine model description. Velocity ratio provides a quick means to determine cowl exit velocity (residual velocity). It is defined as the residual velocity after penetrating cowl skins divided by the initial velocity. The fore and aft spread angles vary slightly across the fragment sizes.

Table 18. HPT disk event, blade characterization

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
HPT						
Disk Event	5					
Blades		14	70%	0.21 (70%)	0.69 (968)	+15 to –45

4.3.1.2 Turbine Disk Damage

Aircraft damage resulting from an HPT disk impact is shown in figure 62. The damage ratio is shown in figure 63. The representative turbine disk debris size for characterization is 60% disk diameter; however, AC 20-128A [5] calls for a 1/3 disk segment, which is defined as 90% of a disk diameter fragment. As discussed in the HPT blade damage section, there were five HPT Disk events, three of which had disk damage on the aircraft. Of the three disk events, seven damage locations resulted in an average of two disk fragments per event. These disk fragments were characterized as a 50% fragment, smaller than the 1/3 disk (90% fragment), defined by AC 20-128A. The trajectory angles range between 0 degrees and -11 degrees. For characterization, the trajectory spread angle ranges from +3 to -11 degrees to cover AC 20-128A requirements. Peak cowl exit velocity for a 50% disk fragment is 602 feet per second with energy of 117,470 ft-lbf (figure 64).

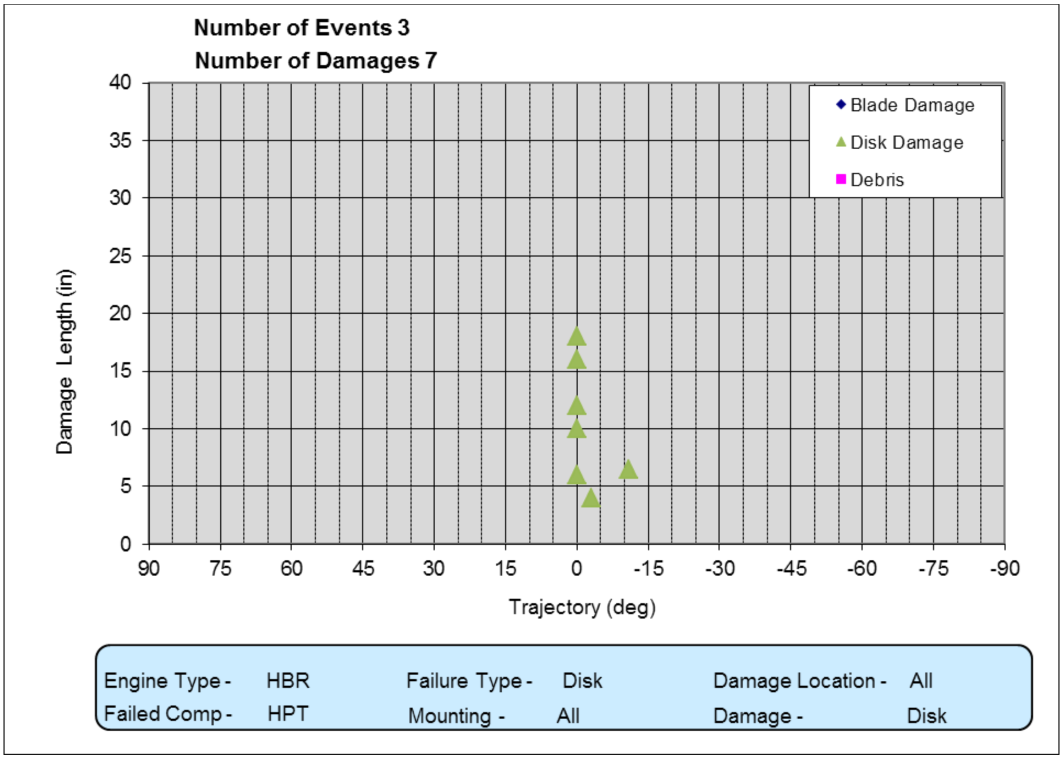


Figure 62. HPT disk damage

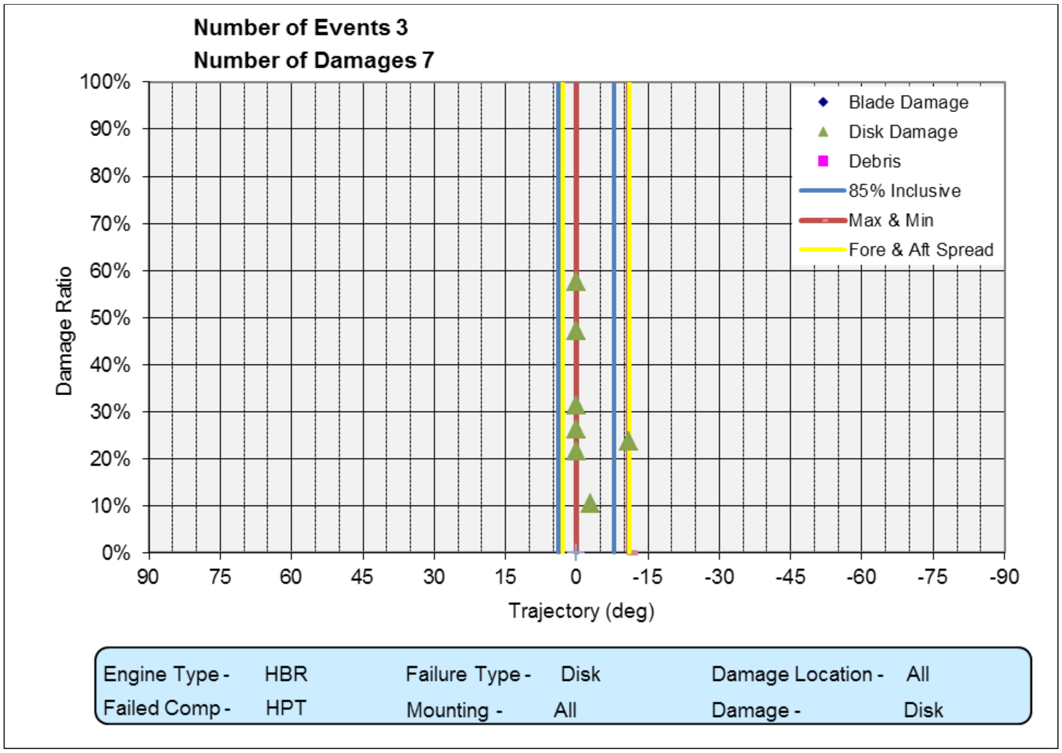


Figure 63. Damage ratio, HPT disk

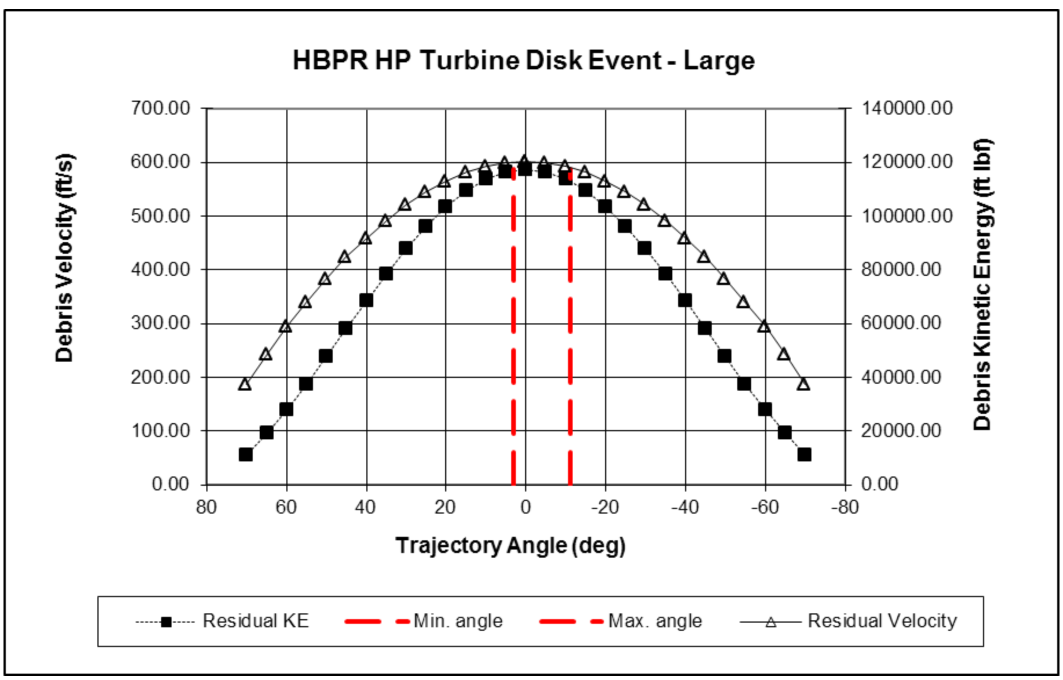


Figure 64. HPT disk velocity and energy

HPT disk damage from an HPT disk event is characterized in table 19.

Table 19. HPT disk characterization, disk event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
HPT						
Disk Event	5					
Disk		2	50%	20.8 (16.7%)	0.75 (602)	+3 to –11

4.3.2 HPT Spacer—Rim Event

4.3.2.1 Blade Damage, HPT Spacer-Rim Event

Aircraft damage resulting from an HPT blade impact from a spacer-rim event is shown in figure 65. The damage ratio is shown in figure 66. Representative turbine blade debris size for characterization is 85% disk diameter. There were 3 HPT spacer-rim events and 33 damage locations, resulting in an average of 11 disk fragments per event. The trajectory angles range between +15 degrees and -40 degrees. Peak cowl exit velocity for an 85% blade fragment is 952 feet per second with energy of 3592 ft-lbf (figure 67). Aerodynamic effects are shown in figure 68.

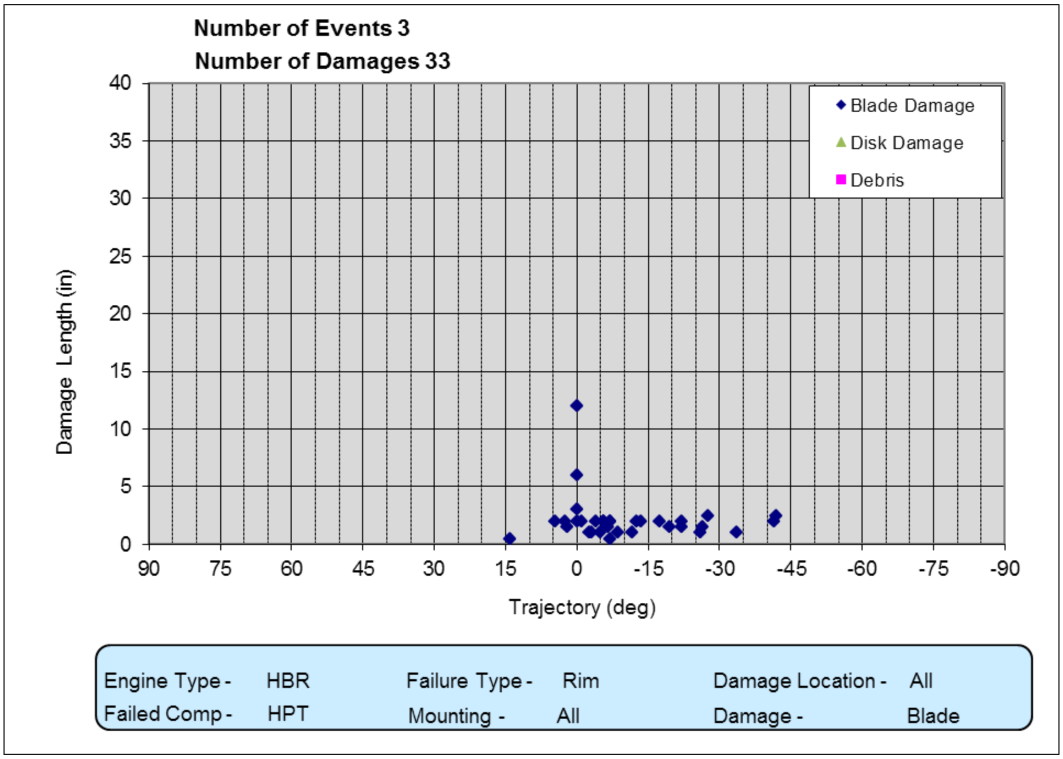


Figure 65. Blade damage, HPT spacer-rim event

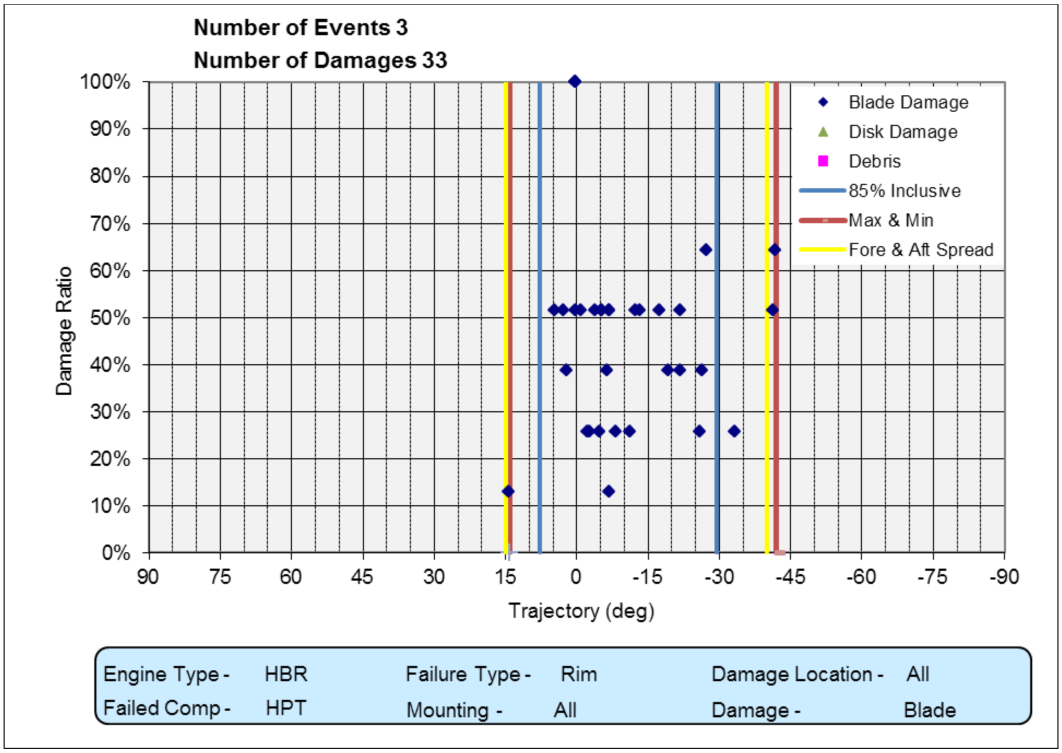


Figure 66. Damage ratio, HPT spacer-rim event

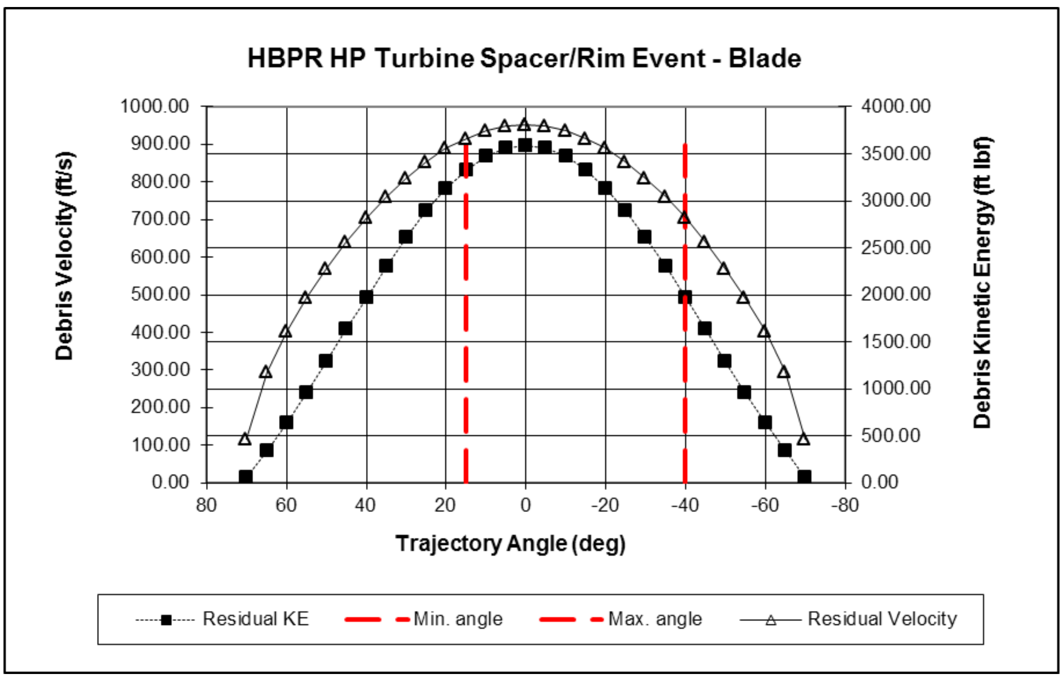
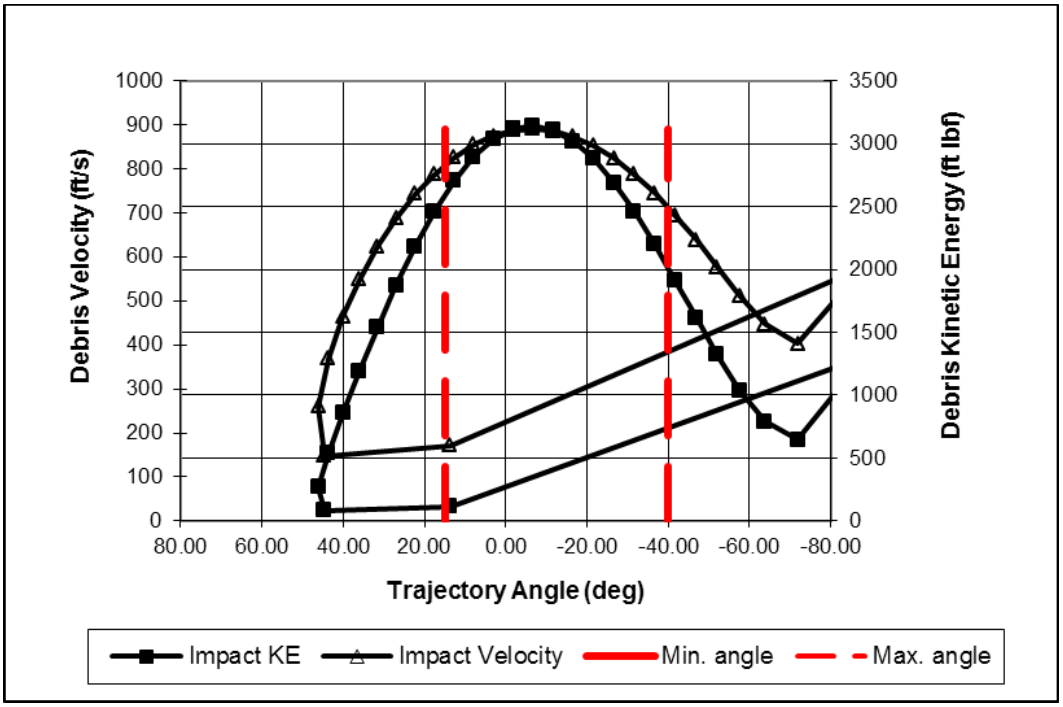


Figure 67. HPT blade velocity and energy, spacer-rim event



The required skin thickness to defeat the fragment is shown in figure 69. The HPT blade characterization from a spacer-rim event is shown in table 20.

Figure 68. Aerodynamic effects HPT blade spacer-rim event

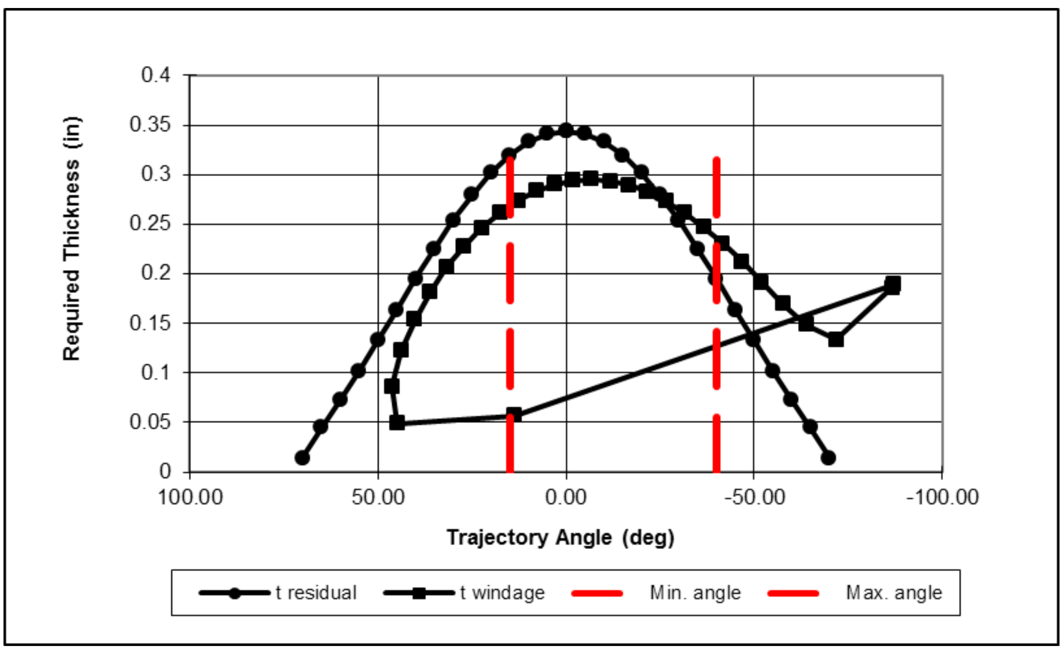


Figure 69. Aluminum skin thickness to defeat an 85% HPT blade fragment

Table 20. HPT blade, spacer-rim event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
HPT						
Spacer – Rim Event	3					
Blades		11	85%	0.26 (85%)	0.69 (952)	+15 to –40

4.3.2.2 Rim Damage, HPT Spacer-Rim Event

The rim of the disk is defined as the outer section of the disk where the blades attach through the fir-tree slots (figure 70). This is generally considered an intermediate fragment by AC 20-128A standards [5].

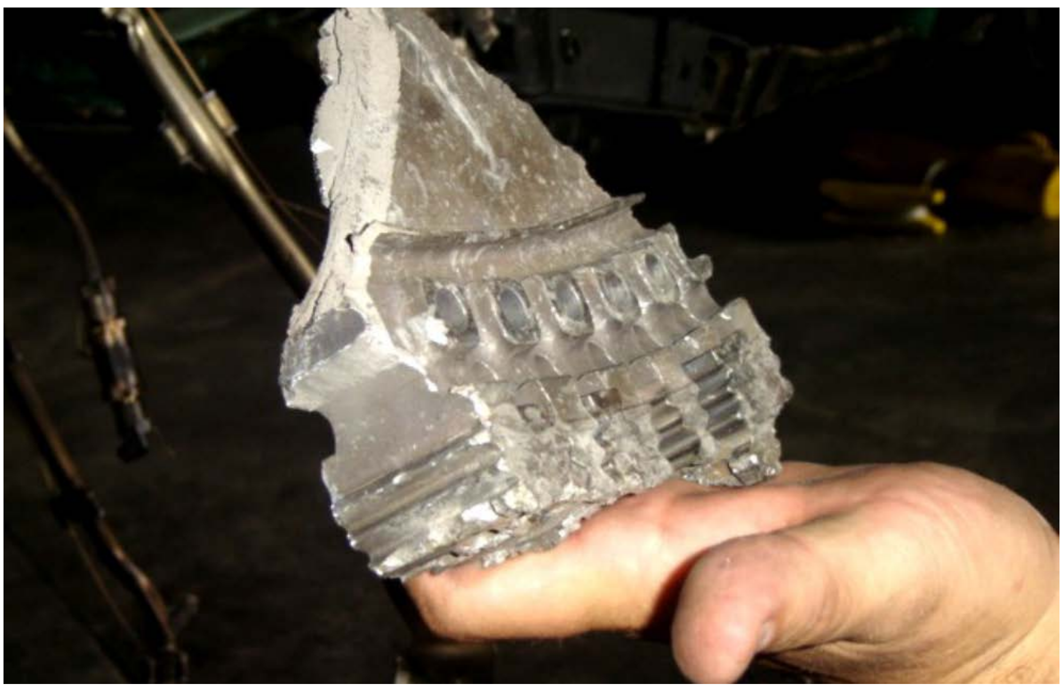


Figure 70. Turbine rim fragment

Aircraft damage resulting from an HPT spacer-rim impact is shown in figure 71. The damage ratio is shown in figure 72. The representative turbine blade debris size for characterization is 50% disk diameter. There were two HPT spacer-rim events and two damage locations, resulting in an average of one disk fragment per event. The trajectory angles range between -6 degrees and -12 degrees. Peak cowl exit velocity for a 50% blade fragment is 745 feet per second with energy of 71,930 ft-lbf (figure 73).

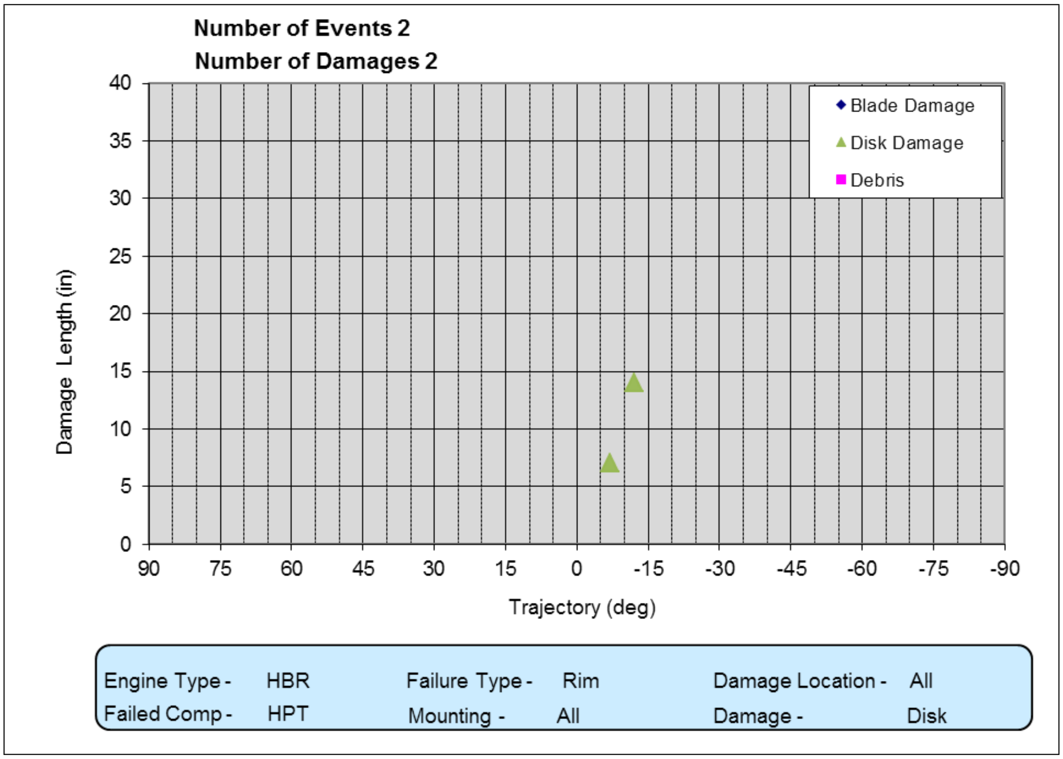


Figure 71. Spacer-rim damage, HPT spacer-rim event

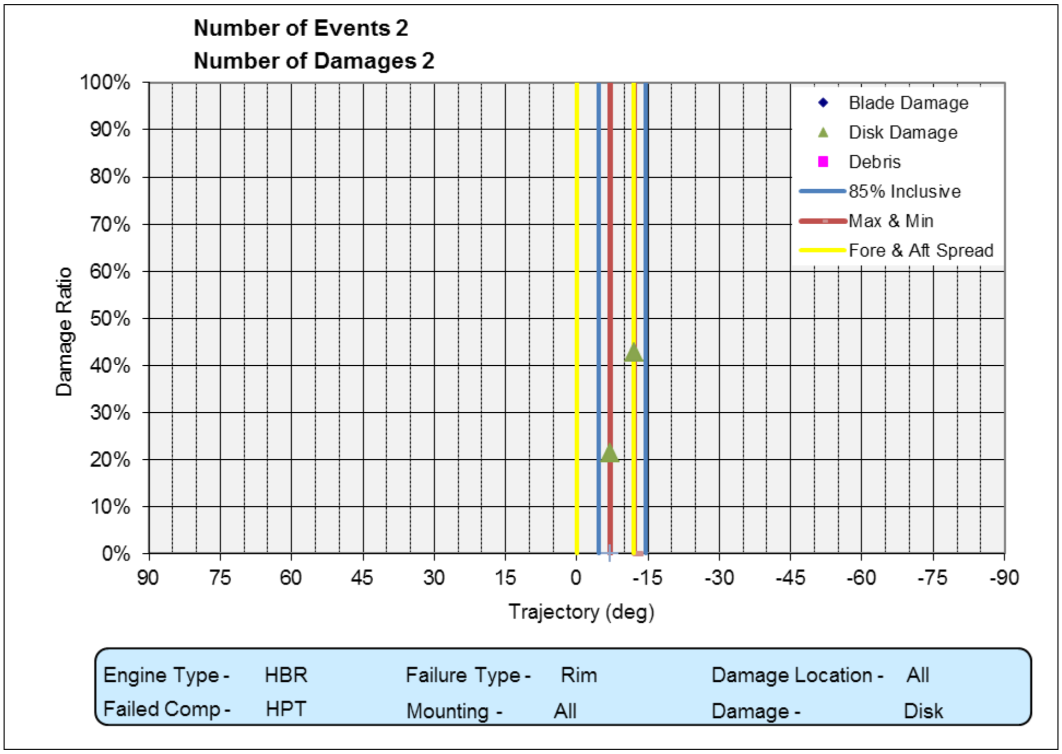


Figure 72. Spacer-rim damage ratio, HPT spacer-rim event

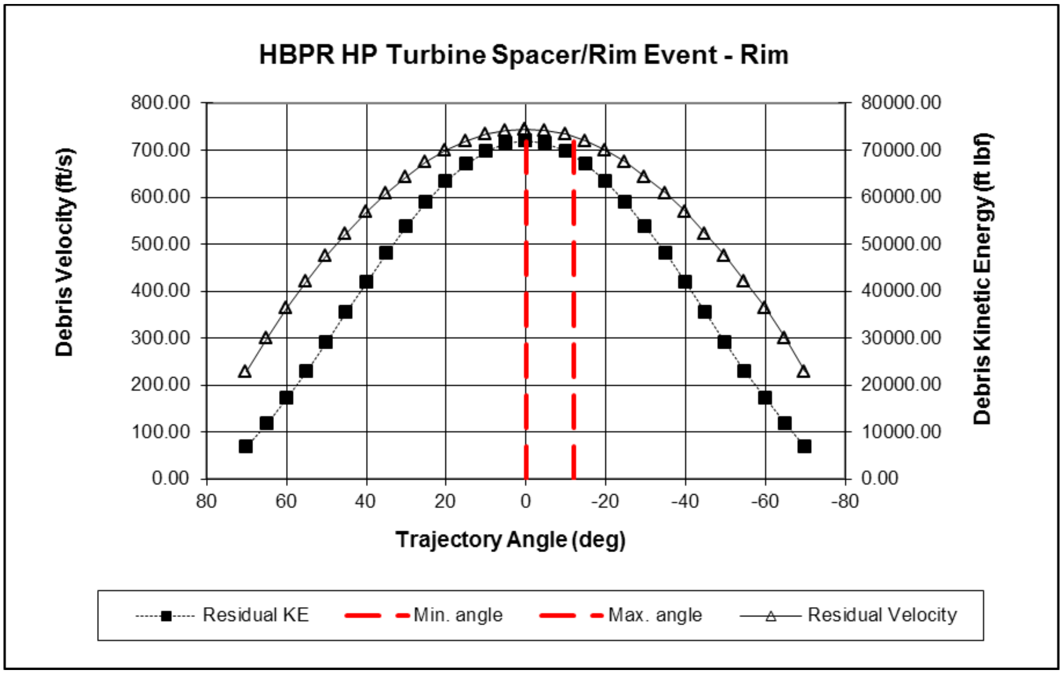


Figure 73. Spacer-rim velocity and energy

HPT blade characterization from a spacer-rim event is shown in table 21.

Table 21. HPT spacer-rim characterization

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
HPT						
Spacer - Rim	2					
Rim		1	50%	8.3 (17%)	0.74 (745)	0 to –12

4.4 LOW PRESSURE TURBINE

Low-pressure turbine (LPT) events were categorized by blade, rim, and disk-failure events (figure 74). There were nine LPT events, three LPT disk events, two LPT rim events, and four LPT blade events. Each of these failure modes is characterized below.

Figure 74. Uncontained LPT disk segment

4.4.1 LPT Disk Event

4.4.1.1 Blade Damage, LPT Disk Event

Aircraft damage resulting from an LPT blade impact is shown in figure 75. Damage ratio is shown in figure 76. Representative turbine blade debris size for characterization is 70% blade length. The 3 disk events produced 22 damage locations, resulting in an average of 7.33 (7) blade fragments per event. The trajectory angles range between 5 degrees and -70 degrees. For characterization, the trajectory spread angle is defined as +5 to -45 degrees. Peak cowl exit velocity for a 70% blade fragment is 436 feet per second with energy of 1399 ft-lbf (figure 77). Aerodynamic effects are shown in figure 78. Required skin thickness to defeat the fragment is shown in figure 79. As can be seen, windage for these lower energy blade fragments can be significant and can account for the large aft trajectories.

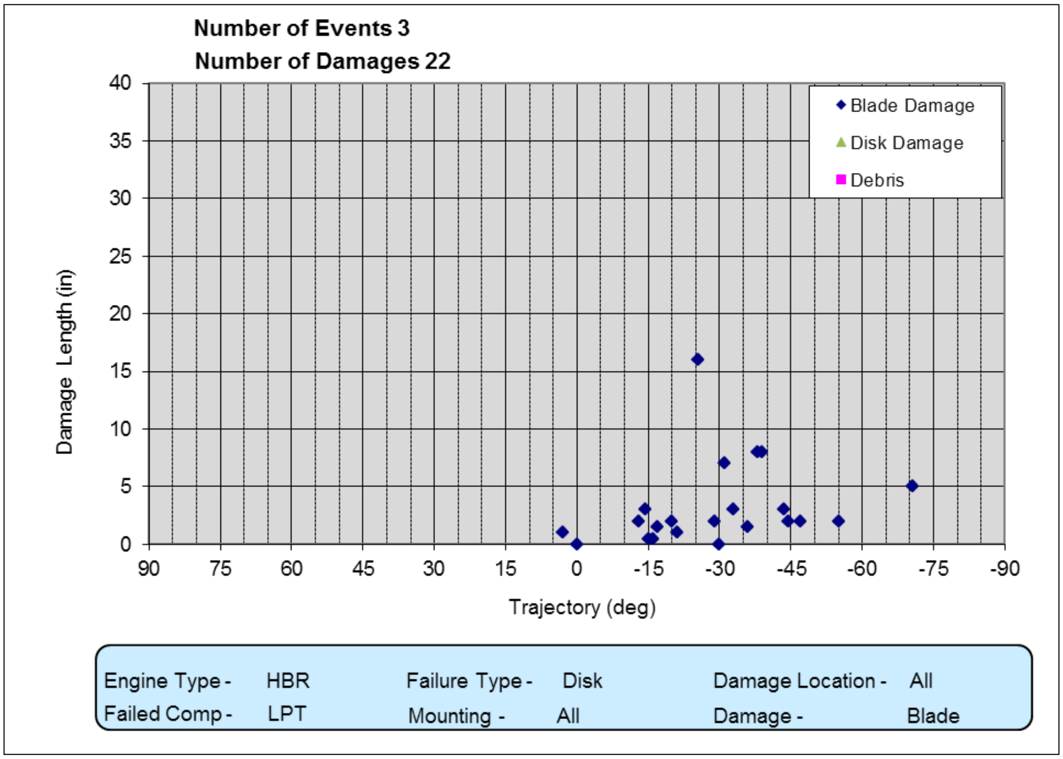


Figure 75. Blade damage, LPT disk event

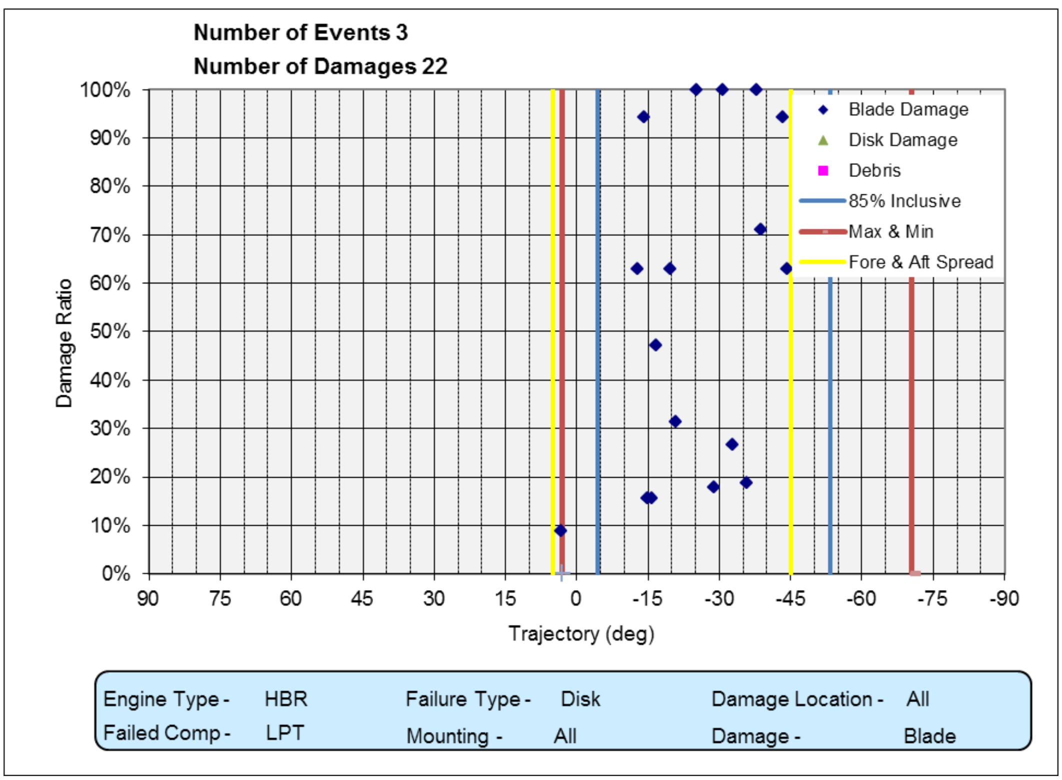


Figure 76. Blade-damage ratio, LPT disk event

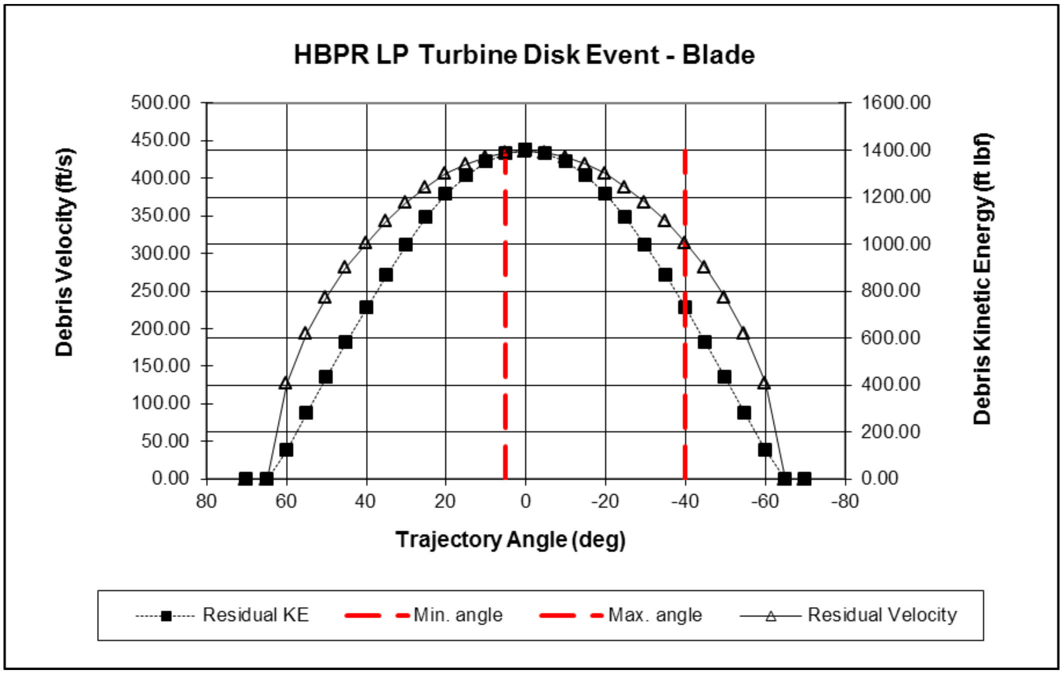


Figure 77. LPT blade velocity and energy

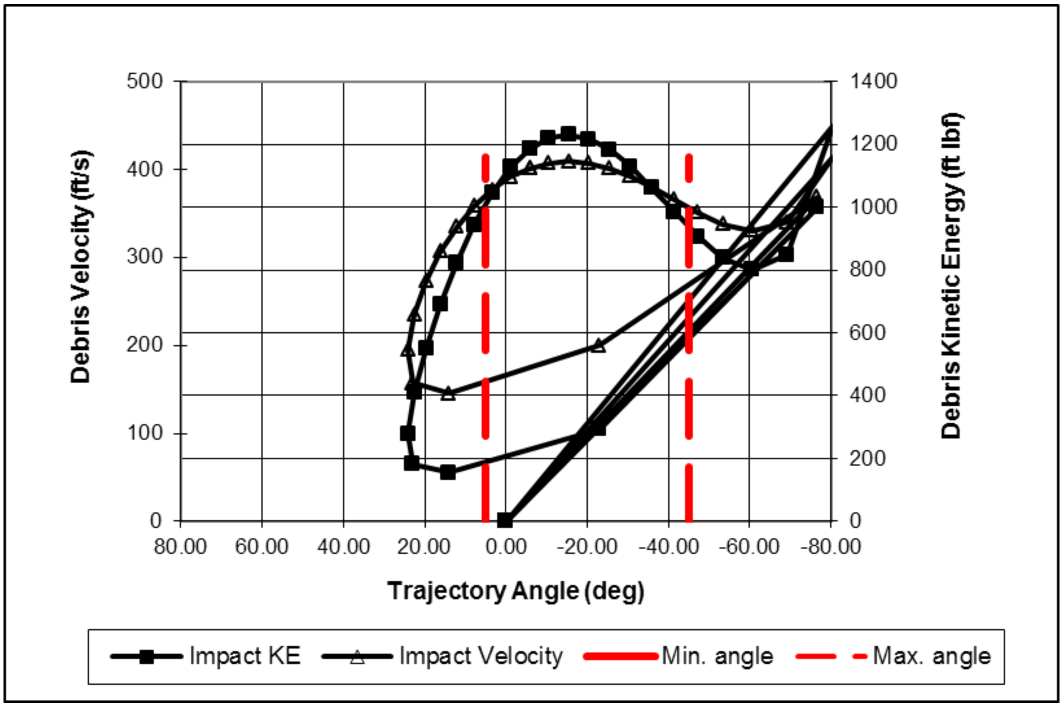


Figure 78. Aerodynamic effects of LPT blade, disk event

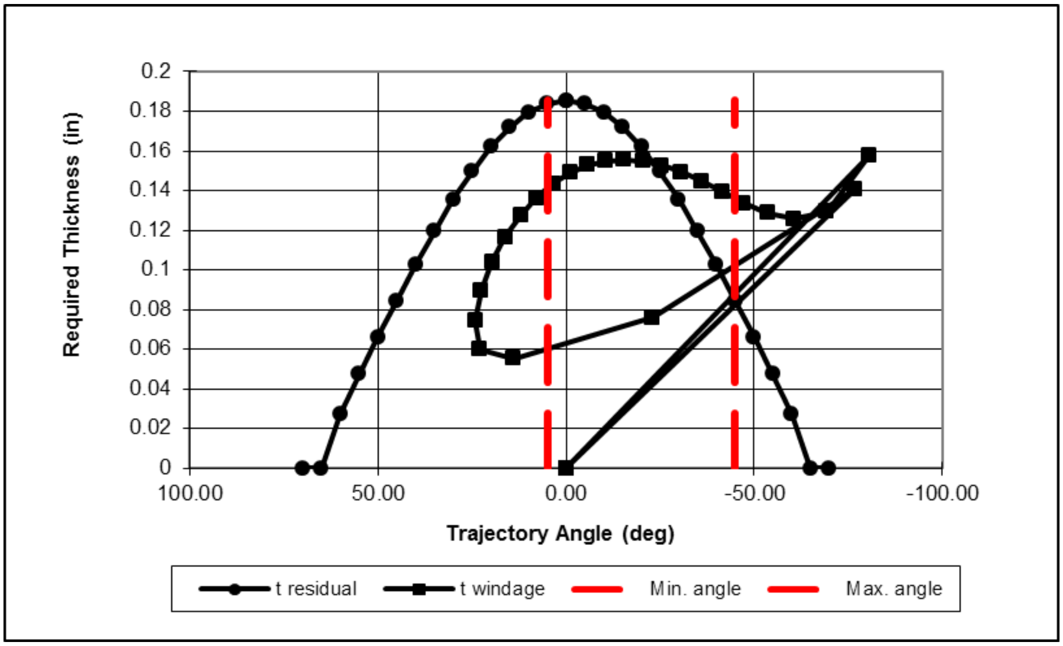


Figure 79. Thickness required to defeat LPT blade fragment

LPT blade characterization from a disk event is shown in table 22.

Table 22. LPT blade characterization, disk event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Disk	3					
Blades		7	70%	0.47 (70%)	0.69 (436)	+5 to –45

4.4.1.2 Disk Damage

An example of aircraft damage resulting from an LPT disk impact is shown in figure 80. Aircraft damage recorded in the database is shown in figure 81. The damage ratio is shown in figure 82. Representative turbine disk debris size for characterization is 90% disk diameter (1/3 disk). Of the three disk events, two produced aircraft damage including two damage locations. The average number of disk fragments per event is one. The trajectory angles range between +3 degrees and -7 degrees. For characterization, the trajectory spread angle is defined as +3 to -5 degrees. The peak cowl exit velocity for a 90% disk fragment is 291 feet per second with energy of 56,466 ft-lbf (figure 83).

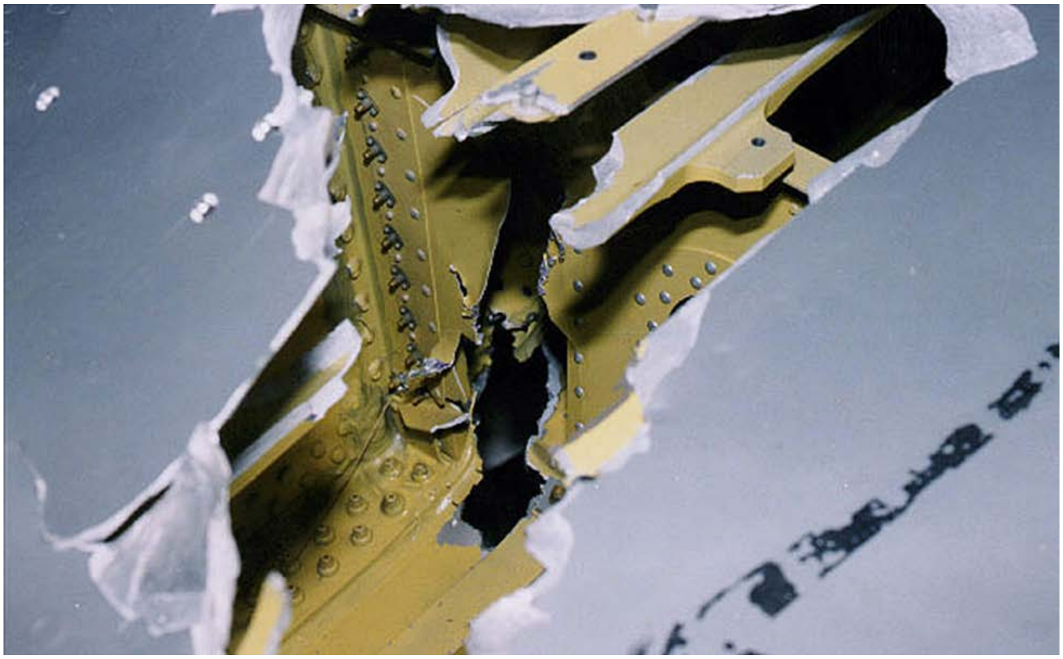


Figure 80. Wing structure damage, LPT disk event

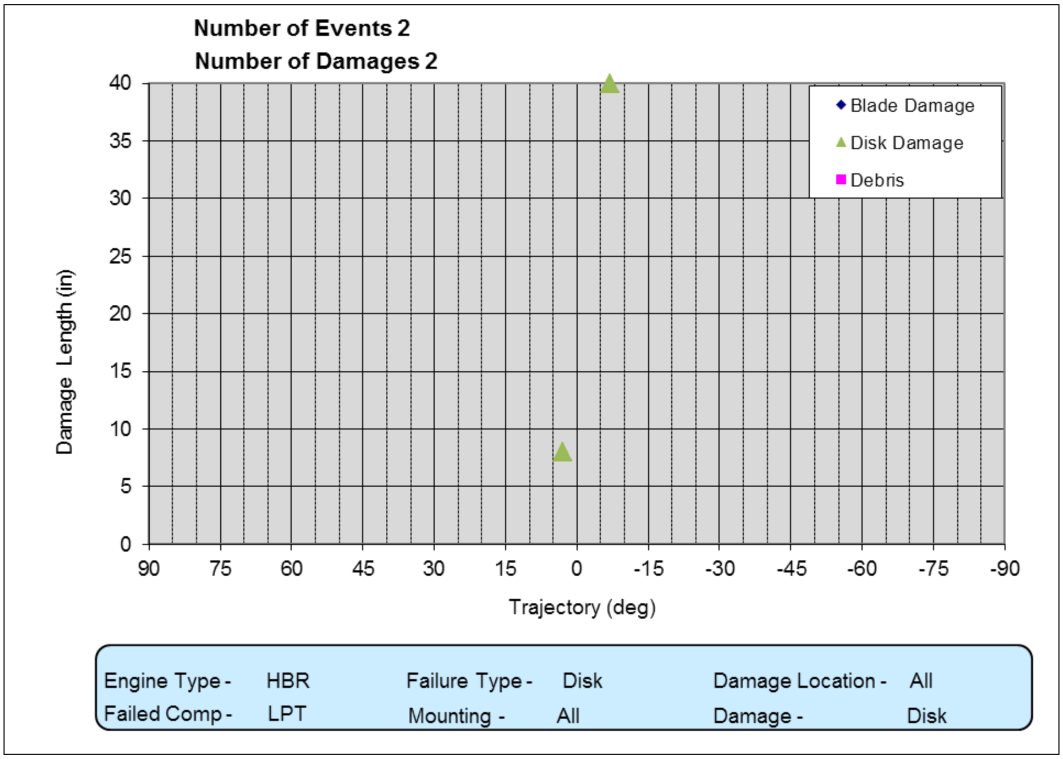


Figure 81. Disk damage, LPT disk event

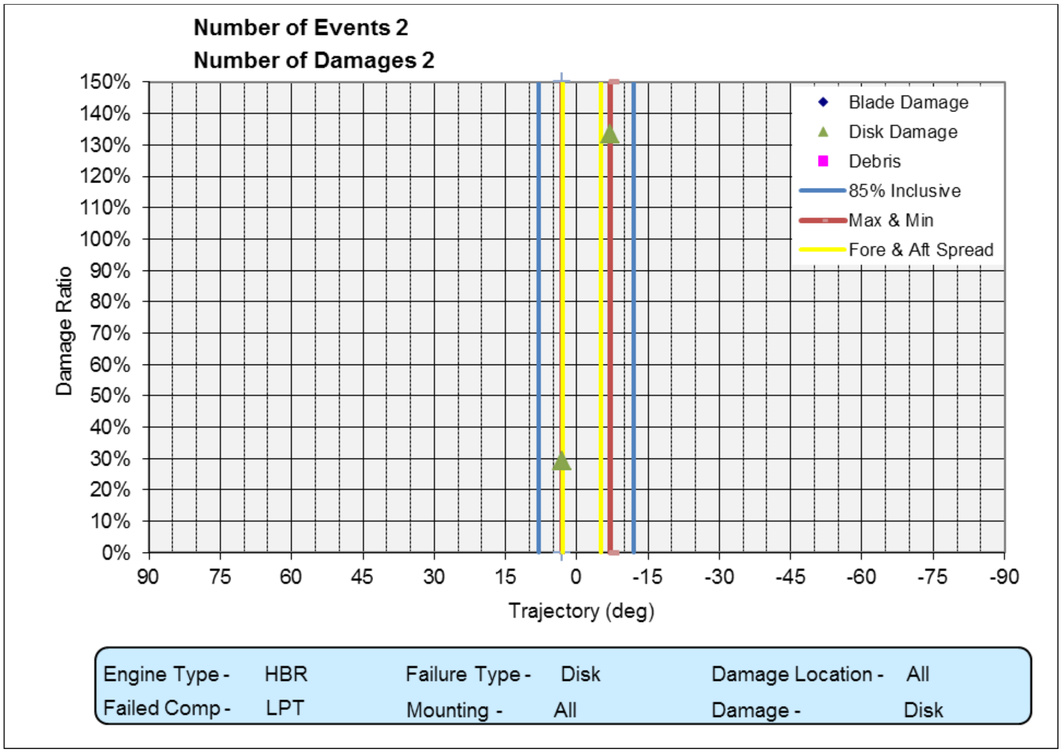


Figure 82. Disk damage ratio, LPT disk event

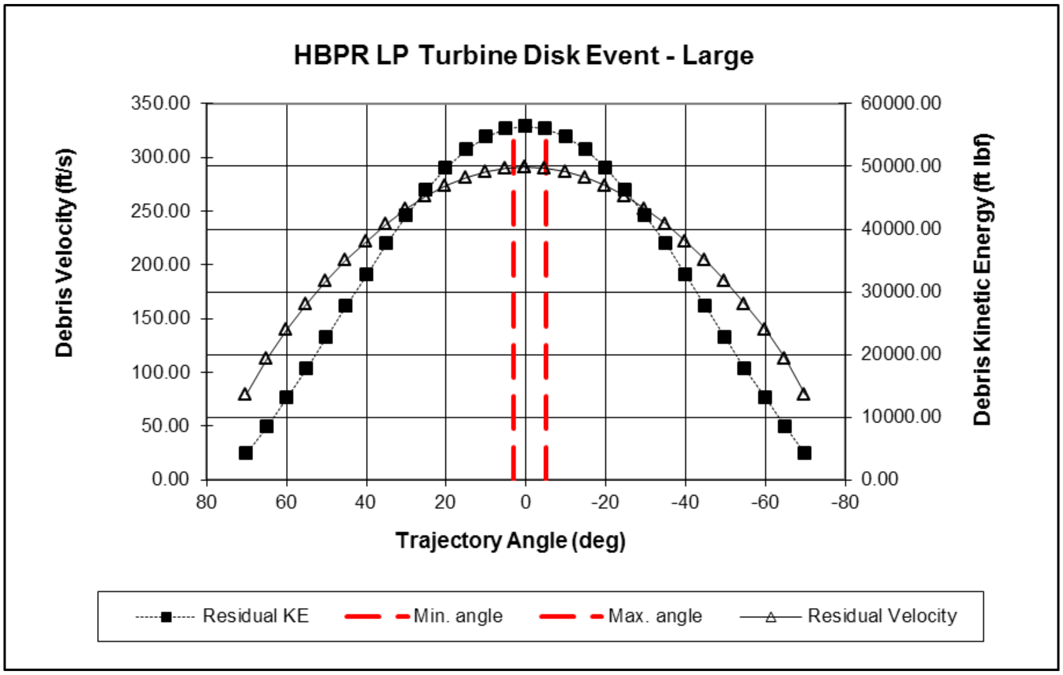


Figure 83. LPT disk velocity and energy

LPT disk characterization from a disk event is shown in table 23.

Table 23. LPT disk characterization, disk event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Disk	1					
Disk		1	90%	42.8 (36%)	0.75 (291)	+3 to –5

4.4.2 Spacer-Rim Event

4.4.2.1 Blade Damage

Aircraft damage recorded in the database is shown in figure 84. The damage ratio is shown in figure 85. Representative turbine blade debris size for characterization is 15% blade length. Of the two spacer-rim events, ten damage locations were recorded. The average number of blade fragments per event is five. The trajectory angles range between +7 degrees and -20 degrees. The peak cowl exit velocity for a 15% blade fragment is 471 feet per second with energy of 350 ft-lbf (figure 86). Aerodynamic effects are shown in figure 87. Required skin thickness to defeat the fragment is shown in figure 88.

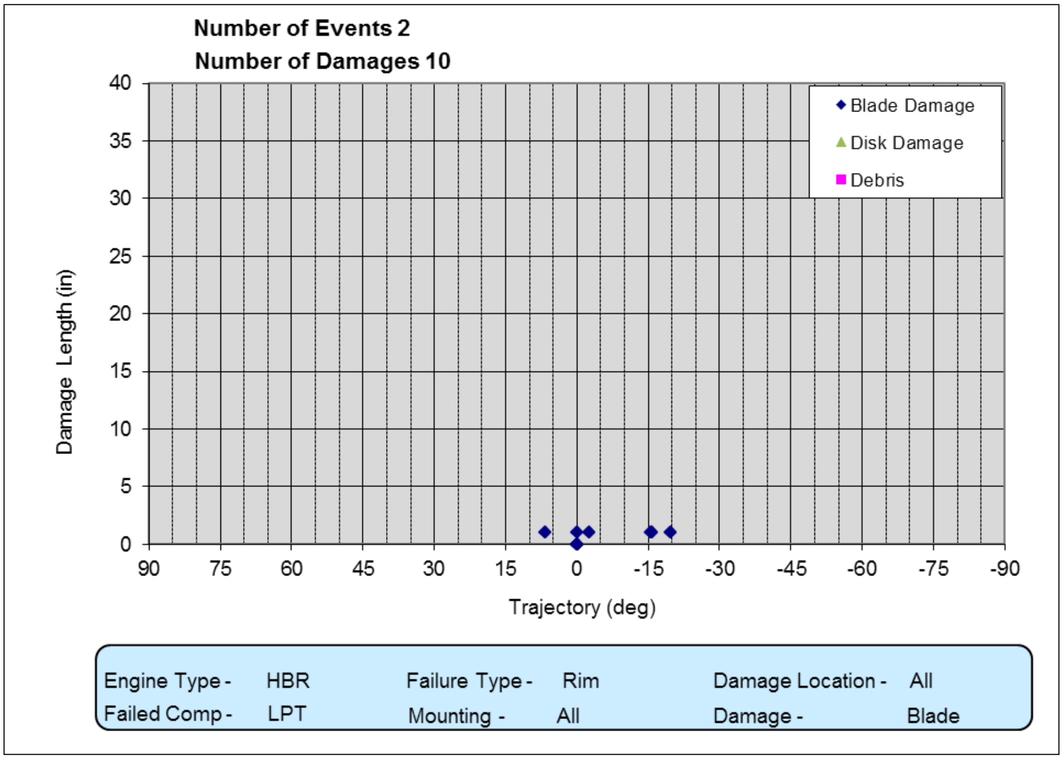


Figure 84. Blade damage, LPT spacer-rim event

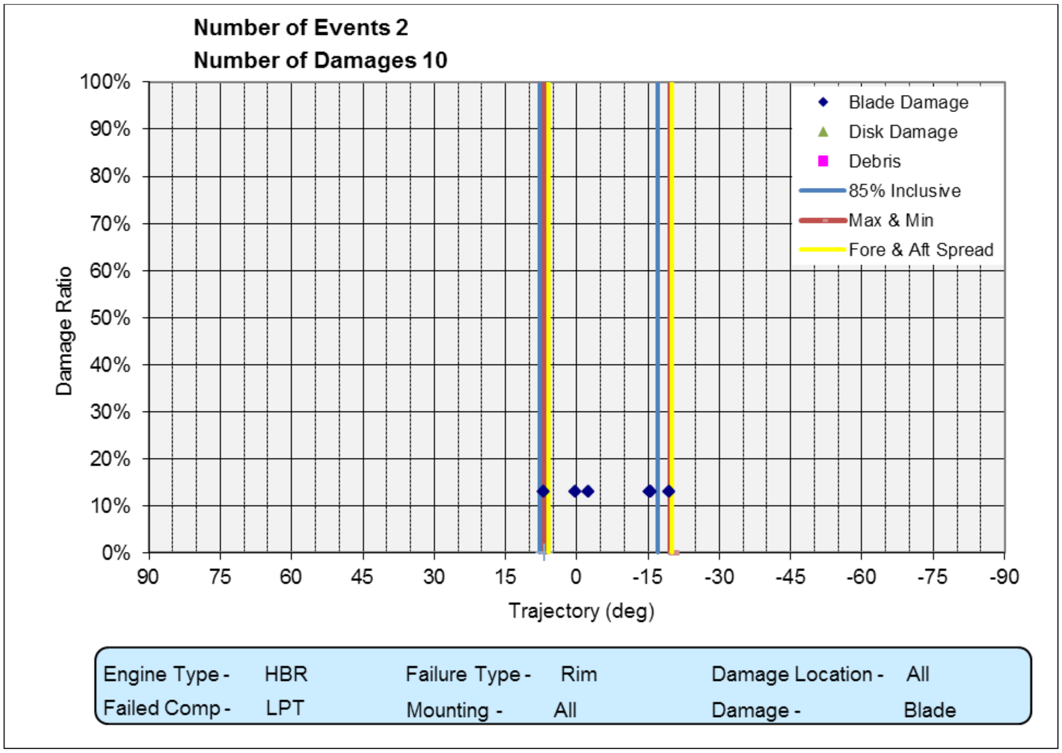


Figure 85. Blade-damage ratio, LPT spacer-rim event

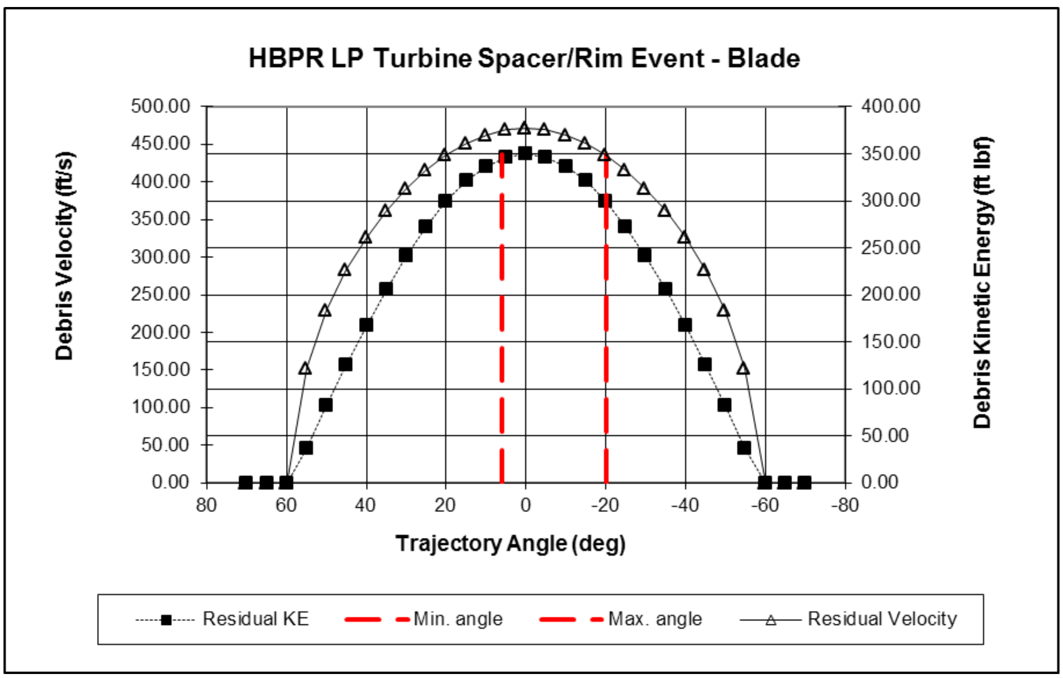


Figure 86. LPT blade velocity and energy, LPT spacer-rim event

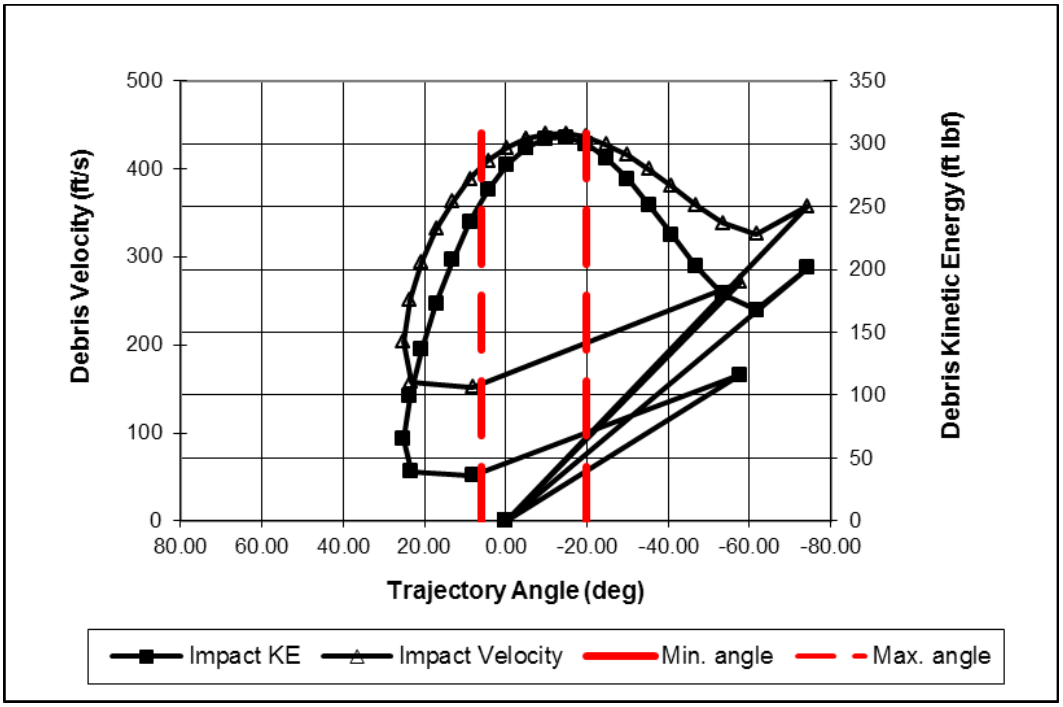


Figure 87. Aerodynamic effects LPT blade, spacer-rim event

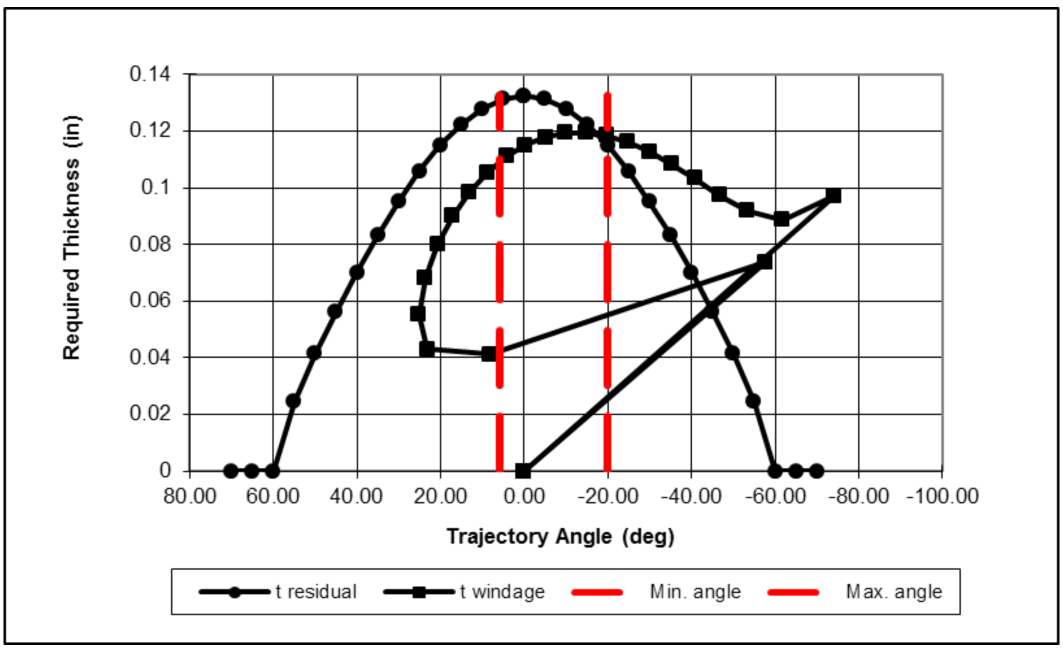


Figure 88. Aluminum thickness required to defeat LPT blade fragment

LPT blade characterization from a rim event is shown in table 24.

Table 24. LPT blade characterization, spacer-rim event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Spacer – Rim Event	2					
Blades		5	15%	0.1 (15%)	0.67 (471)	+7 to -20

4.4.2.2 Spacer-Rim Damage

Aircraft damage recorded in the database is shown in figure 89. The damage ratio is shown in figure 90. The representative turbine spacer-rim debris size for characterization is 20% disk diameter. Of the one spacer-rim event, one damage location was recorded. The average number of disk fragments per event is one. The trajectory angle for the single recorded event is -31 degrees, which, in this case, was a result of a ground impact. For characterization purposes, the fragment size will be captured; however, the trajectory characterization will default to AC 20-128A [5] guidance for an intermediate fragment. The peak cowl exit velocity for a 20% blade fragment is 325 feet per second with energy of 6323 ft-lbf (figure 91).

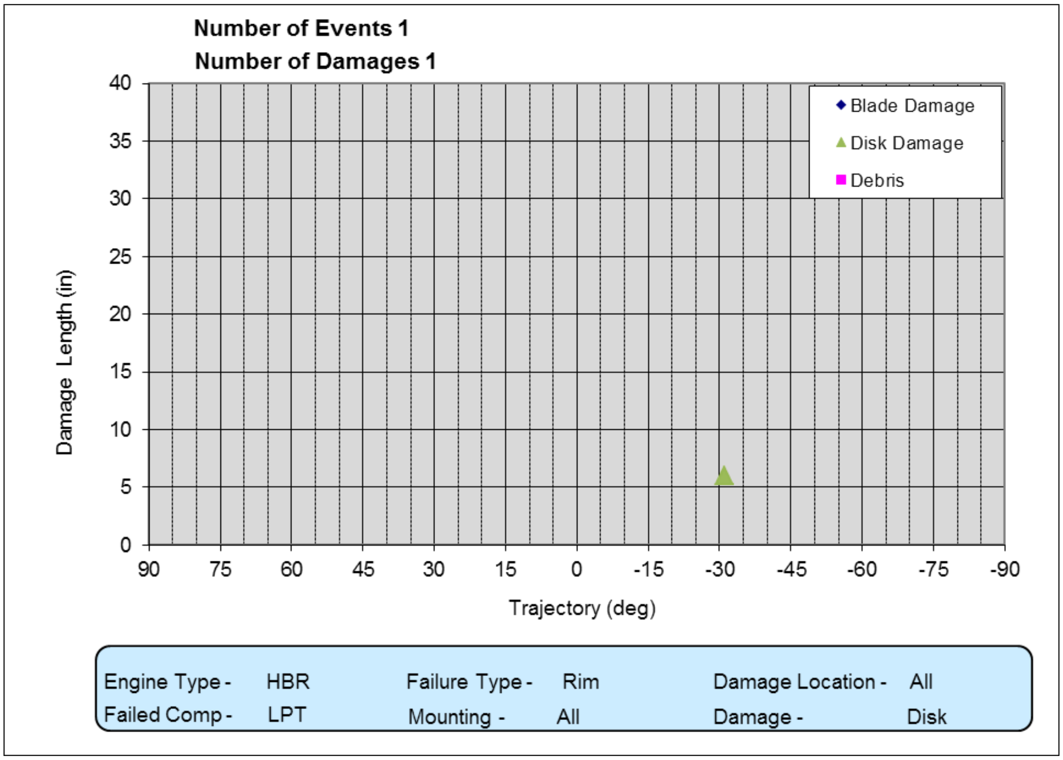


Figure 89. Spacer-rim damage, LPT spacer-rim event

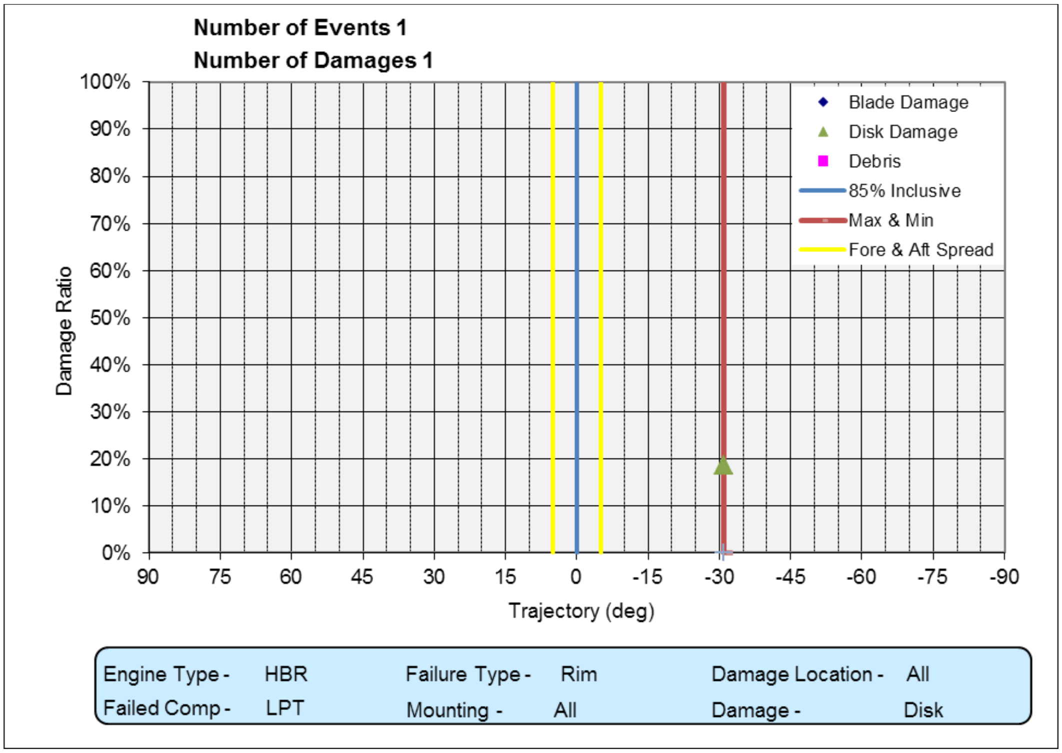


Figure 90. Spacer-rim damage ratio, LPT spacer-rim event

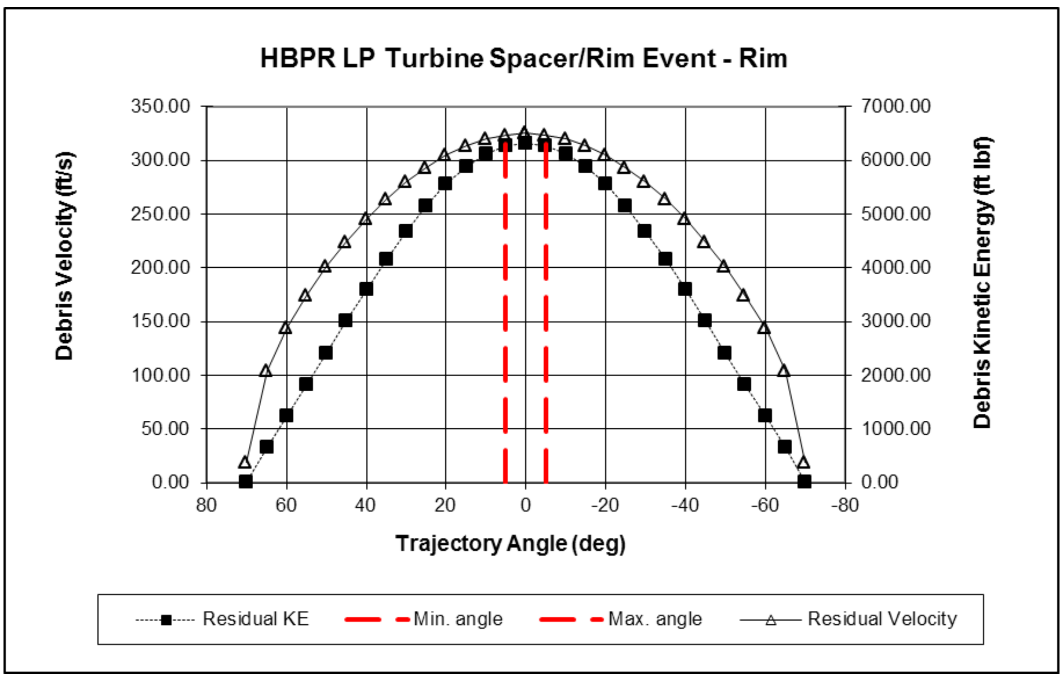


Figure 91. LPT spacer-rim velocity and energy

LPT rim characterization from a spacer-rim event is shown in table 25.

Table 25. LPT rim-spacer—Rim characterization

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Spacer - Rim	1					
Rim		1	20%	11.3 (9%)	0.74 (325)	+5 to –5

4.4.3 LPT Blade Event

LPT blade event data is an event from turbine stages other than last stage, the last stage is covered in 4.4.4. Aircraft damage recorded in the database is shown in figure 92. The damage ratio is shown in figure 93. Representative turbine blade debris size for characterization is 80% of the blade length. One LPT blade failure event generated ten damage locations. The average number of blade fragments per event is ten. The trajectory angle range for this event is +20 degrees to -45 degrees. The peak cowl exit velocity for an 80% blade fragment is 236 feet per second with energy of 470 ft-lbf (figure 94). The aerodynamic effects are shown in figure 95. Again, windage for these lower energy blade fragments can be significant and can account for the large aft trajectories. Required skin thickness to defeat the fragment is shown in figure 96.

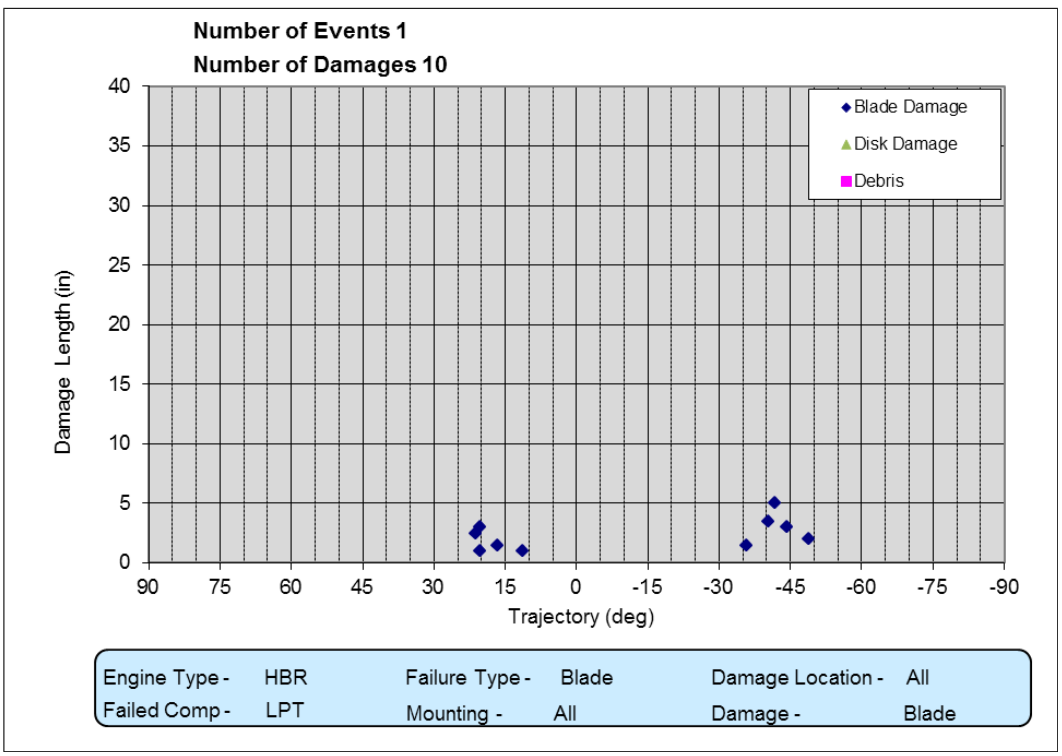


Figure 92. Blade damage, LPT blade event

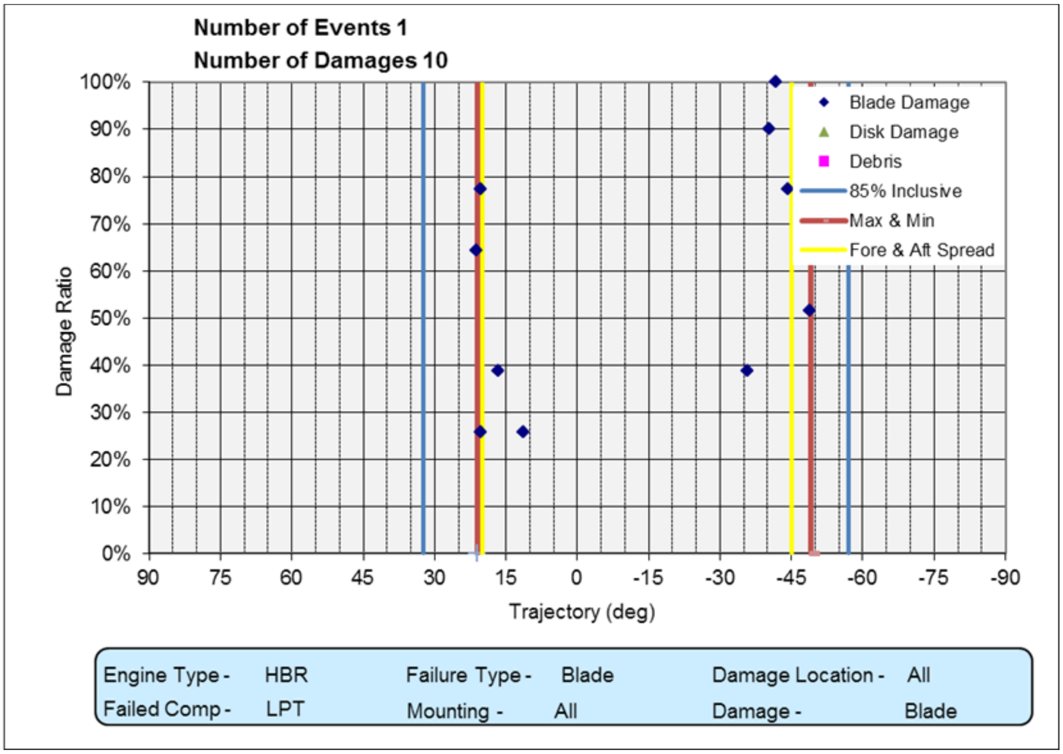


Figure 93. Blade-damage ratio, LPT blade event

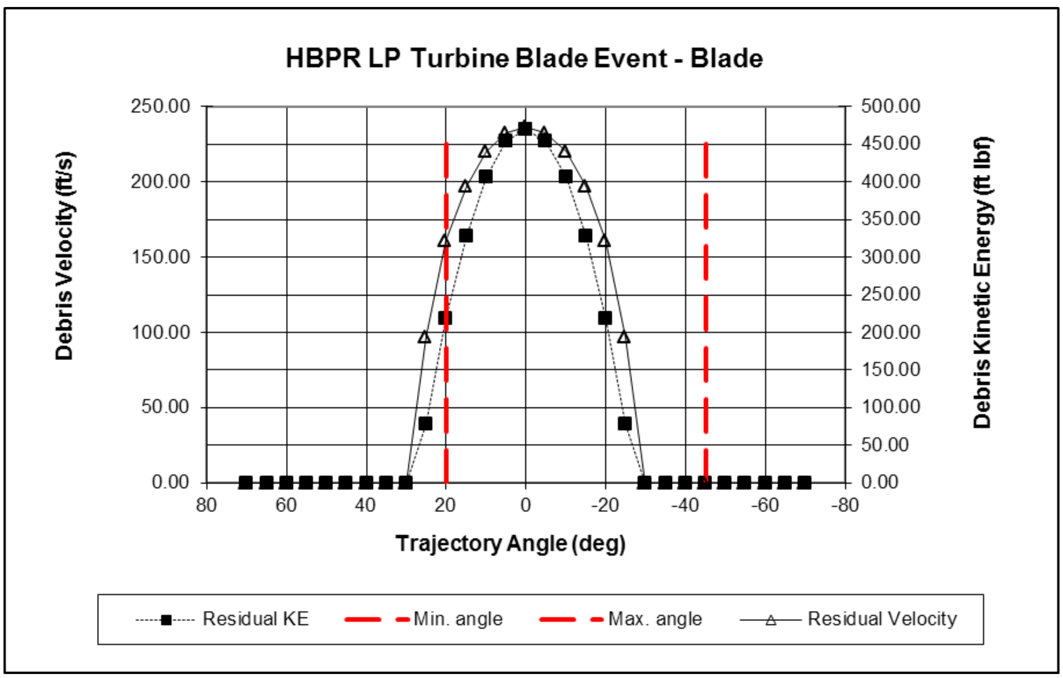


Figure 94. LPT blade velocity and energy, LPT blade event

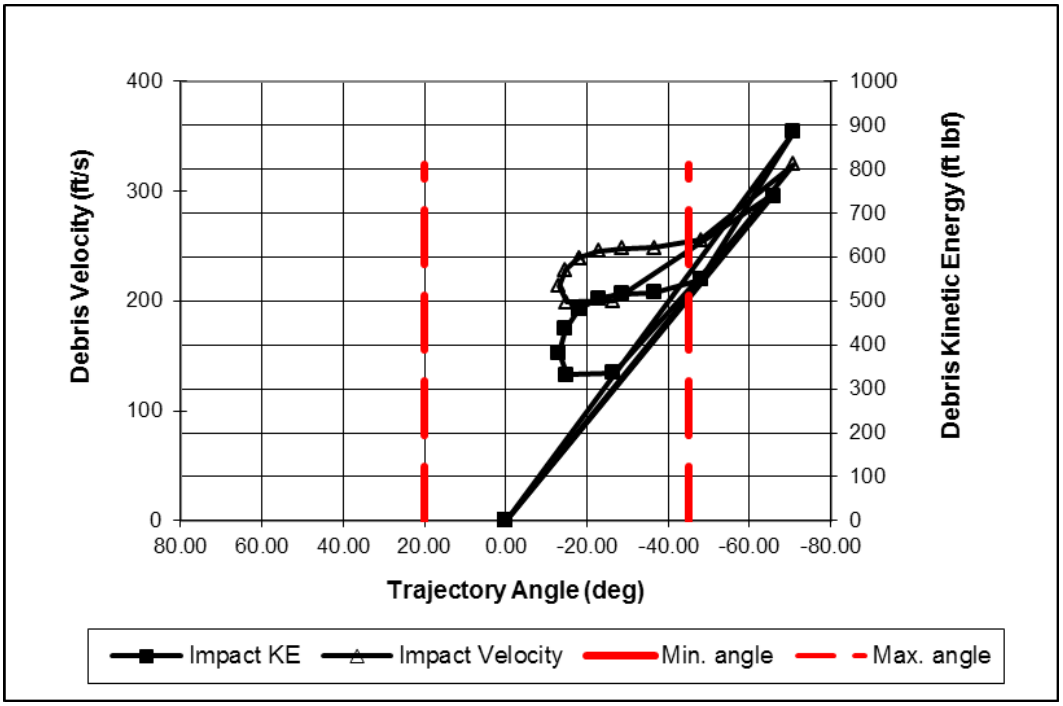


Figure 95. Aerodynamic effects LPT blade, LPT-blade event

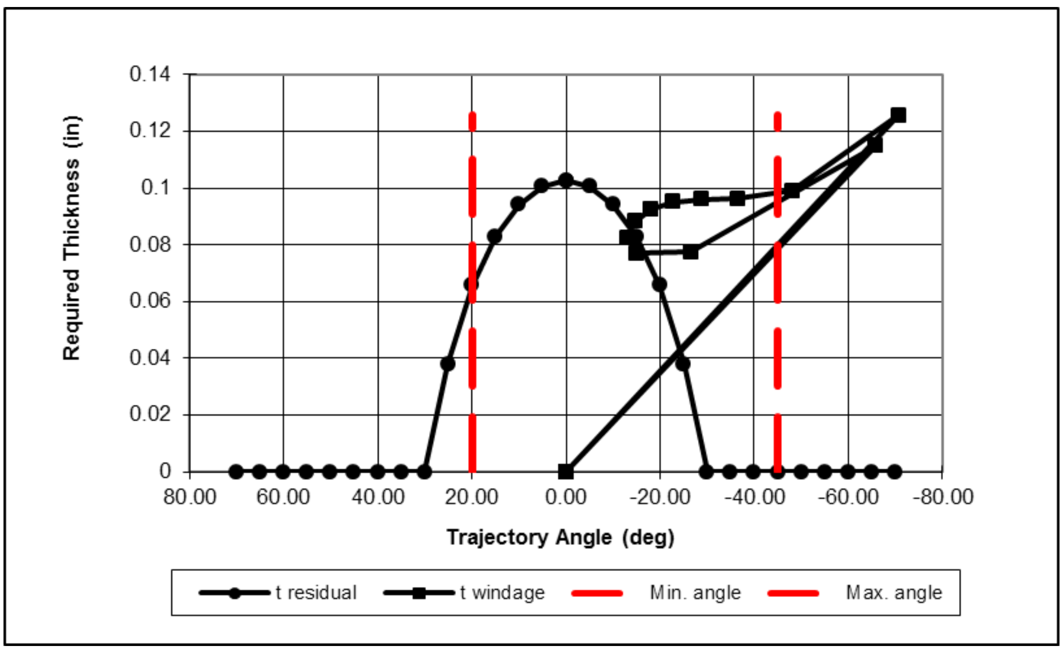


Figure 96. Aluminum thickness required to defeat LPT blade fragment

LPT blade characterization from a blade event is shown in table 26.

Table 26. LPT blade characterization, LPT blade event

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Blade Event	1					
Blade		10	80%	0.54 (80%)	0.38 (236)	+20 to –45

4.4.4 LPT Blade Event, Last Stage

A subset of the LPT blade event data is the LPT last-stage event. Examples of this type of turbine-blade debris are shown in figure 97. These events have high potential for very large aft trajectories because debris exiting the tailpipe can also be included in the damage data. Aircraft damage recorded in the database is shown in figure 98. The damage ratio is shown in figure 99. Representative turbine blade debris size for characterization is 40% blade length. Three LPT blade failure events generated 26 damage locations. The average number of blade fragments per event is nine. The trajectory angle range for this event is +20 to -75 degrees; for characterization purposes, trajectory spread angle is defined as +20 to -60 degrees. Peak cowl exit velocity for a 40% blade fragment is 147 feet per second with energy of 90 ft-lbf (figure 100).

Figure 97. LPT blade fragments

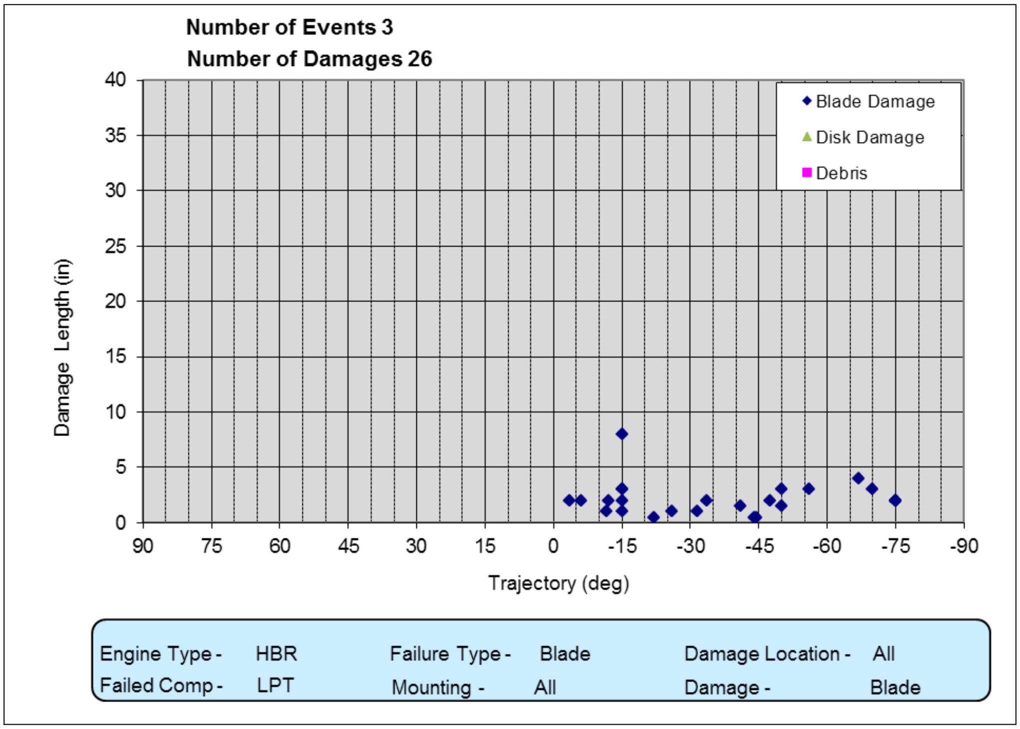


Figure 98. Blade damage, LPT blade event—last stage

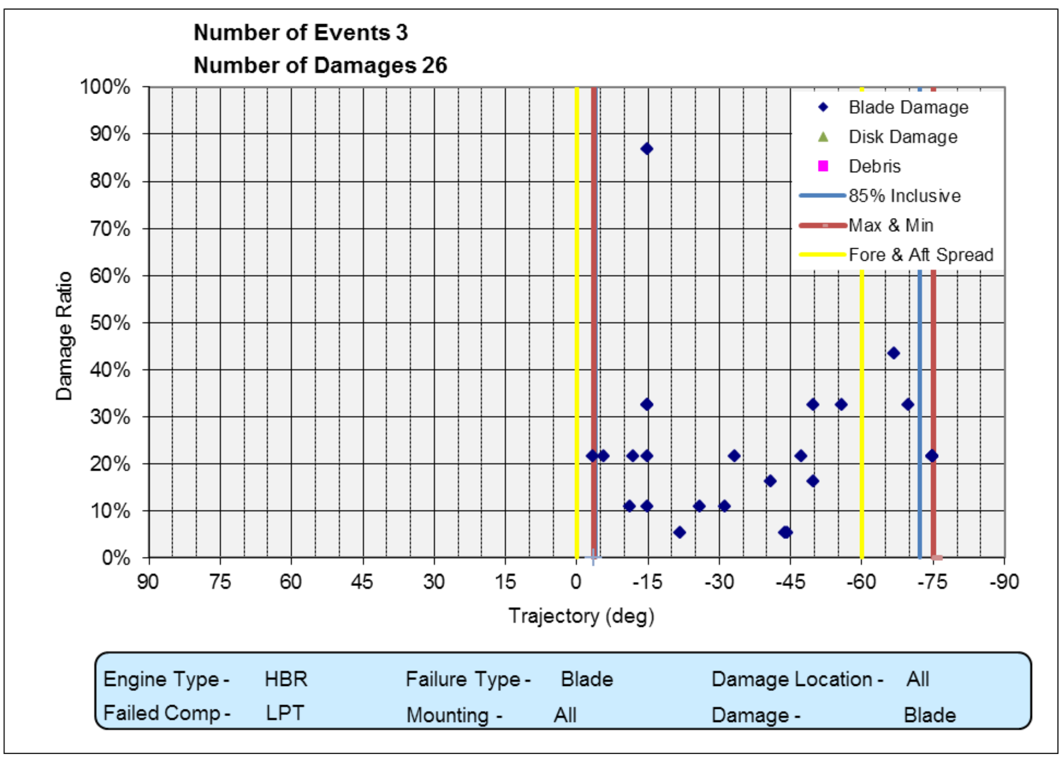


Figure 99. Blade damage ratio, LPT blade event—last stage

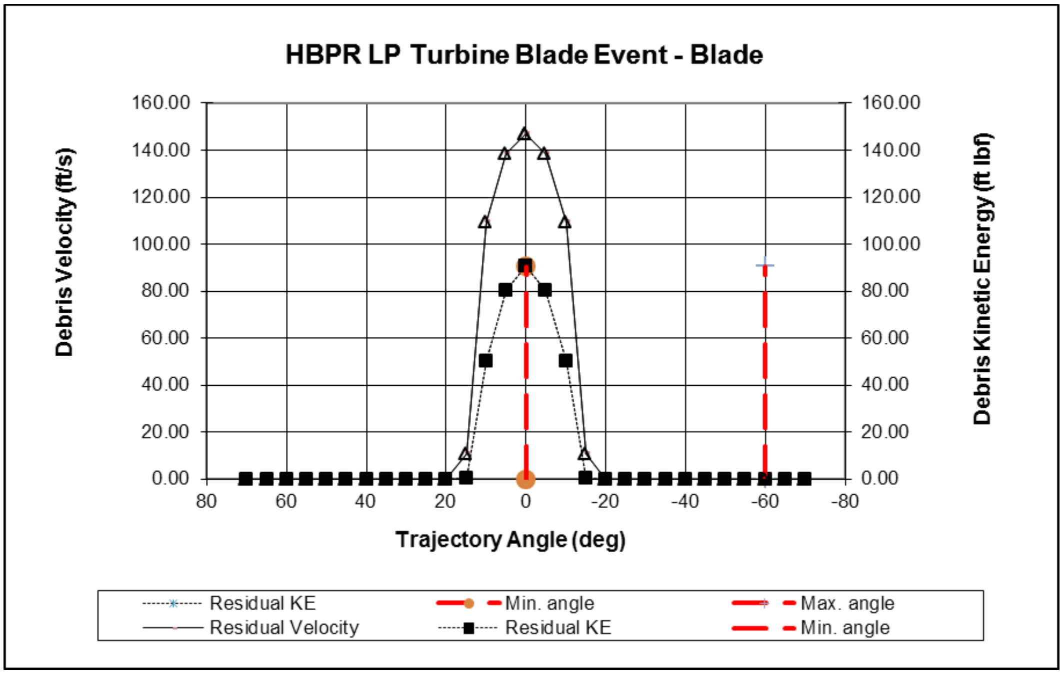


Figure 100. LPT blade velocity and energy, LPT blade event—last stage

LPT blade characterization from a blade event is shown in table 27. Note the exit velocities are the same as LPT Blade event characterization.

Table 27. LPT blade characterization, LPT blade—last stage

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
LPT						
Blade Event Last Stage	3					
Blades		9	40%	0.27 (40%)	0.22 (146)	0 to –60

5. DEBRIS CHARACTERIZATION SUMMARY

The Generic High-Bypass-Ratio Debris Model can now be combined into table 28.

Table 28. Generic HBPR debris fragment model

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
Fan						
Blade Event	12					
Blades		7				
		3	10%	0.33 (3%)	0.67 (954)	+35 to -35
		2	20%	2.0 (16%)	0.67 (925)	+20 to - 45
		1	30%	3.75 (30%)	0.67 (893)	+20 to –30
		1	50%	6.24 (50%)	0.68 (827)	+15 to - 30
		-	70%	-	-	-
		-	100%	-	-	-
Fan (cont)						
Disk Event	5					
Blades		16				
		8	10%	0.33 (3%)	0.70 (1005)	+15 to –22
		4	20%	2.0 (16%)	0.71 (971)	+15 to –22
		1	30%	3.75 (30%)	0.71 (937)	+15 to –22
		2	50%	6.24 (50%)	0.71 (866)	+15 to –22
		1	70%	8.61 (70%)	0.71 (795)	+15 to –22
		1	100%	12.5 (100%)	0.71 (688)	+15 to –22
Disks		3	90%	48.6 (36%)	0.74 (304)	+2 to –3
Compressor						
Disk Event	2					
Blades		5	50%	0.13 (50%)	0.67 (764)	+5 to –25
Disks		1	60%	6.1 (20%)	0.74 (453)	+5 to –5
Rim Event	3					
Blades		5	100%	0.25 (100%)	0.68 (709)	+15 to –3
Rim		2	90%	6.0 (30%)	0.74 (563)	+15 to 0

Table 28. Generic HBPR debris fragment model (continued)

Component	Number of Events	Number of Fragments (Average/ Event)	Normalized Size	Weight lb (% of total)	Velocity Ratio Vr/Vi at 0 deg. Plane (Vel (fps))	Fore to Aft Spread Angle (Degrees)
HP Turbine						
Disk Event	5					
Blades		14	70%	0.21 (70%)	0.69 (968)	+15 to –45
Disk		2	50%	20.8 (17%)	0.75 (602)	+3 to –11
Spacer – Rim Event	3					
Blades		11	85%	0.26 (85%)	0.69 (952)	+15 to –40
Rim		1	50%	8.3 (17%)	0.74 (745)	0 to –12
LP Turbine						
Disk Event	3					
Blades		7	70%	0.47 (70%)	0.69 (436)	+5 to –45
Disk		1	90%	42.8 (36%)	0.75 (291)	+3 to –5
Spacer – Rim Event	2					
Blades		5	15%	0.1 (15%)	0.67 (471)	+7 to –20
Rim		1	20%	11.3 (9%)	0.74 (325)	+5 to –5
Blade Event	1					
Blade		10	80%	0.54 (80%)	0.38 (236)	+20 to –45
Blade Event Last Stage	3					
Blades		9	40%	0.27 (40%)	0.22 (146)	0 to –60

The data in this report are historical and represent the summary of aircraft damaged by fragments. This report has collated damage from uncontained engine debris, specifically holes, in fuselage structure and airplane surfaces that include wing, fuselage, fairings, control surfaces made out of aluminum and composite materials. It does not report the numerous nicks, dings, and scratches caused by fragments that impact surfaces but fail to penetrate. This approach was agreed to during the original ARAC work in the late 1990s because fragments with sufficient energy to penetrate the airplane surfaces were deemed to pose a potential threat to airplane safety.

This update for the high-bypass ratio engines defines a baseline for threat assessment. It is understood that new technology is being used today, especially in the fan section of the engine. Objectively, these lighter weight and sometimes lower speed parts pose less of a threat than their solid metal predecessors. When an analysis is performed using debris models that include the benefits of the new technology, less damage to the aircraft is expected and, therefore, less mitigation is required. The data in this model are based on a limited number of historical events for various sections of the engine. In addition, the configuration and features of stages of the engine may not be representative of the engine type being evaluated. Use of this model should take into consideration the differences in physical features between old and new technology engines. In addition to using the debris model provided in the engine installation manual, the engine manufacturer should be consulted when establishing the engine debris model for the particular engine type.

Additional work will be performed to revise DOT/FAA/AR-04/16 to report use of this debris model with the improved vulnerability capability that has been developed by the FAA Aircraft Catastrophic Failure Prevention Program and FAA Commercial Space, which have made advances in improving the penetration equations for high-obliquity impact.

6. AEROSPACE INDUSTRIES ASSOCIATION REPORT DISCUSSION

In January 2010, the Aerospace Industries Association (AIA) published a report entitled "High Bypass Ratio Turbine Engine Uncontained Rotor Events" [10]. Several findings in the AIA report contradict the data and analysis results attained under this study and deserve discussion. The industry participants in the ARAC group that oversaw the work reported in reference [2] (DOT/FAA/AR-99/11) have long since retired. They provided the data, analysis, and oversight to the NAWC/FAA effort and findings. The intent was to study data-rich events in which a witness shield provided information on the number of fragments that penetrate structure and to document their trajectory to identify the area of the fuselage where critical systems need to be assessed for the rotor burst threat.

6.1 MULTIPLE FRAGMENTS

The threat of uncontained failures with multiple fragments was downplayed by an industry report in 2010. [10]. The report recognized FAA and industry efforts to improve design and inspection of engine rotating components that have been successful in reducing the number of uncontained failures. However, uncontained failures still occur and when they do, the threat to the aircraft is a combination of large and small fragments. This was highlighted in the by Airbus A380-842, VH-OQA event [1] in which 20 fragments impacted the aircraft, damaging multiple redundant aircraft systems. The crew was not able to change thrust or terminate fuel flow to the outboard engine. This engine continued to run on the ground after the aircraft landed until the fire crew shut it down with firefighting foam sprayed into the engine inlet. Following are excerpts from the AIA report [10]:

Disk Uncontainment, Small Fragments

> "Most small fragments do not have enough energy to make holes in airplane structure. Of 8700 small fragment impacts, 450 made holes in the airplane. Most small fragments which make holes in the airplane do not have enough residual energy to damage systems or additional structural layers inside the hole. Of 450 small fragment holes, 27 fragments went on to damage systems or structure inside the hole."

> "Analysis of a limited set of large disk fragment trajectories indicates that they were released from the engine at considerably lower speed than their tangential speed immediately prior to burst. Speeds based on trajectories, for this limited set, were less than 30% of pre-burst speeds. Consequently, small fragments may also have much lower speeds than their tangential speed prior to burst."

Blade Uncontainment

> "Most events result in a small number of superficial nicks, dents and holes in aerodynamic surfaces. The release of multiple whole fan blades, or LPT vane/nozzle spinning has resulted in more extensive damage."

The objective of the original ARAC debris characterization effort and this effort was to define the fragment size, weight, velocity, and trajectory that generate holes in aircraft structure and threaten aircraft systems. This information can then be used to conduct safety analyses to assess the protection afforded by aircraft designs. The number of fragments defined to characterize a specific type of event is the average number of holes generated from the defined events. It is not the worst-case event or the least stressing event. As such, it does not include the significant number of low-energy impacts or the high-energy fragments that miss the aircraft in a given event. It is acknowledged that an uncontained event generates many more low-energy fragments that do not pose a threat to the aircraft.

Ideally, a debris model should characterize all uncontained fragments to allow the analysis process to define the level of protection offered by the aircraft structure. It was determined early on that this effort was to characterize the higher energy fragments that generate holes in the aircraft and pose a threat to aircraft systems. Therefore, the numerous generated fragments that do not penetrate aircraft structure and produce gouges were not considered, even though some of these fragments may be higher energy fragments; however, because of impact orientation and obliquity, these fragments did not produce a hole in the aircraft. Consequently, these fragments are not included in the uncontained debris model defined herein.

6.2 FRAGMENT VELOCITY

The AIA report [10] makes several statements about fragment velocities. The AIA report acknowledges that the disk fragments not found may have had more energy than the disk fragments found, many times on the runway. However, if fragments were found on the runway, the reported velocity was assumed to be 0.

> "The likely ballistic velocities V of small fragments in these events, based on the estimated ballistic velocities of larger pieces in section 4.9, are significantly lower than would be calculated from conditions immediately before burst."

AIA assumes based on observation of debris found that small fragment velocities are linked to large fragment centroid velocities.

> "Based on the limited dataset available, it is clear that these large disk fragments departed the engine with much lower velocities than their pre-burst tangential velocity (i.e., the speed based on the distance from engine centerline of the fragment center of gravity and the engine operating rpm for that rotor immediately before failure)."

The fragment energy analysis conducted in the AIA report is based on observations of dings and dents in the aircraft structure, holes in the aircraft, and found debris. The summary of the AIA debris characterization states:

> "Analysis of a limited set of large disk fragment trajectories indicates that they were released from the engine at considerably lower speed than their tangential speed immediately prior to burst. Speeds based on trajectories, for this limited set, were less than 30% of pre-burst speeds. Consequently, small fragments may also have much lower speeds than their tangential speed prior to burst."

The review of data and uncontained event history contained in this report concludes that the many small blade fragments and disk sections exit with significant energy. Many disk fragments have cut a swath through major aircraft structure: wing skins, spars, ribs, frame structure, and damaged internal systems. The speed required to cleanly cut through wing skins and spars, then fly off to undetermined distances, is well above 30% of the pre-burst speed.

The result of a high-bypass ratio fan-blade test conducted at NAWCWD, Weapons Survivability Lab, was captured on high-speed video. The test is summarized in section 6.2 and clearly shows several fan blade fragments exiting the inlet cowling at a very high velocity, much greater than 30% of the pre-burst/release speed. It also shows a significant number of high-velocity fragments, and a second wave of lower energy fragments.

7. CASE STUDIES

7.1 FAN DISK HUB TRAJECTORY ANALYSIS

An uncontained fan disk event resulted in a 1/3 disk section (figure 101) exiting the engine containment case and cowling passing just over the fuselage and landing in a field approximately 2400 ft abeam of the aircraft. The 1/3 disk hub trajectory analysis was conducted to verify the initial fragment exit conditions. This analysis was based on the event data to attain initial velocity, mass, trajectory angle, fragment presented area, and drag coefficient, the analysis was matched the distance traveled, and the trajectory was understood. In this case, it was assessed that the disk segment did not impact the aircraft fuselage but exited the engine case at an angle of approximately

40 degrees. Disk velocity was determined based on the radius of the disk segment centroid and engine fan speed (7600 RPM) at the time of the event. Initial velocity based on disk inner and outer hub radius was 420 fps. The fan-cowl exit velocity was calculated to be 354 fps using a 0.2″ Ti containment case and 0.04″ cowl skin (figure 102). The fragment trajectory exit angle was estimated to be 40 degrees. The fly-out distance calculated for these conditions is 2502 ft (figure 103).

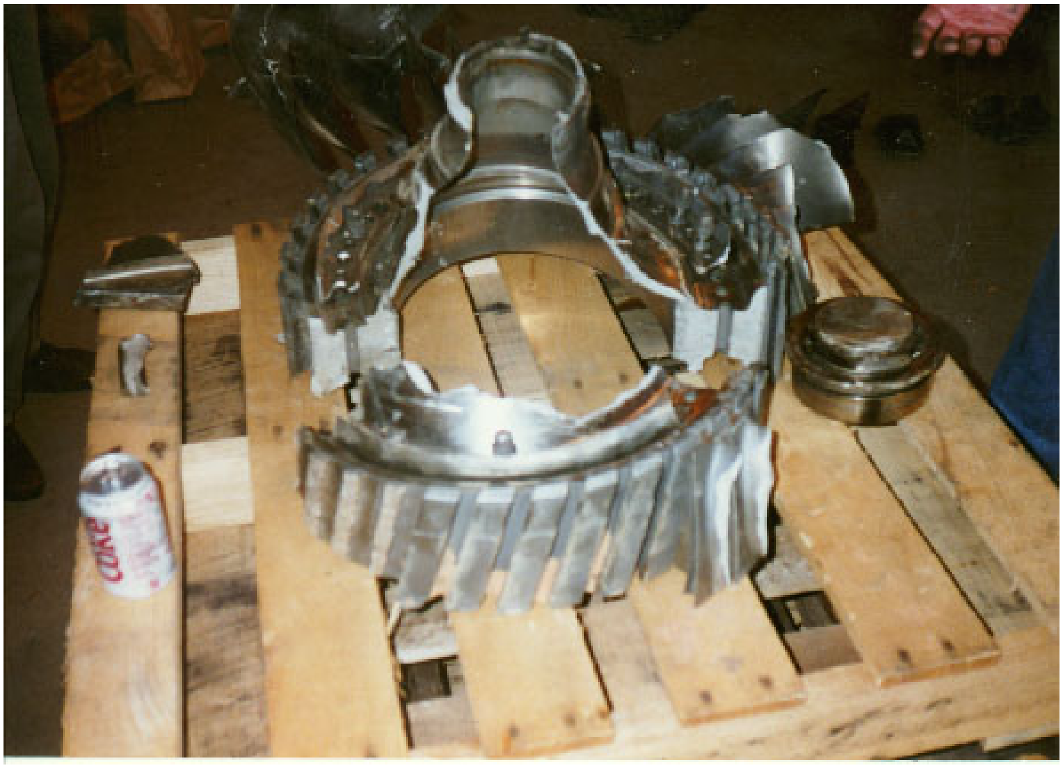


Figure 101. Uncontained disk segments

INPUTS

Fragment					Frag Obliquity	Frag Orientation	Material*
			No. of Plates	2			
Width	4.5	in	plate thickness 1	0.2000 in	0	45	2
Height	20	in	plate thickness 2	0.0400 in	0	45	1
Thickness	6	in	plate thickness 3	0.0100 in	0	45	1
Weight	41	lbf	plate thickness 4	0.0650 in	0	45	1
Release Vel.	421	fps	plate thickness 5	0.0300 in	0	45	1
			plate thickness 6	0.0300 in	0	45	1
			plate thickness 7	0.0000 in	0	0	1
			plate thickness 8	0.0000 in	0	0	1
			plate thickness 9	0.0000 in	0	0	1
			plate thickness 10	0.0000 in	0	0	1

Plate Material
1-2024-T351 Al
2-Titanium 6Al-4V
3-Inconel 625LCF
4-Composite*
5-Stainless Steel*

RUN MAIN

* See Materials

Plate	V50 (ft/s)	Vr (ft/s)	Residual Energy (ft lbf)	tr (in)	KE ratio	Delta Velocity (ft/s)	Presented Area Ap (sq. in.)	Perimeter L (in)
1	174.8	358.1	81693.2	0.482	0.72	62.9	82.7315	45.7696
2	19.6	354.7	80148.1	0.731	0.71	3.4	82.73	45.77

Figure 102. Disk fragment penetration results

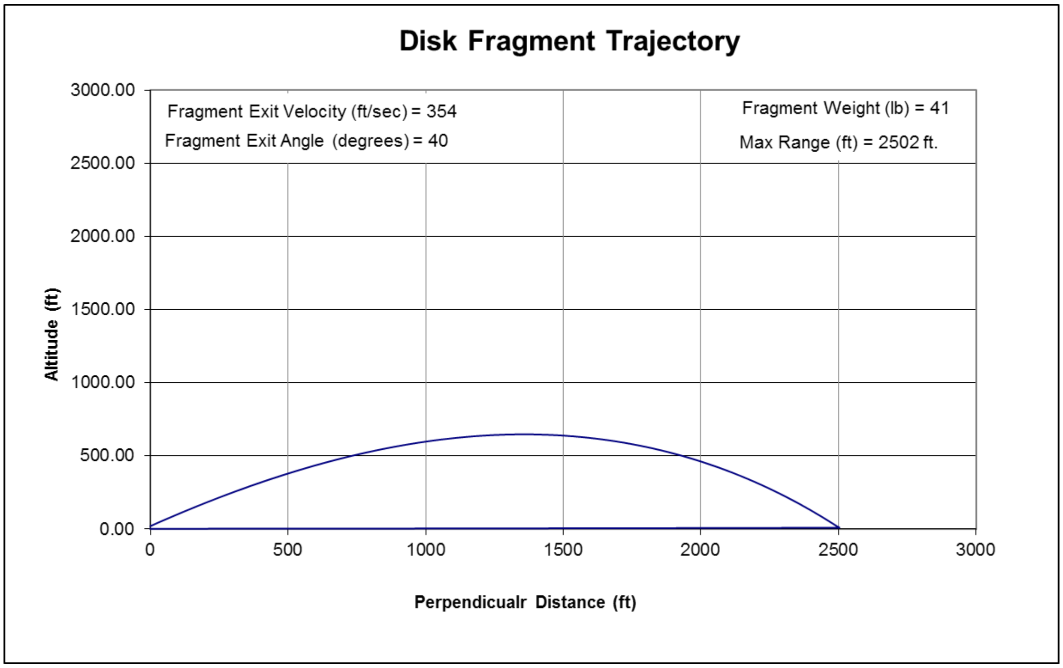


Figure 103. 1/3 disk fly-out trajectory results

7.2 FAN-BLADE UNCONTAINMENT TEST

A large engine test was conducted at the Naval Air Warfare Center, Weapons Division to address fan uncontainment and the engine fragment threat to aircraft from a high-bypass ratio engine. During this test, several fan blades were severed with the engine operating at takeoff power. High-speed video of the event show released fragments moved forward of the fan containment structure. Blade fragments can be seen penetrating the inlet inner barrel exiting through the inlet and cowl structure 6 msec after the event was initiated. Approximately 20 significant-sized fragments can be seen exiting at a high velocity. Six of these fragments were tracked, and velocity estimates are provided below. It was evident that the fragments exiting at high velocity were a fairly localized tangent of the release point. The circumferential location of the release point resulted in the fragment tangent velocity vectors projecting away from the aircraft so none of these high-velocity fragments impacted aircraft structure.

High-speed video was also used to estimate fragment exit velocities (figure 104). This provides a reasonable estimate of fragment velocities during an uncontained fan-blade event (figure 105).

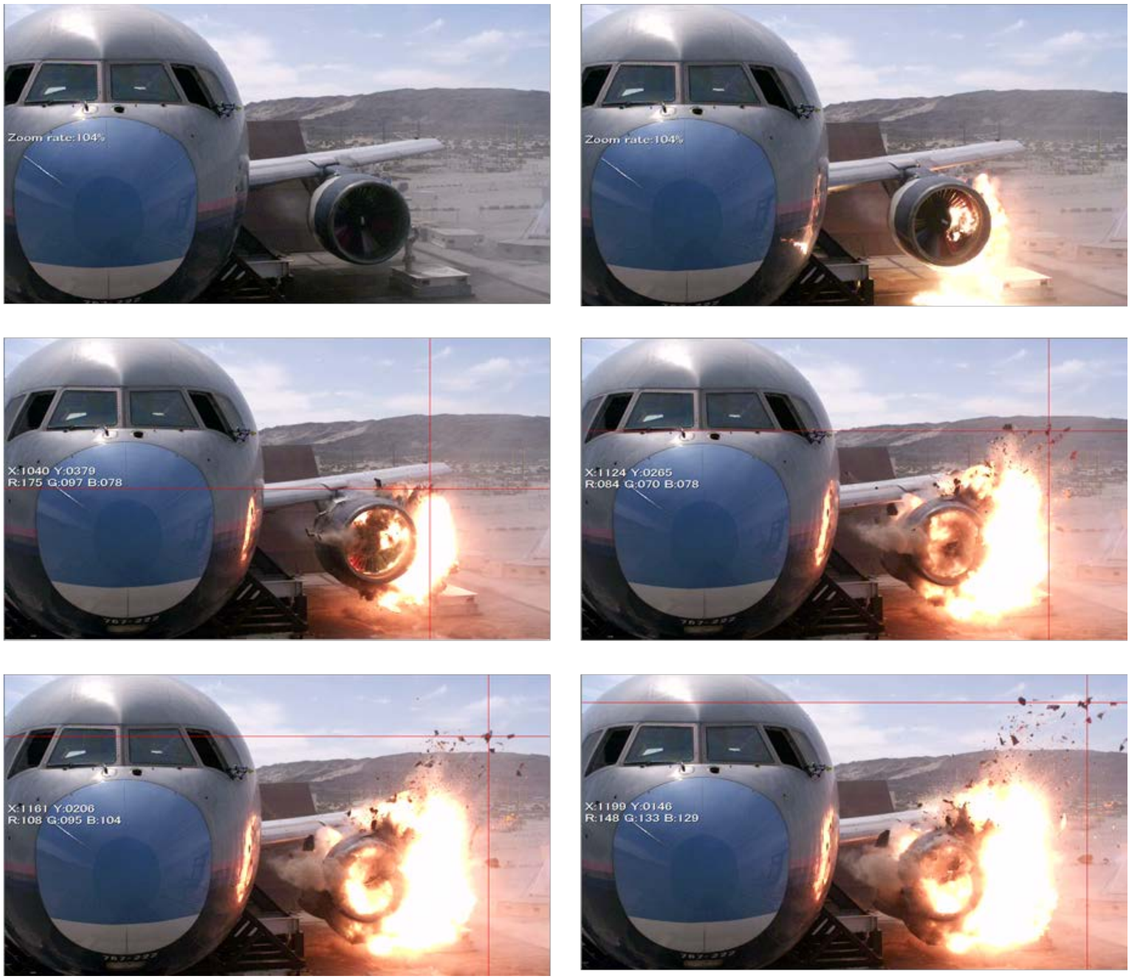


Figure 104. Event high-speed video images

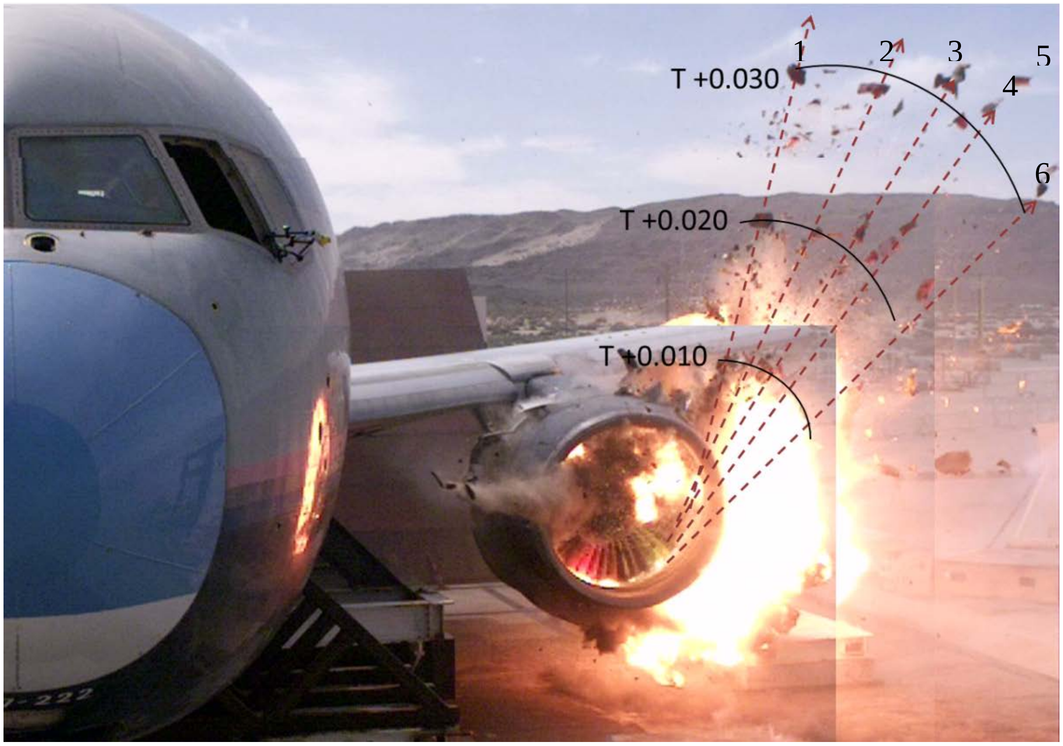


Figure 105. Event time overlay tracking high velocity fragments (Debris ID #, T in seconds)

Fragment-velocity analysis for six of the fragments is shown in table 29. Estimated velocities range from 717 to 1066 fps. Comparing these velocities to the fan-blade-event fragment velocities in the debris model provides a good correlation supporting the methodology for helical fan blade failure events as discussed in section 3.1.2 of this report. Fan-blade failure characterization estimated exit velocities between 827 to 954 fps depending on the fragment size. The size of the high-velocity fragments appears consistent with the fan blade fragment model provided in this report, ranging 10% to 50% in blade length. It can also be noted that in the last image of figure 104, there are a number of additional blade fragments traveling at a slightly slower velocity than the six identified and tracked.

The fan containment structure was completely intact. Post-test inspection indicated that the fan blade fragments exited the inlet cowling in a helical trajectory (figure 106). Figure 107 provides a sample of the fragment size.

Table 29. Fragment Velocity Analysis

Debris ID	Distance (in.)	Velocity (f/s)
1	172.09	717.0
2	180.59	752.4
3	206.26	859.4
4	198.48	827.0
5	255.96	1066.5
6	193.06	804.4

Edgertronic Camera Parameters
Frames per second = 1000
Frames = 20
Time (s) = 0.02

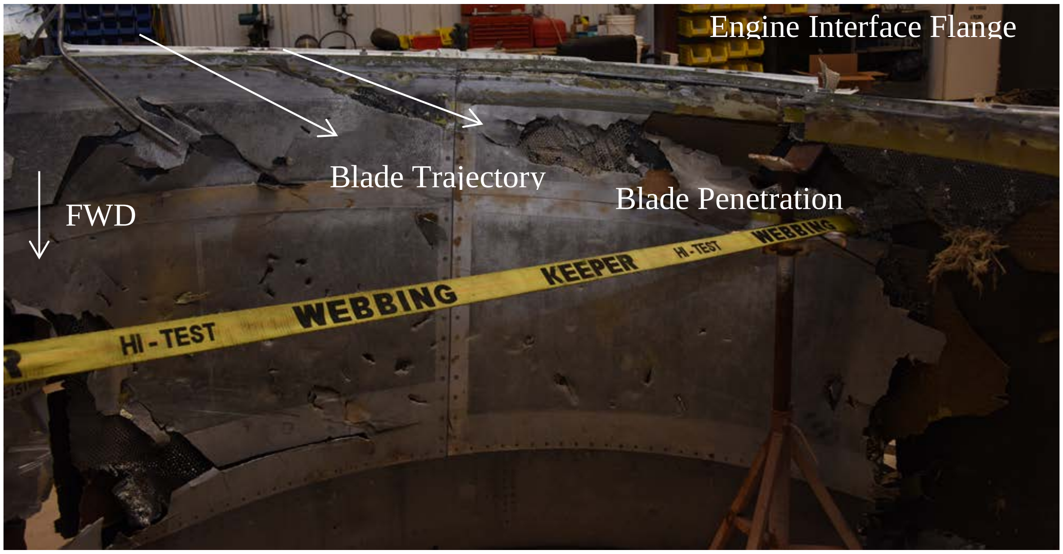


Figure 106. Helical failure trajectory, inlet inner barrel

Figure 107. Fan blade fragments from blade-separation event

8. CONCLUSIONS

This analysis was conducted to assess in-service events and define the potential threat of multiple fragments to aircraft from uncontained engine debris fragments. The focus of this effort was on those fragments with sufficient energy to create holes in aircraft. It did not attempt to address all fragments generated from an uncontained event and those lower energy fragments that cause nicks and dents in aircraft structure. By definition, this study addresses the potential threat to aircraft from higher energy fragments and provides a reasonable representation of the debris characteristics based on the types of failures described herein.

1. A multi-fragment debris model was generated defining the debris size, weight, exit velocity, and trajectory that can be used to update Advisory Circular (AC) 20-128A.
2. The size and trajectory of uncontained fragments with sufficient energy to penetrate aircraft skins are in many cases outside the bounds of AC 20-128A. These impacts, documented herein, should be accounted for in aircraft hazard assessments. *The information provided in this report supports the Australian Transport Safety Bureau recommendation to include this information into advisory material*.
3. Event data show that uncontained engine failures generate multiple fragments, many with sufficient energy to damage aircraft structure and systems.
4. Many blade fragment energy levels are low enough that aircraft skins, inherent airplane features, or a small amount of shielding would provide protection to flight-critical components.

5. High-energy fragment release is directional. Not every event results in the high-energy fragments exiting the engine toward the aircraft, so not all events result in the same number of aircraft damages. This conclusion is supported by comparison of debris impact from a number of events. Although ricochet impacts are not included in the database, there are many examples of high-energy fragments impacting the ground/runway, then ricocheting up into the aircraft. In 2006, a ricochet impacted a wing access panel that was not impact resistant because it was outside the current AC 20-128A zones. Other events like the 1/3 disk hub described in section 7.1 documented fragment trajectories missing the aircraft and debris being found a considerable distance off the runway. High-speed movies documenting the uncontained fan-blade failure event show a small circumferential region of high-energy fragment trajectories exiting the inlet cowling. This is an important consideration when defining the number of fragments per event. In this analysis for each component failure mode, an average was taken across the events regardless of the likely release point and its orientation to the aircraft. This resulted in 2 to 3 times fewer fragments per event than what would be predicted based on data from the worst-case events. A worst-case analysis should consider a subset of the total and use an average of those cases that were above the mean.
6. Release velocities of disk and blade fragments are significant. The analysis provides a reasonable representation of the high-energy fragment in terms of size and velocity and is supported by the uncontained engine test conducted at China Lake. Fragment exit velocities derived from the fan-blade test provided good correlation with the fan-blade exit velocities analysis.

9. RECOMMENDATIONS

1. Update AC 20-128A to use this revised fragment model and debris impact zone to assess multiple fragment debris hazards resulting in loss of redundancy following an uncontained engine failure.
2. Revise DOT/FAA/AR-04/16 [11] to document the performance of the latest revision and, if successful, propose revisions to Title 14 Code of Federal Regulations 25.903 (d)(1) and supporting advisory material.
3. Analysis of these events points to the need for a better evaluation of the protection from smaller debris that is known to accompany uncontained failures and is documented here.

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APPENDIX A—BOEING RELEASABLE UNCONTAINED ENGINE REPORT

BOEING

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UNCONTAINED ENGINE DEBRIS TRAJECTORY STUDY

BCAG Propulsion Research

by Dennis Tilzey

September 1995

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

FORWARD

Improving the level of flight safety of commercial aircraft is a continuous process within the aircraft industry. The propulsion community has been developing an understanding of uncontained turbine engine disintegration events with a view to improving flight safety for many years. Regulations have been developed by government agencies to address the issues relevant to this type of event. The aircraft industry has adopted practices which are in agreement with these regulations.

Recent uncontained engine disintegration events which appear to manifest behavior inconsistent with these regulations and practices for improved flight safety underscore the need to continually update the understanding of these events. The inconsistencies in the historical data coupled with the desire to mitigate aircraft hazards due to uncontained engine disintegration events have provoked the aircraft industry to evaluate present regulatory standards and industry practices.

In this vein an effort has been made to develop a systematic approach to uncontained engine disintegration events. A task force was formed with representation from airframers, engine manufacturers, and regulatory agencies. The committee has met regularly over an extended time period. The problem addressed by the committee has necessitated the development of a database as a valuable tool for analysis as well as a statistical analysis of current data.

The Boeing Company, through the Propulsion Safety Advocate, has expended considerable resources on the study of this information. The Boeing effort has resulted in the collection and analysis of a significant quantity of data. This report is a synopsis of the collection and analysis performed by the BCAG Propulsion Research organization.

Conclusions have been drawn from the available data as analyzed in this study, and recommendations for airframe system separation criteria and hazard mitigation on future Boeing aircraft have been made.

The task which has been undertaken for this study is an on–going effort. The Boeing Propulsion Uncontained Engine Debris database will be updated as new information becomes available. Additional information is available, obtainable by specific request to the Boeing Propulsion Safety Advocate.

Additionally, a proprietary version of this document exists, numbered D6–57019. The proprietary version of the document resides with the Boeing Propulsion Safety Advocate in the BCAG Propulsion Research organization, and may be obtained with permission of the Boeing Propulsion Safety Advocate.

EXPLANATIONS AND CONVENTIONS

- All data has been presented in generic form. Information which is unnecessary for the purposes of this document has been removed from the printed records. This proprietary data exists in the Boeing Propulsion Safety Advocate's database, with all identification retained.

- All references to particular events and holes or fragments are based on the standardized information found in Appendix A. The format [(event #, hole #)] or [(event #, fragment #)] is used regularly to note a specific penetration or fragment in a specific event. This format in all cases refers to the data as contained in Appendix A for that particular event and penetration.

- By convention, in all cases where trajectory angles are noted, positive angles (+) denote trajectories *forward* of the plane of rotation while negative angles (−) denote trajectories *aft* of the plane of rotation.

- All holes known to be caused by fragments which were ejected forward out of the inlet or aft through the engine exhaust nozzle have been intentionally excluded from the analysis. These penetrations are by definition <u>not</u> caused by uncontained fragments (See section 2.0, Key Words / Definitions). Due to uncertainty, however, it is probable that some data included in this study *may* be a result of holes caused by fragments which were ejected forward out of the inlet or aft through the engine exhaust nozzle.

- The dimensions of holes given in Appendix A and used in the plots are as much as possible actual measured sizes, rounded to the nearest $^1/_2$ inch. However, in some cases the available information did not specify the exact size of the hole. This is particularly true for many of the smaller holes, especially in events where the end result of the event was not substantial damage or catastrophe. Available photographic or pictorial evidence from these was projected onto planform drawings of the aircraft where possible and relatively accurate hole sizes were obtained using the scales on the drawings. A small number of hole sizes were estimated from verbal or written descriptions.

- This report is not intended to convey the message that some aircraft types, certain engine types, specific airlines, etc., are more prone to uncontained events than others. Where a significant amount of data exists which might yield this impression, it is important to note that it is simply a consequence of the availability and reliability of data for that particular airplane type/engine model/airline/etc. Limited information has been collected. Until the database is more complete it is not valid to make these types of comparisons.

- The figures in the report are duplicated in Appendix C. All data in Appendix C is identical to data in the report, but some formats have been altered to provide projection−ready prints.

SECTION 1

INTRODUCTION

1.0 INTRODUCTION

Uncontained engine failures are one of the top causes for propulsion system related jet aircraft accidents. The uncontained engine failure related Sioux City DC10 accident in 1989 prompted a new investigation into the nature of such accidents. The objective was to determine whether there were as yet unrecognized opportunities to further minimize the potential for uncontained engine related accidents.

Airframe manufacturers are responsible by regulation, FAR/JAR 25.903(d)(1) and related advisory material, to minimize the hazard to continued safe flight and landing from uncontained engine failures. The then–current regulatory material was based on a pre–1977 characterization of uncontained engine fragment trajectory experience from one engine manufacturer. The advisory material stressed mitigation from damage caused by a single large disk fragment. However, it was clear from the National Transportation Safety Board (NTSB) record that the critical damage in the case of the Sioux City accident had been caused by one of the large number of smaller fragments and not by the two large disk fragments themselves. This generated the focus for this research activity, centered on the following problem statements:

> Is the current advisory material correct or do more recent events suggest that guidance material should be improved?
>
> Is there evidence that some of the uncontained engine failure related accidents were caused by the multiple smaller fragments not definitively addressed in current advisory material?
>
> Is there an opportunity to enhance airplane design to further minimize the non–contained engine related hazard?

This report documents the results of the research directed at answering these questions.

1.1 SCOPE

The records related to uncontained engine failure related events do not always contain the information necessary to answer the needs of this study. Uncontained engine events where no damage to the aircraft occurred were of no value. Similarly, uncontained engine events where the aircraft damage consisted only of dents and scratches were of no direct value (no hazard), but do suggest that current aircraft structure is in many cases providing adequate protection. The study focused on events where there were damage sites (tears and penetrations) in the aircraft. The event data were researched from accident investigation files, covering the time period 1961 to the present. The majority of the events were obtained from Boeing files. However, available records were also provided by McDonnell Douglas and Airbus Industrie, and assistance in interpretation was provided by the three major engine manufacturers.

Appendix A of this report provides the generic synthesized data sheets for each event considered in this study. The data sheets for all events where there was sufficient documentation to aid in answering one or more of the problem statements set forth above are included.

1.2 APPROACH

The approach for this study was to review the historical records (every piece of paper/photograph/drawing/etc.) related to uncontained engine failure related events.

The first task was to collect (copy/document) all relevant data and enter the data into an appropriate form. The completed forms were shared with the appropriate engine manufacturer and the engine manufacturer's data/information was added. Where disagreements were found special effort was undertaken to resolve those differences. The refined data was entered into a computer data base for further analysis.

The process utilized aircraft drawings or computerized (CATIA) aircraft reference systems and involved calculation of trajectory angles and estimation of hole sizes based on recorded data or by knowledge of dimensions of another aspect in the photograph. The straight line trajectory angles for the engine release location to the damage location was computed. The penetration/tear data was utilized to develop refined system separation separation criteria.

The computerized penetration/tear data was further analyzed with respect to the number of damage sites per event and by engine class (high bypass and low bypass). The maximum damage dimensions were normalized to the appropriate 1/3 disk dimension to determine if a means of scaling the damage based engine dimensions was possible. The distribution of the maximum damage dimensions was determined and considered in light of the potential for further minimizing the hazard to the aircraft.

1.3 SUMMARY OF RESULTS

A total of 49 uncontained engine disintegration events are included in this study. These events are individually documented in Appendix A of this report. A brief summary of the statistical results obtained from the database comprised by these events follows.

1) There were 600 documented penetrations in the aircraft structures, resulting in an average number of documented aircraft penetrations of 12.24 holes per event). Of these 600 penetrations, 18 penetrations were not measurable due to fire, structural damage, or other difficulty encountered in data gathering. These are contained in Appendix A without further comment (event 5, holes 2–13, event 29, holes 1–3, and event 50, holes 6–8).

2) 474 out of 582 penetrations (81.44%) in commercial aircraft due to uncontained turbine engine disintegrations had maximum dimensions of 3 inches or less.

3) 515 out of 582 penetrations (88.49%) in commercial aircraft due to uncontained turbine engine disintegrations had maximum dimensions of 5 inches or less.

4) 26 out of 582 penetrations (4.47%) in commercial aircraft due to uncontained turbine engine disintegrations are known to have been caused by disks or disk segments. Other penetrations may have been a result of released disk fragments as well. However, insufficient evidence exists to substantiate these.

5) The trajectories of fragments ejected by uncontained turbine engine disintegrations varies quite widely, from the largest forward angle of 53.0° (event 22, hole 3) to the largest aft angle of 80° (event 9, hole 2).

6) The trajectories of <u>disk</u> fragments ejected in these events varies from 16.5° forward (event 18, hole 14) to 15° aft (event 16, hole 3).

7) The largest trajectory spread of fragments in one event occurred in event 12, with a fragment trajectory spread from 18.5° forward (hole 27) to 56.0° aft (hole 1), a total debris spread of 74.5°.

8) The majority of events occur while the engines are at relatively high power settings. Takeoff, Climb, and Top of Climb phases account for 37 of the 49 events documented (75.5% of events).

9) Appendix D contains definitions for Continued Airwothiness Assessment Methodology (CAAM) hazard levels. There were no CAAM hazard level 0 or 1 events documented in this study. Twenty–one CAAM hazard level 2 events were documented, averaging 7.09 holes per event. Another twenty–one events were classified as CAAM hazard level 3, averaging 16.19 holes per event. The remaining 7 events were classified as CAAM hazard level 4, with an average of 16.57 holes per event. CAAM hazard level 3 and 4 events have considerably more holes per event than events classified in lower hazard levels.

10) Actual fragments recovered following uncontained events ranged in size from a fragment measuring 32.5 inches in maximum dimension (event 39, no aircraft impact) to multiple small fragments with maximum dimensions of 1 inch or less. The trajectory range of known fragments (not penetrations) was from 36° forward to 56° aft of the plane of rotation.

SECTION 2

KEY WORDS / DEFINITIONS

2.0 KEY WORDS / DEFINITIONS

Fragment – A fragment is any piece of an engine component which is released when any portion of the engine fractures. Included in this are pieces of engine casing which become projectiles when engine fragments impact and destroy portions of the case, as well as all rotating component fragments which escape the containment structure of the engine.

Hazard – A hazard to an aircraft is defined as any event which compromises the safety of the aircraft or of the passengers on board the aircraft, including but not limited to events which cause failure of any critical airplane system. For the purposes of this study, only hazards associated with power plant events shall be considered. (See also Appendix D – CAAM Hazard Level Definitions.)

Maximum Dimension – For penetrations, the largest measured linear dimension of the penetration in the aircraft structure is the maximum dimension. For fragments, the largest measured linear dimension of the fragment is considered the maximum dimension.

Penetration – A penetration is a hole in any part of the airplane structure (excluding the engine cowling), caused by uncontained engine debris. [Dents, gouges, scratches, or other superficial impacts are not considered to be penetrations as they did not make "holes" in the aircraft, and were therefore not included in the database for this study. Cracks which propagated from penetrations due to airframe stresses after the uncontained events are also defined as non–penetrations for the purpose of this report.]

Plane of Rotation – The plane of rotation is the plane defined by the rotation of an engine component. All fragment trajectories are calculated using the plane of rotation of the engine component from which fragments were released.

Trajectory – Trajectory is defined as the angle from the plane of rotation of the engine component which released the debris to the impact location of the debris fragment on the aircraft structure.

Uncontained Turbine Engine Disintegration Event – An uncontained turbine engine disintegration event is an engine event which involves the release of turbine engine fragments such that at least one engine fragment passes completely through the engine containment structure and casing. (Events where fragments are ejected forward out of the inlet or aft through the engine exhaust and no fragments are released as described above, or events where fragments do not completely pass through the engine containment structure and casing are not considered uncontained events.)

SECTION 3

DATA COLLECTION SUMMARY

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3.0 DATA COLLECTION SUMMARY

Due to the nature of industry reporting methods for uncontained turbine engine disintegrations, data dealing with these events exists in numerous different formats. Collecting and standardizing this information for use in analysis was a puzzling task. Because of the lack of a standardized reporting method, many known uncontained turbine engine disintegration events are not included in the analysis. Reliable data for these events were not obtained.

3.1 DATA SOURCES

Sources used in collection of data include (but are not limited to):

- Local databases
- Boeing Air Safety Group files
- General airplane program files
- Employee trip reports and/or customer support personnel telexes/faxes
- Engine manufacturer data
- FAA, NTSB or other government agency report.

The primary source of data for each individual uncontained disintegration event is shown in Appendix A under "Source", near the end of each event record.

3.1.1 LOCAL DATABASES

The Propulsion Research organization has been tracking uncontained turbine engine disintegration events for several years. A series of databases have been utilized in maintaining data for these events. These data sets contain much information concerning most of the events used in this study. Most of this information is found on Personal Computers, using R:BASE, PARADOX, and Lotus 123 software.

3.1.2 BOEING AIR SAFETY FILE

The Boeing Air Safety organization maintains records of all incidents and accidents involving Boeing aircraft. Also maintained in the Air Safety organization are records of non–Boeing aircraft incidents and accidents where available. Often the government agency reports described in section 3.1.7 are available from this source. This file provided essential data for most of the events used in this study.

3.1.3 AIRPLANE PROGRAMS

Data collected from airplane programs within The Boeing Company was limited. Most of this information was used to supplement data already known concerning specific events. These data often included specific information contained in other sources, such as those described in sections 3.1.2 and 3.1.4.

3.1.4 EMPLOYEE TRIP REPORTS AND CUSTOMER SUPPORT SOURCES

Where available, direct input concerning specific events was obtained from The Boeing Company employee who investigated the event. In some cases this was Customer Support personnel, while in other cases Propulsion Research employees or program employees supplied the data. In general these data were more complete with respect to desired information than most of the data from other sources.

3.1.5 ENGINE MANUFACTURERS' DATA

Information was solicited from each engine manufacturer where its engines were known to be involved in a disintegration event. These data generally confirmed facts already known, as well as updating and completing the record for further analysis. This was particularly useful in determining the sizes of ejected fragments and energies associated with those fragments. These data are contained in the "Engine Manufacturer's Update" section of the Uncontained Engine Disintegration database and in Appendix A at the conclusion of each individual event record.

3.1.6 AIRFRAME MANUFACTURERS' DATA

Information was solicited from each airframe manufacturer concerning events where that manufacturer's aircraft were known to be involved in an uncontained disintegration event. Again, these data were generally found to be confirmation of already known facts. Certain events were completed using this information. Data from this source have been included in the individual event records in Appendix A of this report.

3.1.7 FAA / NTSB / GOVERNMENT AGENCY REPORTS

Reports from government agencies were included in the data collection. Some useful data was obtained from these, particularly for non–Boeing aircraft engine disintegration events. However, the information pertaining to uncontained turbine engine disintegration events contained in this public record is relatively general in nature. Applicable data concerning these events were often scarce in the reports.

3.1.8 OTHER SOURCES

Other data sources include word–of–mouth, telephone conversations with persons involved in event investigations, newspaper articles, and other general information sources. This information was helpful in locating accurate and reliable sources for the data used in the study, but no precise data was obtained in this fashion. The general data obtained from these sources was not directly integrated into the analysis.

3.2 DATA COLLECTION PROCESS

The data collection process began with the identification of 90 significant uncontained turbine engine disintegration events. A quest for meaningful data for each of these events was initiated. After careful search, a variety of sources yielded beneficial data on 50 of these 90 events.

A standardized data entry form (Figure 1) was created to expedite data handling and analysis. Data from each of the uncontained turbine engine disintegration events was added to the database in this standardized format. Data fields in the standard form have been filled where data was available.

Event#.Pg

UNCONTAINED ENGINE DEBRIS ANALYSIS

Date:	Airplane Model:	Location:	Power Level:
Airline:	Engine Model:	Flight Phase:	Altitude:
Tail Number:	Engine Position:	Flight Effect:	Airspeed:
	Eng Serial No.:		Hazard Level *(see Definitions)*:

PRIMARY MALFUNCTION (Rotor Stages):

SECONDARY MALFUNCTION (Rotor Stages):

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)

NARRATIVE:

SOURCE ***(Data obtained from)*:**
DRAWINGS/PICTURES IDENTIFICATIONS:

ENGINE MANUFACTURER'S UPDATE:

FIGURE 1. Standardized Data Entry Form for Trajectory Study

49 of the 50 events identified have been integrated into this analysis. It is believed that these events provide a significant statistical database from which results and conclusions can be drawn. It should be noted that several uncontained turbine engine disintegration events have been excluded from the analysis. After careful consideration of these events, it was decided that either the event data was incomplete or the data source was unreliable. Future additions may be made to this study when complete reliable information becomes available for these events.

To the greatest extent possible, only factual data has been used in the analysis. Estimates (hole sizes, fragment sizes and weights, and trajectories) have been deliberately excluded from initial analysis, except as noted. Further analysis has been performed using estimates provided either by the engine manufacturer or by other data sources. Where indicated, these estimates are included in the narrative or in the engine manufacturer's update for each event (see Appendix A).

Major obstacles were encountered in the attempt to standardize the reporting format for uncontained turbine engine disintegration events due to the nature of such events. Since the majority of events occur while the aircraft is in flight, uncontained fragments can be scattered over very wide geographical areas. Because of this it is virtually impossible to recover all fragments from every event. Hence the dimensions and weight of particular fragments often cannot be known. Additionally, it is often impossible to determine which engine fragment caused a specific impact or hole in an aircraft which has experienced an uncontained turbine engine disintegration. Even when fragments have been recovered, the task of matching fragments with structural impact locations can be quite forbidding.

Based on these difficulties, it was decided to use the holes in the aircraft structure as the best measure of uncontained turbine engine disintegration events. It was obvious that as long as the aircraft maintained structural integrity, the holes caused by engine fragments from a disintegration event could be measured. It was assumed that if a fragment impacted but did not penetrate the aircraft structure, the likelihood of that fragment adversely affecting critical aircraft systems was extremely remote, whereas a fragment which did penetrate the aircraft would be much more likely to adversely affect critical aircraft systems. Therefore dents, scratches, or other relatively superficial marks in the airplane structure were deliberately excluded from the analysis, as there were no cases found during the data collection process where these impacts were sufficient to cause a significant hazard to the aircraft.

In at least two documented cases a rather lengthy crack propagated from a hole caused by an uncontained engine fragment. The evidence shows that these cracks were not part of the initial impact, but propagated due to stresses in the airframe during subsequent flight. It is not readily apparent that these cracks had any adverse effect on aircraft systems. Therefore these cracks have also been deliberately excluded from the analysis.

A detail of the standardized data entry form in Figure 1 has been completed for each of the events used in the analysis. These events are recorded in Appendix A. In some cases more than one page of the entry form was required to accurately record all of the necessary information for a particular event. In many instances there was no reliable data to be inserted into a particular data field. In these cases the data fields have been left blank. Future additions to these event records in the BCAG Propulsion Research database will be made as data become available. This document will not be updated with these changes.

SECTION 4

RESULTS OF ANALYSIS

4.0 RESULTS OF ANALYSIS

The results of the study are contained in the following sections of this reports (sections 4.1 through 4.9).

4.1 NUMBER OF AIRCRAFT PENETRATIONS

4.1.1 PENETRATIONS BY ALL FRAGMENTS

In the 49 valid events studied, there were a combined total of 600 aircraft penetrations by engine debris. Figure 2 shows the number of airframe penetrations for each event. The average as shown is 12.24 holes per uncontained turbine engine disintegration event.

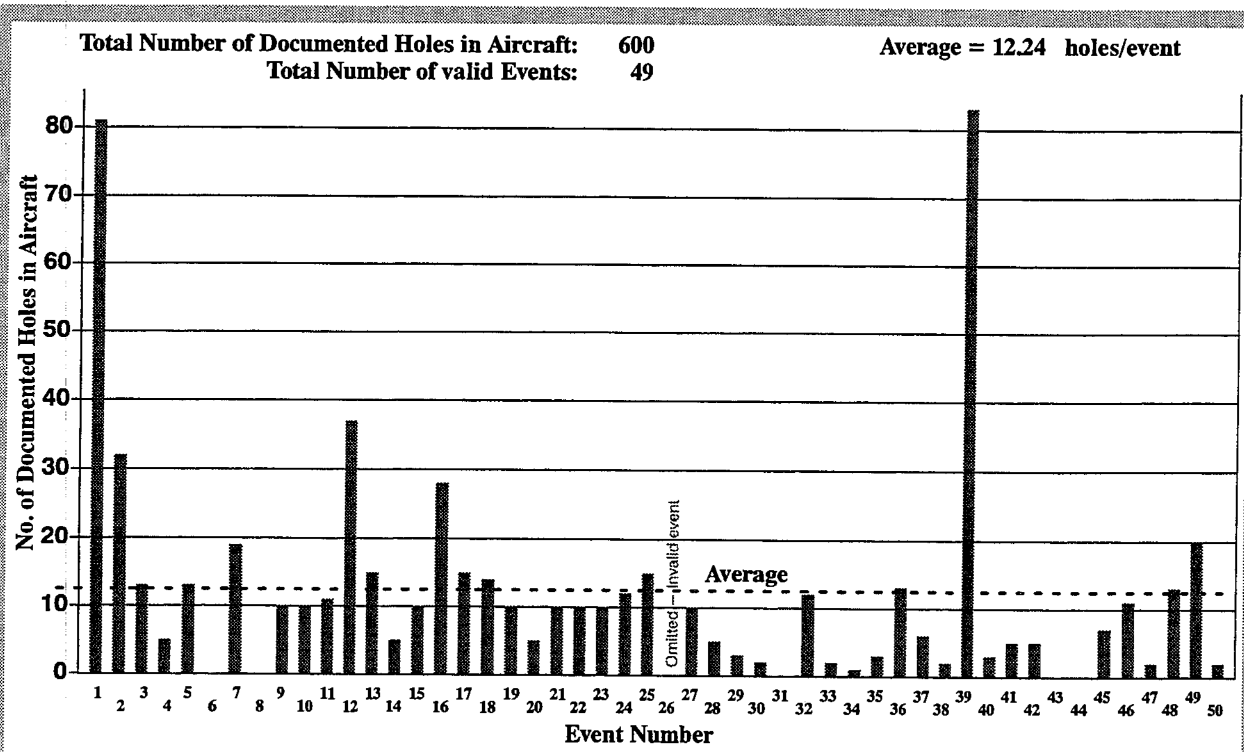

FIGURE 2. Aircraft Penetrations by Event

The number of documented holes in the aircraft in the 49 valid events ranges from a low of 0 (events 6, 8, 31, 43, and 44) to a high of 84 (event 39). In each of the "zero" events an uncontained turbine engine disintegration occurred, but sources indicate that either 1) no fragments hit the aircraft; 2) the fragments which impacted the aircraft did not have sufficient energy to penetrate the aircraft structure; or 3) fragment(s) severed a fuel line or critical system within the engine nacelle or pylon causing significant consequences, but no evidence exists concerning aircraft penetrations.

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4.1.2 PENETRATIONS BY DISK FRAGMENTS

26 out of the 582 documented penetrations (4.47%) in commercial aircraft due to uncontained turbine engine disintegrations are known to have been caused by disks or disk segments (one was of unknown severity). A total of 18 events contributed to the 25 penetrations used in this study. Four of these holes had maximum dimensions of 5 inches or less. One disk fragment ejection has been incorporated into the database, but has not been documented as an aircraft penetration for this study. The fragment did not impact the aircraft after passing through the engine case. It was found in the vicinity of the aircraft following the event. Further information on this fragment is found in Section 4.4.

Figure 3 shows the distribution of penetrations by disk segments. The averages as shown are 0.53 disk fragment penetrations per event (all events), or 1.44 disk fragment penetrations per disk event (excluding non–disk only events).

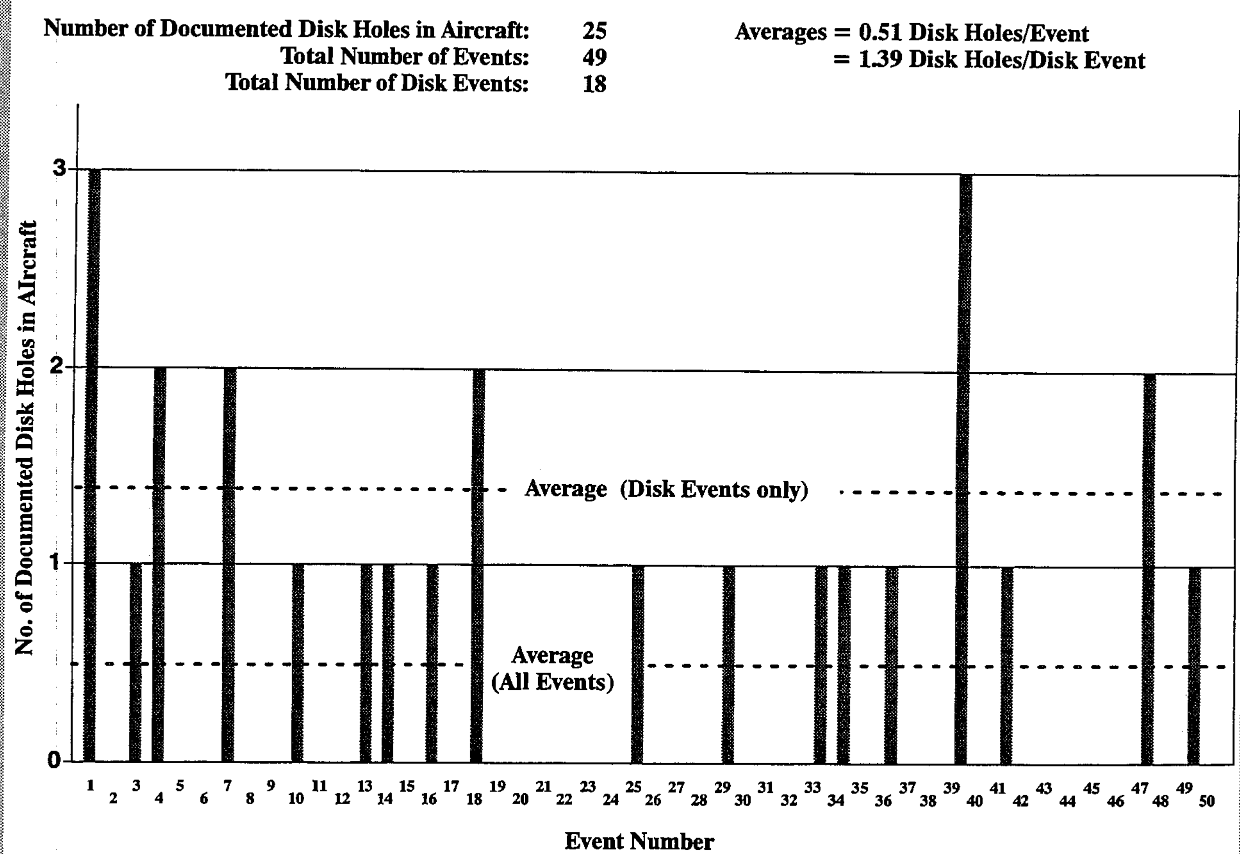

FIGURE 3. Disk Fragment Penetrations by Event

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UNCONTAINED ENGINE DEBRIS TRAJECTORY STUDY

BCAG PROPULSION RESEARCH

by Dennis Tilzey

September 1995

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

FORWARD

Improving the level of flight safety of commercial aircraft is a continuous process within the aircraft industry. The propulsion community has been developing an understanding of uncontained turbine engine disintegration events with a view to improving flight safety for many years. Regulations have been developed by government agencies to address the issues relevant to this type of event. The aircraft industry has adopted practices which are in agreement with these regulations.

Recent uncontained engine disintegration events which appear to manifest behavior inconsistent with these regulations and practices for improved flight safety underscore the need to continually update the understanding of these events. The inconsistencies in the historical data coupled with the desire to mitigate aircraft hazards due to uncontained engine disintegration events have provoked the aircraft industry to evaluate present regulatory standards and industry practices.

In this vein an effort has been made to develop a systematic approach to uncontained engine disintegration events. A task force was formed with representation from airframers, engine manufacturers, and regulatory agencies. The committee has met regularly over an extended time period. The problem addressed by the committee has necessitated the development of a database as a valuable tool for analysis as well as a statistical analysis of current data.

The Boeing Company, through the Propulsion Safety Advocate, has expended considerable resources on the study of this information. The Boeing effort has resulted in the collection and analysis of a significant quantity of data. This report is a synopsis of the collection and analysis performed by the BCAG Propulsion Research organization.

Conclusions have been drawn from the available data as analyzed in this study, and recommendations for airframe system separation criteria and hazard mitigation on future Boeing aircraft have been made.

The task which has been undertaken for this study is an on−going effort. The Boeing Propulsion Uncontained Engine Debris database will be updated as new information becomes available. Additional information is available, obtainable by specific request to the Boeing Propulsion Safety Advocate.

Additionally, a proprietary version of this document exists, numbered D6−57019. The proprietary version of the document resides with the Boeing Propulsion Safety Advocate in the BCAG Propulsion Research organization, and may be obtained with permission of the Boeing Propulsion Safety Advocate.

EXPLANATIONS AND CONVENTIONS

- All data has been presented in generic form. Information which is unnecessary for the purposes of this document has been removed from the printed records. This proprietary data exists in the Boeing Propulsion Safety Advocate's database, with all identification retained.

- All references to particular events and holes or fragments are based on the standardized information found in Appendix A. The format [(event #, hole #)] or [(event #, fragment #)] is used regularly to note a specific penetration or fragment in a specific event. This format in all cases refers to the data as contained in Appendix A for that particular event and penetration.

- By convention, in all cases where trajectory angles are noted, positive angles (+) denote trajectories *forward* of the plane of rotation while negative angles (−) denote trajectories *aft* of the plane of rotation.

- All holes known to be caused by fragments which were ejected forward out of the inlet or aft through the engine exhaust nozzle have been intentionally excluded from the analysis. These penetrations are by definition <u>not</u> caused by uncontained fragments (See section 2.0, Key Words / Definitions). Due to uncertainty, however, it is probable that some data included in this study *may* be a result of holes caused by fragments which were ejected forward out of the inlet or aft through the engine exhaust nozzle.

- The dimensions of holes given in Appendix A and used in the plots are as much as possible actual measured sizes, rounded to the nearest $^1/_2$ inch. However, in some cases the available information did not specify the exact size of the hole. This is particularly true for many of the smaller holes, especially in events where the end result of the event was not substantial damage or catastrophe. Available photographic or pictorial evidence from these was projected onto planform drawings of the aircraft where possible and relatively accurate hole sizes were obtained using the scales on the drawings. A small number of hole sizes were estimated from verbal or written descriptions.

- This report is not intended to convey the message that some aircraft types, certain engine types, specific airlines, etc., are more prone to uncontained events than others. Where a significant amount of data exists which might yield this impression, it is important to note that it is simply a consequence of the availability and reliability of data for that particular airplane type/engine model/airline/etc. Limited information has been collected. Until the database is more complete it is not valid to make these types of comparisons.

- The figures in the report are duplicated in Appendix C. All data in Appendix C is identical to data in the report, but some formats have been altered to provide projection−ready prints.

SECTION 1

INTRODUCTION

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1.0 INTRODUCTION

Uncontained engine failures are one of the top causes for propulsion system related jet aircraft accidents. The uncontained engine failure related Sioux City DC10 accident in 1989 prompted a new investigation into the nature of such accidents. The objective was to determine whether there were as yet unrecognized opportunities to further minimize the potential for uncontained engine related accidents.

Airframe manufacturers are responsible by regulation, FAR/JAR 25.903(d)(1) and related advisory material, to minimize the hazard to continued safe flight and landing from uncontained engine failures. The then–current regulatory material was based on a pre–1977 characterization of uncontained engine fragment trajectory experience from one engine manufacturer. The advisory material stressed mitigation from damage caused by a single large disk fragment. However, it was clear from the National Transportation Safety Board (NTSB) record that the critical damage in the case of the Sioux City accident had been caused by one of the large number of smaller fragments and not by the two large disk fragments themselves. This generated the focus for this research activity, centered on the following problem statements:

> Is the current advisory material correct or do more recent events suggest that guidance material should be improved?
>
> Is there evidence that some of the uncontained engine failure related accidents were caused by the multiple smaller fragments not definitively addressed in current advisory material?
>
> Is there an opportunity to enhance airplane design to further minimize the non–contained engine related hazard?

This report documents the results of the research directed at answering these questions.

1.1 SCOPE

The records related to uncontained engine failure related events do not always contain the information necessary to answer the needs of this study. Uncontained engine events where no damage to the aircraft occurred were of no value. Similarly, uncontained engine events where the aircraft damage consisted only of dents and scratches were of no direct value (no hazard), but do suggest that current aircraft structure is in many cases providing adequate protection. The study focused on events where there were damage sites (tears and penetrations) in the aircraft. The event data were researched from accident investigation files, covering the time period 1961 to the present. The majority of the events were obtained from Boeing files. However, available records were also provided by McDonnell Douglas and Airbus Industrie, and assistance in interpretation was provided by the three major engine manufacturers.

Appendix A of this report provides the generic synthesized data sheets for each event considered in this study. The data sheets for all events where there was sufficient documentation to aid in answering one or more of the problem statements set forth above are included.

1.2 APPROACH

The approach for this study was to review the historical records (every piece of paper/photograph/drawing/etc.) related to uncontained engine failure related events.

The first task was to collect (copy/document) all relevant data and enter the data into an appropriate form. The completed forms were shared with the appropriate engine manufacturer and the engine manufacturer's data/information was added. Where disagreements were found special effort was undertaken to resolve those differences. The refined data was entered into a computer data base for further analysis.

The process utilized aircraft drawings or computerized (CATIA) aircraft reference systems and involved calculation of trajectory angles and estimation of hole sizes based on recorded data or by knowledge of dimensions of another aspect in the photograph. The straight line trajectory angles for the engine release location to the damage location was computed. The penetration/tear data was utilized to develop refined system separation separation criteria.

The computerized penetration/tear data was further analyzed with respect to the number of damage sites per event and by engine class (high bypass and low bypass). The maximum damage dimensions were normalized to the appropriate 1/3 disk dimension to determine if a means of scaling the damage based engine dimensions was possible. The distribution of the maximum damage dimensions was determined and considered in light of the potential for further minimizing the hazard to the aircraft.

1.3 SUMMARY OF RESULTS

A total of 49 uncontained engine disintegration events are included in this study. These events are individually documented in Appendix A of this report. A brief summary of the statistical results obtained from the database comprised by these events follows.

1) There were 600 documented penetrations in the aircraft structures, resulting in an average number of documented aircraft penetrations of 12.24 holes per event). Of these 600 penetrations, 18 penetrations were not measurable due to fire, structural damage, or other difficulty encountered in data gathering. These are contained in Appendix A without further comment (event 5, holes 2–13, event 29, holes 1–3, and event 50, holes 6–8).

2) 474 out of 582 penetrations (81.44%) in commercial aircraft due to uncontained turbine engine disintegrations had maximum dimensions of 3 inches or less.

3) 515 out of 582 penetrations (88.49%) in commercial aircraft due to uncontained turbine engine disintegrations had maximum dimensions of 5 inches or less.

4) 26 out of 582 penetrations (4.47%) in commercial aircraft due to uncontained turbine engine disintegrations are known to have been caused by disks or disk segments. Other penetrations may have been a result of released disk fragments as well. However, insufficient evidence exists to substantiate these.

5) The trajectories of fragments ejected by uncontained turbine engine disintegrations varies quite widely, from the largest forward angle of 53.0° (event 22, hole 3) to the largest aft angle of 80° (event 9, hole 2).

6) The trajectories of <u>disk</u> fragments ejected in these events varies from 16.5° forward (event 18, hole 14) to 15° aft (event 16, hole 3).

7) The largest trajectory spread of fragments in one event occurred in event 12, with a fragment trajectory spread from 18.5° forward (hole 27) to 56.0° aft (hole 1), a total debris spread of 74.5°.

8) The majority of events occur while the engines are at relatively high power settings. Takeoff, Climb, and Top of Climb phases account for 37 of the 49 events documented (75.5% of events).

9) Appendix D contains definitions for Continued Airwothiness Assessment Methodology (CAAM) hazard levels. There were no CAAM hazard level 0 or 1 events documented in this study. Twenty–one CAAM hazard level 2 events were documented, averaging 7.09 holes per event. Another twenty–one events were classified as CAAM hazard level 3, averaging 16.19 holes per event. The remaining 7 events were classified as CAAM hazard level 4, with an average of 16.57 holes per event. CAAM hazard level 3 and 4 events have considerably more holes per event than events classified in lower hazard levels.

10) Actual fragments recovered following uncontained events ranged in size from a fragment measuring 32.5 inches in maximum dimension (event 39, no aircraft impact) to multiple small fragments with maximum dimensions of 1 inch or less. The trajectory range of known fragments (not penetrations) was from 36° forward to 56° aft of the plane of rotation.

SECTION 2

KEY WORDS / DEFINITIONS

2.0 KEY WORDS / DEFINITIONS

Fragment – A fragment is any piece of an engine component which is released when any portion of the engine fractures. Included in this are pieces of engine casing which become projectiles when engine fragments impact and destroy portions of the case, as well as all rotating component fragments which escape the containment structure of the engine.

Hazard – A hazard to an aircraft is defined as any event which compromises the safety of the aircraft or of the passengers on board the aircraft, including but not limited to events which cause failure of any critical airplane system. For the purposes of this study, only hazards associated with power plant events shall be considered. (See also Appendix D – CAAM Hazard Level Definitions.)

Maximum Dimension – For penetrations, the largest measured linear dimension of the penetration in the aircraft structure is the maximum dimension. For fragments, the largest measured linear dimension of the fragment is considered the maximum dimension.

Penetration – A penetration is a hole in any part of the airplane structure (excluding the engine cowling), caused by uncontained engine debris. [Dents, gouges, scratches, or other superficial impacts are not considered to be penetrations as they did not make "holes" in the aircraft, and were therefore not included in the database for this study. Cracks which propagated from penetrations due to airframe stresses after the uncontained events are also defined as non–penetrations for the purpose of this report.]

Plane of Rotation – The plane of rotation is the plane defined by the rotation of an engine component. All fragment trajectories are calculated using the plane of rotation of the engine component from which fragments were released.

Trajectory – Trajectory is defined as the angle from the plane of rotation of the engine component which released the debris to the impact location of the debris fragment on the aircraft structure.

Uncontained Turbine Engine Disintegration Event – An uncontained turbine engine disintegration event is an engine event which involves the release of turbine engine fragments such that at least one engine fragment passes completely through the engine containment structure and casing. (Events where fragments are ejected forward out of the inlet or aft through the engine exhaust and no fragments are released as described above, or events where fragments do not completely pass through the engine containment structure and casing are not considered uncontained events.)

SECTION 3

DATA COLLECTION SUMMARY

3.0 DATA COLLECTION SUMMARY

Due to the nature of industry reporting methods for uncontained turbine engine disintegrations, data dealing with these events exists in numerous different formats. Collecting and standardizing this information for use in analysis was a puzzling task. Because of the lack of a standardized reporting method, many known uncontained turbine engine disintegration events are not included in the analysis. Reliable data for these events were not obtained.

3.1 DATA SOURCES

Sources used in collection of data include (but are not limited to):

- Local databases
- Boeing Air Safety Group files
- General airplane program files
- Employee trip reports and/or customer support personnel telexes/faxes
- Engine manufacturer data
- FAA, NTSB or other government agency report.

The primary source of data for each individual uncontained disintegration event is shown in Appendix A under "Source", near the end of each event record.

3.1.1 LOCAL DATABASES

The Propulsion Research organization has been tracking uncontained turbine engine disintegration events for several years. A series of databases have been utilized in maintaining data for these events. These data sets contain much information concerning most of the events used in this study. Most of this information is found on Personal Computers, using R:BASE, PARADOX, and Lotus 123 software.

3.1.2 BOEING AIR SAFETY FILE

The Boeing Air Safety organization maintains records of all incidents and accidents involving Boeing aircraft. Also maintained in the Air Safety organization are records of non–Boeing aircraft incidents and accidents where available. Often the government agency reports described in section 3.1.7 are available from this source. This file provided essential data for most of the events used in this study.

3.1.3 AIRPLANE PROGRAMS

Data collected from airplane programs within The Boeing Company was limited. Most of this information was used to supplement data already known concerning specific events. These data often included specific information contained in other sources, such as those described in sections 3.1.2 and 3.1.4.

3.1.4 EMPLOYEE TRIP REPORTS AND CUSTOMER SUPPORT SOURCES

Where available, direct input concerning specific events was obtained from The Boeing Company employee who investigated the event. In some cases this was Customer Support personnel, while in other cases Propulsion Research employees or program employees supplied the data. In general these data were more complete with respect to desired information than most of the data from other sources.

3.1.5 ENGINE MANUFACTURERS' DATA

Information was solicited from each engine manufacturer where its engines were known to be involved in a disintegration event. These data generally confirmed facts already known, as well as updating and completing the record for further analysis. This was particularly useful in determining the sizes of ejected fragments and energies associated with those fragments. These data are contained in the "Engine Manufacturer's Update" section of the Uncontained Engine Disintegration database and in Appendix A at the conclusion of each individual event record.

3.1.6 AIRFRAME MANUFACTURERS' DATA

Information was solicited from each airframe manufacturer concerning events where that manufacturer's aircraft were known to be involved in an uncontained disintegration event. Again, these data were generally found to be confirmation of already known facts. Certain events were completed using this information. Data from this source have been included in the individual event records in Appendix A of this report.

3.1.7 FAA / NTSB / GOVERNMENT AGENCY REPORTS

Reports from government agencies were included in the data collection. Some useful data was obtained from these, particularly for non–Boeing aircraft engine disintegration events. However, the information pertaining to uncontained turbine engine disintegration events contained in this public record is relatively general in nature. Applicable data concerning these events were often scarce in the reports.

3.1.8 OTHER SOURCES

Other data sources include word–of–mouth, telephone conversations with persons involved in event investigations, newspaper articles, and other general information sources. This information was helpful in locating accurate and reliable sources for the data used in the study, but no precise data was obtained in this fashion. The general data obtained from these sources was not directly integrated into the analysis.

3.2 DATA COLLECTION PROCESS

The data collection process began with the identification of 90 significant uncontained turbine engine disintegration events. A quest for meaningful data for each of these events was initiated. After careful search, a variety of sources yielded beneficial data on 50 of these 90 events.

A standardized data entry form (Figure 1) was created to expedite data handling and analysis. Data from each of the uncontained turbine engine disintegration events was added to the database in this standardized format. Data fields in the standard form have been filled where data was available.

Event#.Pg **UNCONTAINED ENGINE DEBRIS ANALYSIS**

Date: Airline: Tail Number:

Airplane Model: Engine Model: Engine Position: Eng Serial No.:

Location: Flight Phase: Flight Effect:

Power Level: Altitude: Airspeed: Hazard Level *(see Definitions)*:

PRIMARY MALFUNCTION (Rotor Stages):

SECONDARY MALFUNCTION (Rotor Stages):

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)

NARRATIVE:

SOURCE ***(Data obtained from)*****:**
DRAWINGS/PICTURES IDENTIFICATIONS:

ENGINE MANUFACTURER'S UPDATE:

FIGURE 1. Standardized Data Entry Form for Trajectory Study

49 of the 50 events identified have been integrated into this analysis. It is believed that these events provide a significant statistical database from which results and conclusions can be drawn. It should be noted that several uncontained turbine engine disintegration events have been excluded from the analysis. After careful consideration of these events, it was decided that either the event data was incomplete or the data source was unreliable. Future additions may be made to this study when complete reliable information becomes available for these events.

To the greatest extent possible, only factual data has been used in the analysis. Estimates (hole sizes, fragment sizes and weights, and trajectories) have been deliberately excluded from initial analysis, except as noted. Further analysis has been performed using estimates provided either by the engine manufacturer or by other data sources. Where indicated, these estimates are included in the narrative or in the engine manufacturer's update for each event (see Appendix A).

Major obstacles were encountered in the attempt to standardize the reporting format for uncontained turbine engine disintegration events due to the nature of such events. Since the majority of events occur while the aircraft is in flight, uncontained fragments can be scattered over very wide geographical areas. Because of this it is virtually impossible to recover all fragments from every event. Hence the dimensions and weight of particular fragments often cannot be known. Additionally, it is often impossible to determine which engine fragment caused a specific impact or hole in an aircraft which has experienced an uncontained turbine engine disintegration. Even when fragments have been recovered, the task of matching fragments with structural impact locations can be quite forbidding.

Based on these difficulties, it was decided to use the holes in the aircraft structure as the best measure of uncontained turbine engine disintegration events. It was obvious that as long as the aircraft maintained structural integrity, the holes caused by engine fragments from a disintegration event could be measured. It was assumed that if a fragment impacted but did not penetrate the aircraft structure, the likelihood of that fragment adversely affecting critical aircraft systems was extremely remote, whereas a fragment which did penetrate the aircraft would be much more likely to adversely affect critical aircraft systems. Therefore dents, scratches, or other relatively superficial marks in the airplane structure were deliberately excluded from the analysis, as there were no cases found during the data collection process where these impacts were sufficient to cause a significant hazard to the aircraft.

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A detail of the standardized data entry form in Figure 1 has been completed for each of the events used in the analysis. These events are recorded in Appendix A. In some cases more than one page of the entry form was required to accurately record all of the necessary information for a particular event. In many instances there was no reliable data to be inserted into a particular data field. In these cases the data fields have been left blank. Future additions to these event records in the BCAG Propulsion Research database will be made as data become available. This document will not be updated with these changes.

SECTION 4

RESULTS OF ANALYSIS

D1 4100 7780 REV. 6/87

4.0 RESULTS OF ANALYSIS

The results of the study are contained in the following sections of this reports (sections 4.1 through 4.9).

4.1 NUMBER OF AIRCRAFT PENETRATIONS

4.1.1 PENETRATIONS BY ALL FRAGMENTS

In the 49 valid events studied, there were a combined total of 600 aircraft penetrations by engine debris. Figure 2 shows the number of airframe penetrations for each event. The average as shown is 12.24 holes per uncontained turbine engine disintegration event.

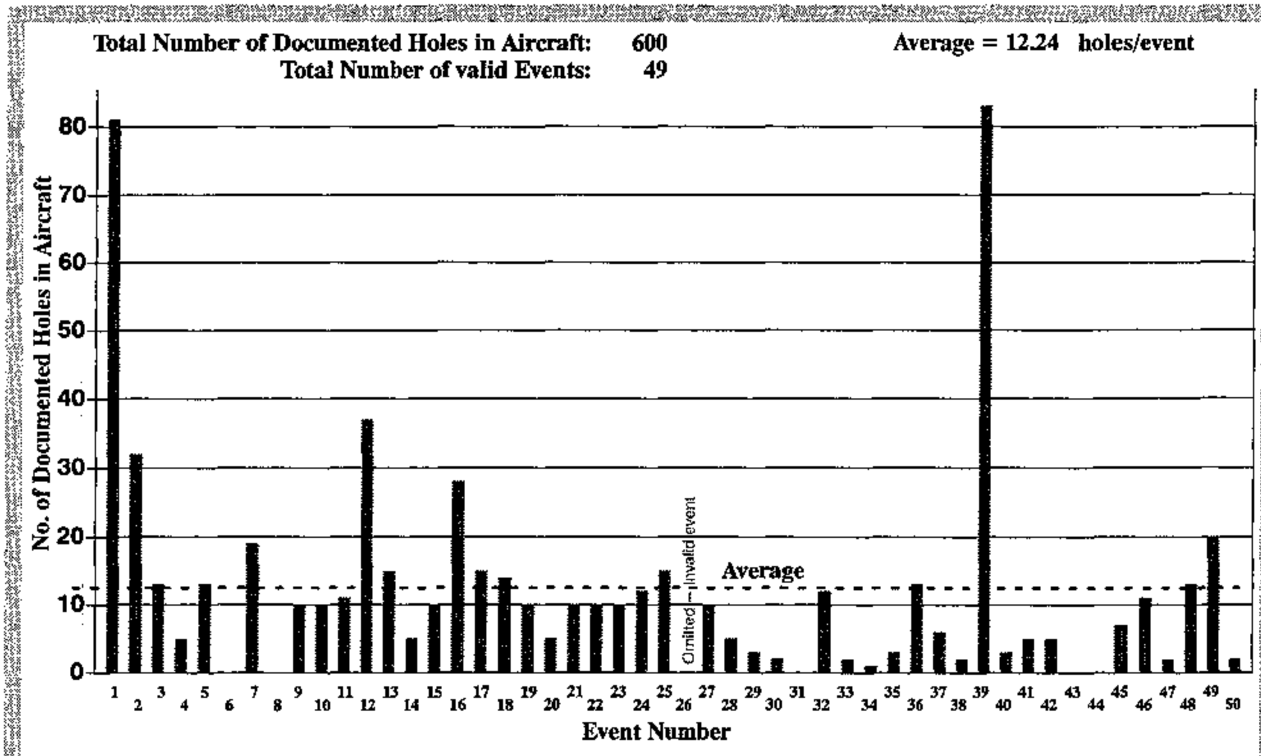

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FIGURE 2. Aircraft Penetrations by Event

The number of documented holes in the aircraft in the 49 valid events ranges from a low of 0 (events 6, 8, 31, 43, and 44) to a high of 84 (event 39). In each of the "zero" events an uncontained turbine engine disintegration occurred, but sources indicate that either 1) no fragments hit the aircraft; 2) the fragments which impacted the aircraft did not have sufficient energy to penetrate the aircraft structure; or 3) fragment(s) severed a fuel line or critical system within the engine nacelle or pylon causing significant consequences, but no evidence exists concerning aircraft penetrations.

4.1.2 PENETRATIONS BY DISK FRAGMENTS

26 out of the 582 documented penetrations (4.47%) in commercial aircraft due to uncontained turbine engine disintegrations are known to have been caused by disks or disk segments (one was of unknown severity). A total of 18 events contributed to the 25 penetrations used in this study. Four of these holes had maximum dimensions of 5 inches or less. One disk <u>fragment</u> ejection has been incorporated into the database, but has not been documented as an aircraft penetration for this study. The fragment did not impact the aircraft after passing through the engine case. It was found in the vicinity of the aircraft following the event. Further information on this fragment is found in Section 4.4.

Figure 3 shows the distribution of penetrations by disk segments. The averages as shown are 0.53 disk fragment penetrations per event (all events), or 1.44 disk fragment penetrations per disk event (excluding non–disk only events).

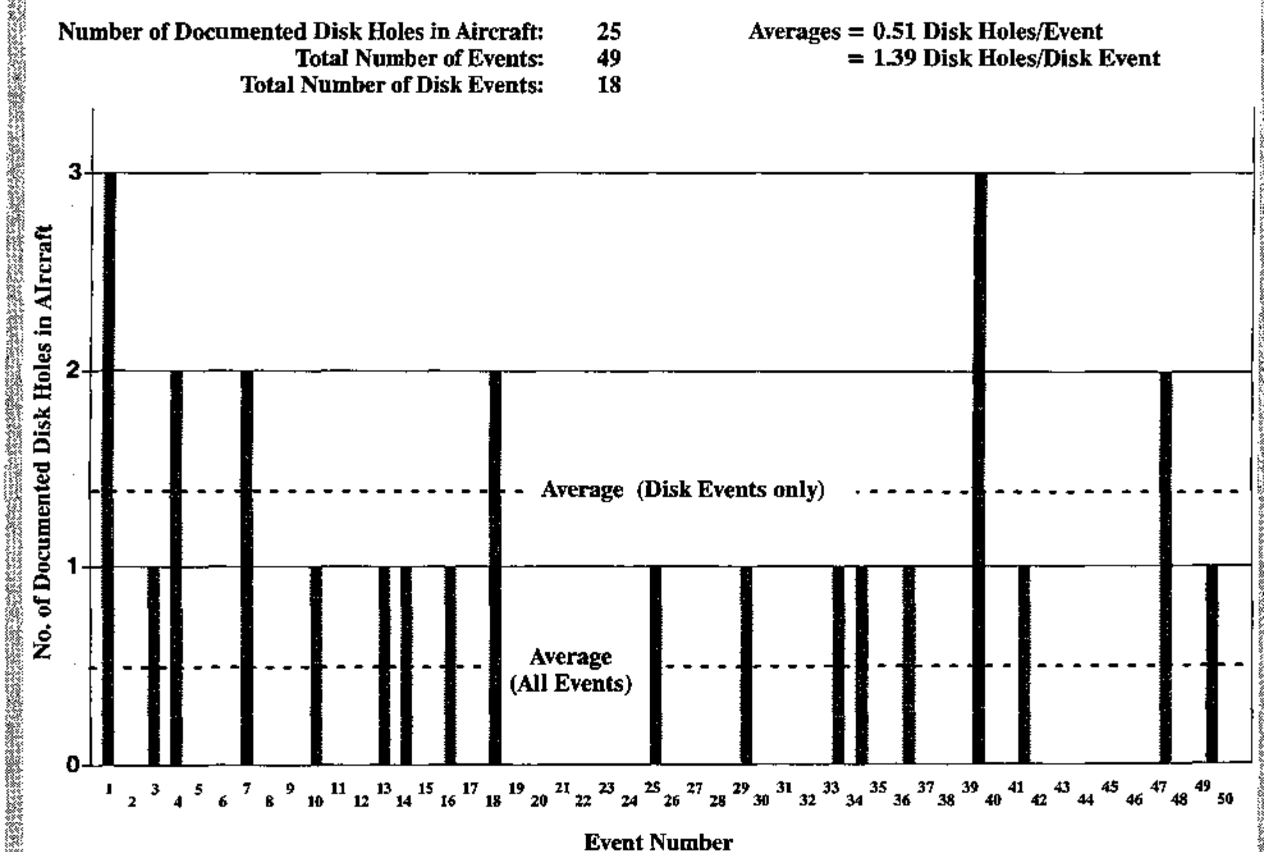


FIGURE 3. Disk Fragment Penetrations by Event

4.2 SIZE OF AIRCRAFT PENETRATIONS

4.2.1 ALL FRAGMENTS – MAXIMUM DIMENSIONS

Of the 600 holes counted in the 49 events used in the study, 18 holes (event 5, holes 2–13, and event 29, hole 1) were not measurable for use in analysis. These holes were found in the airplane where either fire or other structural damage or lack of data made the measuring of holes impossible, though it was evident that penetrations occurred. In the calculations for all of this study, the total number of holes used in analysis was 582, as these 18 holes were excluded.

Figure 4 contains a bar graph showing the distribution of hole size for all documented airplane penetrations, using the maximum dimension of each.

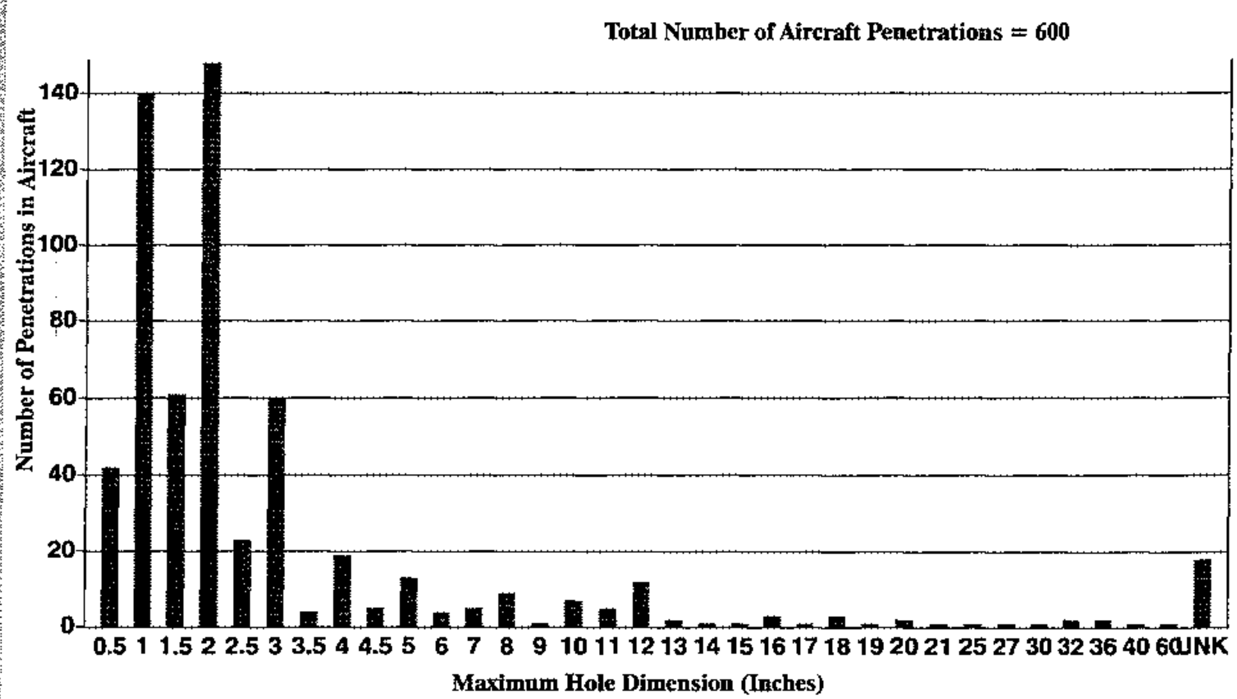


FIGURE 4. Size Distribution of Penetrations (Maximum Dimension)

474 holes (81.44%) had maximum dimensions of 3 inches or less. 515 holes (88.49%) had maximum dimensions of 5 inches or less. 67 holes (11.17%) had maximum dimensions of more than 5 inches. The cumulative percent of holes documented by increasing hole size is shown in figure 5.

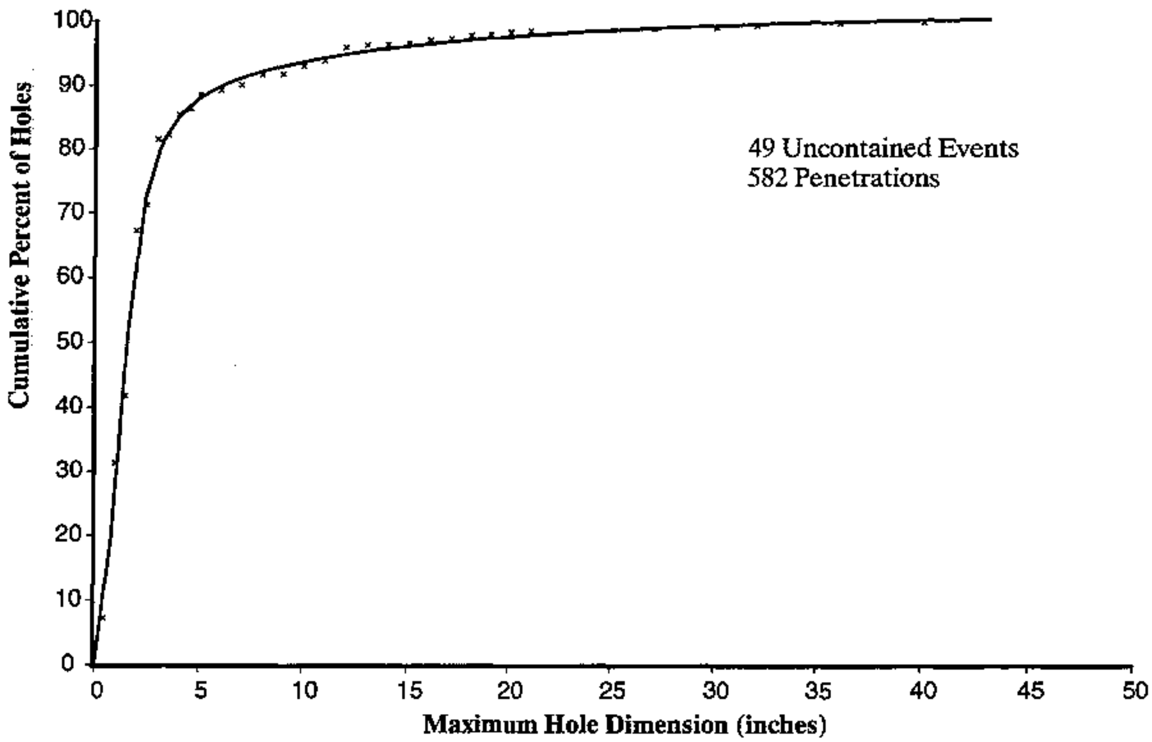


FIGURE 5. Cumulative Size Distribution of Penetrations (Maximum Dimension)

The penetration with the largest maximum dimension was a tangential slice in the fuselage by a disk rim segment (described in section 4.2.2), which opened up a hole approximately 5 inches by 60 inches. The smallest documented holes for the purposes of this study measured approximately $^1/_2$ inch by $^1/_2$ inch (some were even smaller). There were 42 penetrations of approximately this size and smaller. The sizes of the fragments which caused these penetrations are unknown.

4.2.2 DISK FRAGMENTS – MAXIMUM DIMENSIONS

Of the 582 penetrations documented, 25 penetrations (4.3%) were caused by disk or disk rim fragments. The largest penetration was a 5 inch by 60 inch hole, which was a tangential strike on the fuselage (event 4, hole 5). The disk segment which caused this hole was estimated by the engine manufacturer to be approximately 12 inches long and 3 inches wide, weighing about 10 pounds. Three of the documented disk penetrations resulted in holes with maximum dimensions of 5 inches or smaller. The average maximum dimension of all holes caused by the penetration of a disk fragment is 17.9 inches, as noted in Figure 6, which shows the distribution of hole sizes caused by disk fragments, using the maximum hole dimension for each event.

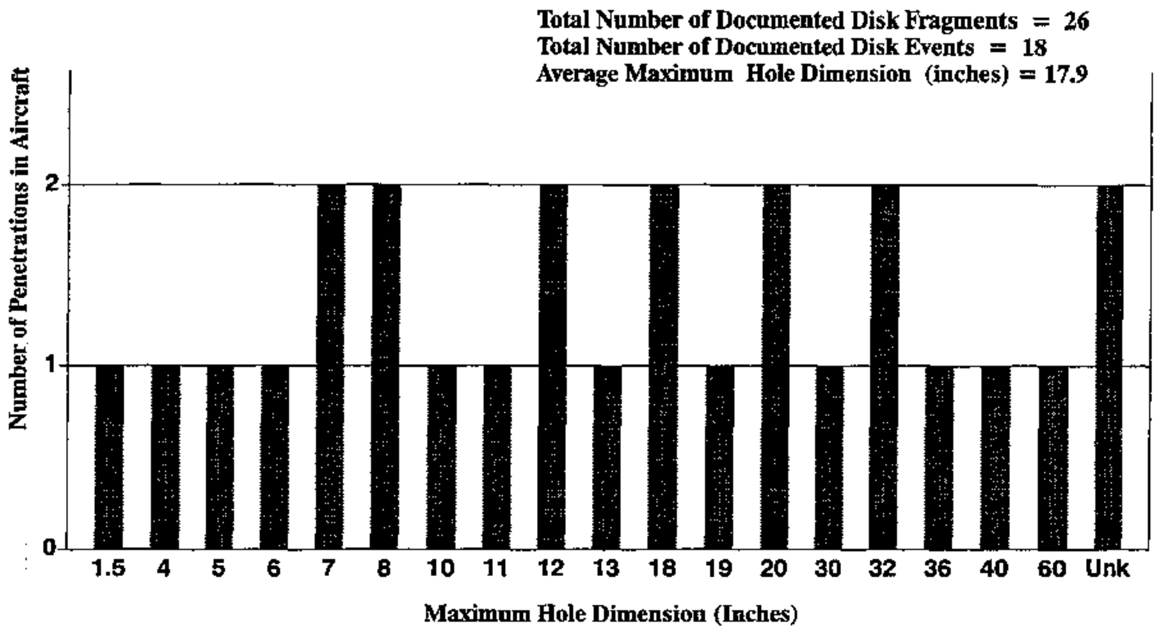


FIGURE 6. Size Distribution of Disk Penetration (Maximum Dimension)

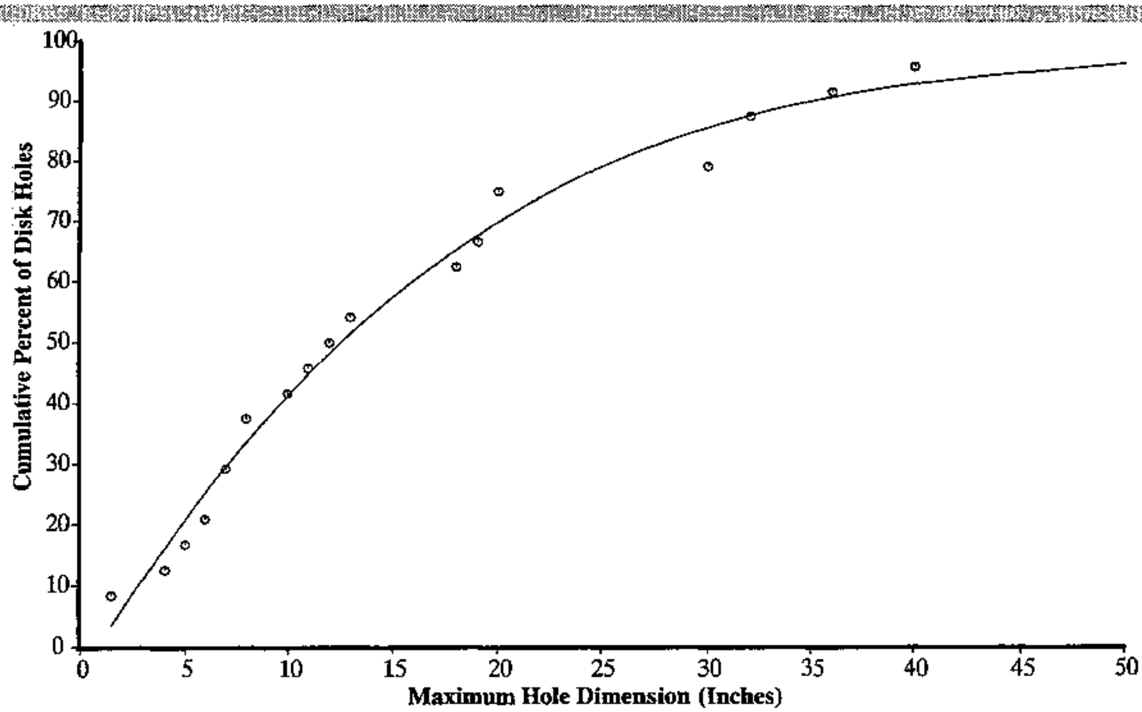


FIGURE 7. Cumulative Size Distribution of Disk Penetrations (Maximum Dimension)

D1 4100 7780 REV. 6/87

Figure 7 (previous page) shows the size distribution of disk penetrations based on the cumulative percent of holes of each size.

4.3 FRAGMENT TRAJECTORIES AS DEFINED BY PENETRATIONS

This study was initiated to provide useful data concerning uncontained turbine engine disintegration fragment trajectory and hazard mitigation requirements from historical events on all aircraft. In order to give a complete picture of the results of the analysis which has been performed, trajectory data has been separated according to multiple criteria. Hence the data may be repeated for each event as it fits into the different criteria.

Data has been separated for analysis using the following trajectory criteria:

- Trajectories are calculated as a straight line from the plane of rotor disintegration to the point of fragment impact on the aircraft (as determined by the hole).

- Events are separated into the following categories:
  1) All event trajectories and hole sizes (Section 4.3.2);
  2) Disk only event trajectories and hole sizes (Section 4.3.3);
  3) Maximum fragment trajectory spread in a single event (Section 4.3.4);
  4) Fragment trajectories and holes sizes separated by airplane model (Section 4.3.5).
  5) Fragment trajectories and holes sizes separated by engine manufacturer (Section 4.3.6).
  6) Fragment trajectories and hole sizes separated by flight phase (Section 4.3.7);
  7) Fragment trajectories and hole sizes separated by CAAM hazard level (Section 4.3.8).
  8) Fragment trajectories and hole sizes separated by low bypass ratio engine (LBR) and high bypass ratio engine (HBR) types (Section 4.3.9).

4.3.1 CURRENT AC 20–128 / ACJ 25.903(d)(1) REQUIREMENTS

The current federal requirements concerning uncontained turbine engine disintegration fragment trajectories are found in FAR 25.903(d)(1) and the associated Advisory Circular, AC 20–128. As part of this study these requirements have been examined and compared with historical experience. In order to fully understand the implications of the analysis in this study, the reader must be familiar with these regulations, which are reproduced in Appendix B.

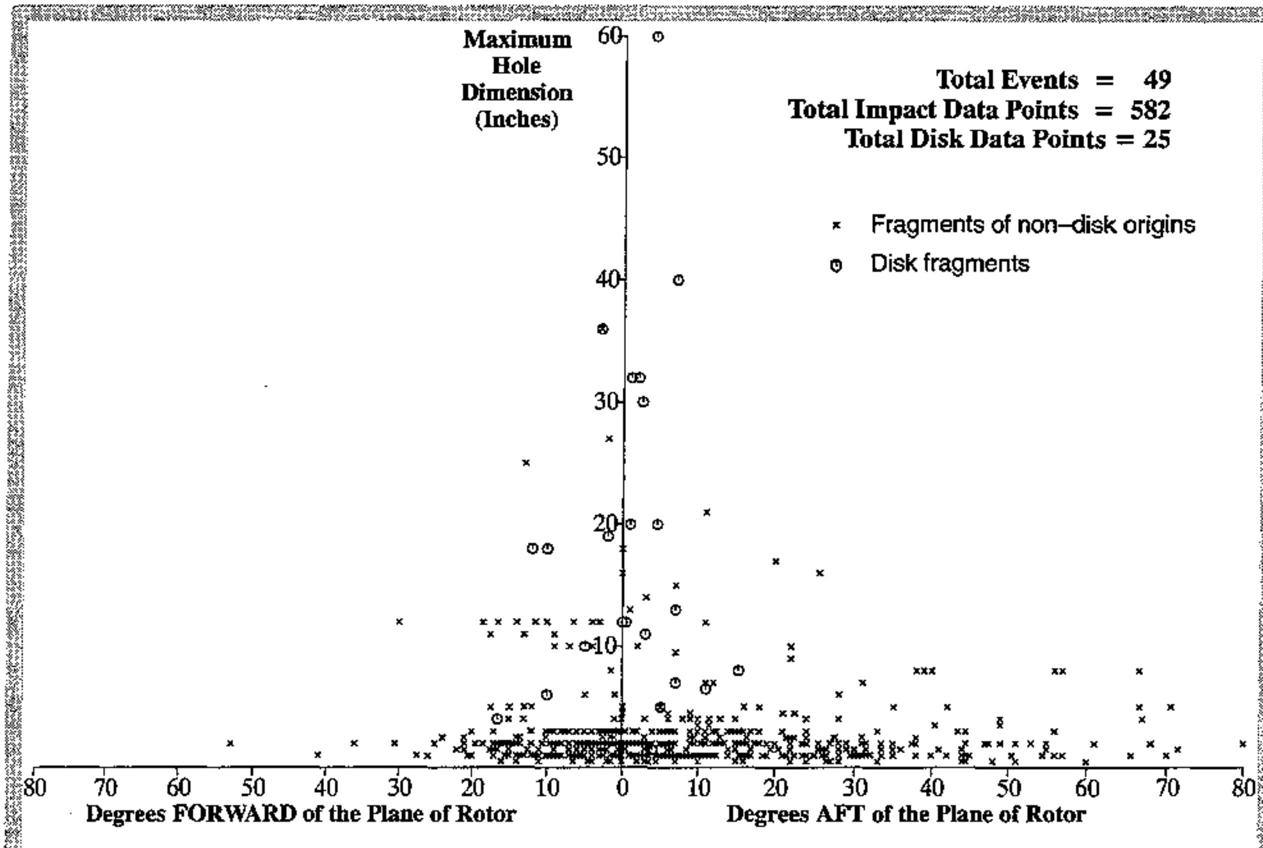


FIGURE 8. Fragment Trajectory versus Hole Size

4.3.2 FRAGMENT TRAJECTORIES – ALL PENETRATIONS

The trajectories from the plane of engine disintegration to the penetration location have been calculated for 582 holes in the 49 events. Figure 8 is a "splatter" plot of this data, showing the trajectory and size of all fragments which have been documented for this study.

In many instances, multiple data points are found at the same location on the plots. In these situations, only one symbol has been used on the plot.

The trajectories of fragments ejected by uncontained turbine engine disintegrations varies from the largest forward angle of 53.5° to the largest aft angle of 80°. The penetration at 53.5° forward angle (event 22, hole 3) was relatively small. The hole left by the fragment was in the lower cargo section of the fuselage, measuring 2 inches by 2 inches. The fragment which caused this was a part of the fan section. The penetration at 80° aft (event 9, hole 2) was also small, measuring 2 inches by 1 inch. The fragment which caused this hole was from the first stage of the low pressure turbine (LPT). It impacted the aircraft on the horizontal stabilizer lower skin.

The trajectory of the fragment which caused the largest hole (event 4, hole 5) was calculated to be 4° aft of the plane of disintegration, and resulted in a lengthy slice (60 inches by 5 inches) in the vertical tail fin of a rear–engine–mounted aircraft.

4.3.3 FRAGMENT TRAJECTORIES – DISK PENETRATIONS

The trajectories of <u>disk</u> fragments ejected in these events varies from 16.5° forward to 15.0° aft (figure 9).

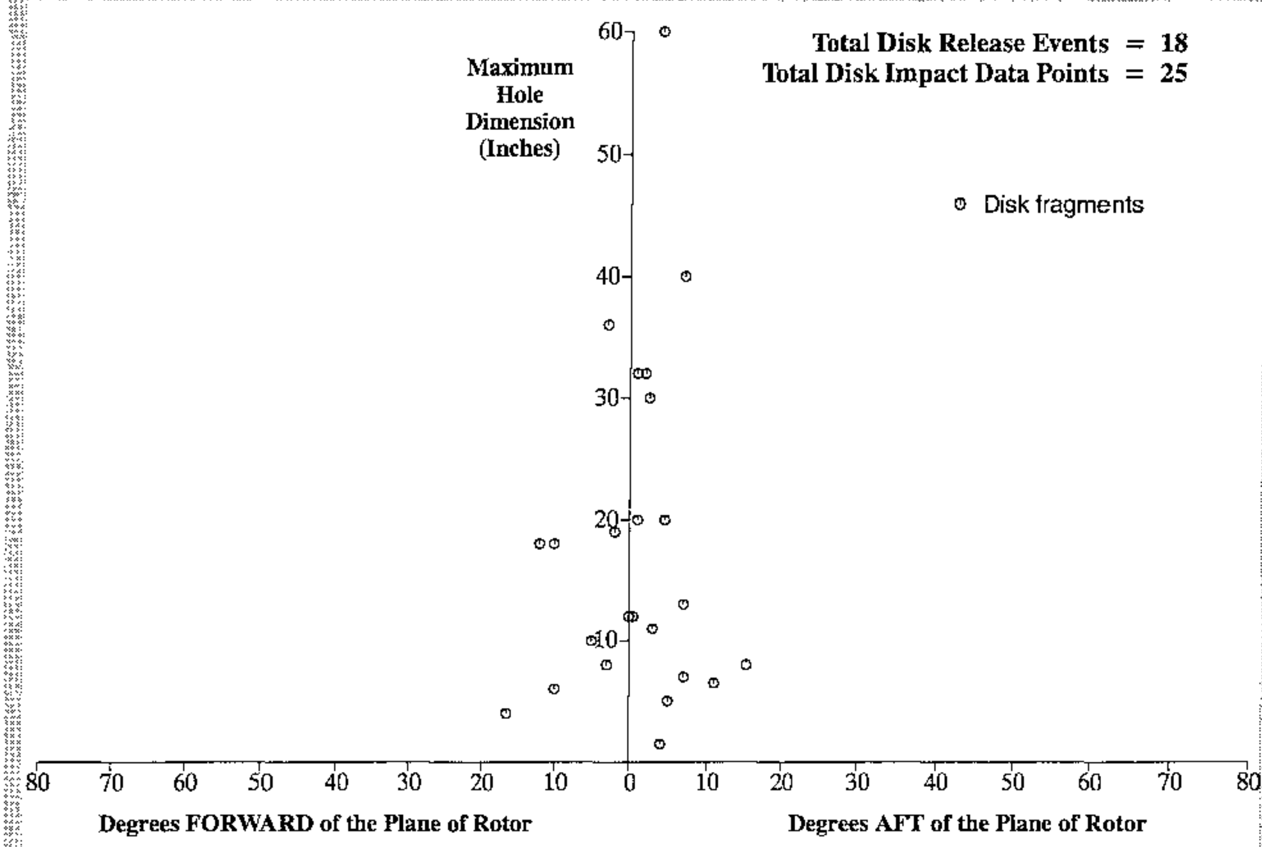


FIGURE 9. Disk Fragment Trajectory versus Hole Size

The forward–most disk penetration at 16.5° forward (event 18, hole 14) measured approximately 4 inches by 4 inches, in the vertical stabilizer of the aircraft (tail–mounted engine). The disk fragment was released from the compressor section of the engine. It is not described in detail.

Photographic evidence indicates multiple pieces of the disk rim were released in the event, measuring in size from about 2 inches in diameter to about 10 inches by 2 inches. It is not known which disk fragment caused this hole.

The furthest aft penetration by a disk fragment, at 15.0° aft (event 16, hole 3), measured 8 inches by 5 inches. The disk rim segment which caused this hole was approximately 20 inches by 2 inches in size, weighing close to 5 pounds. It was released from the high pressure turbine (HPT) section of the engine. The engine manufacturer has estimated the velocity of this fragment to be in the range of 700 feet per second.

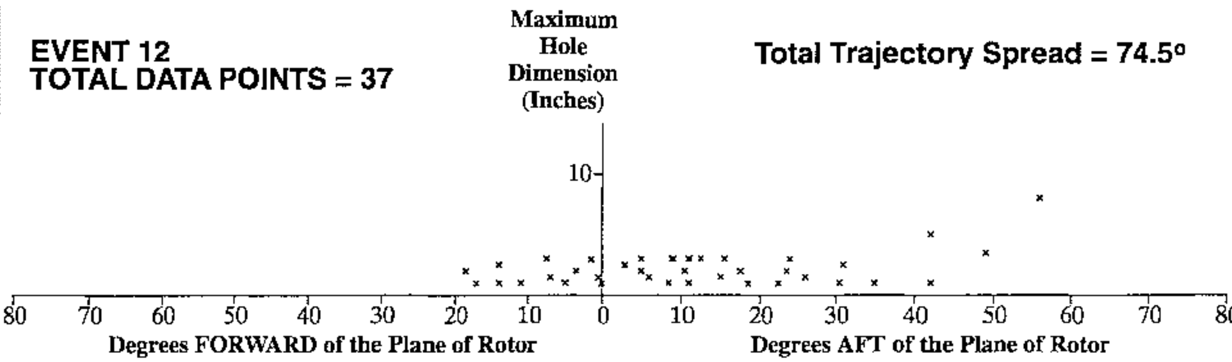


FIGURE 10. Maximum Fragment Trajectory Spread (Single Event)

4.3.4 MAXIMUM FRAGMENT TRAJECTORY SPREAD FOR A SINGLE EVENT

The largest trajectory spread of fragments in one event occurred in event 12, where fragments ejected were spread from 18.5° forward (hole 13) to 56.0° aft (hole 7) (a total debris trajectory spread of 74.5°). Figure 10 contains a graphical summary of this event data. All aircraft penetrations in this event had maximum dimensions of 4 inches or less. There were no disk fragments ejected in this event.

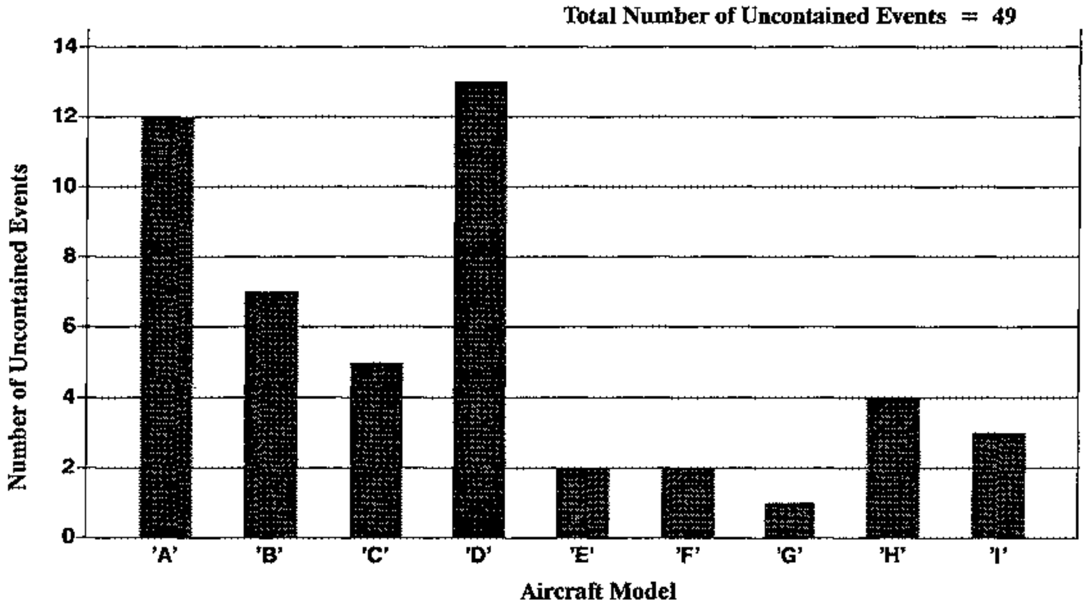


FIGURE 11. Number of Uncontained Events by Aircraft Model**

*****NOTE: This summary chart is not intended to convey the message that some aircraft types are more prone to uncontained disintegrations than others. It is simply a consequence of the availability and reliability of data for each aircraft model, showing the number of events on each aircraft type as documented in this study.*****

4.3.5 FRAGMENT TRAJECTORIES BY AIRPLANE MODEL

The historical record indicates that most aircraft models have experienced uncontained turbine engine disintegrations. In this study, 11 airplane models from four airplane manufacturers were identified in the 50 events used for analysis. The statistical breakdown of the database by aircraft model is found in Figure 11, in bar graph summary format. Specific data plotted by airplane model is contained in Figures E–1 through E–9 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

4.3.6 FRAGMENT TRAJECTORIES BY ENGINE MANUFACTURER

Data collected in this study show that uncontained turbine engine disintegrations are not limited to few engine types or even to one engine manufacturer more than others. Three engine manufacturers were identified in the 49 events used for analysis. Figure 12 (following page) contains a bar graph summary of this data. Specific data plotted by engine manufacturer is contained in Figures E–10 through E–12 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

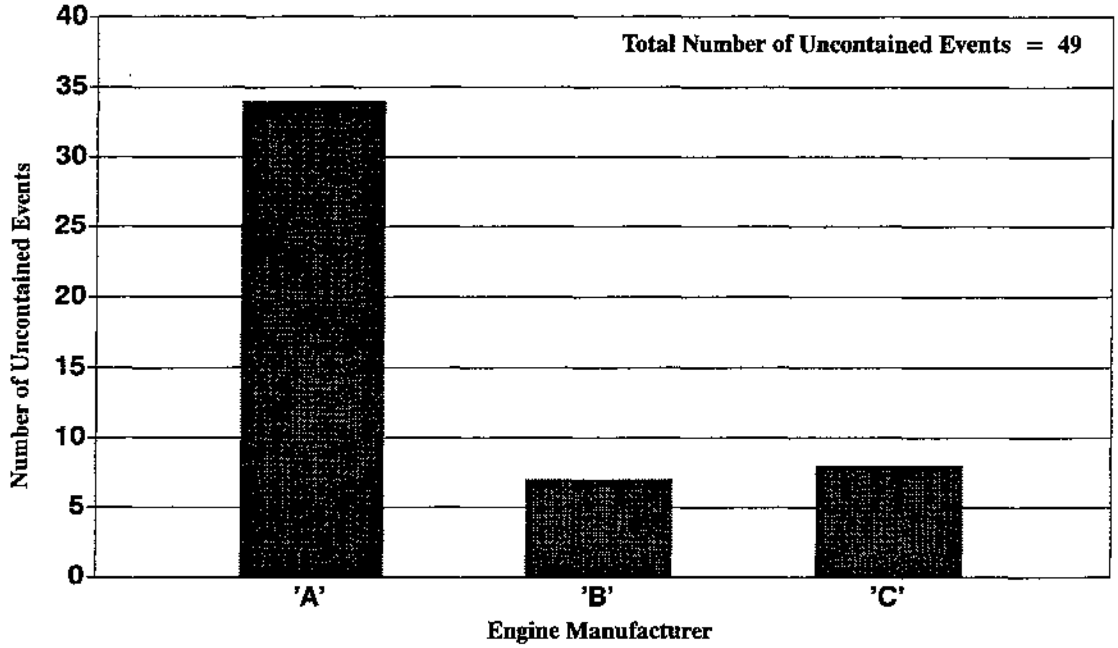


FIGURE 12. Number of Uncontained Events by Engine Manufacturer **

NOTE: This summary chart is not intended to convey the message that some aircraft types are more prone to uncontained disintegrations than others. It is simply a consequence of the availability and reliability of data for each aircraft model, showing the number of events on each aircraft type as documented in this study.

4.3.7 FRAGMENT TRAJECTORIES BY FLIGHT PHASE

The presentation of the Uncontained Turbine Engine Disintegration data from the database can be used to analyze events by flight phase. This is useful in showing the fragment trajectories and impact locations due to flight phase. Figure 13 (following page) summarizes the number of events by flight phase which have been documented in this study. Specific data plotted by flight phase is contained in Figures E–13 through E–17 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

Due to the differences in stresses in the engine at different power settings, it is quite reasonable to assume that hazardous events will occur more often when the engine is at a high power setting (such as takeoff or climb) than at lower settings (such as descent or approach). This assumption is verifiable using the events documented in this study, where 37 of the 49 documented events (75.5%) occurred while engines were at high power settings (takeoff, climb, and top of climb).

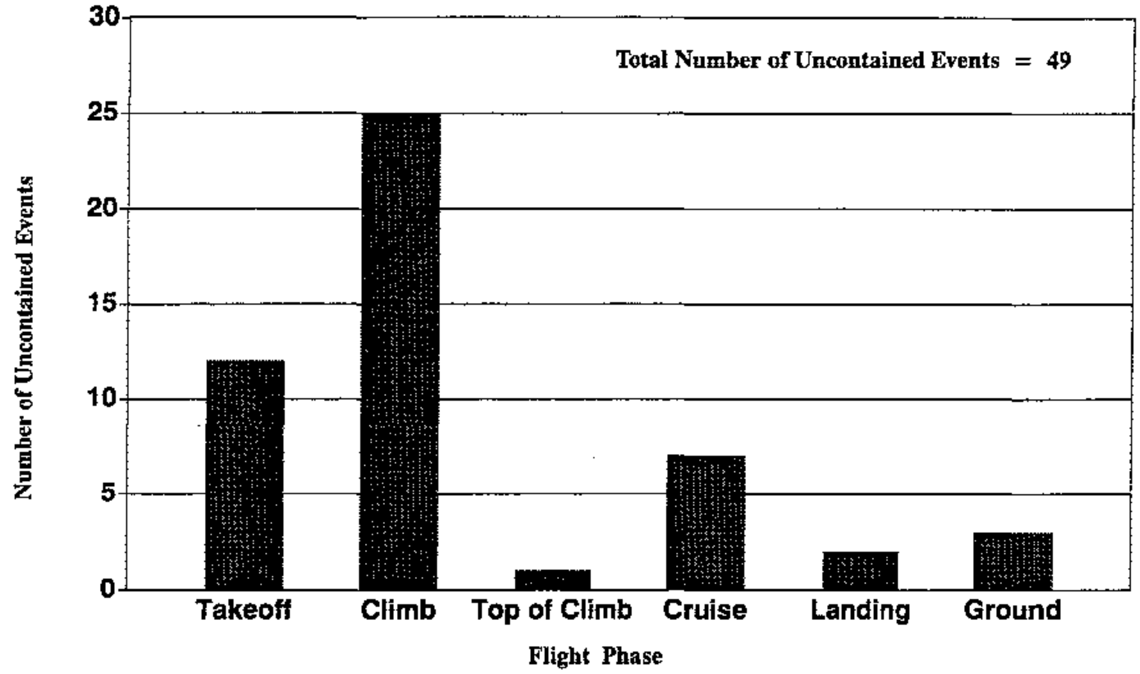


FIGURE 13. Number of Uncontained Events by Flight Phase

No events have been documented during Top of Descent (TOD), Descent, or Approach flight phases. Events which occurred on the ground were either during ground run–up testing (3 events) or during taxi (1 event).

4.3.8 FRAGMENT TRAJECTORIES BY HAZARD LEVEL

The Uncontained Turbine Engine Disintegration data in this study can also be presented based on the "hazard level" associated with each event (as defined by the Continuing Airworthiness Assessment Methodology (CAAM) team). Definitions of CAAM Hazard Levels are found in Appendix D of this report for clarification of this data presentation.

Figure 14 (following page) summarizes the number of events classified in each hazard level which have been documented in this study. Specific data plotted by CAAM hazard level is contained in Figures E–18 through E–20 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

Further analysis shows the fragment trajectories and impact locations for events which are classified by CAAM hazard levels. Figure 15 (following page) repeats the data contained in the database as presented earlier in Figure 8, separated to show the trajectories and hole sizes by

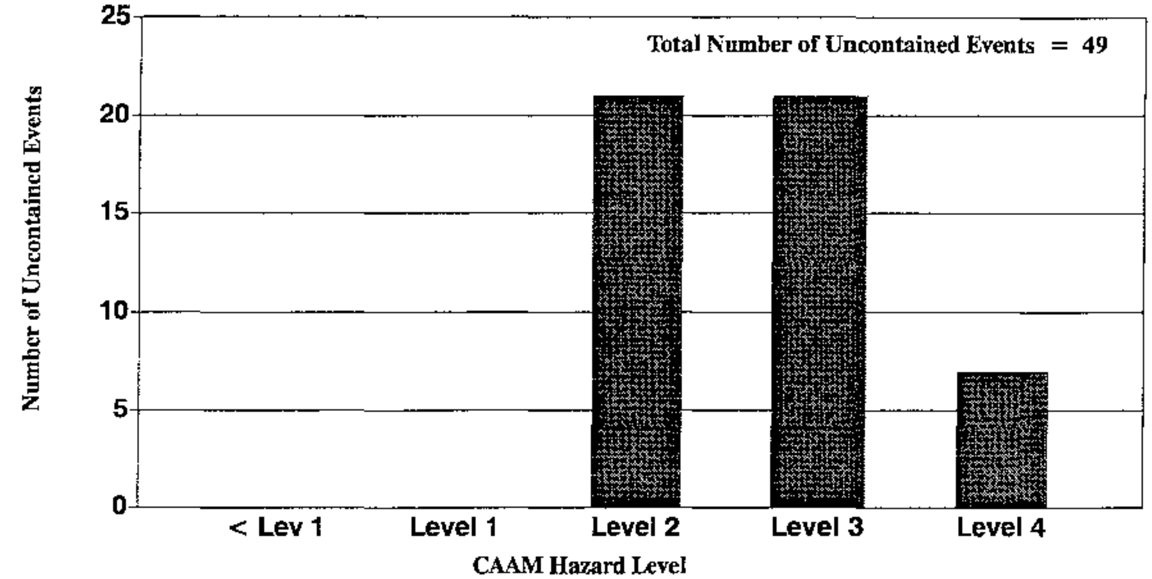


FIGURE 14. Number of Uncontained Events by CAAM Hazard Level

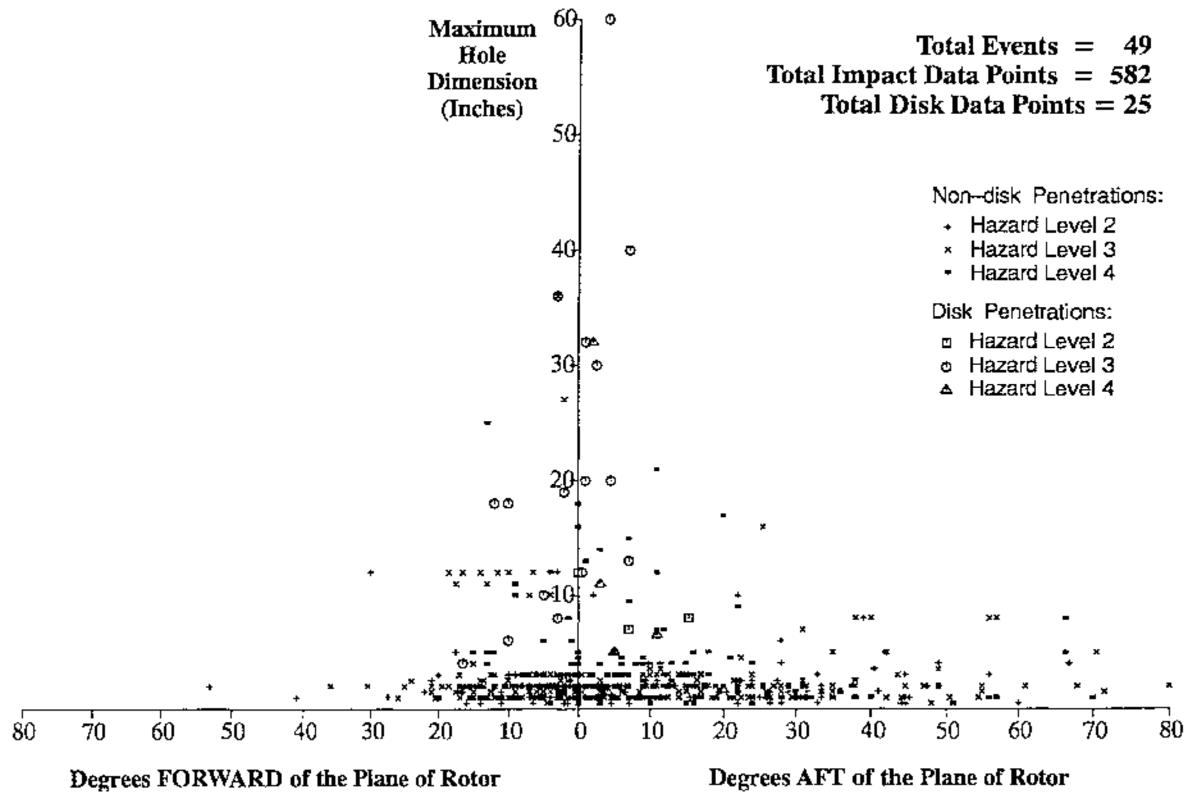


FIGURE 15. Uncontained Trajectories by CAAM Hazard Level

D1 4100 7780 REV. 6/87

CAAM hazard level. The data shown in Figure 15 is contained in the Propulsion Research Uncontained Engine Disintegration Database, and can also be plotted separately to show clearly the trajectories and hole sizes for events of each specific hazard level.

4.3.9 FRAGMENT TRAJECTORIES BY RELATIVE BYPASS RATIO

Further analysis of the data in the Uncontained Turbine Engine Disintegration database can be performed based on whether the engine involved in the event was a high bypass ratio (HBR) or a low bypass ratio (LBR) engine. Information in the database shows that there were twenty–five documented events on LBR engines and twenty–four documented events on HBR engines at the time of this report.

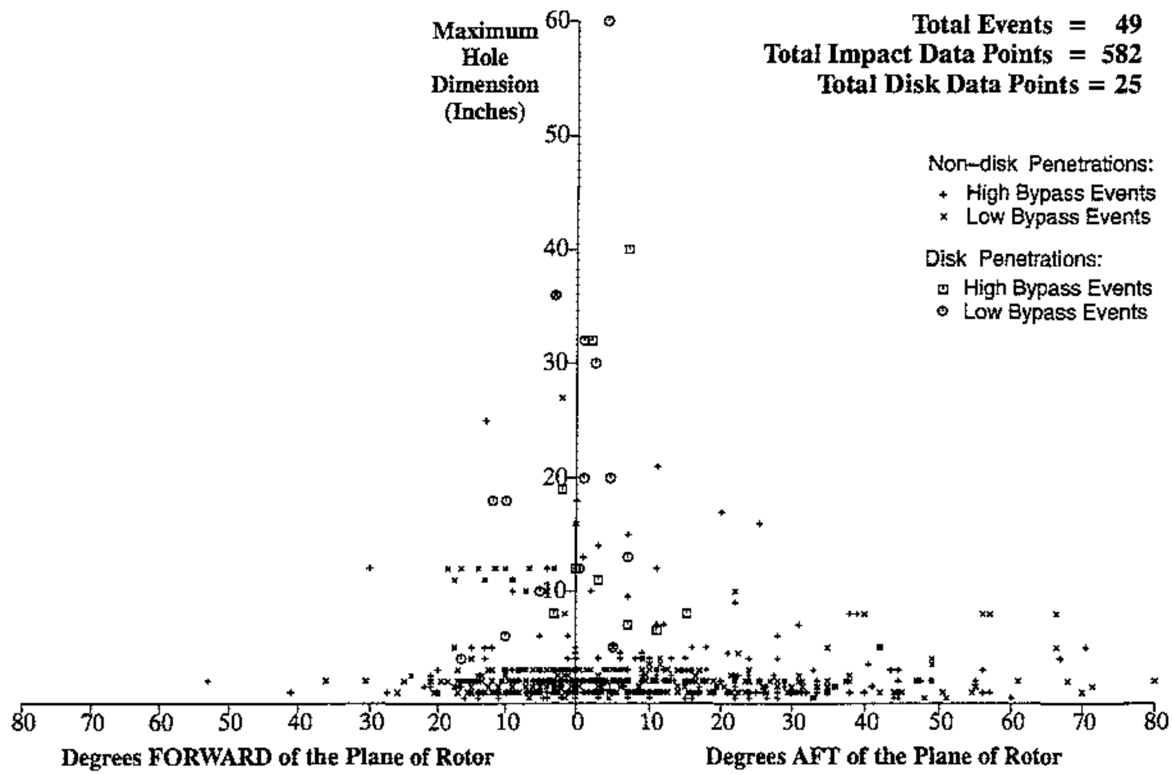


FIGURE 16. Uncontained Trajectories by Relative Bypass Ratio

Figure 16 was extracted from the Uncontained Engine Disintegration Database, once again containing the same data as Figure 8. However, in this instance the data is separated to show a comparison of the fragment trajectories along with respective hole sizes in the aircraft structure due to high bypass ratio engine events and due to low bypass ratio engine events.

4.4 FRAGMENT TRAJECTORIES OF KNOWN FRAGMENTS

Limited fragment size data is available for uncontained turbine engine disintegration events, since in most events the majority of the pieces are not recovered. In addition, even when fragments are recovered it is often difficult to determine which fragment actually caused the noted penetration. However, sufficient information has been collected to create a database containing fragment sizes from twenty eight uncontained disintegration events. In each instance, the maximum dimension of the largest known fragment has been incorporated into the report. Only the LARGEST known fragment from each event has been used in the plot. (This includes only the largest disk fragment if more than one disk fragment was released in a single event.) However, in cases where data exists in a single event for both a disk fragment and a fragment of non–disk origin, the largest fragment of each (disk and non–disk) is included.

There were a total of 36 fragments documented in these 28 events. 20 fragments were of non–disk origins, while the remaining 16 were of disk origins. Figure 17 (following page) shows the trajectories of these fragments by the actual fragment size.

The trajectories of these pieces ranged from 36° forward of the plane of rotor disintegration (event 7, fragment 6) to 56° aft of the plane of rotor disintegration (event 12, fragment 1). The two fragments shown at 66.5° aft of the plane of rotation were the result of a combustor can explosion which caused an aircraft hull loss. Because these fragments were not from a rotating part of the engine, it was decided to show these as separate data points. These data points are represented by the shaded squares in figure 17.

The largest documented fragment ejected in all events was a disk section measuring approximately 60% of the entire disk in event 39. This large fragment did not impact the aircraft, but was recovered from the area where the incident occurred. Because there is no aircraft impact location, the trajectory of this fragment is unknown. The diameter of the disk (and therefore the maximum dimension of the fragment) was 31.4 inches. Figure 17 shows this data point at 0° trajectory, 31.4 inches.

The remaining 40% of the disk in this event split into three major fragments (roughly similar in size to each other). All of these pieces impacted the aircraft in the horizontal stabilizer, and are documented in Appendix A of this report.

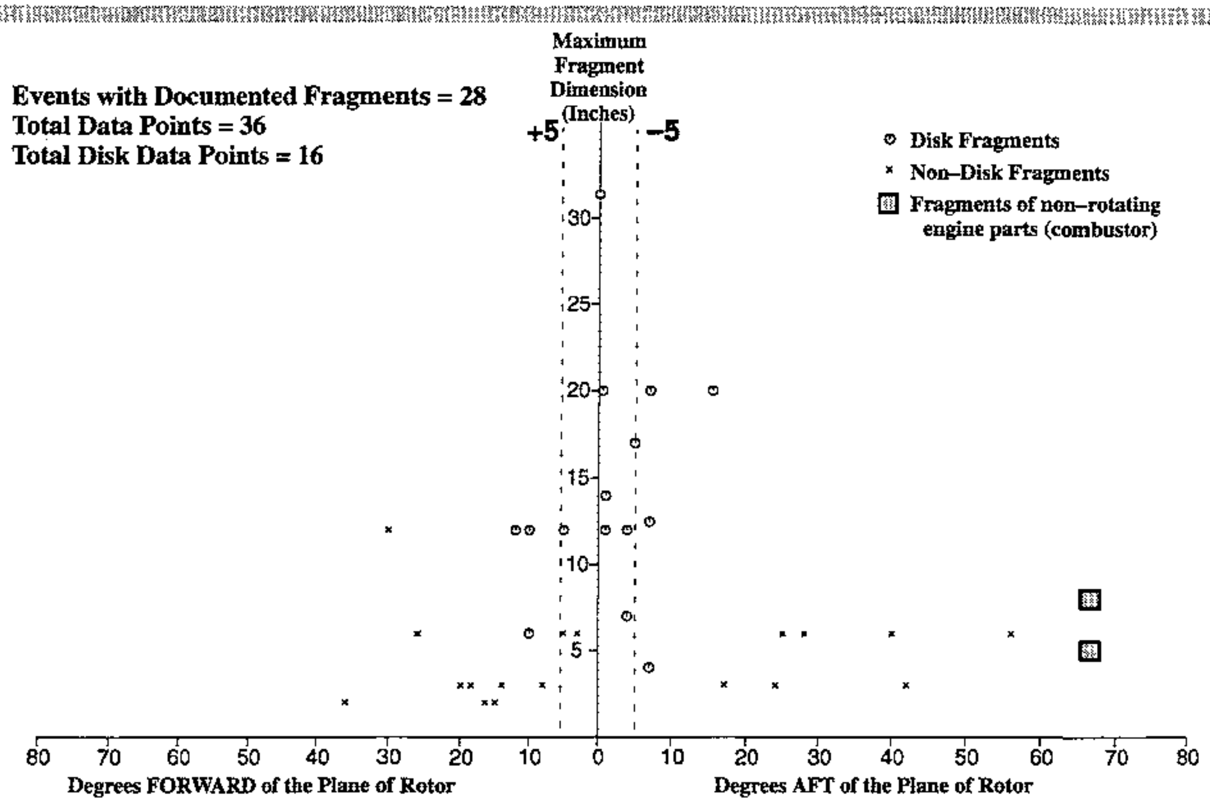


FIGURE 17. Fragment Trajectories of Known Fragments

4.5 FRAGMENT TRAJECTORIES COMPARED WITH CURRENT FAR/JAR REGULATIONS

Current regulations establish a fragment trajectory range for airframe system separation criteria which does not appear to encompass the range of fragment trajectories found in the historical record. The regulations are based on fragment trajectory predictions developed from historical data, much of which has been included in this study. However, the data in this study significantly expands the database upon which the regulations are based. The expanded database shows marked differences between predicted trajectories in the current regulations and historical fact.

Figure 18 (following page) contains a plot showing the data points which have been collected and documented in this study (duplicated from Figure 8), overlaid by dashed lines showing the current regulatory limits. A significant number of trajectory data points, both disk and non–disk, are observed in Figure 18 to lie outside the limits imposed by current regulations. This observation is

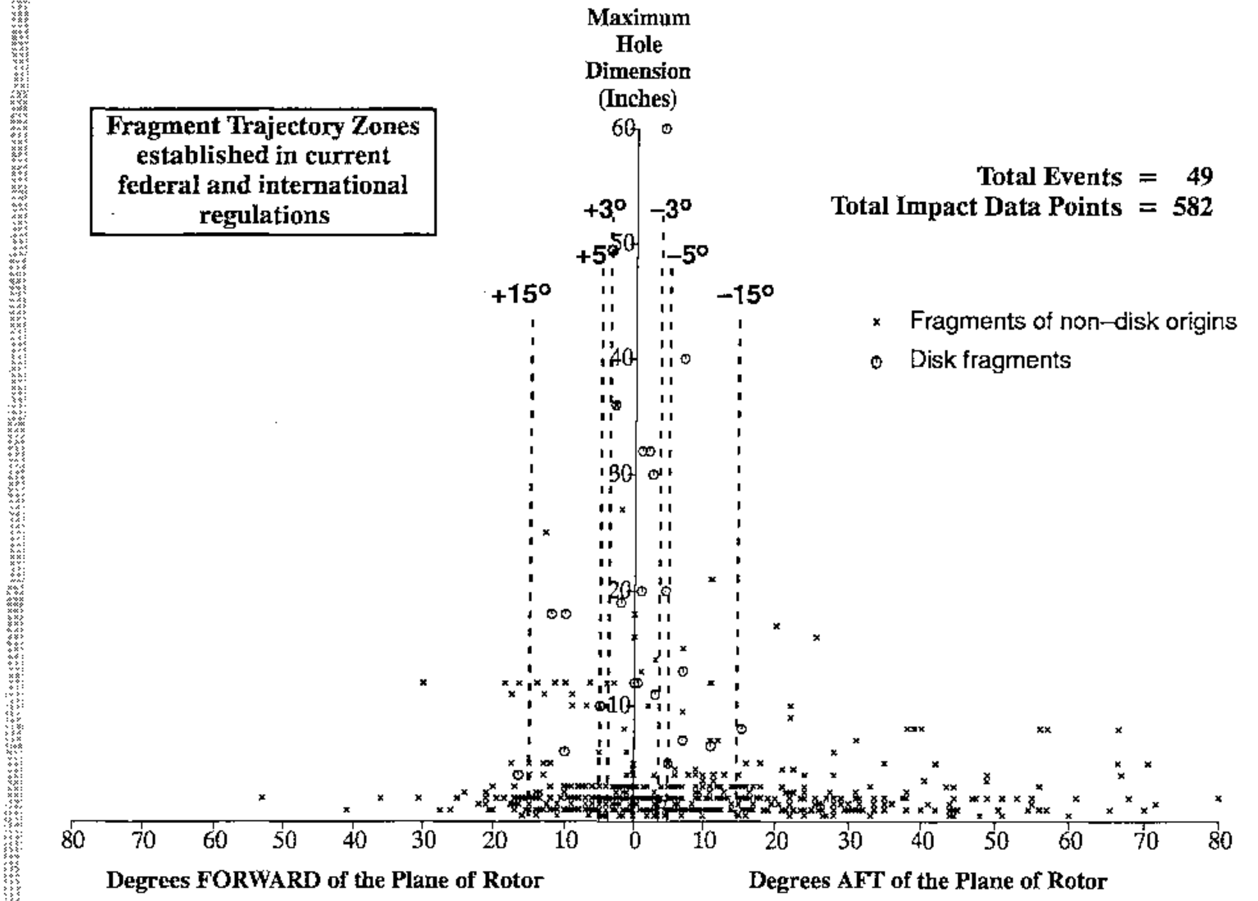


FIGURE 18. Current Trajectory Limits overlaid on Historical Trajectory Data

valid both for penetration trajectory data points *forward* of the plane of the rotor and penetration trajectory data points *aft* of the plane of the rotor.

It is readily apparent from the data shown in figure 18 that a larger number of penetrations have trajectories *AFT* of the plane of rotation than have trajectories *FORWARD* of the plane of rotation, and that the fragments which have aft trajectories generally result in greater trajectory angles than fragments ejected forward. This noticeable rearward shift is presumed to be due to windage effects (drag of released fragments in the airstream). Current regulations do not show compensation for these airstream effects evident in the historical record.

SECTION 5

CONCLUSIONS

5.0 CONCLUSIONS

The results of these studies indicate that refinement of advisory material related to mitigation of the airplane hazards from uncontained engine failures should be undertaken. Internal Boeing Company design related guidance should also be enhanced. The observations and conclusions listed below are presented in order of importance based on the judgment of the authors.

1) In general, the number of airplane damage sites increases with increasing event severity based on Industry–developed severity criteria (SAE–Ad Hoc Committee on Rotor Containment or AIA PC342 Continued Airworthiness Assessment Methodology).

2) In several of the accidents contained within this study, investigation revealed that relatively small fragments caused the critical aircraft damage.

3) The damage (tears and penetrations) sites occur at locations more widely dispersed than envisioned by AC/J 20–128 criteria for both disk and smaller fragments.

4) The majority of damage sites are relatively small, with 81.44% of penetrations 3 inches or less on the major axis.

5) The available data suggests that fragment trajectories and damage are similar for similar uncontained events, whether the engine is a low bypass or a high bypass type, and whether the engine is small or large in terms of thrust class.

6) A significantly larger number of ejected fragments have trajectories *aft* of the plane of the rotor than have trajectories *forward* of the plane of the rotor. The effects of the airstream on the ejected fragments can be used to explain this difference.

5.1 OBSERVATIONS

1) Based on the limited data set available, no conclusions should be drawn concerning differences between specific engine models or specific airplane models. Also, no conclusions should be drawn between respective engine or airframe manufacturers.

2) The data contained in this report is collected for turbojet and turbofan events only. No turboprop propulsion systems events are included.

3) A comparison of this historical record with the current regulations governing the design of commercial aircraft with respect to mitigation of hazard due to uncontained engine disintegrations shows considerable data which does not fit the assumptions made in the current regulations.

5.2 OUTSTANDING ISSUES

1) Critical missing elements in the analysis of uncontained fragments and trajectories are the fragment energy level, dimensions, and mass that caused the airplane damage. To permit more effective design of mitigation systems, additional knowledge concerning fragment characteristics (e.g., energy levels, mass, material, etc.) is needed.

2) Given that a hole occurs in an aircraft structure due to uncontained fragment penetration, there is no currently available calibrated analytical approach which would allow the fragment energy level to be established. Frequently the fragment that made the hole is not reported. A calibrated design system, acceptable to the authorities, is needed which would permit: a) Design of mitigation systems for a known fragment, and b) Calculation of energy level based on knowing the fragment origin, energy, hole dimension, material properties, and other characteristics of interest.

SECTION 6

RECOMMENDATIONS

D1 4100 7780 REV. 6/87

6.0 RECOMMENDATIONS

1) The separation of critical airplane systems should consider the damage site dimension set forth in Figure 19. It is recommended that critical airplane system separation be continued beyond current regulatory boundaries in order to further minimize the potential impact of uncontained failures on continued safe flight and landing.

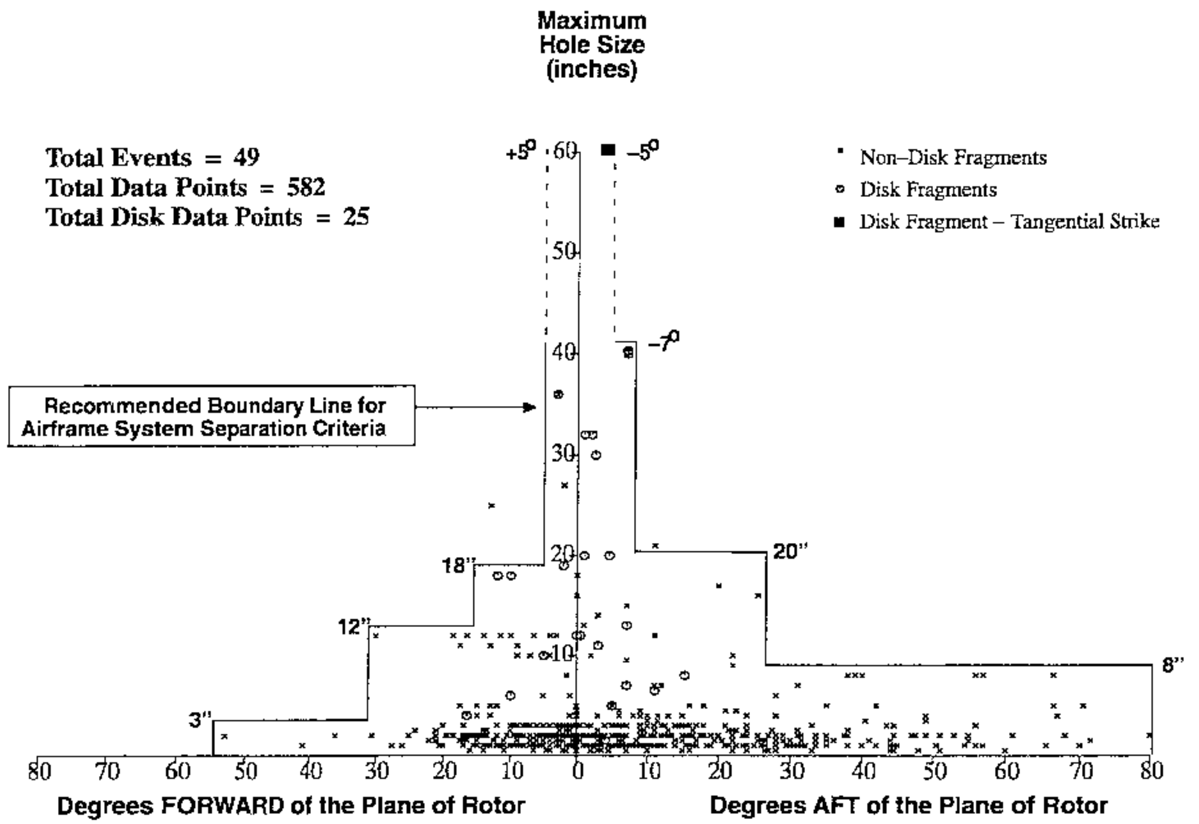


FIGURE 19. Recommended Boundary for Airframe Systems Separation Criteria Based on Penetration Sizes

2) The protection of critical systems elements, by use of existing structure elements for shielding, should be considered in the light of the multiple fragment threat.

3) The selection of advanced materials for airframe structure and/or skins should consider the relative performance of the new material versus current materials from the aspect of resisting penetration by uncontained engine fragments. A reduction in penetration resistance should be considered as a potential reduction in current aircraft safety levels.

D1 4100 7780 REV. 6/87

4) Opportunities to combine functions with fragment energy reduction capabilities should be sought (e.g., passenger cabin acoustic liner material with ballistic energy reduction).

5) Engine manufacturers should be encouraged to share uncontained fragment debris information and estimates early in the airplane design phase to permit minimization of the hazard from uncontained engine failures.

6.1 AVAILABILITY OF ADDITIONAL INFORMATION

The BCAG Propulsion Safety Advocate controls the data in the Uncontained Turbine Engine Disintegration database, currently held in the Propulsion Research organization. Additional analysis may be performed using the data in this database. Requests for additional analysis must be coordinated through the Safety Advocate. Further questions concerning the information contained in this report should be addressed to the BCAG Propulsion Research Safety Advocate.

Appendix A

Uncontained Engine Debris Trajectory Data Individual Event Records

Appendix A – Table of Contents

1.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Power Level: **EPR 1.48**
Flight Phase: **Cruise** Altitude: **FL250**
Flight Effect: **Diversion–Accident** Airspeed: **0.85M**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−38.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
2	Unknown					−38.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
3	Unknown					−36.0	Fuselage (low)	1.5" x 1"	Fuselage Penetration	None noted
4	Unknown					−35.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
5	Unknown					−35.0	Inboard Aileron	1.5" x 0.25"	Inboard Aileron Cut	None noted
6	Unknown					−33.5	Fuselage (low)	1.5" x 0.5"	Fuselage Penetration	None noted
7	Unknown					−31.5	Fuselage (low)	2" x 0.5"	Fuselage Penetration	None noted
8	Unknown					−31.0	Fuselage (low)	2" x 1"	Cargo Compartment Penetration	None noted
9	Unknown					−31.0	Fuselage (mid)	1" x 0.5"	Fuselage Penetration	None noted
10	Unknown					−29.5	Aft Cargo Door	1" x 1"	Cargo Door Penetration	None noted
11	Unknown					−27.0	Aft Cargo Door	2" x 0.75"	Cargo Door Slice (Penetration)	None noted
12	Unknown					−25.5	Inbd Flap Lower	2" x 1"	T.E. Flap Lower Skin Penetration	None noted
13	Unknown					−23.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
14	Unknown					−22.0	Inboard Aileron	2" x 1.5"	Inboard Aileron Penetration	None noted
15	Unknown					−22.0	Fuselage (low)	2.5" x 1"	Cargo Compartment Penetration	None noted
16	Unknown					−21.5	Inboard Aileron	1" x 1"	Inboard Aileron Penetration	None noted
17	Unknown					−21.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
18	Unknown					−19.0	Wing–to–Body Fairing	1" x 0.75"	Fairing Penetration	None noted
19	Unknown					−18.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
20	Unknown					−17.0	Wing–to–Body Fairing	3" x 1.5"	Fairing Penetration	None noted
21	Unknown					−17.0	Wing–to–Body Fairing	1" x 1"	Fairing Penetration	None noted
22	Unknown					−16.5	Wing Lower	2" x 0.5"	Wing Lower Skin Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
23	Unknown					−16.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
24	Unknown					−15.0	Wing–to–Body Fairing	3" x 1"	Fairing Penetration	None noted
25	Unknown					−15.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
26	Unknown					−14.0	Wing–to–Body Fairing	3" x 1.5"	Fairing Penetration	None noted
27	Unknown					−14.0	Wing–to–Body Fairing	1.5" x 1"	Fairing Cut	None noted
28	Unknown					−14.0	Wing–to–Body Fairing	1" x 0.5"	Fairing Penetration	None noted
29	Unknown					−12.5	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
30	Unknown					−12.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
31	Unknown					−12.0	Wing–to–Body Fairing	1" x 1"	Fairing Penetration	None noted
32	Unknown					−11.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
33	Unknown					−10.5	Wing Lower	1" x 0.25"	Wing Lower Skin Tear	None noted
34	Unknown					−9.5	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
35	Unknown					−9.5	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
36	Unknown					−9.0	MLG Door	2" x 0.25"	Main Landing Gear Door Cut	None noted
37	Unknown					−9.0	MLG Door	1" x 1"	MLG Door Penetration	None noted
38	Unknown					−7.5	MLG Door	1" x 1"	MLG Door Penetration	None noted
39	Unknown					−7.0	Fuselage (mid)	2" x 1.5"	Fuselage Penetration	Window entry; Hot Fragment burned hole in carpet
40	Unknown					−7.0	MLG Door	1" x 0.5"	MLG Door Penetration	None noted
41	Unknown					−5.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
42	Unknown					−5.0	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
43	Unknown					−5.0	MLG Door	1" x 1"	MLG Door Penetration	None noted
44	Unknown					−4.5	Wing–to–Body Fairing	1" x 0.5"	Fairing Penetration	None noted
45	Unknown					−3.5	Wing–to–Body Fairing	2" x 0.5"	Fairing Cut	None noted
46	Unknown					−3.5	MLG Door	1" x 0.75"	MLG Door Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.3 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
47	Unknown					−3.0	Wing-to-Body Fairing	2" x 1"	Fairing Penetration	None noted
48	Unknown					−3.0	MLG Door	1.5" x 1"	MLG Door Penetration	None noted
49	Unknown					−3.0	Wing Lower	0.5" x 1"	Wing Lower Skin Penetration	None noted
50	Unknown					−2.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
51	Unknown					−1.5	Wing Lower	2" x 0.25"	Wing Lower Skin Penetration	None noted
52	Unknown					−0.5	MLG Door	2" x 0.5"	Main Landing Gear Door Cut	None noted
53	Unknown					0	Wing Lower	1" x 0.75"	Wing Lower Skin Penetration	None noted
54	Unknown					9.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
55	Unknown					9.0	Fuselage (low)	1" x 1"	Fuselage Penetration	None noted
56	Unknown					9.0	Fuselage (low)	1.5" x 0.5"	Fuselage Cut	None noted
57	Unknown					8.5	Wing Lower	1" x 0.5"	Wing Lower Skin Cut	None noted
58	Unknown					8.0	Wing Lower	1" x 0.5"	Wing Lower Skin Cut	None noted
59	Unknown					7.0	Fuselage (low)	1.5" x 0.5"	Fuselage Cut	None noted
60	Unknown					6.5	MLG Door	1" x 1"	Main Landing Gear Door Cut	None noted
61	Unknown					6.0	MLG Door	1" x 0.75"	MLG Door Penetration	None noted
62	Unknown					6.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
63	Unknown					6.0	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
64	Unknown					5.5	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
65	Unknown					5.0	Wing Lower	3" x 1.5"	Wing Lower Skin Penetration	None noted
66	Unknown					5.0	MLG Door	2" x 1"	MLG Door Penetration	None noted
67	Unknown					5.0	MLG Door	1.5" x 1"	MLG Door Penetration	None noted
68	Unknown					4.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
69	Unknown					4.0	MLG Door	2" x 1"	MLG Door Penetration	None noted
70	Unknown					3.0	MLG Door	2" x 0.75"	MLG Door Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.

† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.4 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
71	Unknown					3.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
72	Unknown					2.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
73	Unknown					2.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
74	Unknown					1.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
75	Unknown					1.5	Fuselage (low)	1" x 1"	Fuselage Penetration	None noted
76	Unknown					1.0	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
77	Unknown					0.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
78	Unknown					0.0	Fuselage (low)	1" x 0.5"	Fuselage Penetration	None noted
79	Disk Fragment					-4.5	Wing Lower	20" x 3"	Large Cut In Lower Wing Skin	Destroyed most of Front Spar at WSTA 635
80	Disk Fragment					-2.5	Wing Lower	30" x 3"	Large Cut In Lower Wing Skin	None noted.
81	Disk Fragment					3.0	Wing Lower	36" x 2"	Large Cut in Fuel Tank Access Cover	Fuel Tank Penetration; Fuel Leak

NARRATIVE: **During cruise the #1 engine disintegrated. Probable cause was the failure of the #2 bearing, resulting in Low Pressure Turbine (LPT) disintegration. Multiple disk fragments were liberated, with three large disk segments (fragments 79, 80, and 81) contacting the aircraft wing. One of these opened a hole in the fuel tank, resulting in a fuel leak. One turbine blade fragment (fragment 39) penetrated the passenger cabin through a window, hit the interior wall on the opposite side, and fell to the floor, burning a hole in the carpet. Numerous small pieces penetrated the cargo compartment. Multiple shrapnel penetrations were found on the lower wing surface in the general area of the #1 engine. Several holes were found in the left main landing gear door. The aft portion of the wing-to-body fairing had 30 to 40 small holes ranging up to 2" in maximum dimension. Inboard aileron had several (around 10) small holes of the same general size. Additional fragment impacts were noted in files concerning multiple dents and scratches which did not penetrate the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: n/a

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 78 were typical blade fragments, averaging approximately 1/4 lb. in weight and measuring an average 2"x3" in size. These fragments were indicated to be 2nd and 3rd stage tri hub fracture fragments, released at an estimated average velocity of 700 ft/sec. Disk fragment sizes were not specified, but trajectories were confirmed.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

2.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **2nd, 4th, and 5th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−6.5	Fuselage (low)	3" x 1"	Fuselage Penetration	None noted
2	Unknown					−5.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
3	Unknown					−5.0	Fuselage (low)	1" x 0.5"	Fuselage Penetration	None noted
4	Unknown					−2.0	Wing Lower	3" x 0.5"	Wing Lower Skin Cut	None noted
5	Unknown					−1.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					19.5	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	None noted
7	Unknown					18.5	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
8	Unknown					17.5	Wing L.E.	11" x 3"	Wing Leading Edge Cut	None noted
9	Unknown					17.0	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	None noted
10	Unknown					17.0	Wing-to-Body Fairing	1.5" x 1"	Fairing Penetration	None noted
11	Unknown					16.5	Wing L.E.	12" x 3.5"	Wing Leading Edge Cut	None noted
12	Unknown					15.0	Wing Lower	2"x 0.5"	Wing Lower Skin Cut	None noted
13	Unknown					15.0	#2 Eng Cowl	1" x 1"	#2 Engine Cowl Penetration	None noted
14	Unknown					14.0	Wing L.E.	12" x 2.5"	Wing Leading Edge Cut	None noted
15	Unknown					13.5	Fuselage (low)	2.5" x 0.5"	Fuselage Penetration	None noted
16	Unknown					13.0	Wing L.E.	11" x 3"	Wing Leading Edge Cut	None noted
17	Unknown					11.5	Wing L.E.	12" x 4"	Wing Leading Edge Cut	None noted
18	Unknown					10.0	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
19	Unknown					9.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
20	Unknown					9.5	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
21	Unknown					9.0	Wing L.E.	11" x 2"	Wing Leading Edge Cut	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

2.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **2nd, 4th, and 5th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
22	Unknown					8.5	Wing-to-Body Fairing	2" x 1"	Fairing Penetration	None noted
23	Unknown					8.5	Wing-to-Body Fairing	1" x 1"	Fairing Penetration	None noted
24	Unknown					7.0	Wing L.E.	10" x 2.5"	Wing Leading Edge Cut	None noted
25	Unknown					6.5	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
26	Unknown					6.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
27	Unknown					5.5	Wing Lower	1" x 0.75"	Wing Lower Skin Penetration	None noted
28	Unknown					3.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
29	Unknown					3.0	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
30	Unknown					2.0	Wing-to-Body Fairing	3" x 1.5"	Fairing Penetration	None noted
31	Unknown					1.5	Wing Lower	2.5" x 0.5"	Wing Lower Skin Cut	None noted
32	Unknown					0.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **Aircraft experienced a 3rd stage compressor failure on the #1 engine during takeoff and aborted. All blades were shed from the 2nd through 5th stages after blade fatigue failure of at least one 3rd stage blade (probably blade #24). The compressor case ruptured over about 270°. The inboard side of the #1 strut had a vertical buckle in the skin. Numerous nicks and scratches were found in the lower surface skin of the wing. The wing-to-body fairing was penetrated in several places. One puncture was found in the fuselage skin aft and below the wing trailing edge. Most of the damage was minor (dents and scratches). Ten holes were found in the wing leading edge control surface between the #1 and #2 engines. In addition some fragments were ejected through the tailpipe, resulting in trailing edge control surface damage.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 32 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average 2"x3" in size. These fragments were from compressor stages 2 through 4, and were released at an estimated average velocity of 700 ft/sec. The release of these fragments caused a "buzz saw" effect on the engine. Additionally, the engine manufacturer indicates that a stator spinner (?) fragment was released, measuring approximately 3"x20" and traveling at an estimated 200 ft/sec. No estimated weight was given, and there is no indication in the engine manufacturer's material as to whether the fragment impacted the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

3.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Power Level: **Unknown**
Flight Phase: **Climb** Altitude: **FL008**
Flight Effect: **Diversion–Accident** Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Disk/Blades/Vanes**

SECONDARY MALFUNCTION (Rotor Stages): **1st, 2nd, and 4th Stage Turbine – Blades and Vanes**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−1.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
2	Unknown					−0.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					8.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					7.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
5	Unknown					6.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					5.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					4.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					3.5	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
9	Unknown					3.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
10	Unknown					2.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
11	Unknown					2.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
12	Unknown					0.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
13	Disk Segment	8" x 14"		3rd Stg		−1.0	Wing Lower	32" x 8"	Fuel Tank Penetration	Fuel Fire

NARRATIVE: **The aircraft experienced an explosive disintegration of the 3rd stage turbine disk on the #4 engine during initial climb at about 800 feet. This disintegration resulted in the shedding of all blades and vanes from the 3rd stage. The 1st, 2nd and 4th stages disintegrated following the 3rd stage. Almost immediately a fuel fire started in the area of the #4 engine, followed by an explosion in the area of the outboard reserve fuel tank. The #4 engine and about 25 feet of the wing separated from the aircraft. The fire was extinguished inflight and an emergency landing was made at an alternate airport. No injuries were reported. The probable cause of the accident was the failure of the 3rd stage disk due to a transient loss of operating clearance between the 3rd stage disk and the inner sealing ring. At least 4 sections of turbine disk were released, with at least one fragment contacting the wing lower surface, resulting in the fuel leak and fire. The portion of the wing which separated was mostly recovered, but fire damage and impact damage combined to make it impossible to determine additional fragment impacts on this section.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 12 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average of 2"x3" in size. These fragments were from 3rd stage turbine blades and vanes, and were released at an estimated average velocity of 500 ft/sec. Fragment 13 was a disk segment as shown, released with a velocity of approximately 700 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

4.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−40.0	BSTA 1183	8" x 3"	Fuselage Penetration	Dented Hydraulic Line and Fuel Feed Line
2	Unknown					−35.0	Fuselage	5" x 4"	Fuselage Penetration	None noted
3	Unknown					−22.5	BSTA 1166	4.5" x 2"	Fuselage Cut	None noted
4	Disk Segment					5.0	BSTA 1148	10" x 7"	Fuselage Penetration	None noted
5	Disk Segment					−4.0	BSTA 1153	60" x 5"	#2 Engine Inlet Duct Penetration	FOD Damage to #2 Engine Compressor

NARRATIVE: **The #1 engine experienced an uncontained failure of the 2nd stage fan disk during takeoff, followed by failure of the #2 engine (due to FOD caused by #1 engine). The crew aborted the takeoff and successfully stopped the aircraft. No fire or injuries were reported. One large disk segment (Fragment 5) from the #1 engine penetrated the #2 engine inlet duct. Fragments entered the #2 engine, causing severe damage to the compressor section. Another large fragment (Fragment 1) severed four fuselage stringers and dented hydraulic return lines and fuel feed lines. Limited information is contained in the files concerning damage from other fragments, although it is evident that multiple fragments were released from the #1 engine during the event.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 3 were blade segments, averaging approximately 1/2 lb. in weight and measuring an average 3"x6" in size. Fragments 4 and 5 are indicated to be disk segments, each measuring 3"x12" and weighing approximately 10 lbs. All fragments shown were released from the fan 2nd stage, and according to estimates were liberated at a velocity of around 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

5.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL045**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **LP Compressor Torque Ring released – Maintenance Error**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					12.5° (est)	BSTA 835	3"x1"	Hole in Fuselage	None noted
2	Unknown					Unk*	Unk*		Not Given	None noted
3	Unknown					Unk*	Unk*		Not Given	None noted
4	Unknown					Unk*	Unk*		Not Given	None noted
5	Unknown					Unk*	Unk*		Not Given	None noted
6	Unknown					Unk*	Unk*		Not Given	None noted
7	Unknown					Unk*	Unk*		Not Given	None noted
8	Unknown					Unk*	Unk*		Not Given	None noted
9	Unknown					Unk*	Unk*		Not Given	None noted
10	Unknown					Unk*	Unk*		Not Given	None noted
11	Unknown					Unk*	Unk*		Not Given	None noted
12	Unknown					Unk*	Unk*		Not Given	None noted
13	Unknown					Unk*	Unk*		Not Given	None noted

NARRATIVE: **During climb at 4500 feet the #1 engine exploded and fire ensued. The aircraft made an emergency landing. Aircraft sustained substantial damage to the #1 engine and pylon, the underside of the left wing (mostly inboard of #1 engine), and the #2 engine pylon. Shrapnel–like penetrations were found in all the areas listed. A small hole was found in the fuselage at BSTA 835. A stator vane penetrated the #2 engine pylon and ruptured a hydraulic line. Twelve other pieces penetrated the #2 engine thrust reverser pneumatic retract line. Investigation determined that the LP compressor torque ring was not properly secured in place during overhaul. As a result, when the restraining effect of the tight fit of the ring and the three borescope inspection ports was overcome by the normal rotational forces within the compressor, the stator assembly and torque ring began to turn. At high rotational speed the torque ring bearing on the LP compressor case literally ground through the case until the case disintegrated with explosive force. No portion of the torque ring was ever found.**

Insufficient information has been found to determine the locations of the penetrations exactly at this time. No useful drawing of the airplane has been found as well. Because of these difficulties it has not been possible to calculate the trajectories of fragments ejected during the event, nor to tabulate the fragments into useful data.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

6.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **HP Compressor 7th Stage Stator Vanes**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a		

NARRATIVE: **There were no documented aircraft structural penetrations due to uncontained engine debris in this event. Uncontained fragments were released, severing a fuel line in the #3 engine pylon. The resulting fuel fire significantly damaged the aircraft empennage, and the aircraft was considered a hull loss.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **None available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

7.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **14th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown	Unk	Unk	14th Stg		-7.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown	Unk	Unk	14th Stg		-5.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown	Unk	Unk	14th Stg		-3.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					-1.5	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
5	Unknown					0.0	Fuselage (low)	2" x 0.5"	Lower Fuselage Penetration	None noted
6	Unknown					36.0	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
7	Unknown					30.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
8	Unknown					24.0	Fuselage (mid)	2.5" x 1"	Fuselage Penetration	None noted
9	Unknown					21.0	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
10	Unknown					17.5	Wing Lower	1.5" x 0.25"	Wing Lower Skin Cut	None noted
11	Unknown					15.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
12	Unknown					12.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
13	Unknown					9.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
14	Unknown					8.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
15	Unknown					6.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
16	Unknown					3.0	Wing Lower	2" x 0.25"	Wing Lower Skin Penetration	None noted
17	Unknown					2.0	Fuselage (low)	1.5" x 0.5"	Lower Fuselage Penetration	None noted
18	Disk Fragment					-7.0	Wing Lower	13" x 4"	Fuel Tank Penetration	Fuel Leak and Fire
19	Disk Fragment					10.0	Cabin Window	6" x 5"	Cabin Window Penetration	Window Shattered

NARRATIVE: **14th stage compressor disk fractured during takeoff roll. Fragment 18 penetrated the RH wing front spar at WSTA 250.0, causing an irregular hole in the #3 fuel tank. Fire started almost immediately. Fragment 19 penetrated the passenger cabin through a cabin window, causing injuries to passengers due to shattered glass. Shrapnel fragments from the #3 engine caused numerous dents and scratches (in addition to the holes noted) on the underside of the RH wing , on the RH side of the fuselage, and FOD to #2 engine. Crew aborted the takeoff. Substantial fire damage occurred on the right side of the aircraft in the area of the #3 engine due to fuel tank penetration by fragment 18.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 17 were typical blade segments, averaging less than 1/4 lb. in weight and measuring an average 1"x2" in size. Fragment 18 was a disk segment as shown, measuring 3"x4" and weighing about 1/2 lb. Fragment 19 was also a disk segment, measuring 12"x6" and weighing approximately 6 lbs. The engine manufacturer estimates that the velocity of all of the fragments shown was in the range of 500 ft/sec. All fragments were ejected from the compressor 14th stage.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

8.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Power Level: **Unknown**
Flight Phase: **Climb** Altitude: **Unknown**
Flight Effect: **Air Turn Back–Accident** Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **5th Stage LP Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **LP Compressor 4/5 Spacer Ring, 5/6 Spacer Ring**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a		

NARRATIVE: **The 5th stage disk of the LP compressor on the #2 engine failed during initial climb. Engine pieces exited the engine cowling but apparently did not contact the aircraft. Pieces of the disk rim and blades penetrated the right side of the compressor case and severed the main fuel line on the #2 engine. This allowed free flow of fuel around the engine pod. The fuel ignited, the engine separated, and the aircraft returned. Fire continued to burn after landing, resulting in 5 fatalities.**

The LP compressor 5th stage disk rim had separated into at least three parts, two of which were later recovered. Both the 4/5 and the 5/6 spacers were found along the flight path near the fallen engine. There was no evidence of wing impact by fragments, but the engine itself showed considerable secondary damage. Multiple blade and vane fragments were found along the flight path, along with the main fuel feed pipe. Examination showed that the fuel feed pipe was displaced by the bursting of the LP compressor disk rim and casing on the left side of the engine. No conclusive evidence was found concerning fragment impacts on the aircraft.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

9.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**
Power Level: **Unknown**
Altitude: **FL120**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Turbine Section (No Further Information)**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−57.0	Fuel Access Plate	8" x 3"	Reserve Fuel Tank Access Plate Penetration	Fuel Leak and Fire
2	Unknown					−80.0	Horizontal Stabilizer	2" x 1"	Horizontal Stabilizer Lower Skin Penetration	None noted
3	Unknown					−71.5	Outbd Aileron	1.5" x 1"	Outboard Aileron Penetration	None noted
4	Unknown					−68.0	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
5	Unknown					−61.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					−55.0	Wing Lower	1.5" x 0.5"	Wing Lower Skin Cut	None noted
7	Unknown					−54.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					−49.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					−48.0	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					−47.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **During climb at FL120 a loud bang was heard by the crew. The #4 engine turbine section had disintegrated, resulting in a fuel fire. The fire was extinguished by the extinguisher bottles. Debris from the disintegrated engine damaged the aircraft in several places, most notably in the lower wing skin near the #4 engine. One fragment penetrated the #4 access plate of the right hand reserve fuel tank. The outboard aileron was damaged by shrapnel, as was the lower skin of the right hand horizontal stabilizer. Multiple dents and scratches were found in the aircraft as well, mostly in the area of the #4 engine.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not disclosed any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

D1 4100 7780 REV. 6/87

10.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **70 Kts**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					26.0	#2 Eng Cowl at BSTA 1120	1" x 1"	#2 Engine Cowl Penetration	#2 Eng S-Duct Damage
2	Unknown					25.0	Fuselage	2" x 1"	Fuselage Penetration	None noted
3	Unknown					20.5	#2 Eng Cowl	1" x 0.5"	#2 Engine Cowl Cut	None noted
4	Unknown					17.5	Fuselage	1.5" x 1"	Fuselage Cut	None noted
5	Disk Segment					12.0	Fuselage at BSTA 1152	18" x 4"	Fuselage Penetration	None noted
6	Unknown					12.0	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	#2 Eng S-Duct Damage
7	Unknown					12.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
8	Unknown					9.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
9	Unknown					8.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
10	Unknown					6.0	#2 Eng Cowl	1" x 1"	#2 Engine Cowl Penetration	#2 Eng S-Duct Damage

NARRATIVE: **The 2nd stage compressor disintegrated during takeoff roll at 70 knots. The compressor departed the aircraft, releasing multiple blade shrapnel and associated debris. Several fragments contacted the #2 engine inlet duct, with at least four fragments (Fragment 1, Fragment 3, Fragment 6, and Fragment 10) penetrating the S-duct. A large hole was torn in the fuselage by Fragment 5. A fuel fire was started when the fuel control unit was severed by an undisclosed fragment. In addition the oil cooler was fractured and separated from the engine. The underside of the #3 engine strut, the aft right side of the #2 engine cowl, and the lower rudder were severely damaged by the fire. The takeoff was aborted and the fire bottles were discharged. Injuries reported were all due to emergency egress.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 4 and fragments 6 through 10 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average 3"x6" in size. Fragment 5 was determined to be a disk segment measuring 4"x12" and weighing 10 lbs. The engine manufacturer estimates all fragments shown to have been ejected with a velocity of around 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

11.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**
Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Intershaft Bearing – LPT Drive Shaft**

SECONDARY MALFUNCTION (Rotor Stages): **LPT Stages 3 and 4 Blades**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−24.0	BSTA 1263	2" x 1'	Fuselage Penetration	None noted
2	Unknown					−22.0	BSTA 1259	2.5" x 1.5"	Fuselage Penetration	None noted
3	Unknown					−17.0		3" x 1.5"	Fuselage Cut	None noted
4	Unknown					−10.0		3" x 2"	Fuselage Penetration	None noted
5	Unknown					−5.0	BSTA 1249	5" x 2.5"	Fuselage Penetration	Damage to ventral stair and Bulkhead
6	Unknown					−1.5	BSTA 1241	3" x 2"	#2 Engine Cowl Penetration	#2 Engine Throttle Cable Severed
7	Unknown					17.0	BSTA 1223	3" x 1.5"	Fuselage Penetration	None noted
8	Unknown					14.0		2" x 2"	#2 Engine Cowl Penetration	None noted
9	Unknown					4.0		10" x 8"	Fuselage Penetration	None noted
10	Unknown					3.0	BSTA 1236	1.5" x 1"	Fuselage Penetration	#2 Engine Control Cable (?) Severed
11	Unknown					1.0		3" x 3"	#2 Engine Cowl Penetration	None noted

NARRATIVE: **The #3 engine turbine section disintegrated due to oil starvation in the #4½ bearing. The bearing oil line was broken in two places. Investigation revealed that all stage 3 and 4 blades had separated and the N1 turbine shaft had fractured. The 3rd and 4th stage blade debris and shrapnel was ejected through the engine casing. Shrapnel penetrated the fuselage in several places between BSTA 1223 and BSTA 1263. The #2 engine outer case was torn and holed as well. One of the two #2 engine throttle control cables was severed by Fragment 6, and the second was damaged. Fragment 10 also severed a control cable (unspecified) to the #2 engine. Fragment 5 entered the fuselage below the #3 engine strut and damaged the aft ventral stair and the rear bulkhead. The ground air service duct was dented in several places. Debris from the disintegration also severely damaged the torque box stringers.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that all fragments were typical blade segments, averaging about 1/4 lb. and measuring an average 2"x3" in size. The engine manufacturer estimates the velocity of these blade segments to be in the range of 700 ft/sec. All fragments were released from the LPT 3rd and 4th stages.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

12.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **EPR 1.92**
Altitude: **FL330**
Airspeed: **0.84M**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Stage 1–2 Spacer**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage Fan Rotor Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					–56.0	FSTA 124	8" x 5"	Vertical Stabilizer Penetration	Rudder/Elevator problems noted inflight
2	Unknown					–49.0	FSTA 10	3.5" x 3"	Vertical Stabilizer Penetration	Rudder/Elevator problems noted inflight
3	Unknown					–42.0	BSTA 1260	5" x 3"	Fuselage Penetration	None noted
4	Unknown					–42.0	BSTA 1260	1" x 1"	Cabin Window Penetration	None noted
5	Unknown					–35.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
6	Unknown					–31.0	Fuselage	2.5" x 2"	Fuselage Penetration	None noted
7	Unknown					–30.5	Fuselage	1" x 0.25"	FuselagePenetration	None noted
8	Unknown					–26.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
9	Unknown					–24.0	BSTA 1040	3" x 3"	Fuselage Penetration	None noted
10	Unknown					–23.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
11	Unknown					–22.5	BSTA 1020	1" x 1"	Cabin Window Penetration	None noted
12	Unknown					–18.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
13	Unknown					–17.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
14	Unknown					–15.5	WSTA 598	3" x 2"	Wing LE Flap Penetration	None noted
15	Unknown					–15.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
16	Unknown					–12.5	WSTA 555	3" x 2"	Wing LE Flap Penetration	None noted
17	Unknown					–11.0	WSTA 529	3" x 2"	Wing LE Flap Penetration	None noted
18	Unknown					–11.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
19	Unknown					–10.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
20	Unknown					–9.0	BSTA 900	3" x 2"	Fuselage Penetration	None noted
21	Unknown					–8.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
22	Unknown					–6.0	BSTA 880	1.5" x 0.5"	Fuselage Penetration	None noted

(CONTINUED)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

12.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan Stage 1−2 Spacer**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage Fan Rotor Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
23	Unknown					−5.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
24	Unknown					−5.0	Fuselage	2" x 2"	Fuselage Penetration	None noted
25	Unknown					−3.0	Fuselage	2.5" x 1"	Fuselage Penetration	None noted
26	Unknown					0.0	Fuselage	1" x 0.5"	Fuselage Penetration	None noted
27	Unknown					18.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
28	Unknown					17.0	Wing LE	1"x 1"	#1 LE Flap Penetration	None noted
29	Unknown					14.0	Fuselage	2.5" x 2"	Fuselage Penetration	None noted
30	Unknown					14.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
31	Unknown					11.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
32	Unknown					7.5	Wing LE	3" x 2"	#5 LE Flap Penetration	None noted
33	Unknown					7.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
34	Unknown					5.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
35	Unknown					3.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
36	Unknown					1.5	Fuselage	3" x 1.5"	Fuselage Penetration	None noted
37	Unknown					0.5	WSTA 501	1.5" x 0.5"	Crack on Front Spar Lower Rail	None noted

NARRATIVE: **The #1 engine fan section and the nose inlet cowl separated from the aircraft during cruise or inflight climb. The crew first heard a loud explosive report, followed by a lurch. A degree of lateral control difficulty ensued. Investigation revealed that the fan hub had fractured and released blades and vanes. Debris from the disintegration penetrated the wing and the fuselage. Some fragments were ejected from the exhaust nozzle of the #1 engine. Damage occurred to the vertical stabilizer (Fragments 1 and 2) and the horizontal stabilizer. Significant rudder damage was noted, but the actual locations of rudder damage were not addressed in the file information. Likewise, limited information on file makes it difficult to determine what caused the damage to the horizontal stabilizer. It has been assumed that this was due to fragments ejected through the exhaust nozzle.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that all fragments listed were typical blade segments, averaging close to 1/2 lb. in weight and measuring an average 3"x6" in size. These fragments were ejected from the fan section at a velocity close to 500 ft/sec. Additionally, the engine manufacturer notes that there was a disk segment measuring about 3"x6" and weighing approximately 1 lb. ejected from the fan section at a velocity of about 500 ft/sec. Engine manufacturer information concerning this disk segment shows that the most likely trajectory was between +3° and −5° from the fan plane of rotation, although no firm data is given.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

13.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back–Accident**
Power Level: **Unknown**
Altitude: **FL028**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **11th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−12.5	BSTA 1203	3" x 1.5"	#2 Engine Cowl Penetration	None noted
2	Unknown					−11.5	#2 Eng Cowl	3.5" x 3"	#2 Engine Cowl Penetration	None noted
3	Unknown					−10.0	Fuselage	3" x 2"	Fuselage Penetration	None noted
4	Unknown					−8.5	BSTA 1199	1.5" x 1"	#2 Engine Cowl Penetration	None noted
5	Unknown					−4.0	Fuselage	2" x 1"	Fuselage Penetration	None noted
6	Unknown					−2.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
7	Unknown					−0.5	Fuselage	3" x 1"	Fuselage Penetration	None noted
8	Unknown					15.0	BSTA 1183	4" x 2"	#2 Engine Cowl Penetration	None noted
9	Unknown					13.5	BSTA 1186	2" x 2"	#2 Engine Cowl Penetration	None noted
10	Unknown					12.5	#2 Eng Cowl	1.5" x 1"	#2 Engine Cowl Penetration	None noted
11	Unknown					10.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
12	Unknown					8.0	#2 Eng Cowl	3" x 1.5"	#2 Engine Cowl Penetration	None noted
13	Unknown					4.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
14	Unknown					3.0	#2 Eng Cowl	3" x 1"	#2 Engine Cowl Penetration	None noted
15	Disk Fragment					−1.0	BSTA 1198–1195	20" x 8"	Fuselage Penetration by Disk Segment	Wiring and Hydraulic Tubing severed; Fuel Line Dented

NARRATIVE: **The aircraft experienced disintegration of the #3 engine 11th stage compressor disk during climb. A 120° section of the disk (Fragment 15) had separated and cut through the firewall and the upper part of the strut, then continued upward and into the side of the fuselage where it severed several body stringers. The disk piece continued inboard, severing the lower web of the torque box, electrical wiring (including the wiring to both fire bottles), and denting the #2 engine fuel feed line. No control cables were damaged in the incident. Numerous blade pieces were ejected through the hole made by the disk fragment, resulting in multiple penetrations (by Fragments 1 through 14) of the fuselage and the #2 engine cowl.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer notes that fragments 1 through 14 were typical blade segments, averaging approximately 1"x2" in size and weighing in the range of 1/8 lb. Fragment 15 was a disk segment weighing about 3 lbs. and measuring 9"x12" in size. The engine manufacturer estimates that all fragments were ejected from the compressor 11th stage at velocities near 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

14.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL005**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine Disk Rim Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−7.0	Wing Lower	0.5" x 0.5"	Fuel Tank Access Cover Penetration	Fuel Leak; No Fire
2	Unknown					−5.0	Wing Lower	1" x 0.75"	Fuel Tank Access Cover Penetration	Fuel Leak; No Fire
3	Unknown					14.0	Wing LE Lower	0.5" x 0.5"	Wing LE Lower Skin Penetration	None noted
4	Unknown					15.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
5	Disk Fragment					−7.0	Wing LE area	7" x 6"	Wing LE Penetration	Wiring and Hydraulic Lines Severed; Pneumatic Ducts Severed

NARRATIVE: **The #1 engine sustained a separation of the 2nd stage turbine disk rim during climb. The crew was alerted by a #1 engine fire warning in the cockpit. Turbine blades and disk fragments were ejected through the HP turbine case and engine cowling. Two small fragments of unspecified origin (Fragments 1 and 2) each punctured a fuel access plate in the lower wing, resulting in fuel leaks. A segment of the disk (Fragment 5) penetrated the lower wing in the leading edge area, severing electrical wiring, hydraulic fluid lines, and pneumatic ducts. Fire was contained to the pylon area and was extinguished by the firing of the bottles. The fuel leaks did not catch fire. Various control surfaces (flaps, LE devices, ailerons) were damaged to varying degrees by shrapnel. Numerous dents and gouges (more than 100) were found on the lower wing skin near the #1 engine in a trajectory which was further aft than any of the few fragments which actually penetrated the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 4 were typical blade segments, released from the turbine 2nd stage at velocities around 500 ft/sec. These fragments averaged 1/4 lb. in weight and measured an average 2"x3" in size. Fragment 5 was a disk rim segment as noted, released from the turbine 2nd stage at a velocity near 700 ft/sec. This fragment measured 20"x2" and weighed approximately 5 lbs., according to the engine manufacturer.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

15.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Landing**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Turbine Stage 2 Blade Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					17.5	BSTA 598 (?)	5" x 2"	Fuselage Penetration	None noted
2	Unknown					15.5	BSTA 606	2" x 2"	Fuselage Penetration	None noted
3	Unknown					11.0	Fuselage (low)	1.5" x 1"	Fuselage Penetration	None noted
4	Unknown					10.5	Fuselage (low)	2"x 1"	Fuselage Penetration	None noted
5	Unknown					10.0	Fuselage (low)	3" x 1.5"	Fuselage Penetration	None noted
6	Unknown					7.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
7	Unknown					6.0	Fuselage (low)	3" x 2"	Fuselage Penetration	None noted
8	Unknown					5.5	Fuselage (low)	2" x 2"	Fuselage Penetration	None noted
9	Unknown					2.5	Fuselage (low)	3" x 2.5"	Fuselage Penetration	None noted
10	Unknown					1.0	Fuselage (low)	2.5" x 1"	Fuselage Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #3 engine turbine section on application of reverse thrust during landing. Fragments from the engine penetrated the aircraft fuselage from forward of BSTA 600 to approximately the plane of failure, mostly just below the passenger cabin floor level. The #3 engine cowling was severely torn and holed by multiple small fragmenrs. Investigation noted that most of the debris from the disintegration did not contact the aircraft. The total number of debris impact points is unknown, with only the known impact locations used in the analysis.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

16.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Ground Test**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **0**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−11.0	Unknown	2.5" x 2"	(See Engine Manufacturer's Update	(See Engine Manufacturer's Update)
2	Unknown					−10.5	Unknown	2" x 1"		
3	Disk Fragment					−15.0	Unknown	8" x 5"		
4	Unknown					−8.5	Unknown	1" x 1"		
5	Unknown					−7.0	Unknown	2" x 1"		
6	Unknown					−7.0	Unknown	2" x 1"		
7	Unknown					−6.5	Unknown	1.5" x 0.5"		
8	Unknown					−5.5	Unknown	2" x 2"		
9	Unknown					−3.0	Unknown	1" x 1"		
10	Unknown					−2.5	Unknown	1" x 1"		
11	Unknown					−1.0	Unknown	2" x 2"		
12	Unknown					0.0	Unknown	2" x 1"		
13	Unknown					4.5	Unknown	2" x 1"		
14	Unknown					2.5	Unknown	2" x 1"		
15	Unknown					2.0	Unknown	1.5" x 1"		
16	Unknown					−33.5	Unknown	1" x 1"		
17	Unknown					−27.5	Unknown	2.5" x 1"		
18	Unknown					−26.5	Unknown	1.5" x 0.5"		
19	Unknown					−26.0	Unknown	1" x 1"		
20	Unknown					−22.0	Unknown	2" x 1"		
21	Unknown					−22.0	Unknown	1.5" x 1"		
22	Unknown					−19.5	Unknown	1.5" x 0.5"		

(CONTINUED)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

16.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
23	Unknown					−17.5	Unknown	2" x 1"	(See Engine Manufacturer's Update)	(See Engine Manufacturer's Update)
24	Unknown					−13.5	Unknown	2" x 1"		
25	Unknown					−12.5	Unknown	2" x 2"		
26	Unknown					−11.5	Unknown	1" x 1"		
27	Unknown					−5.5	Unknown	2" x 1"		
28	Unknown					−4.0	Unknown	2" x 1"		

NARRATIVE: **NOTE: The information contained in this record was drawn from a previous study. Additional analysis was performed using the data obtained from the engine manufacturer. No further narrative information is presently available.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 and 2 were typical blade segments, measuring an average 2"x3" in size and weighing an average of 1/4 lb. These two fragments were liberated from the turbine 2nd stage at a velocity of about 500 ft/sec. Fragment 3 was a disk rim segment as noted, weighing approximately 5 lbs. and measuring about 20"x2" in size. This piece was ejected at a velocity near 700 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

17.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **100 Kts**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage Fan**

SECONDARY MALFUNCTION (Rotor Stages): **2nd Stage Fan due to 1st Stage Blade Walk**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−28.0	#4 Eng Inlet	2" x 1"	#4 Engine Inlet Penetration	None noted
2	Unknown					−25.5	#4 Eng Inlet	2" x 2"	#4 Engine Inlet Penetration	None noted
3	Unknown					−24.0	#4 Eng Inlet	1" x 1"	#4 Engine Inlet Penetration	None noted
4	Unknown					−16.5	Wing Lower	2.5" x 2"	Wing Fuel Tank Penetration	Fuel Leak – No Fire
5	Unknown					−16.0	Wing Lower	2" x 1"	Wing Fuel Tank Penetration	Fuel Leak – No Fire
6	Unknown					−10.0	Wing Lower	3.5" x 2"	Wing Lower Skin Penetration	None noted
7	Unknown					−4.5	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
8	Unknown					−2.0	Fuselage (Low)	2" x 1.5"	Fuselage Penetration	None noted
9	Unknown					16.5	Fuselage (High)	2" x 2"	Fuselage Penetration	None noted
10	Unknown					15.0	Fuselage (Mid)	2" x 1.5"	Fuselage Penetration	None noted
11	Unknown					13.0	Cabin Window	1" x 1"	Cabin Window Damage	None noted
12	Unknown					11.5	Cabin Window	1" x 1"	Cabin Window Damage	None noted
13	Unknown					7.0	Fuselage (Mid)	2" x 1"	Fuselage Penetration	None noted
14	Unknown					7.0	Wing–to–Body	3" x 1.5"	Fairing Penetration	None noted
15	Unknown					3.0	Wing–to–Body	1" x 0.5"	Fairing Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the 1st stage fan disk of the #3 engine during the takeoff roll at about 100 knots, followed by disintegration of the 2nd stage. Crew aborted the takeoff and stopped the aircraft safely. No injuries were reported. Damage to the aircraft was substantial, with fuel leaking from the #3 main fuel tank due to shrapnel holes and numerous penetrations of the fuselage. The #4 engine also received shrapnel damage around the inlet, and had extensive gouging to the fan blades. The wing–to–body fairing received multiple shrapnel damage. There was no evidence of the disk contacting the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer notes that all fragments shown are typical blade segments, averaging approximately 1/2 lb. in weight and measuring an average 6"x3" in size. Additionally, the engine manufacturer notes that a disk segment weighing about 1 lb. and measuring 6"x3" was also liberated from the fan section, but no indication of aircraft impact was given. The engine manufacturer estimates that all pieces ejected had velocities in the range of 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

18.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **8th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					-1.5	Vert. Stabilizer	2" x 2"	Stabilizer Penetration	None noted
2	Unknown					0.0	Vert. Stabilizer	1.5" x 1"	Stabilizer Penetration	None noted
3	Unknown					16.5	Vert. Stabilizer	2" x 2"	Stabilizer Penetration	None noted
4	Unknown					15.0	Vert. Stabilizer	1.5" x 0.5"	Stabilizer Penetration	None noted
5	Unknown					14.5	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
6	Unknown					13.5	Vert. Stabilizer	1" x 1"	Stabilizer Penetration	None noted
7	Unknown					10.5	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
8	Unknown					9.5	Vert. Stabilizer	1" x 1"	Stabilizer Penetration	None noted
9	Unknown					6.0	Vert. Stabilizer	3" x 2"	Stabilizer Penetration	None noted
10	Unknown					3.0	Vert. Stabilizer	36" x 12"	RH side of Stabilizer Penetration	None noted
11	Unknown					2.5	Vert. Stabilizer	2.5" x 2"	RH side of Stabilizer Penetration	None noted
12	Unknown					2.0	Vert. Stabilizer	27" x 3"	RH side of Stabilizer Penetration	None noted
13	Disk Fragment					10.0	Vert. Stabilizer	18" x 10"	RH side of Stabilizer Penetration	None noted
14	Disk Fragment					16.5	Vert. Stabilizer	4" x 4"	RH side of Stabilizer Penetration	None noted

* **The 'A' hydraulic system was lost due to fragment penetration, but no indication is given as to which fragment caused the hydraulic loss.**

NARRATIVE: **The 8th stage compressor disk on the #2 engine disintegrated during climb. Crew noted loss of power on #2 engine followed by noise heard in the cockpit. Hydraulic system 'A' was lost. Flight diverted successfully. Investigation showed that the disk rim had separated and punched a hole in the engine cowling, progressing up the side of the vertical stabilizer, leaving two large holes. Multiple small penetrations were noted in the same area. The right hand rear spar chord and web were severed for about 18 inches. Multiple holes were also noted in the #2 engine casing.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available in files.**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 12 were typical blade segments weighing on average less than 1/4 lb. and measuring an average 1"x2" in size. The engine manufacturer notes that fragment 13 was a disk fragment measuring 6"x3" and weighing about 1 lb. Fragment 14 is not confirmed, although accompanying photograph shows multiple pieces of disk rim broken away from disk. The engine manufacturer also disputes the size of hole caused by fragment 10, although no data is given to support the dispute.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

19.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **EPR 1.93**
Altitude: **FL130**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage Compressor Rotor**

SECONDARY MALFUNCTION (Rotor Stages): **7th, 8th, 10th, 11th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−31.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown					−22.0	Wing LE Outbd	10" x 3"	Wing Outbd Slat Penetration	None noted
3	Unknown					−20.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					−16.0	Fuselage (Low)	1" x 1"	LH Drain Mast aft of Wheel Well	None noted
5	Unknown					−15.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
6	Unknown					−11.5	Wheel Well	4" x 2.5"	Wheel Well Penetration	None noted
7	Unknown					−9.5	Wheel Well	2.5" x 1"	Wheel Well Penetration	None noted
8	Unknown					−4.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
9	Unknown					−4.0	Wing Lower	3" x 1.5"	Wing Lower Skin Penetration	None noted
10	Unknown					0.0	#1 Eng Cowl	16" x 3"	Engine Cowl Penetration	None noted

* The #1 hydraulic system was lost due to fragment penetration, but no indication is given as to which fragment caused the hydraulic loss.

NARRATIVE: **The #1 engine 9th stage compressor disintegrated during climb at about 13,000 feet, releasing multiple blades and vanes as well as at least one disk fragment. This was closely followed by the disintegration of the 7th, 8th, 10, and 11th stages. The engine cowl was sawn in two around 360º. The side cowl had a 16" gash in it (Fragment 10). Other aircraft damage was noted, particularly in the area of the left hand wheel well (Fragments 6 and 7). Several fragments(fragments 1, 3, 5, 8, and 9) penetrated the lower wing skin. No indications of fuel leaks are given. A fragment or fragments penetrated the #1 hydraulic lines, causing the loss of the #1 system due to fluid loss (no indication as to which fragment or fragments caused this). The flight diverted without further incident.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

20.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL180**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					3.0	Wing Lower	12" x 8"	Wing Lower Skin Gouge with Small (3" x 0.25") Cut	None noted
2	Unknown					3.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					3.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					1.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
5	Unknown					0.5	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The #1 engine disintegrated during climb. The low pressure turbine section came apart, penetrating the bottom of the engine casing and cowl. Shrapnel damage was found in numerous places on the lower wing skin, with several penetrations along with multiple scrapes and gouges. Additional perforations were noted in the engine cowl itself. One deep gouge was noted (Fragment 1) which had left a small cut in the lower wing skin at the deepest part of the gouge. The crew initiated an air turn back and landed without further incident.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

21.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Turbo Compressor Duct**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
4	Unknown					−49.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown					−45.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					−33.0	Wing Lower	0.5" x 0.25"	Wing Lower Skin Penetration	None noted
1	Unknown					−31.5	Wing LE	4" x 4"	Wing Leading Edge Penetration	None noted
5	Unknown					−22.0	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
6	Unknown					−11.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					−6.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
8	Unknown					12.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					6.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					2.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The #4 engine throttle in the cockpit jumped violently during climb. The crew shutdown the #4 engine and elected to divert. Examination revealed that the turbo compressor duct had ruptured, tearing away a large piece of the cowling. Shrapnel from the explosion punctured the wing lower skin in several places, and a larger hole was found in the wing leading edge about 8 feet outboard from the #4 engine (Fragment 4). No injuries were reported. It is assumed from the evidence that many of the fragments released did not contact the aircraft, as most of the blast seemed to be directed downward and outboard from the #4 engine.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

22.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL320**
Airspeed: **0.84M**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Section**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−3.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
2	Unknown					−1.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					53.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
4	Unknown					41.0	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
5	Unknown	12" x 8"				30.0	Wing LE	12" x 8"	Wing Leading Edge Penetration	None noted
6	Unknown					27.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Piece of Fan Mid Shroud					22.0	Cabin Window	1.5" x 1"	Outer Window Penetration	None noted
8	Unknown					11.0	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
9	Unknown					8.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
10	Unknown					3.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #3 engine during cruise at 32,000 feet. The engine was shutdown and the flight returned. Shrapnel from the disintegration pierced several small holes in the lower skin of the wing inboard of the #3 engine (fragments 2, 6, 8, 9, and 10) as well as three places in the fuselage below the floor line (fragments 1, 3, and 4). One fragment (fragment 7) penetrated the outer pane of the #16 window in the passenger cabin, but did not penetrate the inner pane. This fragment remained between the window panes. A large fragment (fragment 5) was found imbedded in the wing leading edge slat inboard of the #3 engine. Damage to the aircraft is listed as minor, and no injuries were reported.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

23.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL350**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Compressor Fan Stage 1 Assembly**

SECONDARY MALFUNCTION (Rotor Stages): **Drive Arm due to Fatigue**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−5.0	BSTA 1108	2" x 2"	Fuselage Penetration	None noted
2	Unknown					−2.5	#3 Eng Cowl	2" x 1"	#3 Engine Core Cowl Penetration	#3 Engine Damage noted
3	Unknown					−2.0	#3 Eng Cowl	10" x 2"	#3 Engine Nose Cowl Penetration	#3 Engine Damage noted
4	Unknown					10.0	BSTA 983	3" x 2"	Fuselage Penetration	None noted
5	Unknown					9.0	WSTA 155	3" x 2"	Wing Leading Edge Penetration	None noted
6	Unknown					8.0	BSTA 1000	3" x 1"	Fuselage Penetration	Hydraulic Lines Damaged
7	Unknown					5.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					5.0	Fuselage (Low)	1" x 0.5"	Fuselage Penetration	None noted
9	Unknown					2.0	Fuselage (Low)	0.5" x 0.5"	Fuselage Penetration	None noted
10	Unknown					0.5	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #1 engine low pressure compressor fan assembly during cruise. The crew heard a loud report followed by indications of #1 engine problems. Two hydraulic systems were lost almost immediately due to fragments severing hydraulic lines (fragment 6). Debris (fragments 5 and 7) damaged the wing. Several holes were found in the fuselage (due to fragments 1, 4, 6, 8, 9, and 10). Shrapnel also damaged the #3 engine (fragments 2 and 3), causing significant damage to the engine. The #3 engine was able to continue to operate despite damage.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

D1 4100 7780 REV. 6/87

24.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Ground Test**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Zero**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage LP Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−50.5	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
2	Unknown					−44.0	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
3	Unknown					−38.0	Fuselage (Low)	2.5" x 2"	Fuselage Penetration	None noted
4	Unknown					−29.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
5	Unknown					−28.0	Fuselage (Low)	1.5" x 1"	Fuselage Penetration	None noted
6	Unknown					−27.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
7	Unknown					−26.5	Fuselage (Low)	1" x 0.5"	Fuselage Penetration	None noted
8	Unknown					−24.0	Cabin Window	2" x 1.5"	Cabin Window Cracked	None noted
9	Unknown					−21.5	Fuselage (Low)	2.5" x 1"	Fuselage Penetration	None noted
10	Unknown					−19.5	Fuselage (Low)	1.5" x 1"	Fuselage Penetration	None noted
11	Unknown					−19.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
12	Unknown					−15.5	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted

NARRATIVE: **During a routine ground test, the #1 engine experienced an uncontained disintegration of the 2nd stage turbine disk. Segments of the disk were released, as were multiple blades and blade pieces. Parts of the disk rim and all of the blades had separated. Blade fragments contacted the fuselage in many locations with 12 penetrations noted. One cabin window was cracked by debris (fragment 8). Indications of lower wing skin penetrations were given in the associated file material, but no firm evidence (written or pictorial) has been found to substantiate this. Two large pieces of the disk were found up to 500 feet away from the aircraft in the approximate plane of the 2nd stage. Preliminary inspection showed that the disk had burst into two main pieces due to a fracture between the rim and the inside edge of the disk.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

25.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL013**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Stator Guide Vane Lug Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Disk, 4th Stage Guide Vane Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−5.5	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
2	Unknown					−4.0	Wing Lower	3" x 3"	Wing Lower Skin Penetration	None noted
3	Unknown					−2.5	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
4	Unknown					−1.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
5	Unknown					0.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					20.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					17.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
8	Unknown					16.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					15.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					10.0	Wing Lower	2.5" x 1"	Wing Lower Skin Penetration	None noted
11	Unknown					8.0	Wing Lower	3" x 0.25"	Wing Lower Skin Cut	None noted
12	Unknown					5.0	MLG Door	2" x 1"	Main Landing Gear Door Hole	None noted
13	Unknown					3.0	#3 Eng Strut	3" x 0.5"	Sailboat Fairing Penetration	None noted
14	Unknown					0.5	#3 Eng Strut	1.5" x 1"	Sailboat Fairing Penetration	None noted
15	Disk Rim Fragment					0.5	Wing Lower	12" x 4"	Wing Lower Skin Penetration, Aft of Front Spar – Fuel Tank	Fuel Leak – No Fire

* Hydraulic system pressure loss due to fragment penetration accompanied disintegration, but no indication is given as to which fragment caused the hydraulic system loss.

NARRATIVE: **The #4 engine disintegrated shortly after takeoff during initial climb. The 3rd stage turbine stator guide vane lug failed, with subsequent aft shift of the whole stator assembly and collision with the 3rd stage turbine disk. Pieces of the the 3rd and 4th stage turbine guide vane assemblies and about 1/2 of the 3rd stage disk rim were recovered from the ground at the point of the disintegration. Substantial damage to the wing was noted, including both large and small holes. Fuel was leaking from several holes in the lower wing skin including the large hole caused by the disk fragment (fragment 15). The #3 engine sailboat fairing was punctured in two places (fragments 13 and 14). Flaps and leading edge slats were substantially damaged in the area near the #4 engine. Some debris was ejected through the tailpipe and damaged the trailing edge devices.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 14 were typical blade segments, released from the turbine 3rd and 4th stages at velocities near 500 ft/sec. These fragments averaged about 1/4 lb. in weight and approximately 2"x3" in size. Fragment 15, a disk rim segment, was released from the turbine 3rd stage at an approximate velocity of 700 ft/sec. This disk rim segment measured 2"x20" in size and weighed about 5 lbs.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

26.1 **UNCONTAINED ENGINE DEBRIS ANALYSIS**

EVENT OMITTED FROM DATABASE PER ENGINE MANUFACTURER REQUEST

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

27.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **HP Turbine 12 Stage Inner Rotating Airseal**

SECONDARY MALFUNCTION (Rotor Stages): **LP Turbine Blades and Vanes**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−49.0	Incomplete Data	2" x 1"	Incomplete Data	Incomplete Data
2	Unknown					−44.5	Incomplete Data	3" x 1"	Incomplete Data	Incomplete Data
3	Unknown					−42.0	Incomplete Data	5" x 4"	Incomplete Data	Incomplete Data
4	Unknown					−40.5	Incomplete Data	3.5" x 1.5"	Incomplete Data	Incomplete Data
5	Unknown					−36.0	Incomplete Data	1.5" x 1"	Incomplete Data	Incomplete Data
6	Unknown					21.0	Incomplete Data	2.5" x 2"	Incomplete Data	Incomplete Data
7	Unknown					20.0	Incomplete Data	3" x 3"	Incomplete Data	Incomplete Data
8	Unknown					20.0	Incomplete Data	1" x 1"	Incomplete Data	Incomplete Data
9	Unknown					16.5	Incomplete Data	1.5" x 1"	Incomplete Data	Incomplete Data
10	Unknown					11.0	Incomplete Data	1" x 1"	Incomplete Data	Incomplete Data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **NO DETAILED INFORMATION AVAILABLE.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **No additional information available.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

28.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Landing**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture due to Bird Strike**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−26.0	Incomplete data	6" x 4"	Incomplete data	Incomplete data
2	Unknown					−25.5	Incomplete data	2" x 2"	Incomplete data	Incomplete data
3	Unknown					−25.0	Incomplete data	1" x 1"	Incomplete data	Incomplete data
4	Unknown					−24.0	Incomplete data	2.5" x 2"	Incomplete data	Incomplete data
5	Unknown					−22.5	Incomplete data	2.5" x 2"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **Wing front spar web was punctured by debris, resulting in a fuel leak.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event was caused by a bird strike, resulting in fan blade fracture. The only fragment confirmed is a fan blade segment measuring 6"x6" and weighing 1.1 lb. The estimated velocity of this fragment is given as approximately 500 ft/sec. The engine manufacturer notes that this event resulted in a fuel tank rupture. Further information is available from a video referenced by the engine manufacturer.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

29.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion–Accident**

Power Level: **EPR 1.4745**
Altitude: **FL110**
Airspeed: **304 Knots**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **LP Location Bearing followed by Fan Shaft Assembly shift and disintegration**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Fan Module?					Unk	9 ft Fwd of eng Front Flange	Unk	Fuselage Penetration	Hydraulic System problems noted
2	Unknown					Unk	S–duct	36"x12"	Unknown	None noted
3	Unknown					Unk	S–duct	48"x24"	Unknown	None noted

NARRATIVE: **The #2 engine fan shaft had fractured and the fan assembly moved forward as much as 12 feet in the inlet before penetrating both sides of the inlet. A section of the LP compressor fan module was missing from the engine. As the fan module departed it cut a spiral path through the inlet and struck the left side of the fuselage about 9 feet forward of the engine's front flange. This fragment then penetrated the fuselage, leaving impact marks at the upper right hand side of the inlet. Some hydraulic systems problems resulted along with various other control difficulties.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

30.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture due to Bird Strike**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					5.0	Not Given	3" x 2"	Incomplete data	Incomplete data
2	Unknown					3.5	Not Given	2" x 2"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **NO DETAILED INFORMATION AVAILABLE. Cracks in fuselage noted but no locations given.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event was a bird ingestion event resulting in fan blade damage. The only fragment noted was approximately 1.1 lbs. and about 6"x6" in size. Estimated velocity of this fragment was 500 ft/sec. The engine manufacturer makes reference to a video for further information.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

31.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Spinner Fatigue – FAN Stage**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a	n/a	n/a

NARRATIVE: **This event did not result in significant aircraft damage. There were two significant holes in the nose cowl, but no evidence that any fragments penetrated the aircraft**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files.**
DRAWINGS/PICTURES IDENTIFICATIONS: **???**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that according to their records, this event did not result in any significant damage to the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

32.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Turbine 5th and 6th Stage Disintegration**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−67.0	Lower Wing	4" x 3"	Incomplete data	Incomplete data
2	Unknown					−56.0	Lower Wing	3" x 3"	Incomplete data	Incomplete data
3	Unknown					−47.5	Lower Wing	2" x 2"	Incomplete data	Incomplete data
4	Unknown					−44.5	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
5	Unknown					−44.0	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
6	Unknown					−41.0	Lower Wing	1.5" x 1"	Incomplete data	Incomplete data
7	Unknown					−33.5	Lower Wing	2" x 1"	Incomplete data	Incomplete data
8	Unknown					−31.5	Lower Wing	1" x 1"	Incomplete data	Incomplete data
9	Unknown					−22.0	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
10	Unknown					−11.5	Lower Wing	1" x 0.25"	Incomplete data	Incomplete data
11	Unknown					−6.0	Lower Wing	2" x 2"	Incomplete data	Incomplete data
12	Unknown					−3.5	Lower Wing	2" x 1"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **A loud bang was heard during climb. The 5th and 6th stage LPT blades and stator vanes came apart, penetrating the case and cowl. The case split open around 3/4 of its circumference. Numerous cuts and abrasions were noted on the lower wing skin.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

33.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **80 Kts**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **13th Stage HP Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−9.0	Wing Lower	4" x 2"	Penetration of Fuel Tank	Fuel Leak and Fire
2	Disk Fragment	3"x17"	n/a	13th Stg		−5.0	Wing Lower	5" x 4.5"	Penetration of Wing Lower Skin	None noted

NARRATIVE: **A 13th stage HPC disk fragment (Fragment 2) fractured during the takeoff roll at 80 Knots due to high cycle fatigue. Multiple blades and vanes were released along with the disk fragment or fragments. Fragment 1 penetrated the fuel tank, allowing fuel to leak and ignite. This fragment, a relatively small piece, may have been part of the 13th stage HPC, or it may have been a piece of the casing (which exploded due to overpressure) −− the origin is uncertain. The fire was almost certainly ignited by fuel dripping onto the hot engine, and was apparently immediate. Multiple other fragments followed the same general trajectory as Fragment 2, but did not have sufficient energy to penetrate the lower wing skin. These pieces are also of uncertain origin, similar to Fragment 2. Most of these pieces were found on the runwaye. The total number of these pieces has not been specified, but it is clear that most of these did not contact the aircraft. Fire destroyed the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

34.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Taxi**
Flight Effect: **n/a**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **n/a**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **7th Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **8th through 13th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Disk Segment	40% of Disk	Unk	7th Stg		-4.0	BSTA 624, WBL 172 (Wing Lower)	1.5" x 1.5"	Penetration of Fuel Tank	Fuel Leak and Fire

NARRATIVE: **During taxi, #2 engine 7th stage compressor disintegrated. A 170° segment of the disk (Fragment 1) departed. A fragment penetrated the fuel tank in the plane of the 7th stage, resulting in almost immediate fuel fire. The resulting fire consumed the aircraft, incurring fatalities. Multiple other fragments were released from the 7th stage, peppering the lower wing skin inboard of the #2 engine. These fragments apparently did not penetrate in any location. 7th stage vane fragments also contributed to these dents and scratches. The 8th through 10th stages liberated multiple blade and vane fragments, also contributing to the lower wing skin damage. The 7–8 stage spacer was also released, apparently without making contact with the aircraft. A large hole approximately 12" in diameter was found in the fuselage at BSTA 937, RBL 12. Thorough investigation of this area did not yield evidence that an engine part caused this hole, however. (The trajectory from the disintegration plane of the #2 engine has been calculated to be 58.5 degrees aft for this location. Due to the uncertainty of its origin, this hole was intentionally omitted from trajectory analysis results.)**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available in Files**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer disputes the data shown above. They note that the disk fragment which penetrated the fuel tank was not 40% of the disk, but measured approximately 6"x2" and weighed about 1/2 lb. Estimated velocity was 500 ft/sec. It is noted that multiple fragments were released due to the disintegration of the compressor. The engine manufacturer contends that this disintegration was the result of a missile which apparently was fired at the aircraft. This missile passed through the engine causing the disintegration, and impacted the aircraft fuselage 58.5° aft of the compressor 7th stage plane of rotation leaving a large hole (note Narrative).**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

35.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−29.0	Incomplete data	1.5" x 1"	Incomplete data	Incomplete data
2	Unknown					−28.0	Incomplete data	4" x 3"	Incomplete data	Incomplete data
3	Unknown					−28.0	Incomplete data	0.5" x 0.5"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM A PREVIOUS STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE, SO INFORMATION IS SKETCHY.

NARRATIVE: **INSUFFICIENT INFORMATION**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that the three fragments shown measured approximately 1/2 lb. each. No dimensions were given. Estimated velocities were in the range of 500 ft/sec. (Information remains somewhat sketchy.)**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

36.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL310**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **7th Stage Air Cooling Duct**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage LPT Disk Disintegration due to Creep Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					-55.0	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
2	Unknown					-47.0	Rear Cargo Dr	2" x 2"	Tear in lower part of cargo door	None noted
3	Unknown					-44.5	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
4	Unknown					-43.5	Fuselage (Low)	3" x 2"	Fuselage Penetration	None noted
5	Unknown					-31.0	Fuselage (Mid)	7" x 2"	Fuselage Tear	None noted
6	LPT Case Frag					-21.0	Flap (Rt Outbd)	1" x 1"	Flap skin penetration	None noted
7	Unknown					-20.0	Flap	2" x 1"	Flap skin penetration	None noted
10	Unknown					-17.0	Wing-to-Body	1.5" x 1"	Fairing Penetration	None noted
11	Unknown					-16.0	Wing-to-Body	0.5" x 0.5"	Fairing Penetration	None noted
12	Unknown					-15.0	Fuselage (Low)	0.5" x 0.5"	Fuselage Penetration	None noted
13	Unknown					-14.5	Wing-to-Body	3" x 2"	Fairing Penetration	None noted
14	Unknown					-13.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
16	Disk Fragment		20% Dsk	LPT1	*See GE update	3.0	Wing	8" x 2"	Wing fuel tank penetration (all the way thru the wing)	Fuel Leak – no fire noted

NARRATIVE: **The aircraft experienced a loud noise on the #4 engine during climb, followed by a drop in all #4 engine parameters. Engine was shutdown. Crew observed a hole in the upper right hand wing between #3 and #4 engines and elected to return. There was no fire warning. Multiple small engine fragments penetrated the fuselage aft of the wing as noted. One fragment (fragment 1) penetrated the vertical stabilizer. Several small fragments impacted the wing and penetrated a fuel tank access panel and fairings between the #3 and the #4 engines. Two major pieces of disk were ejected. One piece (fragment 15) did not hit the aircraft after exiting the core cowl in a downward direction. Another piece (fragment 16) passed entirely through the wing, leaving a 2"x8" hole in the bottom of the wing (plus a 3" crack from the hole) and a much larger 50"x19" hole in the top of the wing. Other fragments caused dents and scratches without penetrating the aircraft structure. The cause of the incident was attributed to failure of the 7th stage air cooling duct which went undetected by the operator during letter check, consequent loss of cooling air to the LPT rotor forward cavity and eventual creep rupture of the LPT Stage 1 disk. Fragments 8, 9, and 15 are being excluded since these fragments did not impact the aircraft after being ejected from the engine.**

SOURCE *(Data obtained from)*: **GPS Database Files -- CRASH.RBF; Boeing Air Safety Files; Engine manufacturer letter to Boeing dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer information has been integrated into the data. Estimated velocity of fragment 16 was 781 ft/sec. at blade tips and 574 ft/sec. at disk rim. The engine manufacturer indicates that fragment 15 (not included) left a hole 8"x35" in the core cowl, but did not impact the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

37.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **124 Knots**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **Combustor Explosion (No Rotor Failure noted)**

SECONDARY MALFUNCTION (Rotor Stages): **Case Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Combustor Case Fragment			Case		-70.0	Wing TE Devices	1" x 1"	Small Penetration in wing trailing edge device	None noted
2	Dome Section of Combustor Can	7" x 8"		Combstr		-66.5	Fuel Tank Access Door	8" x 7"	Penetration of Fuel Tank Access Door (by both Fragment 2 and fragment 2A)	Fuel Leak and Fire (caused by impact of both Fragment 2 and Fragment 2A, most likely simultaneously)
2A	Combustor Case Fragment	4" x 5"		Case		-66.5	Fuel Tank Access Door	(See narrative)	Same as above -- contact was almost simultaneous	See fragment 2
3	Combustor Case Fragment			Case		-51.0	Wing Lower	0.5" x 0.5"	Wing lower skin penetration	None noted
4	Combustor Case Fragment			Case		-37.5	Wing Lower	2" x 1"	Wing lower skin penetration	None noted
5	Combustor Case Fragment			Case		-30.0	Wing Lower	1.5" x 1"	Wing lower skin penetration	None noted

NARRATIVE: **The #1 engine combustor case exploded during the takeoff roll due to the fracture of the #9 combustor can. The combustor case shattered into multiple pieces. One small piece about 4"x5" (Fragment 2A) was carried or ejected along the same trajectory as the combustor can dome section (Fragment 2). Metallurgical analysis shows that both Fragment 2 and Fragment 2A penetrated the fuel tank access panel, probably almost simultaneously. This impact created a hole approximately 42 square inches in size, from which fuel leaked onto the hot engine and ignited almost immediately. Fire consumed the aircraft aft sections and resulted in fatalities. Fragments 3, 4, and 5 made smaller holes in the bottom of the wing, but apparently did not cause fuel leak. Fragment 1 impacted the trailing edge flaps and left a small hole. Multiple small pieces were found in the area of the event. However, no significant information was given concerning these pieces. A section of the can was blown downward and outward, striking the inner surface of the fan case as it exited. There is no evidence as to whether this piece contacted the aircraft, and it has not been incorporated into the trajectory results. The engine cowling had broken into several pieces as a result of the multiple impact locations of debris on the inside of it.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragment 2 weighed about 1 lb. and fragment 2A weighed about 1/2 lb. Estimated velocity of fragment 2 was 100 ft/sec., while estimated velocity of fragment 2A was 200 ft/sec. The engine manufacturer also contends that fragment 2A did not contact the fuel tank access door, and disputes portions of the narrative.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

38.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage Fan Blade**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−33.0	Wing Lower	0.5" x 0.5"	Wing lower skin penetration	None noted
2	Unknown					16.0	Wing Lower	0.5" x 0.25"	Wing lower skin penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the fan section during cruise and diverted. The 1st stage fan shed multiple blade fragments, many of which were contained. Several pieces exited the nacelle, but most did not contact the aircraft. Fragments 1 and 2 hit the underside of the wing and left very small holes, but no system damage was noted. Multiple pieces hit the wing lower skin in many locations, but the energy of these pieces was quite low, and none left more than minor scratches or dents. The engine was substantially damaged, with damage to fan rub strip, outlet guide vanes, reverser cowl, and side cowl. The engine nose cowl was punctured, but no firm evidence was noted as to the location at which this penetration occurred. No other aircraft damage was noted.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event in their records is NOT a non−contained disintegration. Indications of fragments released aft (through the fan discharge area) and forward (out the inlet) are given, but the engine manufacturer does not believe any pieces passed through the engine containment structure.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL370**
Airspeed: **270 KIAS**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−26.0	RH Inbd Elevator	1" x 1"	Small penetration in inboard elevator trailing edge	None noted
2	Unknown					−24.0	RH Inbd Elevator	1" x 0.5"	Small penetration in inboard elevator trailing edge	None noted
3	Unknown					−16.0	RH Inbd Elevator	5" x 3"	Penetration in inboard elevator (outbd portion)	Ground Impact Damage
4	Unknown					−28.0	RH Outbd Elevator	1" x 0.75"	Cut in outboard elevator (inbd portion)	Ground Impact Damage
5	Fan Shaft Nut					−9.0	RH Stabilizer Outbd Fwd	4" x 1.5"	Cut in stabilizer upper skin (outbd area)	Fan Shaft Nut found in hole
6	Unknown					−20.0	LH Outbd Elevator	17" x 2"	Cut in outboard elevator (inbd portion)	Ground Impact Damage
7	Unknown					−9.0	LH Stabilizer Outbd	4.5" x 1"	Penetration in stabilizer upper skin (outbd area)	None noted
8	Inlet Guide Vane					−11.0	LH Stabilizer Outbd	12" x 3"	Cut in stabilizer upper skin (outbd area)	Vane found in hole
9	Unknown					−7.0	LH Stabilizer Center	15" x 2"	Penetration in stabilizer upper skin (center area)	None noted
10	Unknown					−7.0	LH Stabilizer Center	3" x 2"	Cut in stabilizer upper skin (center area)	Probably ground impact damage
11	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Penetration in stabilizer leading edge (outbd)	None noted
11A	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Small hole next to hole #11 – possible secondary damage	None noted
11B	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Small hole next to hole #11 – possible secondary damage	None noted
12	Unknown					−16.0	LH Stabilizer Outbd Aft	0.5" x 0.5"	Penetration in stabilizer upper skin (outbd area)	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
13	Unknown					−18.0	LH Outbd Elevator Center	5" x 2"	Cut with 8" tear propagating from it in stabilizer at outbd elevator hinge point (center)	Ground Impact Damage
14	Unknown					−11.0	LH Stabilizer upper center	7" x 1"	Cut in LH stabilizer upper skin center area, no penetration	Probably Ground Impact Damge
15	Unknown					−10.0	LH Stabilizer upper center	4" x 3"	Skin piece gone from LH stabilizer upper skin center area	None noted
16	Unknown					−3.0	LH Stabilizer upper center	4" x 1"	Cut in LH stabilizer upper skin center area	Probably Ground Impact Damage
17	Unknown					−4.0	LH Stabilizer upper center	3" x 2"	Hole in LH stabilizer upper skin center area	None noted
18	Unknown					−1.0	LH Stabilizer upper center	13" x 6"	Large hole in LH stabilizer upper skin center area	None noted
19	Fan Blade Fragment					4.0	LH Stabilizer upper center	12" x 4"	Hole in LH stabilizer upper skin center area	Fragment found in hole
20	Fan Blade Fragment					1.0	LH Stabilizer upper center	6" x 2"	Small hole in LH stabilizer upper skin center forward area	Fragment found in hole
21	Unknown					1.0	LH Stabilizer upper center	4" x 2"	Small hole in LH stabilizer upper skin center forward area	None noted
22	Unknown					−1.0	LH Stabilizer upper center	1" x 0.5"	Small hole in LH stabilizer upper skin center area	Ground Impact Damage
22A	Unknown					−3.0	LH Stabilizer upper center	0.5" x 0.5"	Small hole in LH stabilizer upper skin center area	Ground Impact Damage
23	Fan Blade Fragment					0.0	RH Elevator upper inbd	18" x 16"	Large hole in RH inboard elevator (close to fuselage)	Fragment found in hole
24	Unknown					−6.0	RH elevator	3" x 1"	Cut in RH inboard elevator	None noted
25	Unknown					15.0	RH Stabilizer inbd forward	5" x 2"	Hole in RH stabilizer upper skin; #3 hydraulic systems in RH stabilizer severed	All hydraulic fluid lost from #3 hydraulic system
26	Unknown					13.0	RH Stabilizer inbd forward	25" x 1"	Cut in RH stabilizer inbd – close to hydraulics damage	None noted
27	Unknown					12.0	RH Stabilizer inbd forward	5" x 1"	Cut in RH stabilizer upper skin inbd forward area	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.3 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
28	Unknown					13.0	RH Stabilizer inbd center	4" x 0.5"	Cut in RH stabilizer inbd center	Ground Impact Damage
29	Unknown					13.0	RH Stabilizer inbd forward	5.0" x 2.5"	Tear in RH stabilizer inbd center	None noted
30	Unknown					9.0	RH Stabilizer inbd forward	11" x 5"	Large hole in RH stabilizer inbd center near hydraulic damage	None noted
31	Unknown					9.0	RH Stabilizer inbd forward	10" x 9"	Hole in RH stabilizer inbd center, close to fuselage	None noted
32	Unknown					−12.0	RH Stabilizer extreme outbd forward	3" x 3"	Hole in extreme outbd end of RH stabilizer – forward	Ground Impact Damage
33	Unknown					−8.0	RH Stabilizer outbd forward	1" x 0.25"	Crack and puncture hole in RH stabilizer outbd forward	None noted
34	Unknown					−8.0	RH Stabilizer outbd center	4" x 1.5"	Hole in RH stabilizer outbd center	None noted
35	Unknown					5.0	RH Stabilizer inbd forward	6" x 3"	Hole in RH stabilizer inbd forward	None noted
36	Unknown					−10.0	RH Stabilizer outbd center	0.5" x 0.5"	Cut in RH stabilizer outbd center, upper surface	None noted
37	Unknown					−15.0	RH Stabilizer outbd center	2" x 0.5"	Hole in RH stabilizer outbd center	Ground Impact Damage
38	Unknown					−22.0	RH outbd elevator center	1.5" x 0.75"	Hole in RH stabilizer outbd center	None noted
39	Unknown					−19.0	RH outbd elevator center	1" x 1"	Score in RH stabilizer outbd center surface	None noted
40	Unknown					−20.0	RH outbd elevator center	2" x 1"	Dent in RH stabilizer outbd center	None noted
41	Unknown					−16.0	RH outbd elevator forward	3" x 0.5"	Hole in RH outbd elevator surface forward portion	None noted
42	Unknown					Unk	RH inbd elevator forward	3" x 2"	Hole in RH inbd elevator forward portion	None noted
43	Unknown					Unk	RH inbd elevator forward	5" x 3.5"	Hole in RH inbd elevator forward portion	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.4 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
44	Unknown					Unk	RH inbd elevator center	1" x 0.75"	Hole in RH inbd elevator top surface	None noted
45	Unknown					Unk	RH inbd elevator center	1.5" x 0.25"	Cut in RH inbd elevator bottom surface	None noted
46	Unknown					Unk	RH inbd elevator center	0.5" x 0.25"	Hole in RH inbd elevator top surface	None noted
47	Unknown					Unk	RH inbd elevator center	0.25" x 0.25"	Hole in RH inbd elevator	None noted
48	Unknown					Unk	RH inbd elevator center	2" x 1"	Hole in RH inbd elevator	None noted
49	Unknown					−22.0	LH inbd elevator aft outer edge	9" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
50	Unknown					−15.0	LH inbd elevator outer edge	2" x 0.5"	Hole in LH inbd elevator top surface	None noted
51	Unknown					−9.0	LH Stabilizer center	4" x 0.5"	Cut in LH stabilizer	Ground Impact Damage
52	Unknown					−24.0	LH inbd elevator aft center	0.5" x 0.5"	Hole in LH inbd elevator top surface	None noted
53	Unknown					−21.0	LH inbd elevator aft center	4.5" x 3"	Hole in LH inbd elevator top surface	Ground Impact Damage
54	Unknown					−17.0	LH inbd elevator outer	0.75" x 0.5"	Hole in LH inbd elevator top surface	None noted
55	Unknown					−15.0	LH inbd elevator outer	4" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
56	Unknown					−22.0	LH inbd elevator aft center	1.5" x 1"	Hole in LH inbd elevator	None noted
57	Unknown					−18.0	LH inbd elevator center	3" x 0.5"	Cut in LH inbd elevator top surface	None noted
58	Unknown					−24.0	LH inbd elevator aft center	4" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
59	Unknown					−11.0	LH inbd elevator center	21" x 0.5"	Cut in LH inbd elevator top surface	Ground Impact Damage

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.5 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
60	Fan Blade Fragment					-3.0	LH Stabilizer center	14" x 10"	Hole in LH stabilizer top Surface	Midspan shroud found in cavity
61	Unknown					-15.0	LH inbd elevator inner	0.5" x 0.5"	Cut in LH inbd elevator top surface	None noted
62	Unknown					-6.0	LH inbd elevator inner	4" x 4"	Dent in LH inbd elevator	Believed to be ground impact damage
63	Unknown					0.0	LH inbd elevator inner forward	4.5" x 1.5"	Hole in LH inbd elevator	Ground impact damage
64	Unknown					-13.0	LH inbd elevator inner	2.5" x 1"	Cut in LH inbd elevator top surface	Ground impact damage
65	Unknown					-6.0	LH inbd elevator inner	4.5" x 0.5"	Cut in LH inbd elevator top surface	None noted
66	Unknown					-9.0	LH inbd elevator inner	2" x 2"	Cut in LH inbd elevator top surface	None noted
67	Unknown					4.0	LH inbd elevator inner forward	0.5" x 0.5"	Hole in LH inbd elevator top surface	None noted
68	Unknown					-9.0	LH inbd elevator outer forward	2.5" x 2.5"	Hole in LH inbd elevator	None noted
69	Disk Fragment					2.0	RH Stabilizer center	19" x 15" (est.)	Irregular hole in RH stabilizer just forward of the inbd elevator	Probable location of damage to Hydraulic system #1
70	Disk Fragment					-2.0	RH Stabilizer Leading Edge Outer end	32" x 16" (est.)	Hole in RH stabilizer leading edge about 3/4 of the way from fuselage to end	None noted
71	Unknown					2.0	RH Stabilizer Center	2" x 1"	Hole in RH stabilizer top surfacr	None noted
72	Unknown					0.0	RH Stabilizer Center	2" x 1"	Hole in RH stabilizer top surface	None noted
73	Unknown					6.0	RH Stabilizer Center	2" x 2"	Hole in RH stabilizer top surface	None noted
74	Unknown					5.0	RH Stabilizer Center	2" x 2"	Cut in RH stabilizer top surface	None noted
75	Unknown					3.0	LH Stabilizer center	3" x 1"	Cut in LH stabilizer top surface	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.6 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
90	Unknown					−7.0	RH Stabilizer Center	2" x 2"	Hole in RH stabilizer top surface	None noted
91	Stage 2 Booster Blade					−12.0	RH Stabilizer Center	7" x 0.5"	Hole in RH stabilizer top surface	Blade found in hole
92	Disk Fragment					−3.0	RH Inbd Elevator Center	11" x 5" (est.)	Large Hole in RH inbd elevator	None noted
93	Unknown					−7.0	RH Inbd Elevator Inner	9.5" x 3.5"	Hole in RH inbd elevator	None noted
94	Fan Blade Fragment					0.0	RH Inbd Elevator Inner Forward	4" x 0.5"	Cut in RH inbd elevator top surface	Fragment found in hole

NARRATIVE: **The aircraft experienced a #2 engine fan disk failure. Multiple fragments impacted the stabilizer, leading to the loss of all three hydraulic systems that powered the flight controls. The crew declared an emergency and diverted the aircraft. Without flight controls the aircraft was controllable only to a limited degree by the use of asymmetric thrust from the wing mounted engines. Control difficulties caused the aircraft to crash upon landing, resulting in breakup of the airframe, with associated fire and multiple fatalities.**

Three large holes due to fragments were deduced to exist in the RH stabilizer (Ground impact damage obscured many details). One hole (caused by fragment 70) was in the outboard leading edge. A second hole (caused by fragment 69) was found forward of the inboard elevator. A third large hole (caused by fragment 92) was found in the inboard elevator. Multiple holes were noted in both left and right hand stabilizer surfaces. Detailed investigation revealed that the damage caused by fragment 25 resulted in the loss of hydraulic fluid in hydraulic system 3. Hydraulic system 1 sustained damage from other fragments which led to loss of fluid in that system. Hydraulic system 2 was damaged as the fan containment ring struck the accessory gearbox and hydraulic pumps during the disk separation. None of the fragments which damaged the left hand stabilizer appeared to cause any system damage, although multiple shrapnel holes were noted. Investigators noted that the disintegration of the disk resulted in liberation of shrapnel−type debris with a trajectory pattern that exceeded the level of protection provided by design features on the aircraft.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files; NTSB Accident Report; Engine manufacturer letter to Boeing dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos available**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer information concerning this event has been integrated into the record for this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

40.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					3.0	Fuselage (Mid)	2" x 1.25"	Fuselage Penetration	None noted
2	Unknown					1.5	Fuselage (Mid)	8" x 1"	Fuselage Penetration	None noted
3	Unknown					0.0	Fuselage (Mid)	16" x 6.5"	Fuselage Penetration	Fuel fire from severed fuel feed line

NARRATIVE: **The aircraft experienced a #3 engine fire warning during takeoff roll and crew aborted. The aircraft was brought to a stop successfully. The 9th stage compressor disk rim had separated over the entire circumference, with most of the debris exiting the engine case at about 8:00 position. Fragments penetrated the fuselage just ahead of the aft pressure bulkhead. The fuel feed line to the #3 engine was severed by exiting debris, but it is impossible to determine which fragment severed the line. Fuel fire was almost immediate, and due to conditions was quickly transferred into the cargo compartment. The aircraft was a complete hull loss. Investigators determined that crack progression from a blade root corrosion pit was the cause of the disintegration.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that the three fragments shown were all about the same size, measuring 6"x1" and weighing about 1/2 lb. The estimated velocities were approximately 700 ft/sec. No further information was given.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

41.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **1000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage LP Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Cut Drive Arm / OS**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−70.5	Vert Stabilizer FSTA 220	5" x 3"	Vertical Stabilizer penetration	None noted
2	Unknown					−38.0	BSTA 1374.4	8" x 8"	Puncture of wing landing gear door	None noted
3	Unknown					−36.0	ILES 620.0	1.5" x 1.5"	Hole in wing leading edge flaps	None noted
4	Unknown					−25.5	ILES 626.0	16" x 11"	Tear in wing leading edge skin	None noted
5	Disk Fragment					−7.0	ILES 602.6	40" x 24"	Large hole completely through wing leading edge	Electrical wiring, pneumatic tubing severed

NARRATIVE: **The aircraft experienced a #2 engine disintegration. The uncontained fragments from the #2 engine were ejected in multiple directions. Some debris passed through the engine and was ejected aft, resulting in secondary damage to other engine sections. A large fragment of the disk (fragment 5) was released inboard of the #2 engine, passing completely through the wing leading edge. This fragment severed electrical wiring and pneumatic ducts. One fragment (fragment 1) penetrated the vertical stabilizer. A significant hole was found in the landing gear door, caused by fragment 2. Multiple dents and scratches associated with the uncontained disintegration were noted in file material. Some debris also was noted to have caused FOD in the #1 engine, although the extent of this damage is not specified.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files; C/S PROP−BN37B−C92−104**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

42.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **16,000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Oil Leak from cracked #4 bearing pressure tube**

SECONDARY MALFUNCTION (Rotor Stages): **6th Stage LPT Disk Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					+3.0	Wing LE Flap	1"x1"	Leading Edge Flap penetration	None noted
2	Unknown					−29.0	Main Landing Gear Door	2"x2"	Landing Gear Door Penetration	None noted
3	Unknown					−33.0	Inboard Canoe Fairing	3"x1"	Canoe Fairing penetration	None noted
4	Unknown					−39.0	Inboard Canoe Fairing	8"x2"	Canoe Fairing penetration and ensuing tear	None noted
5	Unknown					−30.0	#1 Engine Inlet	Unknown	Damage to #1 engine fan blades	None noted

NARRATIVE: **The airplane experienced an uncontained failure of the #2 engine during climb while passing through 16,000 feet. The crew shut down the engine and elected to continue to destination. Ground maintenance inspected the engine in the destination city and noted that the 6th stage of the LPT had ruptured, liberating all blades. Several blade fragments had impacted the aircraft, mostly inboard of the #2 engine. Penetrations were found as noted above. Multiple scratches and dents were also found. The number 1 engine had ingested at least one small metal fragment (probably more), causing damage to the #1 engine fan blades. The engine operated without incident into the destination, but the fan blades were all replaced after reaching the destination. An unscheduled stop had been made due to low oil quantity indications in the #2 engine. On the ensuing flight the 6th stage disk ruptured following an oil fire in the area of the turbine exhaust case and the #3 bearing. It was found that oil had leaked from a cracked #4 bearing pressure tube and filled the triangular compartment in the exhaust case. This oil then spilled forward into the space between the exhaust case and the LP turbine case, and auto ignition occurred.**

SOURCE *(Data obtained from)*: **Boeing Customer Service Telexes, Engine manufacturer reports**
DRAWINGS/PICTURES IDENTIFICATIONS: **photocopies of pictures available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

43.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Power Level: **Unknown**
Flight Phase: **Climb (TOC)** Altitude: **Unknown**
Flight Effect: **Air Turn Back** Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **6th Stage HPC Air Seal Rupture**

SECONDARY MALFUNCTION (Rotor Stages): **5th, 6th Stage HPC Blades Fractured, Vanes Damaged**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*

NARRATIVE: **There are no indications that any uncontained fragments impacted the aircraft structure. The aircraft did not sustain any noticeable damage. Some of the blade fragments were contained, but a number of pieces were not found inside the engine. The engine case and cowling sustained some damage, but specific details are unknown.**

SOURCE *(Data obtained from)*: **Boeing Customer Service Telexes**
DRAWINGS/PICTURES IDENTIFICATIONS: **Not available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

44.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **8000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **5th Stage LPT Disk Rim Separation**

SECONDARY MALFUNCTION (Rotor Stages): **5th Stage LPT Blades Fractured**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*

NARRATIVE: **The LPT disk rim separated during climb. No significant impact damage was noted on the aircraft structure. All damage was limited to the engine and the engine case/cowl.**

SOURCE *(Data obtained from)*: **Boeing Customer Service Telexes**
DRAWINGS/PICTURES IDENTIFICATIONS: **Not available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

45.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **7000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage HPC Disk Fracture due to Material Defect (Hard Alpha)**

SECONDARY MALFUNCTION (Rotor Stages): **Low Cycle Fatigue**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					0.0	Wing LE	1"x0.125"	Hole in Wing leading edge	None noted
2	Unknown					−3.0	Flap Track Canoe Fairing	1"x0.5"	Hole in Flap Track Fairing just fwd of flap. (Large gouge near)	None noted
3	Unknown					+4.0	Wing−to−Body Fairing	0.75"x0.5"	Small hole in wing−to−body fairing, just fwd and below cargo lamp	None noted
4	Unknown					−26.5	Fuselage (over Emerg Exit R5)	0.35"x0.35"	Hole 2 ft above emergency exit door R5	None noted
5	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted
6	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted
7	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted

NARRATIVE: **During climb the aircraft experienced a failure of the #4 engine. The flight returned without further incident. Ground inspection revealed that the 9th stage disk of the HP compressor had fractured, resulting in small shrapnel damage to the aircraft wing and empennage. Small debris impacted the aircraft in multiple locations, but indications are that most fragments did not penetrate. Gouges and scratches were found on the underside of the wing, the wing−to−fuselage fairing, and on the empennage. Seven holes were noted (see above). Thorough detailed inspection of recovered fragments showed the presence of a hard alpha defect in the 9th stage disk, causing the fracture.**

SOURCE *(Data obtained from)*: **Boeing Uncontained Event Reports, Engine manufacturer detailed event reports**
DRAWINGS/PICTURES IDENTIFICATIONS: **photocopies of pictures available**

ENGINE MANUFACTURER'S UPDATE: **The detail of this event in Boeing records is quite sketchy. Most of the specific information concerning fragments was gathered from engine manufacturer information. The updated information was added to the Uncontained Event database after analysis of the engine manufacturer material.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

46.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **102.5% N_2**
Altitude: **FL215**
Airspeed: **305 Kts**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage HPT Disk Fracture due to Arc Weld Burn – Bore Face**

SECONDARY MALFUNCTION (Rotor Stages): **Stage 2 HPT Disk release, probable fracture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g. Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1				HPT		–3.5	#1 Eng Cowl	0.5"x0.5"	Penetration of cowl	None noted
2						–3.5	#1 Eng Cowl	1"x1"	Penetration of cowl	None noted
3						–3.5	#1 Eng Nozzle	0.5"x0.5"	Hole in #1 Engine Tailpipe	None noted
4						–3.5	#1 Eng Nozzle	0.5"x0.5"	Hole in #1 Engine Tailpipe	None noted
5						–2.0	#1 Eng T/R Cowl	0.5"x0.5"	Hole in #1 Engine Thrust Reverser Cowl	None noted
6						+1.0	WSTA 255	1"x0.5"	Hole in Lower Wing Skin	Fuel Leak – No fire
7						–3.0	WSTA 344	1"x0.5"	Hole in Lower Wing Dry Bay Access Door	None noted
8						+4.5	Lower Anti–collision light lens	.125"x.125"	Small Hole in Red light lens	None noted
9						0.0	Fuselage	2"x1"	Hole in Fuselage below wing TE	None noted
10						–11.0	Fuselage	2"x2"	Hole in lower Fuselage (A/C bay)	Air Conditioning system ducting penetrated
11						–6.5	Aft Flap Actuator	1"x1"	Hole in Aft Flap Actuator housing	None noted

NARRATIVE: **During climb the crew heard a loud noise which lasted approximately four seconds. The noise was immediately followed by a thrust reverser in transit indication and momentary fire warning indication on the right hand engine. The engine was shut down and the flight diverted. The landing was without incident. During taxi to the parking area, the local tower advised the crew that fuel was leaking from the right wing. There was no fire and no injuries. Investigation revealed that the HPT 1 disk had fractured, causing the release of the HPT 2. The fan midshaft was fractured in the HPT 1 plane. Some sections of the departed stages were later located and returned to the engine manufacturer, but the majority of the HPT 2 was not recovered.**

SOURCE *(Data obtained from)*: **Boeing Uncontained Files; Engine manufacturer Incident Report; C.A. Oncina Trip – Investigation Notes; engine manufacturer letter dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos of incident contained in Engine manufacturer's Report; Numerous photos available from C.A. Oncina trip**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer indicates that there were approximately 300 dings, scratches and holes in the aircraft. Most of these were considered superficial, and only about 10 fragments actually penetrated the aircraft structure. The largest of these was a 2" square hole in the flap fairing which also punctured the air conditioning system ducting (Hole 10). The fuel leak was from a hole measuring 1"x0.5" (hole 6).**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

47.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **T/O Power (1.35 EPR)**
Altitude: **Ground**
Airspeed: **45 Kts**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **6th Stage Disk of Intermediate Compressor Stage 6–7 Rotor Shaft Assembly Rupture**

SECONDARY MALFUNCTION (Rotor Stages): **None**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	70° arc of 6th stage disk	15" chord, 5" rad	~ 9 lb	6th Stg Comp.	590 fps	0.0	#3 eng cowl impact, no a/p impact	12" x 10" in #3 Cowl	Hole in #3 engine cowl, superficial unspecified damage to a/p	No effect on a/p systems
2	57° arc of 6th stage disk	10" chord, 5" rad.	~ 8 lb.	6th Stg Comp.	590 fps	0.0	#1 Eng	12" x 8" in #3 Cowl, 12" x 2" in #1 eng	Hole in #3 cowl. Fragment penetrated #1 engine nacelle and entered HP compressor	Fuel leak from severed LP Fuel Pipe (at #3 engine fragment exit location) – #3 eng fire warning, #1 engine thrust loss from damaged turbine blades

NARRATIVE: **Early in the takeoff roll, just as full power was reached, the 6th Stage disk in the #3 engine ruptured. The main fuel line to the engine was severed and fuel fire ensued. A disk segment from the #3 engine (fragment 2) penetrated the #1 engine HPT case, destroying the first stage turbine blades and causing loss of thrust from the #1 engine. (Fragment 1 did not impact the aircraft except at the #3 engine cowl.) The aircraft was stopped and airport fire personnel extinguished the fire. Preliminary inspection showed at least six radial fractures through the bolt holes used for securing the stage 6–7 rotor shaft assembly to the stage 5 disk. There was evidence of pre-existing fatigue cracks originating from corrosion pitting.**

SOURCE *(Data obtained from)*: **Boeing Field Report; Air Safety Week magazine, Engine manufacturer data**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information was received from the engine manufacturer in August 1994, including fragment description, piece sizes, masses, velocities, and trajectories as shown in table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

D1 4100 7780 REV. 6/87

48.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **109%**
Altitude: **Ground**
Airspeed: **123 Kts**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disks Released from Stages 1 & 2**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Turb Bld Frag	1"x0.5"				+3.0	Fuselage (Low)	1.25"x 1"	Puncture in lower fuselage A/C pack bay	Air Cond. system damage
2	Bld Frag	Unk				+7.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
3	Bld Frag					+5.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
4	Bld Frag					+4.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
5	Bld Frag					0.0	#2 Eng Cowl	2"x1"	Pncture in RH Eng transcowl, no passthrough	None
6	Bld Frag					+4.0	#2 Eng Cowl Door	2"x2"	Puncture in RH Eng cowl door	None
7	Bld Frag					0.0	#1 Eng Pylon	1"x1"	Pylon spar penetrated on LH side	None
8	Bld Frag					−60.0	Wing LE	0.25"x0.25"	Wing Leading Edge slat damage outbd of pylon	None
9	Bld Frag					−60.0	Wing LE	0.25"x0.25"	Wing Leading Edge slat damage outbd of pylon	None
10	Bld Frag					−60.0	Wing L Inbd Flap Fairing	0.5"x0.5"	Puncture in LH Inbd Flap Actuator fairing	None
11	Bld Frag					−60.0	Wing L Inbd Flap Fairing	0.5"x0.5"	Puncture in LH Inbd Flap Actuator fairing	None
12	Bld Frag					−60.0	Wing L #4 Flap Fairing	0.25"x0.25"	Puncture in LH #4 Flap Actuator fairing	None
13	Bld Frag					−60.0	Wing L #4 Flap Fairing	0.25"x0.25"	Puncture in LH #4 Flap Actuator fairing	None

NARRATIVE: **During the takeoff roll at 123 Kts, the aircraft experienced an uncontained disk rim fragment separation of the HPT1 disk, leading to separation of both HPT disks on the left hand engine. A successful abort was performed. There were no injuries to passengers or crew. Multiple small impacts were found in the fuselage, the #1 engine pylon underside, the wing leading edge, and the right hand engine cowling. Most impacts did not result in airplane penetrations. There was some damage to the air conditioning ducts due to penetrations by four fragments (fragments 1 through 4).**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

49.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **118% N1**
Altitude: **Ground**
Airspeed: **95 Kts**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disk Released from Stage 1**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	HPT Bld Dovetail	Unk				−21.0	Wing Lower	1"x1"	Fuel Tank punctured	Fuel Leak, Fire
2	HPT Bld Dovetail					−13.0	Wing Lower	4"x1"	Fuel Tank punctured	Fuel Leak, Fire
3	HPT Bld Dovetail					−12.0	Wing Lower	2"x1"	Fuel Tank punctured	Fuel Leak, Fire
4	HPT Bld Dovetail					−13.0	Wing Lower	2.5"x2"	Fuel Tank punctured	Fuel Leak, Fire
5	Unknown					−7.0	Wing Lower	1"x1"	Wing Skin punctured	None noted
6	Nozzle Guide Vane	16" long				−38.0	Wing LE	1"x1"	Electrical wire severed	None noted
7	HPT Bld Frag Support Section					−40.0	Wing LE	1"x1"	Electrical cooling fan motor destroyed	None noted
8	Unknown					−57.0	Wing LE	1"x1"	None	None
9	Unknown					−56.0	Wing LE	1"x1"	None	None
10	6" Disk Rim Segment				Rebound	−11.0	#1 Eng Pylon	6.5"x3"	Penetration of #1 Eng Pylon access door & RH wing flap fairing	None
11	Unknown				Rebound from Runway	−11.0	#1 Eng Pylon	1"x1"	Penetration of #1 Engine Pylon access door	Electrical wires severed
12	Unknown				Rebound from Runway	−10.0	#1 Eng Pylon	1"x1"	Penetration of #1 Eng Pylon access door	None
13	Turb Blade				from Runway	TBD	Fuselage (Cabin)	0.5"x0.5"	Penetration of fuselage. Fragments found in pax cabin	Pressurized cabin breach
14	Turb Blade					TBD	Fuselage (Cabin)	0.5"x0.5"	Penetration of fuselage. Fragments found in pax cabin	Pressurized cabin breach
15	Turb Blade					+14.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
16	Turb Blade					−28.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
17	Turb Blade					−32.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

49.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disk Released from Stage 1**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
18	Turb Blade	Unk				−35.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
19	Turb Blade					−40.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
20	Turb Blade					−40.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None

NARRATIVE: **(Details for this event are limited.) The #2 engine experienced an uncontained disk rim fragment separation of the HPT1 disk, leading to separation of both HPT disks. The event occurred during takeoff roll at about 95 Kts. Impacts were found in the lower RH wing skin, the fuselage, and the #1 engine pylon due to fragments rebounding from the runway. The passenger cabin was penetrated with two small fragments found in the cabin area following the accident. Some wiring was cut in the LH engine pylon. Several fragments penetrated the lower wing skin into the fuel tank, resulting in a fuel leak which ignited, causing major fire damage to the external surface of the fuselage and wing.**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 18 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Sketches provided by engine manufacturer**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

50.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL290**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Blade Separation resulting from blue ice ingestion**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Fan Bld Frag	Unk		Fan		+21.0	Fuselage (Cabin)	1.5"x 1"	Hole in fuselage 2 feet aft of cabin door 2R	None
3	Unknown			Fan		0.0	#1 Fan Cowl	0.5"x0.5"	Puncture of #1 Eng Cowl (no through penetration)	None

NARRATIVE: **Two #2 engine fan blades sustained transverse separations due to blue ice ingestion during cruise. One small fragment impacted the passenger cabin, creating a hole just aft of the 2R door (Fragment 1). Another fragment impacted the #1 engine transcowl, putting a small hole in the outer skin. This fragment (Fragment 3) did not actually penetrate into the #1 engine cowl. Several other fragment impacts were noted from material exiting the engine exhaust.**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 18 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

APPENDIX B

FEDERAL AND INTERNATIONAL REGULATIONS
APPLICABLE TO UNCONTAINED EVENTS

Appendix B – Table of Contents

CODE OF FEDERAL REGULATIONS
Title 14 – Aeronautics and Space
Part 25.903(d)(1)

"(d) *Turbine engine installations.* For turbine engine installations –

(1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case."

ADVISORY CIRCULAR
AC 20–128
09 March 1988

D1 4100 7780 REV. 6/87

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: DESIGN CONSIDERATIONS FOR MINIMIZING HAZARDS CAUSED BY UNCONTAINED TURBINE ENGINE AND AUXILIARY POWER UNIT ROTOR AND FAN BLADE FAILURES

Date: 3/9/88
Initiated by: ANM-110
AC No: 20-128
Change:

1. PURPOSE. This advisory circular (AC) sets forth a method of compliance with the requirements of §§ 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 (compressor and turbine) failure and engine fan blade failures. 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 SECTIONS. Sections 23.903(b)(1), 25.365(e)(1), 25.571(e)(2), (3), (4), 25.901(d) and 25.903(d)(1) of the FAR.

3. BACKGROUND. Although turbine engine and APU manufacturers are making efforts to reduce the probability of uncontained rotor and fan blade failures, service experience shows that uncontained compressor and turbine rotor and fan blade 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 airplane. Since it is unlikely that uncontained rotor and fan blade failures can be completely eliminated, Parts 23 and 25 require that airplane design precautions be taken to protect the airplane from such events.

a. Uncontained gas turbine engine rotor failure statistics presented in Society of Automotive Engineers (SAE) Reports AIR 1537 and AIR 4003, "Report on Aircraft Engine Containment", cover two study periods, 1962 to 1975, and 1976 to 1983, respectively. During this time period (21 years total) there were 478 incidents of noncontained engine rotor failures reported for 768.2 million engine operating hours on commercial transport airplanes. The failures were due to high cycle fatigue, low cycle fatigue, material and manufacturing defects, rubbing against static parts and foreign object damage (FOD). The major cause of FOD was bird strikes which principally affected the fan sections of the high bypass ratio engines. It is noted that since 1975 the use of this engine type has increased from about 5 percent of the fleet hours to 23 percent of the total hours.

b. The statistics in the SAE studies indicate the existence of many different failure modes not readily apparent or predictable by failure analysis methods. Because of the variety of uncontained rotor and fan blade 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 an airplane from uncontained rotor and fan blade failures. These guidelines, therefore, assume a rotor or fan blade 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. Rotor. Rotors include hubs, discs, rims, drums, seals, and spacers. 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.

b. Blade. Blades include fan, compressor and turbine blades.

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 or blade fragments from the engine 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.

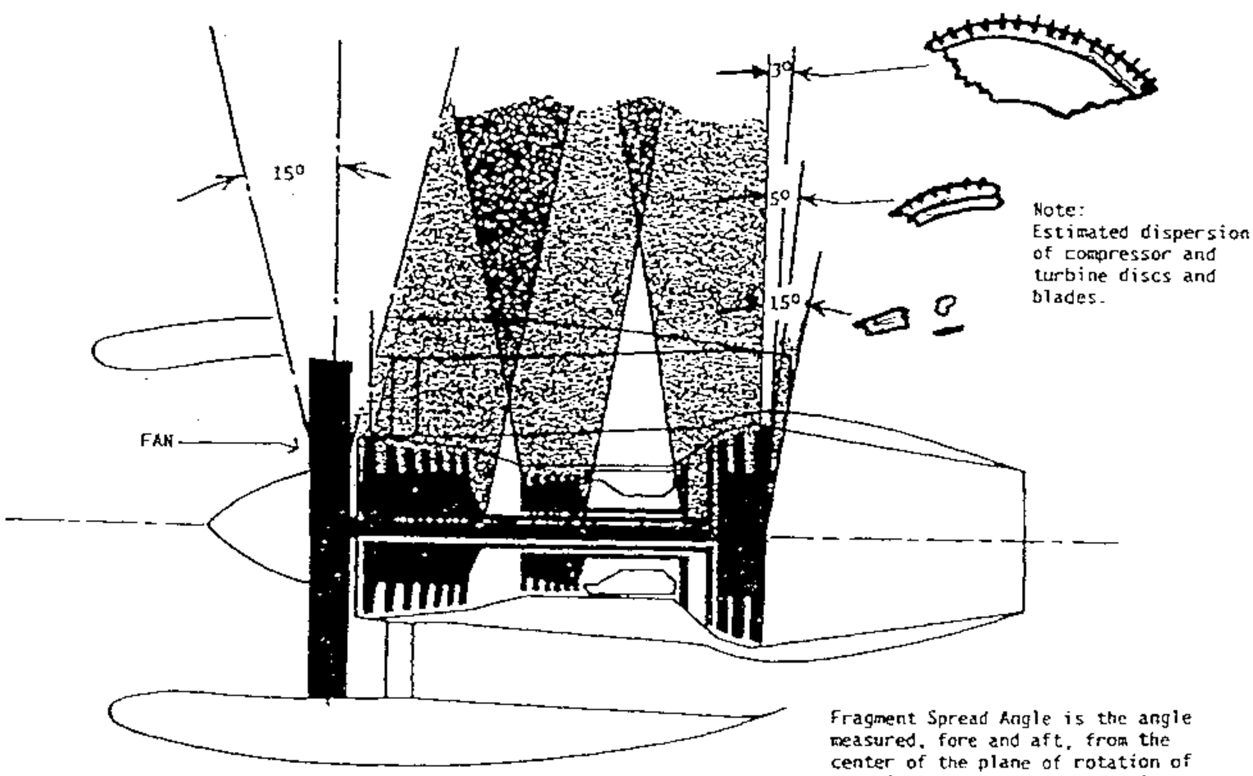
d. Critical Component. A critical component is any component (or system) whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the airplane. These components should be considered on an individual basis and in relation to other components which could be damaged by the same fragment or by other fragments at the same time.

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, after any failure which has not been shown to be extremely remote.

f. Fragment Spread Angle. The fragment spread angle is the angle measured, fore and aft from the center of the plane of rotation of the disc or fan blade, initiating at the engine or APU shaft centerline. (Refer to Figure 1)

FIGURE 1

ESTIMATED PATH OF FRAGMENTS



Fragment Spread Angle is the angle measured, fore and aft, from the center of the plane of rotation of the disc or fan blade initiating at the engine or APU shaft centerline.

g. Impact Area.

(1) Rotor Failures. The impact area is that area likely to be impacted by uncontained rotor or disc rim segment fragments. Recorded observations of impact areas resulting from uncontained engine rotor failures show that heavy fragments tend to remain within a spread angle of ±3 degrees. Smaller fragments have been deflected at spread angles as much as ±15 degrees. Spread angles which should be considered in designs to minimize the hazards of uncontained rotor failures are ±3 degrees for the 1/3 disc sector with 1/3 of the blade length above the rim intact; ±5 degrees for other large fragments (3 bladed rim sector with blade root serrations); and ± 15 degrees for the smaller fragments (shrapnel).

(2) Fan Blade Failures. Service experience has shown that fan blade fragments have been contained initially by the engine but have been expelled from the plane of rotation of the fan in both the forward and aft directions. In forward trajectory failures, blade tip fragments have been expelled forward of the engine front flange and lodged in or penetrated the nacelle inlet or departed without contacting the nacelle inlet. In one aft trajectory failure incident, blade fragments lodged in the fan case wall, shearing a hydraulic line and impacting a main fuel line. The design impact area for fan blade fragments is within a spread angle of ±15 degrees.

(3) Auxiliary Power Unit. If an APU is installed which has not been shown to have rotor containment, the impact areas and spread angles identified above, along with the energy level of the uncontained fragments specified by the manufacturer, should be used. Even though rotor containment may have been demonstrated, a subjective review of the APU location and rotor failure consequences should be made to assure that the hazardous condition would not be created in the unlikely event of an uncontained APU rotor failure.

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

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

(1) The other engine(s) on the same and/or opposite wing and engine(s) mounted on the aft fuselage and in the empennage;

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

(3) Pilot compartment area (NOTE: Normally engine rotors and fans are not in line with the pilot compartment area. However, for turbine engine installations on Part 23 airplanes, satisfactory service experience relative to rotor and fan blade integrity and containment in similar engine installations can be considered in assessing the acceptability of installing engines in line with the pilot compartment area.);

(4) 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.);

(5) Essential or 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;

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

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

(8) Instrumentations essential for continued safe flight and landing.

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 have been used:

(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.

(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 or fan blade fragments.

(7) Consider the likely damage extent caused by multiple fragments (smaller fragments or shrapnel in the ± 15 degree spread angle areas).

(8) 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, as deflectors on the fluid lines have been used to minimize the likely damage and hazards.

c. External Shield and Deflectors. When shields, deflection devices or airplane structure are proposed to be used to protect systems or components, the adequacy of the protection should be shown by testing or analysis supported by test data, using the fragment energies suggested in paragraph 6.

d. Airplane Modifications. Modifications made to current certificated airplanes should not compromise the original airplane safety level relative to uncontained engine or APU rotor or fan blade failures. Examples are reengining installations, APU installations and auxiliary fuel tank installations.

6. FRAGMENT ENERGIES.

a. The energy level the designer needs to consider is that associated with the total mass in the 1/3 sector of a disk identified in paragraph 4g(1), at the critical rotating speed and translational velocity. This energy level would be the most severe in terms of catastrophic damage. Damage caused by these fragments can be minimized by the design considerations outlined in this AC.

b. Service experience primarily on high bypass engines without inlet guide vanes has shown that the engine can eject blade fragments beyond the engine case (forward and aft) even with a containment ring that remains intact. Some of the most severe incidents involved large blade tip fragments (up to 3 pounds) which spiral forward of the engine front flange. These fragments have velocities up to 900 feet per second. Another type of fragment is one that may be reingested and rebounds forward. These fragments shear and puncture at the point of impact. The fragments can weigh as much as 0.6 pounds and have velocities up to 400 feet per second. As previously noted, some occurrences have resulted in engine case penetration of basically full-sized fan blades aft of the engine containment ring.

c. The size and trajectory of the fragments vary with each particular engine design. The use of soft case containment systems, such as Kevlar, has changed the failure dynamics relative to fan blade failure events. Therefore, the engine installer should consider the engine manufacturer's data on fragment energies and trajectories in relation to the engine installation for the particular location on the airplane.

Deputy Director of Airworthiness

ACJ No. 2
to
JAR 25.903(d)(1)

ACJ No. 2 to JAR 25.903(d)(1)
Uncontained Engine Rotor Failures (Acceptable Means of Compliance and Interpretative Material)
See JAR 25.903(d)(1)

1 *Turbine Engine Installations.* Where containment of engine rotor debris has not been established, the following material provides a basis on which compliance may be shown with JAR 25.903(d)(1).

2 *Aeroplane Design Considerations*

2.1 All practical design precautions should be taken to minimise, on the basis of good engineering judgement the risk of catastrophic damage due to non-contained engine rotor debris. This should include the position of the engine with respect to critical components or regions of the aeroplane such as —

a. The other engine(s) (especially those located on the same side of the aeroplane);

b. Fuselage pressurised hull and other primary structure;

c. Flight deck region;

d. Fuel system/tanks. (Consideration should be given to spillage of fuel into the engine compartment and any other region of the aeroplane where a fire hazard could result);

e. Essential control systems, including primary flight controls, electrical systems, hydraulic systems and shut-off means;

f. Engine fire extinguisher systems; and

g. Instrumentation essential for continued safe flight.

2.2 Practical design measures to minimise the risk of catastrophic damage may include for example, location of critical components or systems outside the vulnerable areas; duplication and adequate separation of critical components of systems, and/or protection by substantial airframe structure, taking account of the possible risk of simultaneous damage caused by the release (in random directions) of single fragments; location of shut-off means so that flammable fluids can be isolated in the event of damage to the system; use of protective armour or deflection shields; precautions to ensure that flammable fluids released from damaged lines or other components are not likely to contact possible ignition sources; possible redundant design or crack stoppers to limit the dynamic propagation of tears which have been caused by debris impact.

2.3 Where protection by substantial airframe structure or by protective armour or deflection shields is claimed, the adequacy of protection should be demonstrated by tests and/or analysis based on test data, using the criteria of the engine failure model of paragraph 3.

ACJ No. 2 to JAR 25.903(d)(1) (continued)

3 *Engine Failure Model.* The safety analysis required in paragraph 4 should be made using the following engine failure model unless, for the particular engine type concerned, evidence can be produced based on operating experience or engine design features to justify a different model.

3.1 *Single One-Third Piece of Disc.* It should be assumed that the one-third piece of disc has the maximum dimension corresponding to one-third of the disc with one-third blade height and an angular spread of ±3° relative to the plane of rotation of the disc. Where energy considerations are relevant, the mass shuld 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 1.)

3.2 *Small Pieces of Debris.* It should be assumed that the small piece of debris has a maximum dimension corresponding to one-third the bladed disc radius and an angular spread of ±5° relative to the plane of the disc. Where energy considerations are relevant, the mass should be assumed to be $\frac{1}{30}$th of the bladed disc mass and its energy the translational energy (neglecting rotational energy) of the piece travelling at rim speed (see Figure 2).

3.3 *Alternative Engine Failure Model.* For the purpose of the analysis, as an alternative to the engine failure model of paragraphs 3.1 and 3.2, the use of a single one-third piece of disc having an axial spread angle of ±5° would be acceptable, provided that the objectives of paragraphs 2.1, 2.2 and 4.3 a. are satisfied.

4 *Means of Compliance – Safety Analysis*

4.1 An analysis should be made using the engine model defined in paragraph 3 to determine the critical areas of the aeroplane likely to be damaged by rotor debris and to evaluate the consequences. This should be determined in relation to the most critical flight phases.

4.1.1 A minimum delay of at least 15 seconds but in any event not more than 60 seconds should be assumed for the emergency engine shut down drill depending on the circumstances resulting from non-containment, taking into account the various phases of flight, and the fact that damage due to non-containment could result in a considerable increase in flight crew work load and delay in starting any of the emergency drills, for example, where there may be a multiplicity of warnings which require analysis of the situation by the flight crew to determine the cause.

4.1.2 Some degradation of the flight characteristics of the aeroplane or operation of a system may be permissible subject to the safe continuation of the flight. Account should be taken of the behaviour of the aeroplane under asymmetrical engine thrust or power conditions together with any possible damage to the flight control system, and of the predicted aeroplane recovery manoeuvre.

4.2 Drawings showing the trajectory paths of engine debris relative to critical areas should be provided. The analysis should include at least the following:

a. Damage to primary structure including the pressure cabin, engine mountings and airframe surfaces.

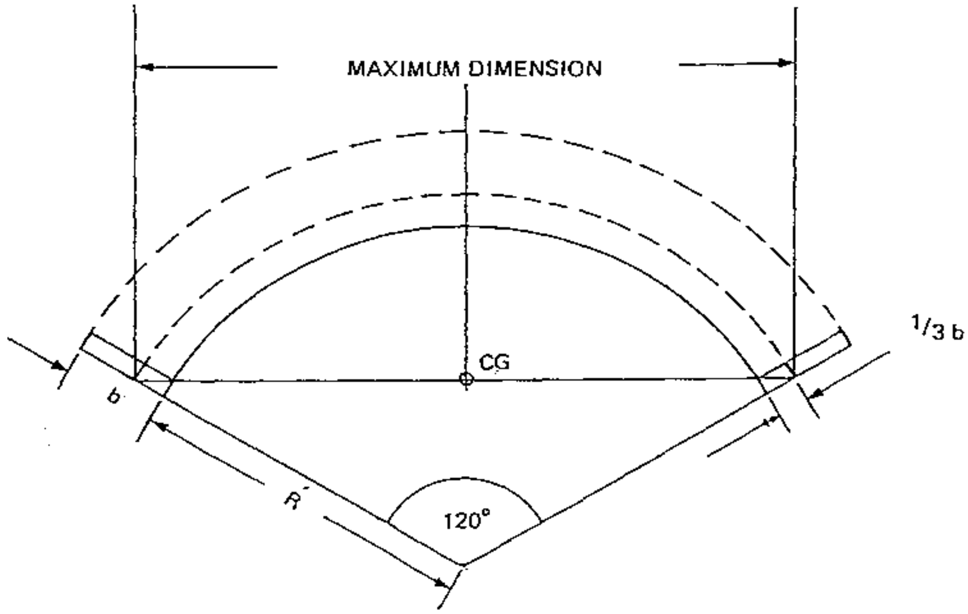
NOTE: The structural analysis should be made in accordance with ACJ 25.571.

b. Damage to any other engines (the consequences of subsequent non-containment of debris from the other engine(s), need not be considered).

c. Damage to services and equipment essential for safe flight (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.

d. Pilot incapacitance.

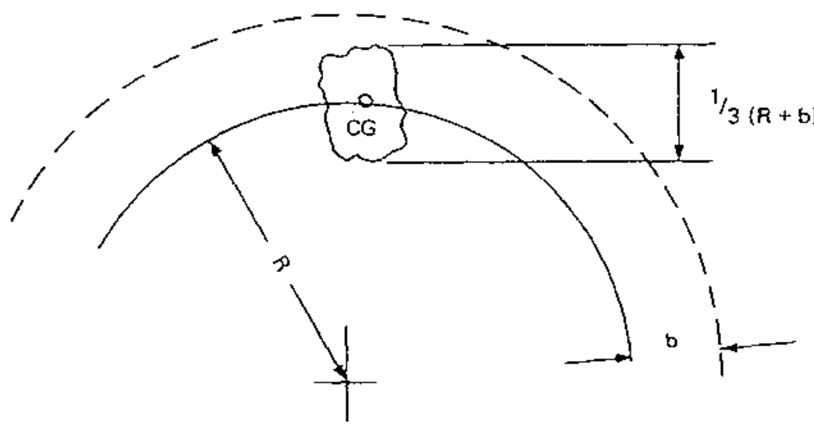
ACJ No. 2 to JAR 25.903(d)(1) (continued)



Where R = disc radius
b = blade length

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

FIGURE 1 — SINGLE ONE-THIRD DISC FRAGMENT



Where R = disc radius
b = blade length

Maximum dimension = ⅓ (R + b)

Mass assumed to be 1/30th of bladed disc

CG is taken to lie on the disc rim

FIGURE 2 — SMALL PIECE OF DEBRIS

ACJ No. 2 to JAR 25.903(d)(1) (continued)

e. 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 aeroplane where this could lead to a fire (or explosion).

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

g. Penetration and distortion of firewalls and cowling permitting a spread of fire.

NOTE: Consideration of the effect of damage should include degradation of the performance and handling characteristics of the aeroplane.

4.3 When all practical design precautions have been taken (see paragraph 2.1) and the safety analysis made using the engine failure model defined in paragraph 3 shows that catastrophic risk still exists for some components or systems of the aeroplane, the level of catastrophic risk should be evaluated. It is [considered that the objective of the requirement will have been met if the levels of risk stated in a. b. and c.,] as appropriate, have been achieved.

NOTE: It is accepted that due allowance should be made for the size and broad configuration of the aeroplane and that this may prevent the prescribed levels of risk being achieved.

a. *Single One-third Piece of Disc.* There is not more than a 1 in 20 chance of catastrophe resulting from the release of a single one-third piece of disc as defined in paragraph 3.1.

b. *Small Piece of Debris.* 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 3.2.

[c. *Multiple Fragments.* (Only applicable to any duplicated or multiplicated 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 centreline). There is not more than a 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 ±3° relative to the plane of the disc) causing coincidental damage to systems which are duplicated or multiplcated.

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 sub-paragraph.]

4.4 The aeroplane risk levels specified, resulting from the release of rotor debris, are the mean values obtained by averaging those for all discs on all engines of the aeroplane, assuming a typical flight. Individual discs or engines need not meet these risk levels nor need these risk levels be met for each phase of flight if either —

a. No disc shows a higher level of risk averaged throughout the flight greater than twice those stated in paragraph 4.3.

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

b. Where failures would be catastrophic in particular phases of flight only, 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 take-off. The proportional risk of engine failure during the particular phases of flight is given in SAE Paper AIR 1537 dated October 1977 'Report on Aircraft Engine Containment'. See also data contained in the CAA paper 'Engine Non-Containment —The CAA View', which includes Figure 3. This paper is published in NASA Report CP—2017, 'An Assessment of Technology for Turbo-jet Engine Rotor Failures', dated August 1977.

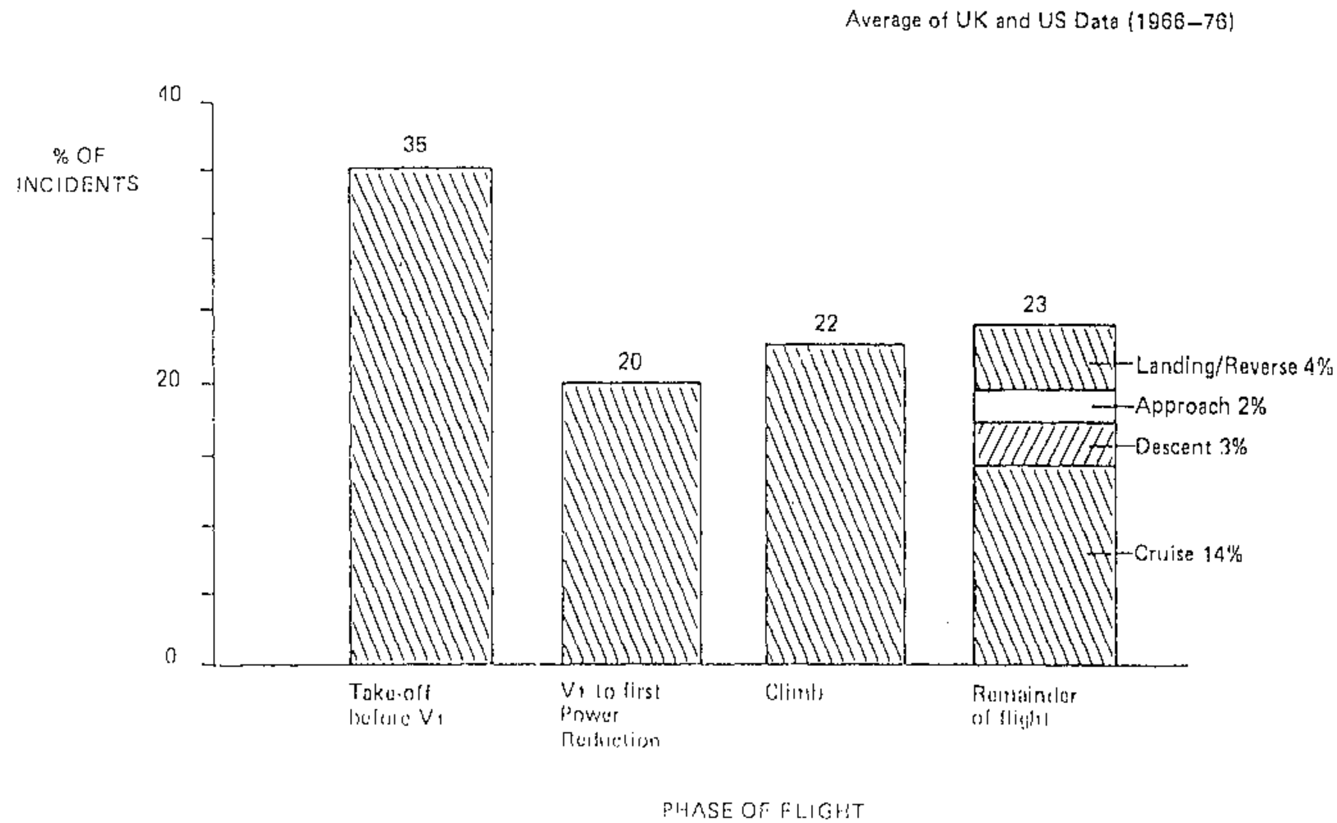


FIGURE 3 – ALL NON-CONTAINMENTS BY PHASE OF FLIGHT

APPENDIX C

UNCONTAINED ENGINE DEBRIS TRAJECTORY FIGURES

Appendix C – Table of Contents

Event#.Pg

UNCONTAINED ENGINE DEBRIS ANALYSIS

Date:	Airplane Model:	Location:	Power Level:
Airline:	Engine Model:	Flight Phase:	Altitude:
Tail Number:	Engine Position:	Flight Effect:	Airspeed:
	Eng Serial No.:		Hazard Level *(see Definitions)*:

PRIMARY MALFUNCTION (Rotor Stages):

SECONDARY MALFUNCTION (Rotor Stages):

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)

NARRATIVE:

SOURCE ***(Data obtained from)*****:**
DRAWINGS/PICTURES IDENTIFICATIONS:

ENGINE MANUFACTURER'S UPDATE:

FIGURE 1. Standardized Data Entry Form for Trajectory Study

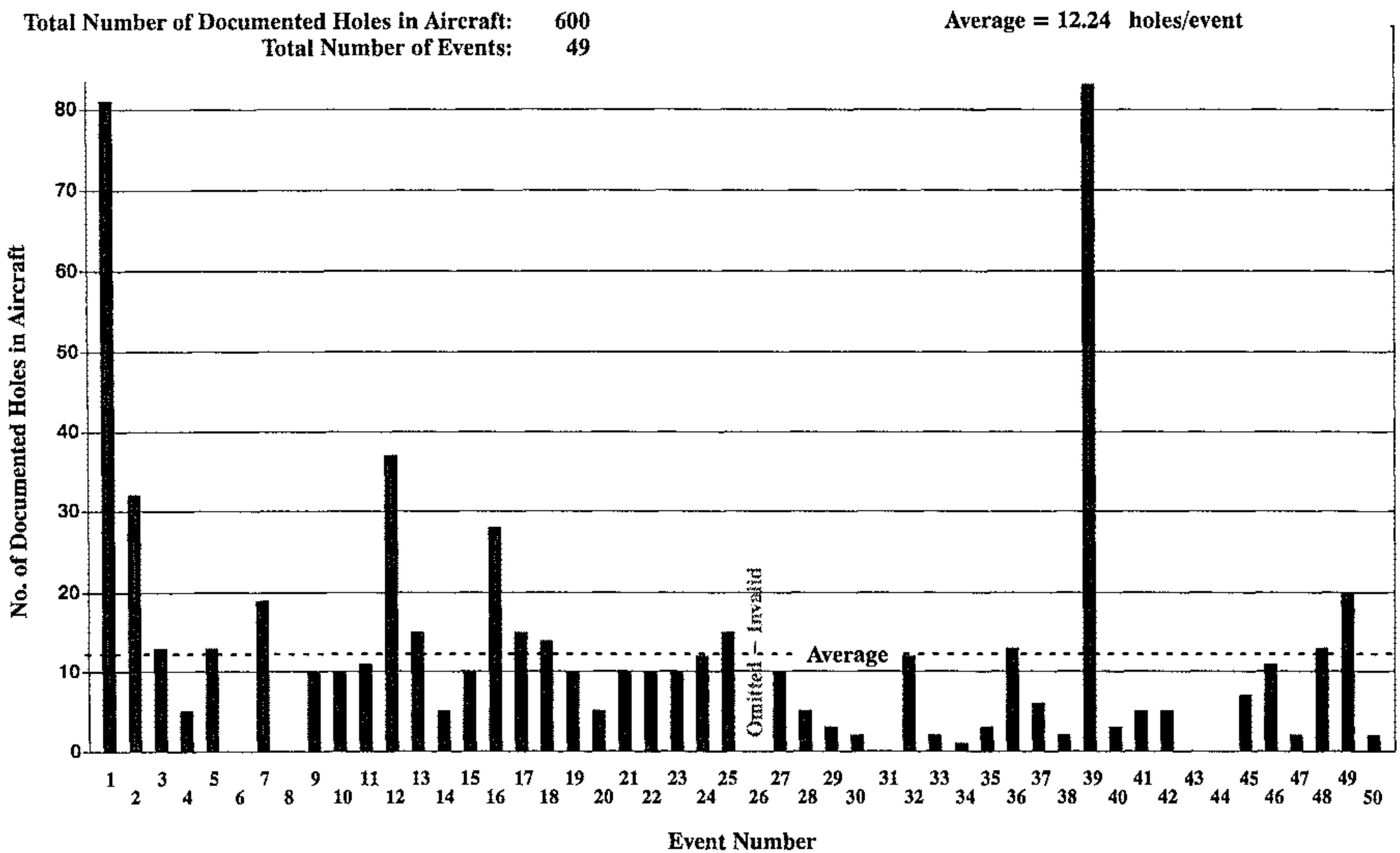


FIGURE 2. Aircraft Penetrations by Event

Number of Documented Disk Holes in Aircraft: 25
Total Number of Events: 49
Total Number of Disk Events: 18

Averages = 0.53 Disk Holes/Event
= 1.44 Disk Holes/Disk Event

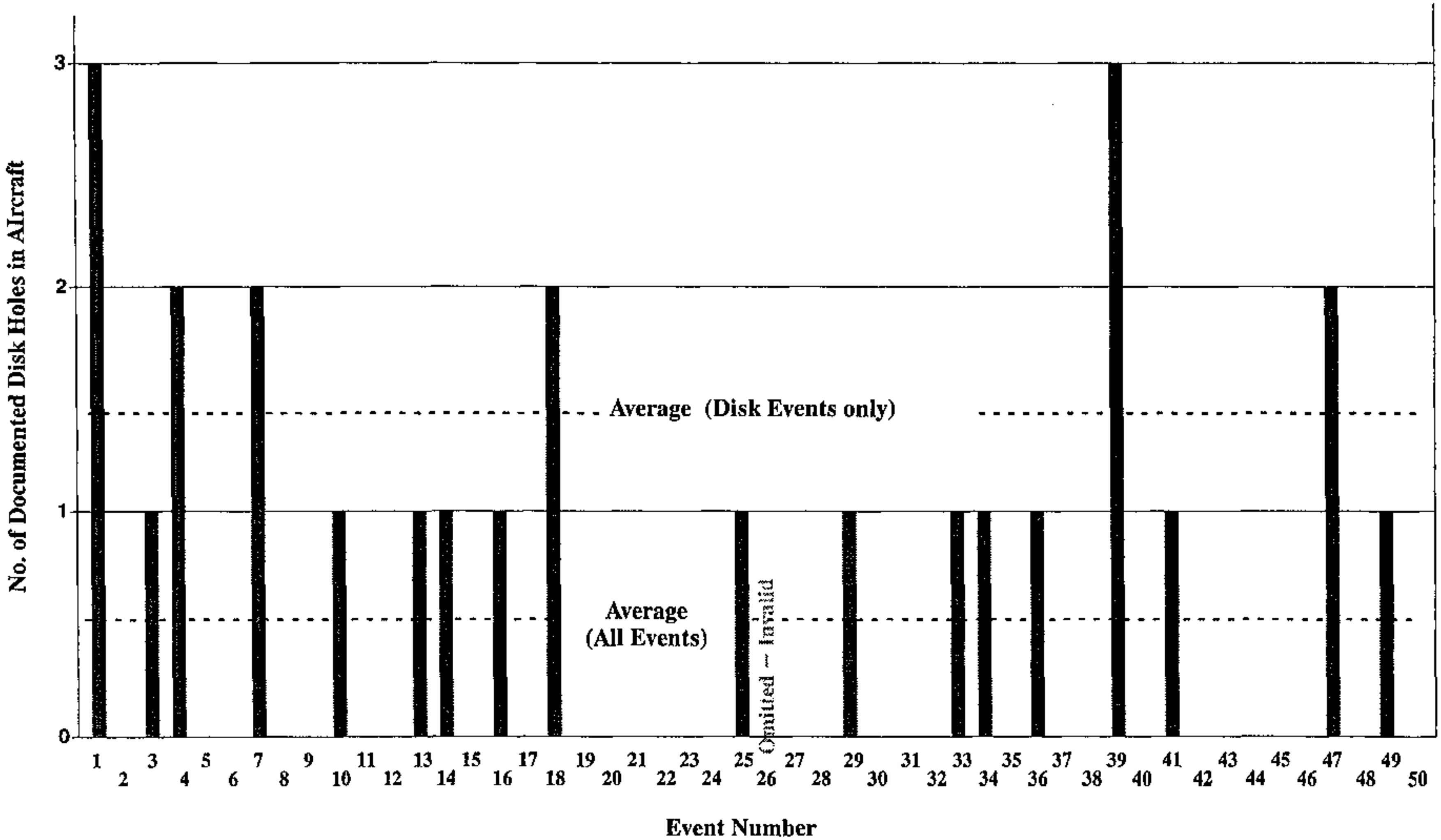


FIGURE 3. Disk Fragment Penetrations by Event

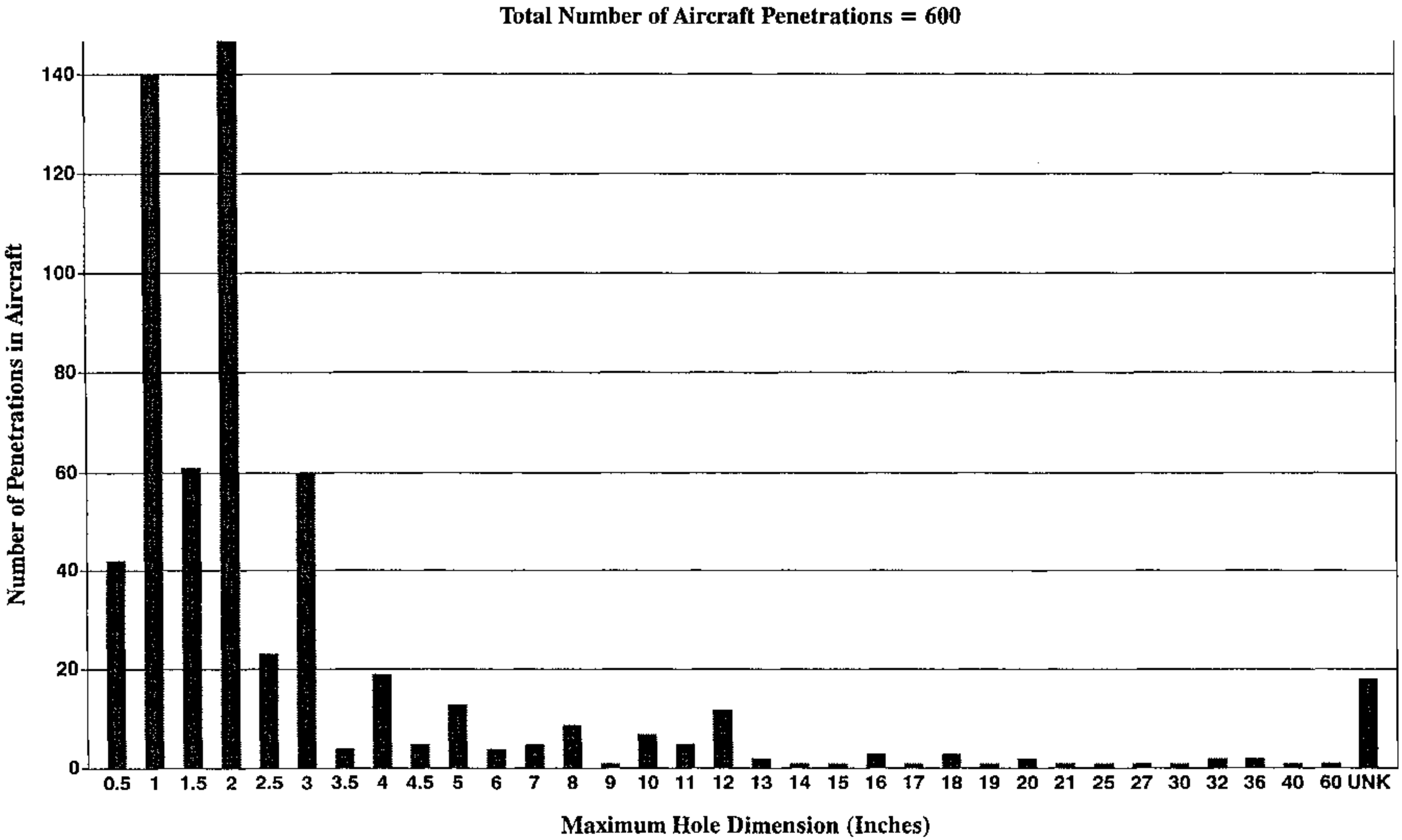


FIGURE 4. Size Distribution of Penetrations (Maximum Dimension)

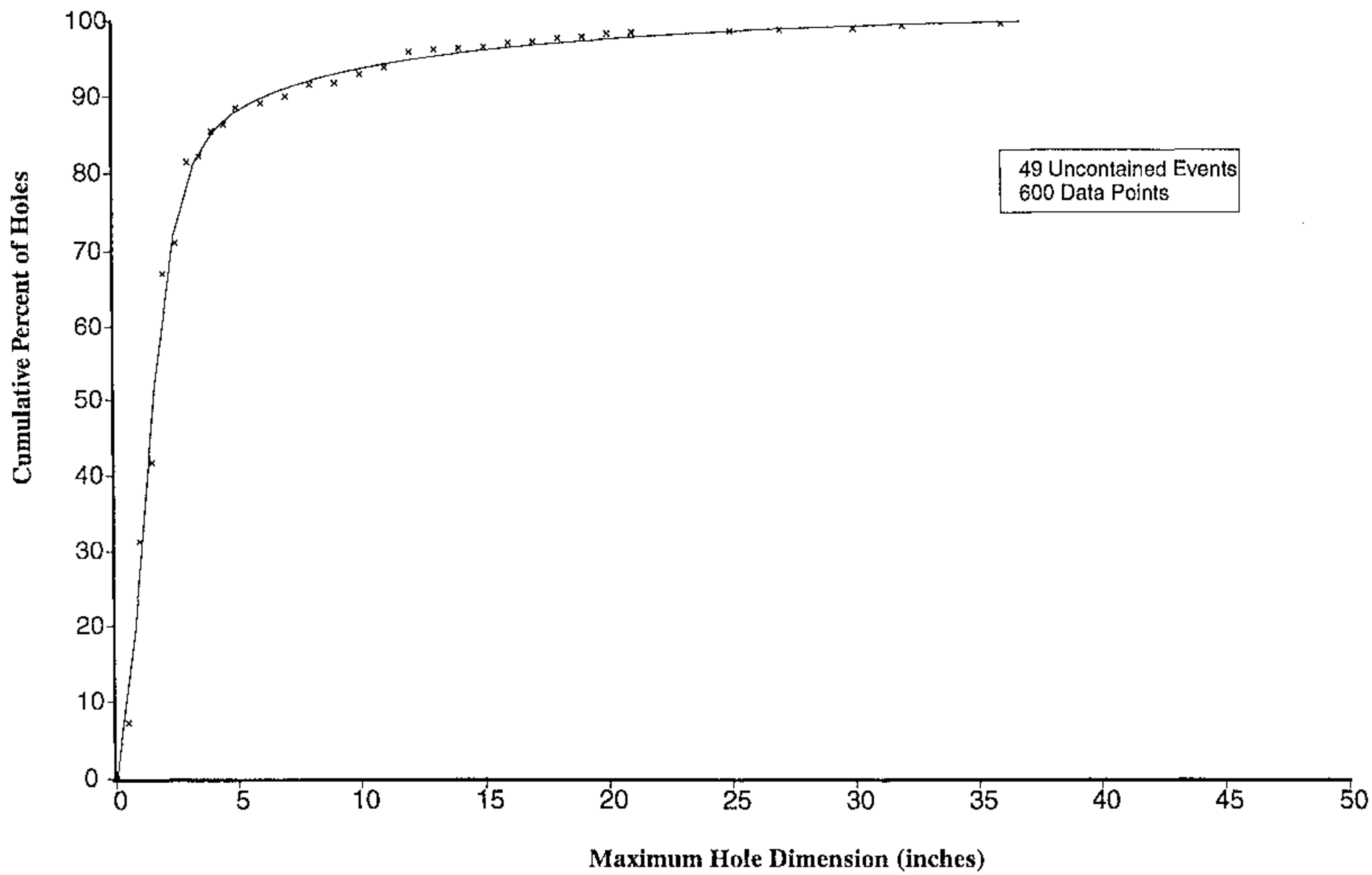


FIGURE 5. Cumulative Size Distribution of Penetrations (Maximum Dimension)

Total Number of Documented Disk Penetrations = 25
Total Number of Documented Disk Events = 18
Average Maximum Hole Dimension (inches) = 17.9

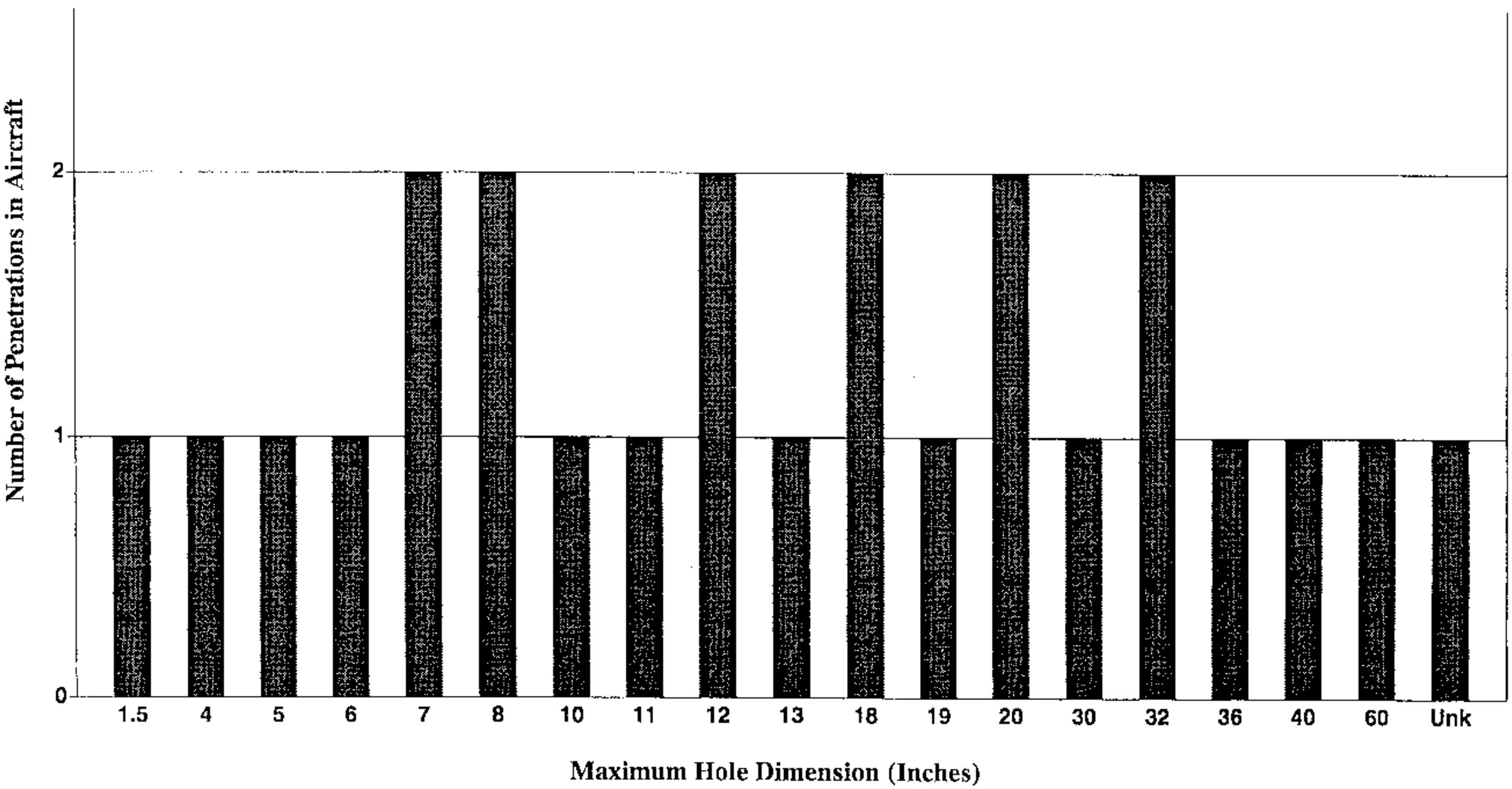


FIGURE 6. Size Distribution of Disk Penetrations (Maximum Dimension)

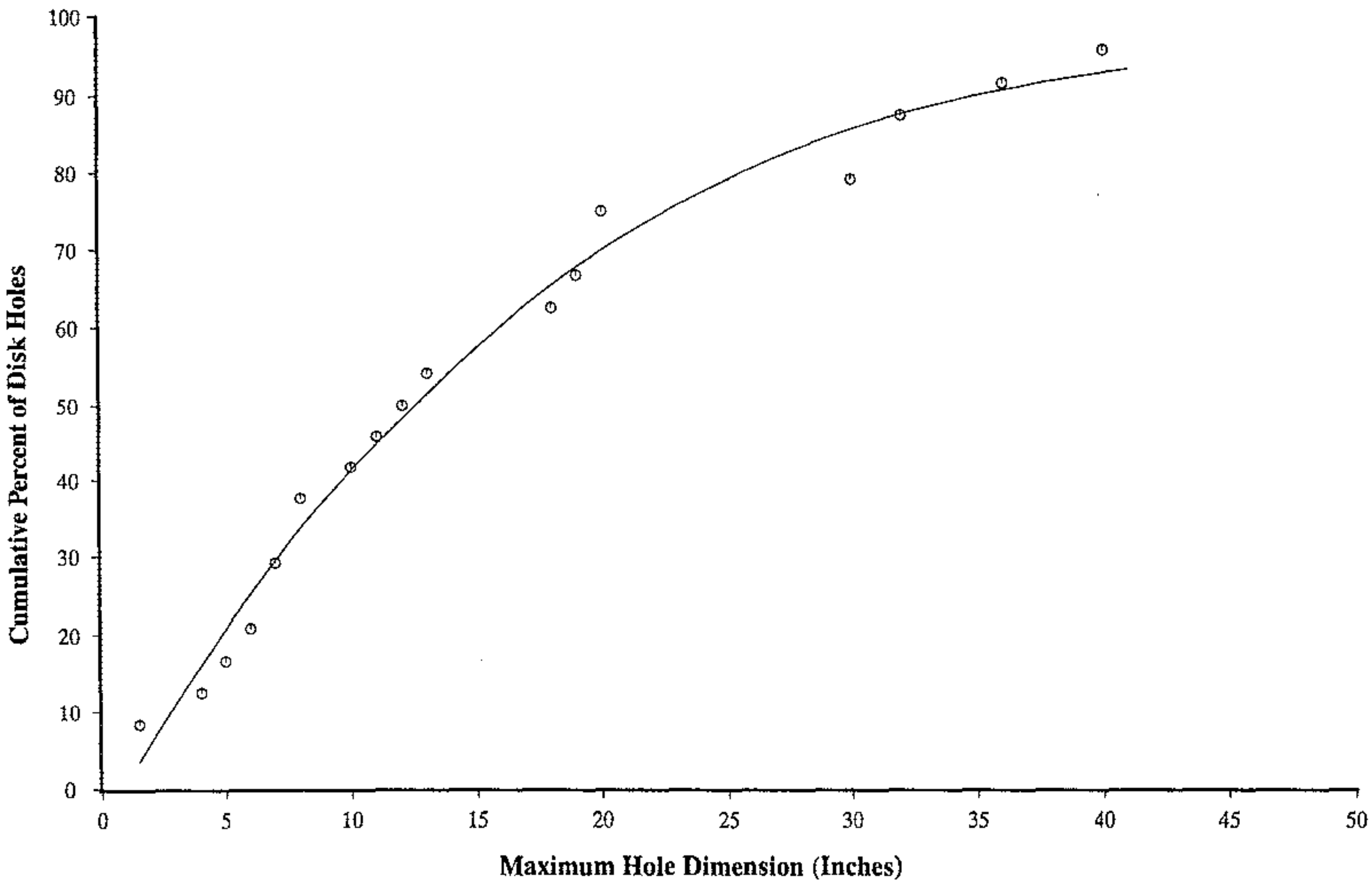


FIGURE 7. Cumulative Size Distribution of Disk Penetrations (Maximum Dimension)

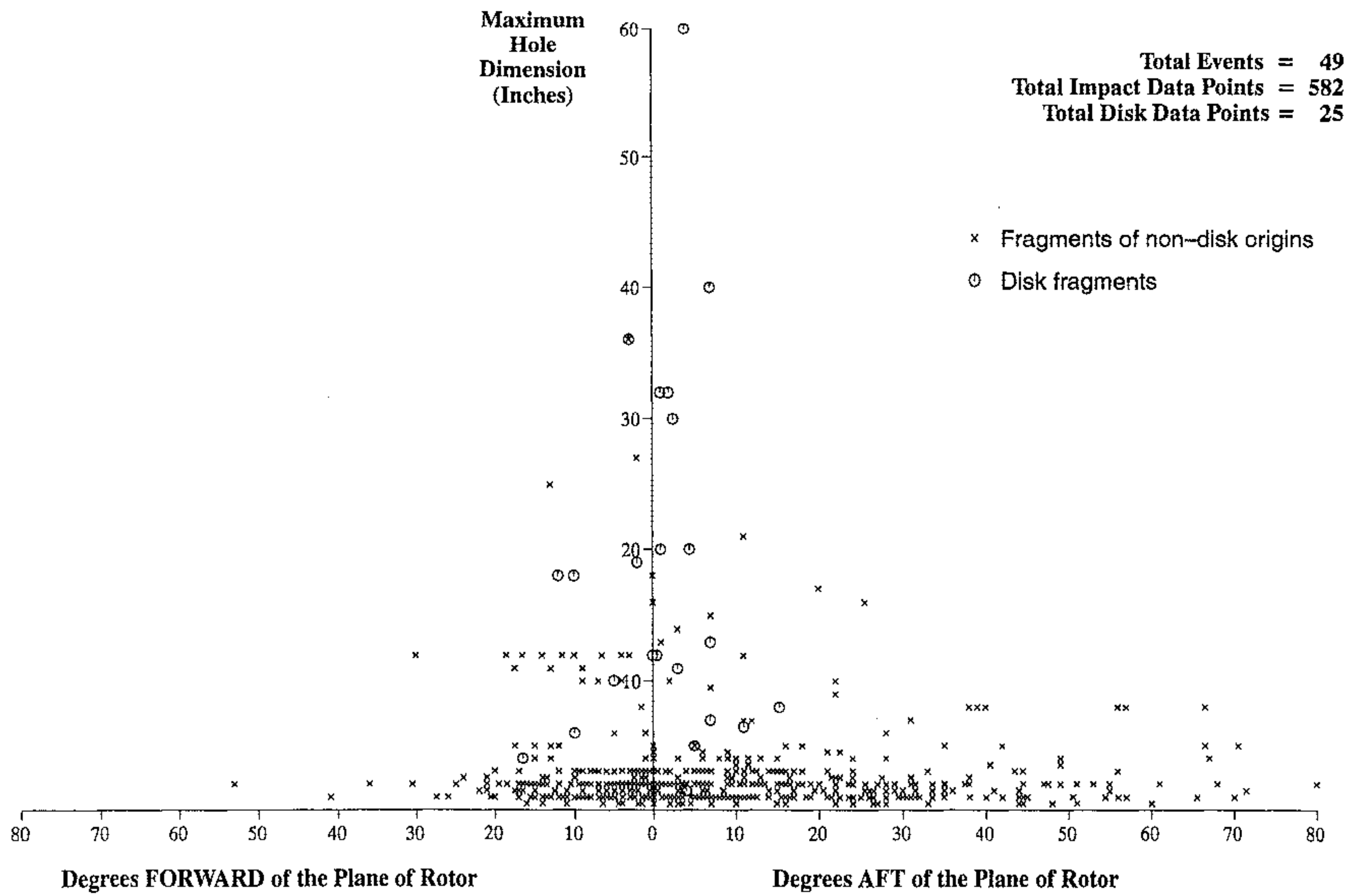


FIGURE 8. Fragment Trajectory versus Hole Size

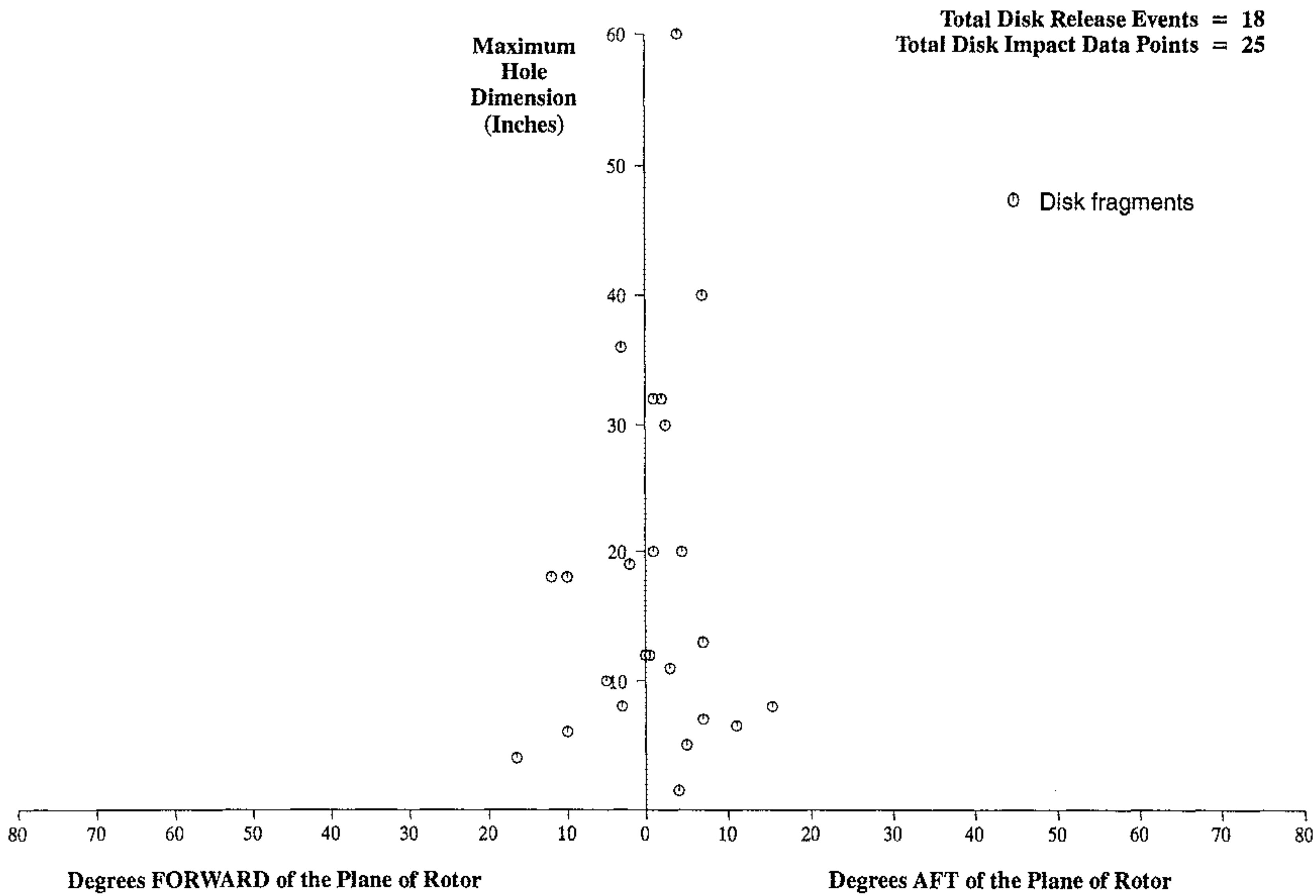


FIGURE 9. Disk Fragment Trajectory versus Hole Size

EVENT 12
TOTAL DATA POINTS = 37

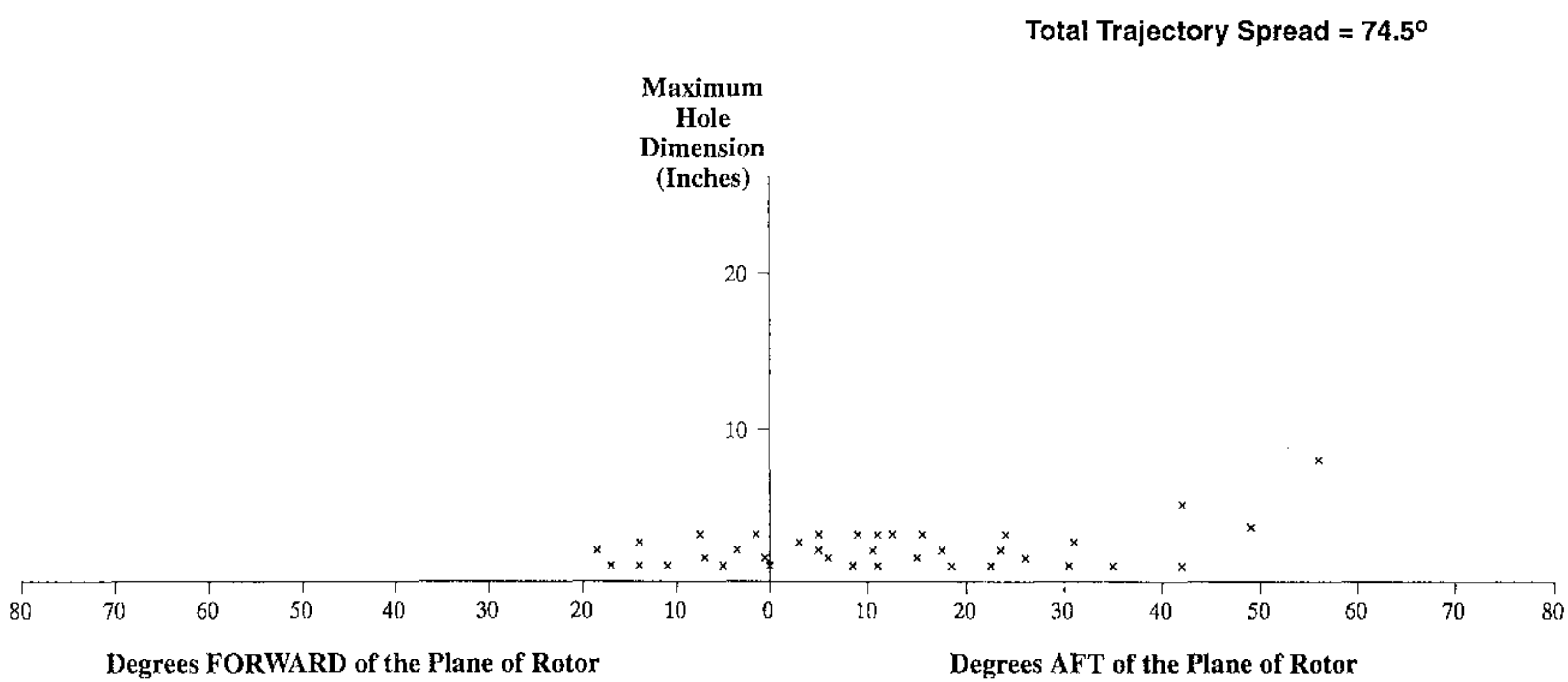


FIGURE 10. Maximum Fragment Trajectory Spread (Single Event)

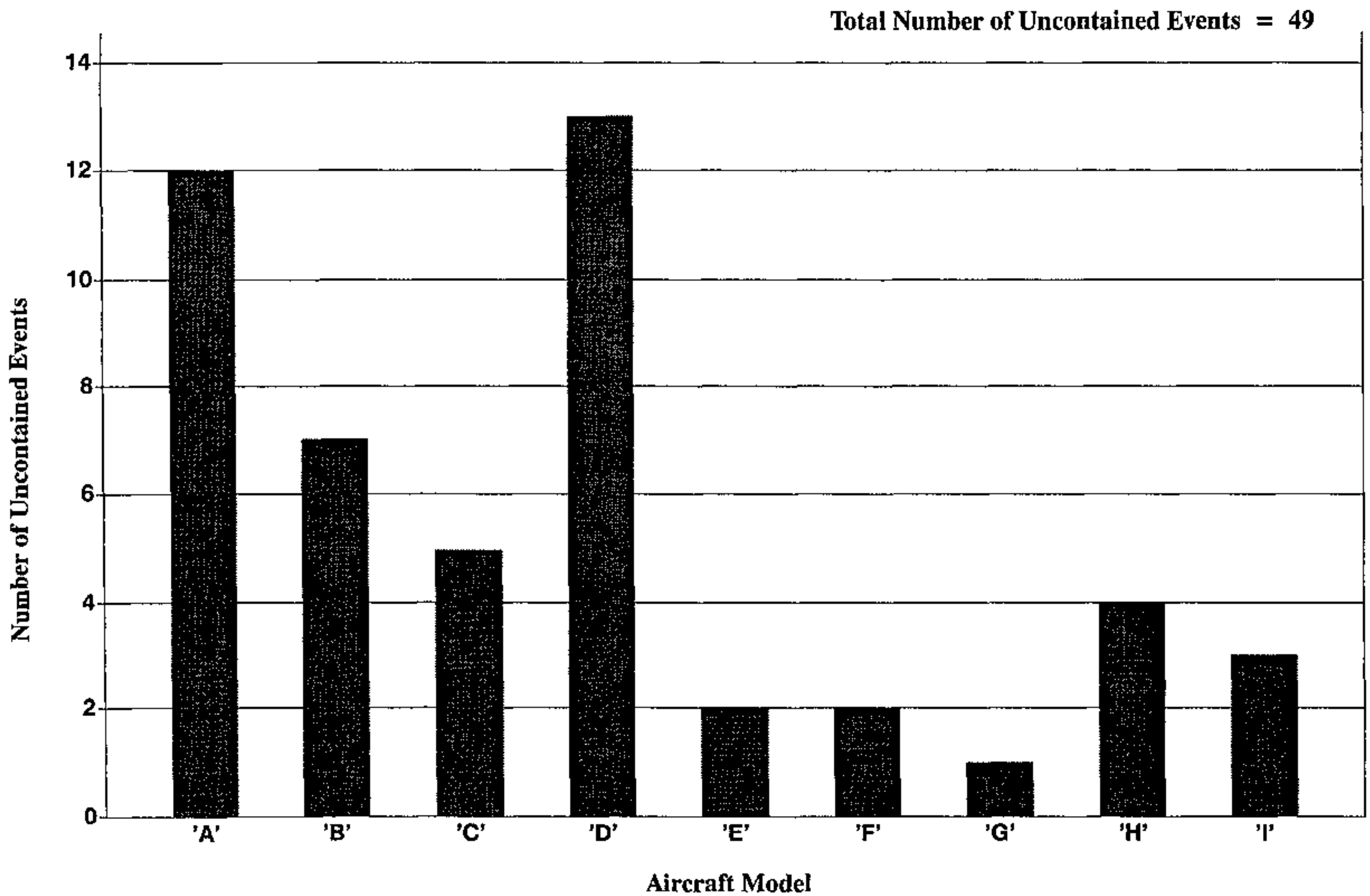


FIGURE 11. Number of Uncontained Events by Aircraft Model

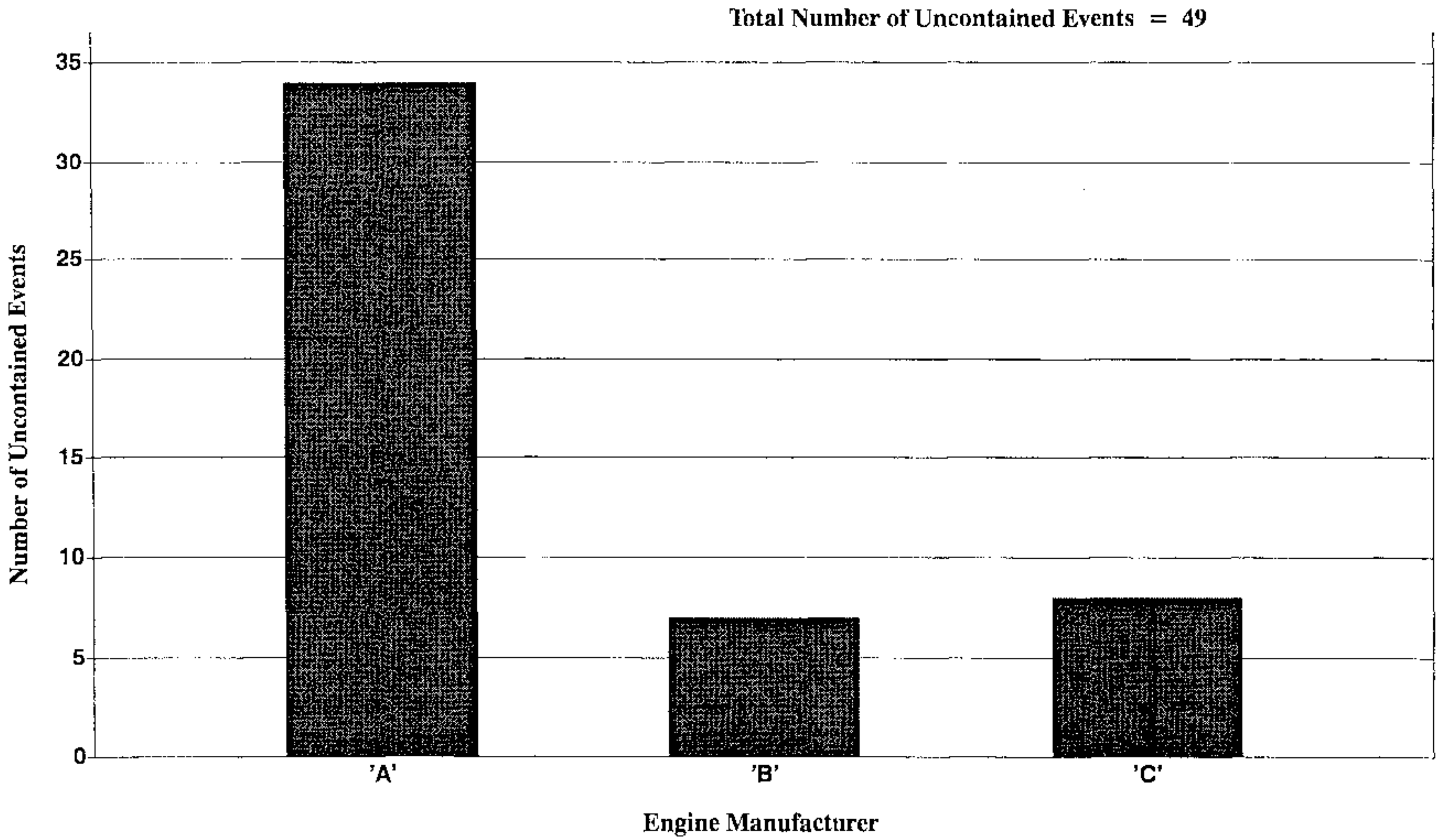


FIGURE 12. Number of Uncontained Events by Engine Manufacturer

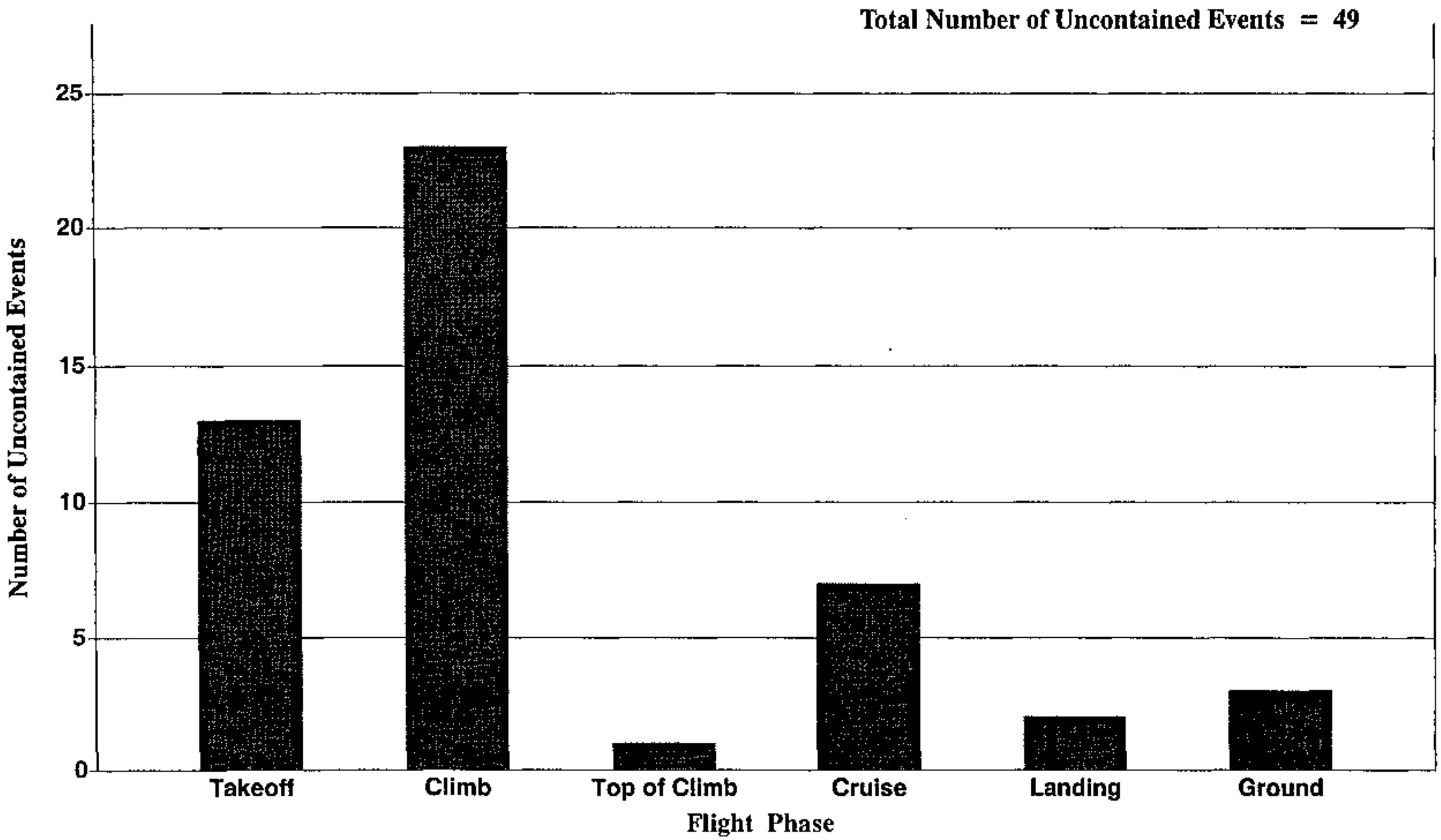


FIGURE 13. Number of Uncontained Events by Flight Phase

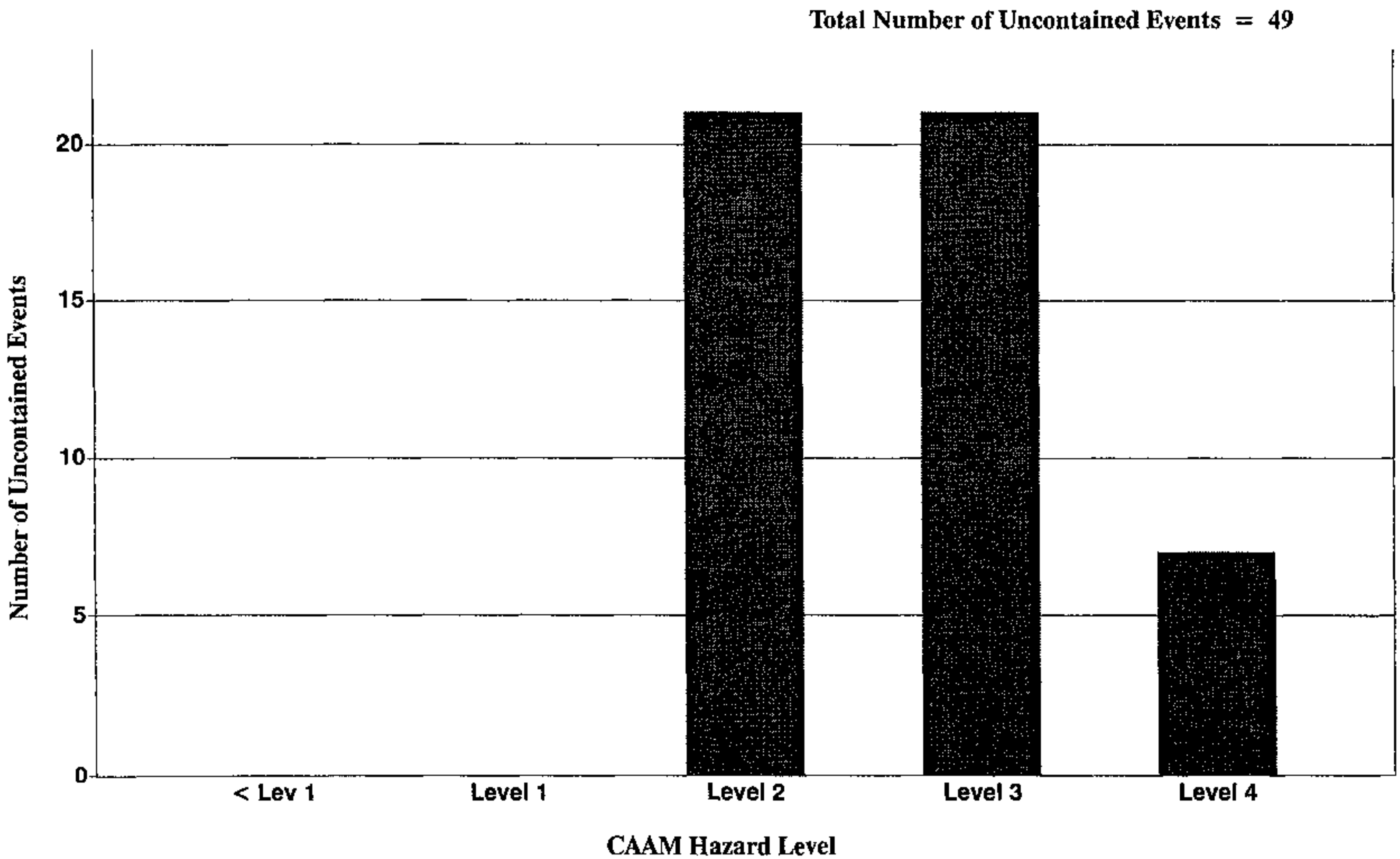


FIGURE 14. Number of Uncontained Events by CAAM Hazard Level

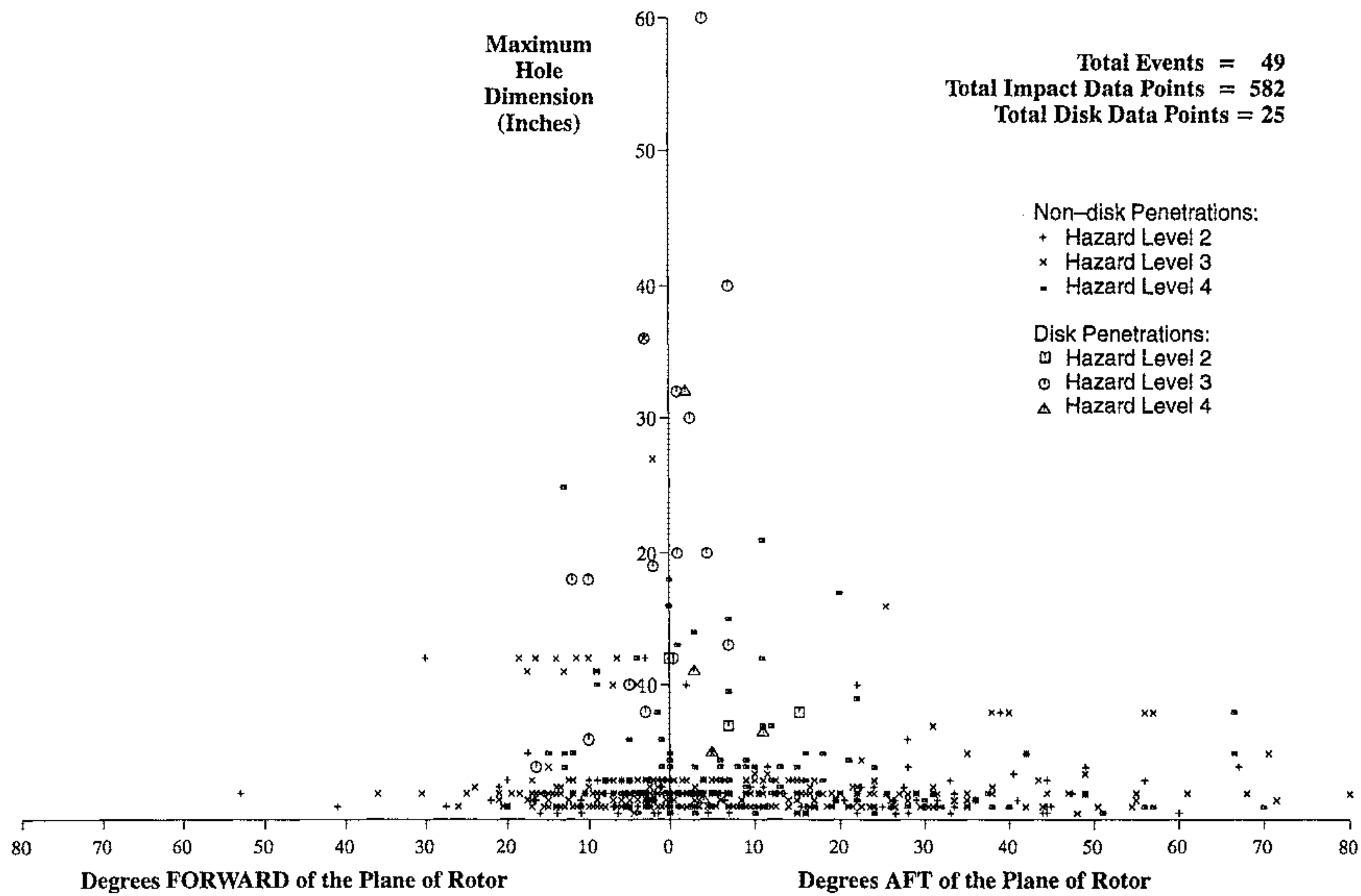


FIGURE 15. Uncontained Trajectories by CAAM Hazard Level

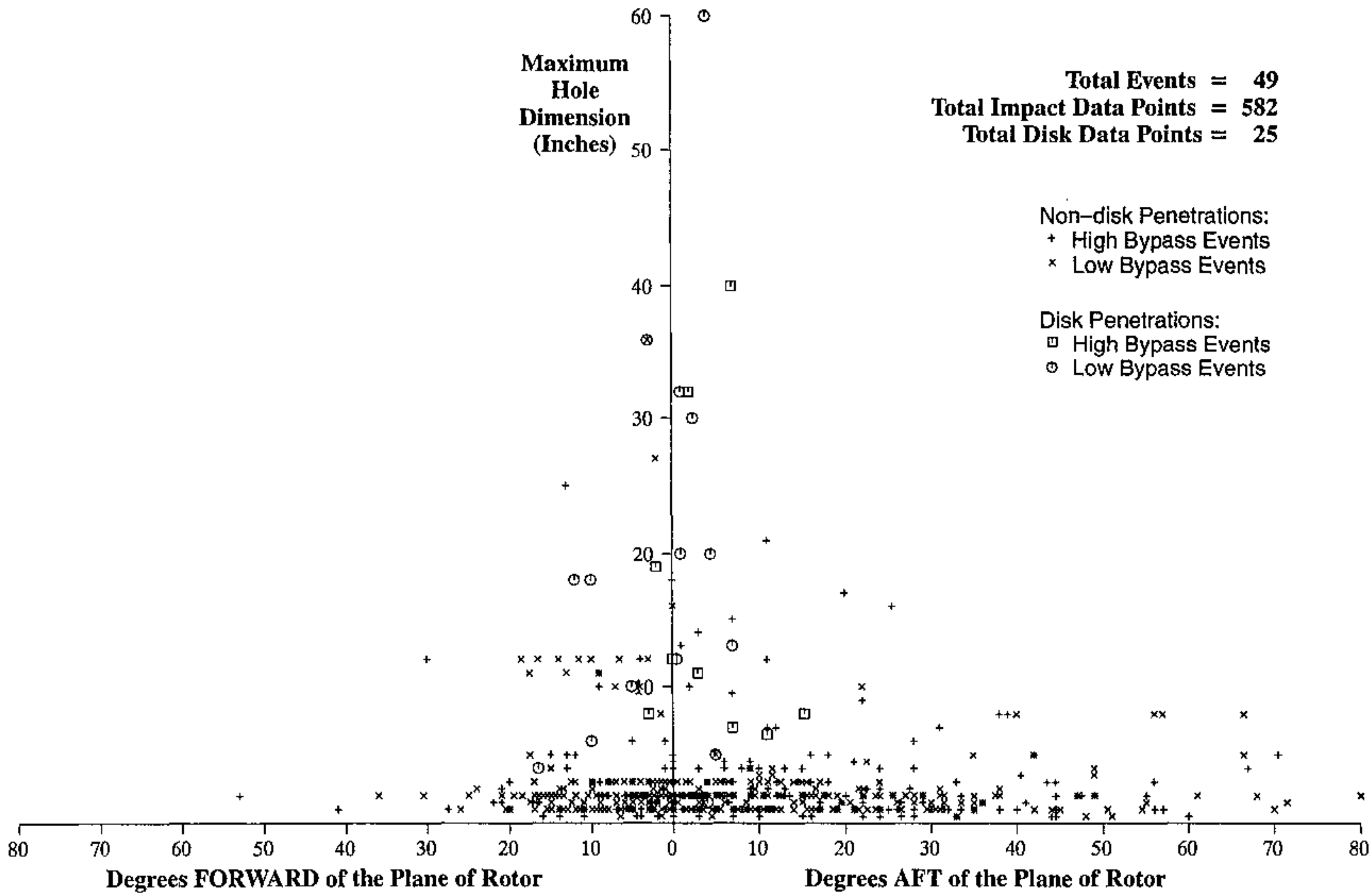


FIGURE 16. Uncontained Trajectories by Relative Bypass Ratio

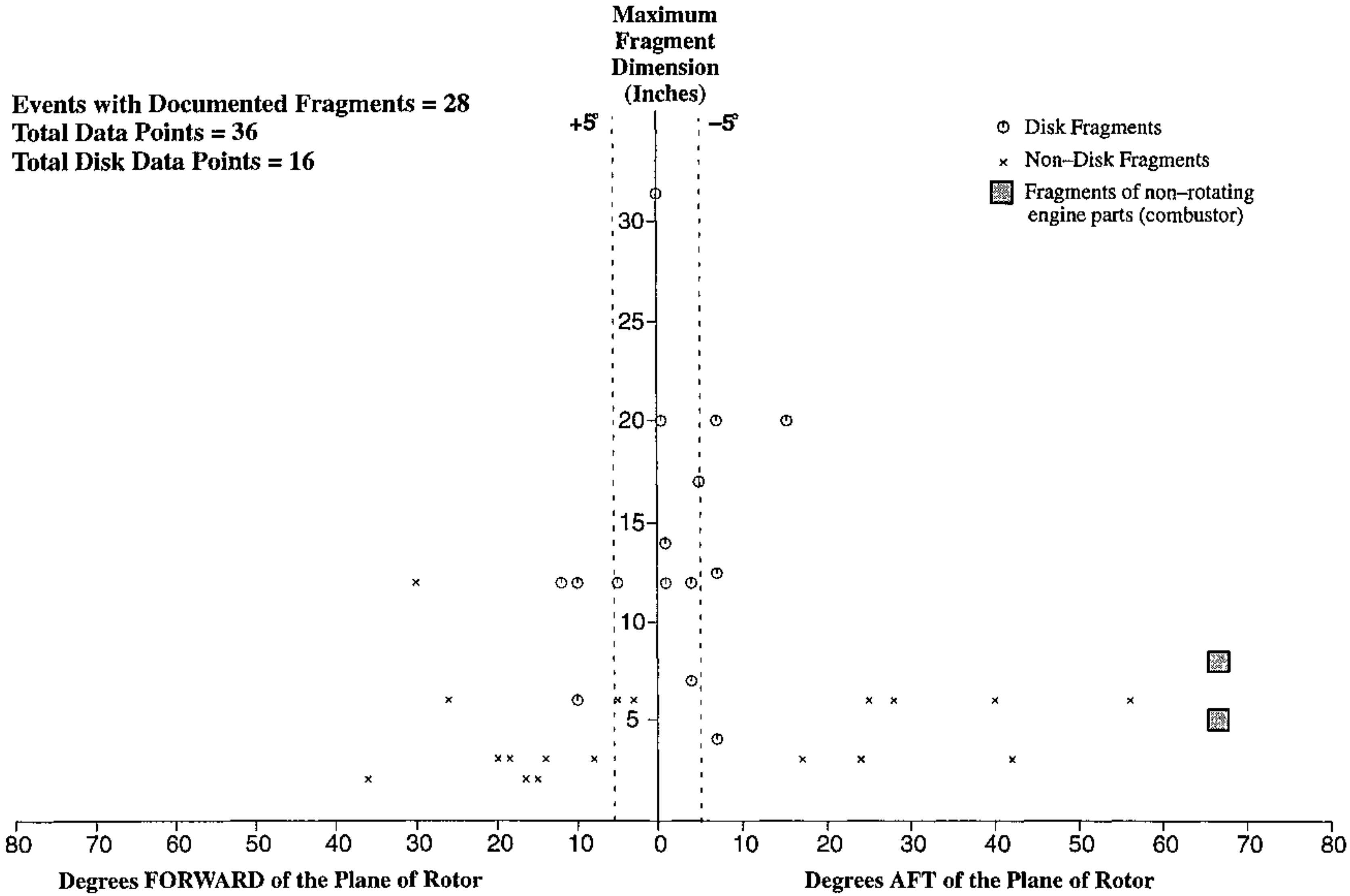


FIGURE 17. Fragment Trajectories of Known Fragments

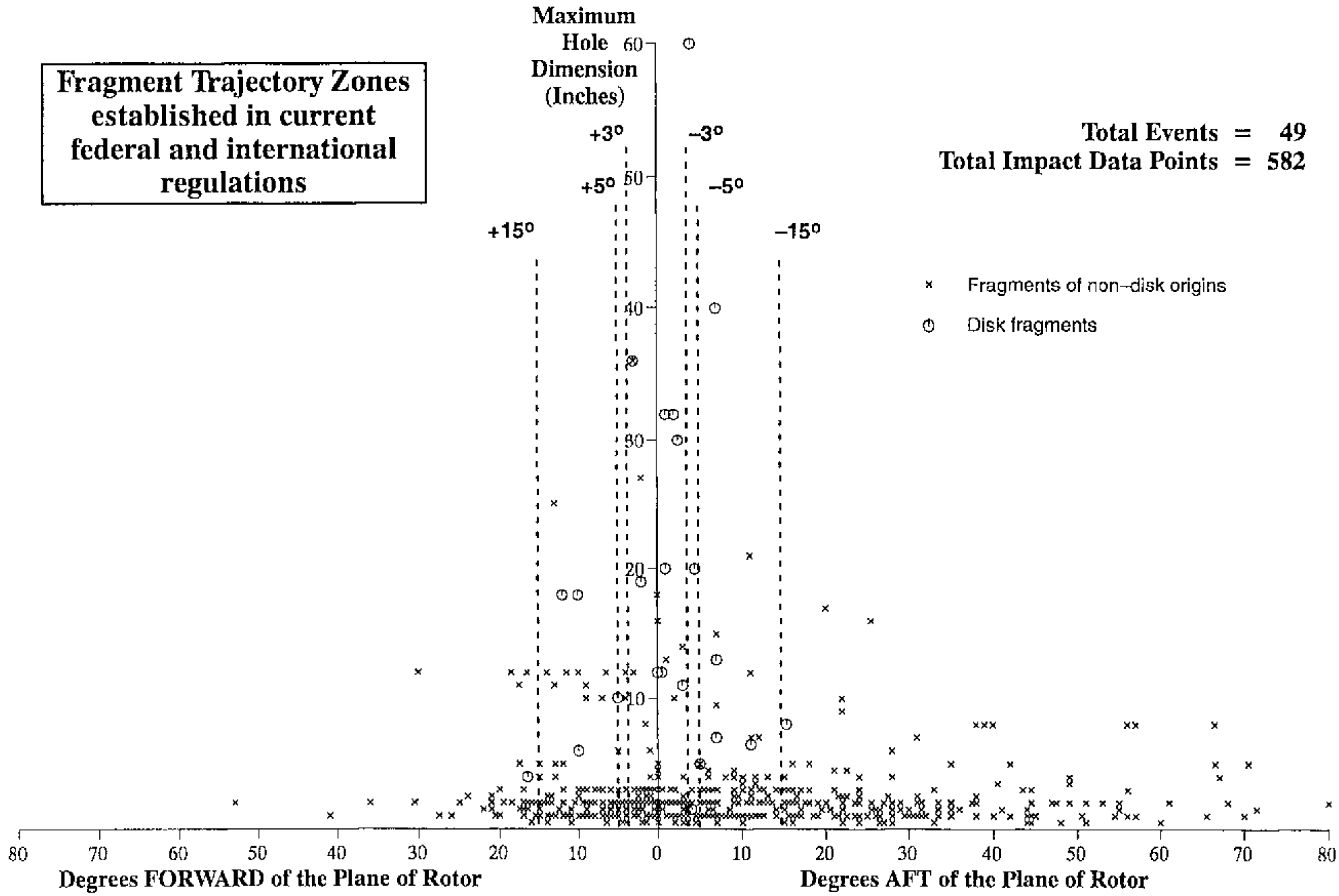


FIGURE 18. Current Trajectory Limits overlaid on Historical Trajectory Data

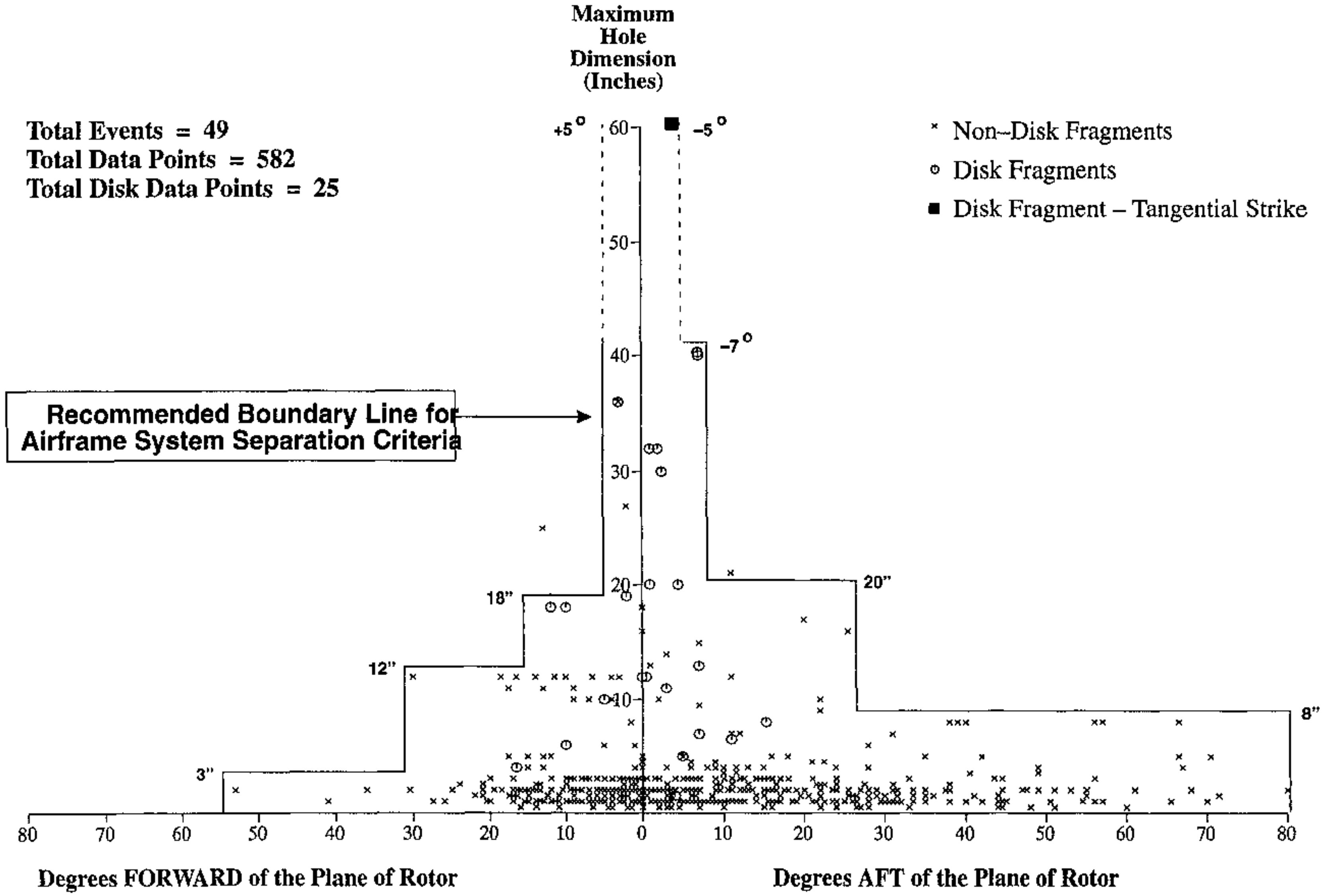


FIGURE 19. **Recommended Boundary for Airframe Systems Separation Criteria Based on Penetration Sizes**

APPENDIX D

HAZARD LEVEL DESCRIPTIONS

as defined by the
Continuing Airworthiness Assessment Methodology (CAAM) Team

PC342 – CAAM
STANDARDIZED AIRCRAFT HAZARD LEVELS
5/1/93

Propulsion system/APU malfunctions or related incidents, in certain cases coupled with crew error or other aircraft system malfunctions, resulting in the following consequences to the aircraft or its passengers/crew.

Level 4 – Severe Consequences

4a. Forced Landing.

Note: Forced landing is defined as the inability to continue flight due to the consequences of damage, uncontrolled fire or thrust loss where imminent landing is obvious but aircraft controllability is not necessarily lost. (i.e. Total power loss due to fuel exhaustion will result in a "forced landing". The term "emergency landing" may also be used to mean a forced landing if there is an urgent requirement to land. An air turn back or diversion due to a malfunction is not a forced landing since there is a lack of urgency and the crew has the ability to select where it will perform the landing. However, off airport landings are almost always forced landings.)

4b. Loss of Aircraft (Hull Loss)

4c. Serious Injuries or Fatalities (see NTSB Definition below)

Note: "Serious injury" means any injury that (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in the fracture of any bone (except simple fractures of fingers, toes or nose); (3) involves lacerations that cause severe hemorrhages, nerve, muscle or tendon damage; (4) involves injury to any internal organ: or (5) involves second–or–third degree burns or any burns affecting more than 5% of the body surface. In addition, "Fatal Injury" is defined as an injury that results in death within 30 days of the accident. (Egress injuries are excluded from establishing the threat category by mutual agreement of the CAAM membership).

Level 3 – Serious Consequences

(Serious Incident as defined by ICAO is "Any event involving the operation of an aircraft other than an accident where the event, or the event coupled with any other reasonably probable second event, has the direct potential to result in an accident.)

3a. Substantial damage to the aircraft or second unrelated system.

Note 1: "Substantial damage" means damage or structural failure that adversely affects the structural strength, performance or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected components. (Not considered substantial damage are engine failure damage limited to the engine, bent fairings or cowlings, dented skin, small puncture holes in the skin or fabric, damage to landing gear, wheels, tires, flaps, engine accessories, brakes or wing tips. Generally, if the aircraft can be repaired in a 48 hour period to allow a ferry flight to a repair base, the damage in not considered to be substantial.)

Note 2: Damage to a second unrelated system must impact the ability to continue safe flight and landing. Coordination and agreement between the engine/propeller/APU manufacturer and the airframe manufacturer may be required to properly categorize events related to second system damage. In general aircraft are designed to be dispatched with one part of a redundant system inoperative with no affect on flight safety. Therefore an uncontained rotor event which severed an unrelated hydraulic system line which did not significantly degrade the ability to continue safe flight should not be considered a Hazard Level 3a event.

Note 3: Small penetrations of aircraft fuel lines , or aircraft fuel tanks where the combined penetration areas exceed two square inches will be the basis for a Hazard Level 3a classification. Assistance of the airframe manufacturer should be sought when questions arise.

Note 4: Damage to a second engine (cross engine debris) which results in a significant loss of thrust or pilot action to reduce power (creates an operational problem) is a Hazard Level 3a event. Minor damage, unobserved by the crew during flight and which did not impact the ability of the engine to continue to operate safely for the rest of the flight, is Hazard Level 2.

3b. Uncontrolled fires – not extinguished by on–board aircraft systems. (Note: Internal tailpipe fires that hazard the aircraft are considered uncontrolled fires.)

3c. Rapid depressurization of the cabin.

3d. Permanent loss of thrust greater than one propulsion system.

3e. Temporary or permanent inability to climb and fly 1000 feet above terrain along the intended route. (i.e. multiple propulsion system malfunctions or single malfunctions and/or other aircraft system malfunction/crew error, which results in restricted flight capability (increased threat from terrain, inclement weather, etc.)).

3f. Any temporary or permanent impairment of aircraft controllability (includes propulsion system malfunction and/or thrust reverser in–flight deployment, propeller control malfunction, etc. May be coupled with aircraft control system malfunction or crew error).

Level 2 – Significant Consequences

2a. Nicks, dents and small penetrations in aircraft structure.

2b. Slow depressurization.

2c. Controlled fires (i.e. extinguished by on–board aircraft systems).

2d. Fuel leaks beyond normal extinguishing capabilities, i.e. if fire had resulted. (Note: "All fuel leaks resulting from aircraft fuel cell or fuel line penetrations".)

2e. Minor injuries.

2f. Multiple propulsion system/APU malfunctions, or related events, where one engine remains shutdown but continued safe flight at an altitude 1000 feet above terrain along the intended route is possible.

2g. Any high speed takeoff abort (usually 100 knots or greater).

2h. Separation of propulsion system, inlet, reverser blocker door, translating sleeve inflight without Level 3 damage consequences to the aircraft structure or systems. (Separations on the ground are excluded.)

2i. Partial inflight reverser deployment or propeller pitch change malfunction(s) which do not result in loss of aircraft control or damage to aircraft primary structure.

Level 1 – Minor Consequences

1a. Uncontained nacelle damage confined to affected nacelle/APU area.

1b. Uncommanded power increase, or decrease, at an airspeed above V1 and occurring at an altitude below 3000 feet (includes inflight shutdowns (IFSD) below 3000 feet).

1c. Multiple propulsion system malfunctions or related events, temporary in nature, where normal functioning is restored on all propulsion systems and the propulsion systems function normally for the rest of the flight. Includes common cause environmental hazard induced events.

1d. Separation of propeller/component releases which cause no other damage.

1e. Uncommanded propeller feather.

General Notes Applicable to All Hazard Levels:

(1) The severity of aircraft damage is based on the consequences and damage that actually occurred, or

(2) Damage is classified as serious aircraft damage if the event resulted in the aircraft being exposed to circumstances outside the certified limits.

(3) Uncontained event damage definitions have been modified from those used in SAE AIR 1537/4003/4770 with respect to Hazard Level 3 – secondary system damage event. The objective has been to more clearly define and separate those events which had a major impact on continued safe flight and landing from those with lesser consequences. (See notes on Hazard Level 3a.)

4.2 SIZE OF AIRCRAFT PENETRATIONS

4.2.1 ALL FRAGMENTS – MAXIMUM DIMENSIONS

Of the 600 holes counted in the 49 events used in the study, 18 holes (event 5, holes 2–13, and event 29, hole 1) were not measurable for use in analysis. These holes were found in the airplane where either fire or other structural damage or lack of data made the measuring of holes impossible, though it was evident that penetrations occurred. In the calculations for all of this study, the total number of holes used in analysis was 582, as these 18 holes were excluded.

Figure 4 contains a bar graph showing the distribution of hole size for all documented airplane penetrations, using the maximum dimension of each.

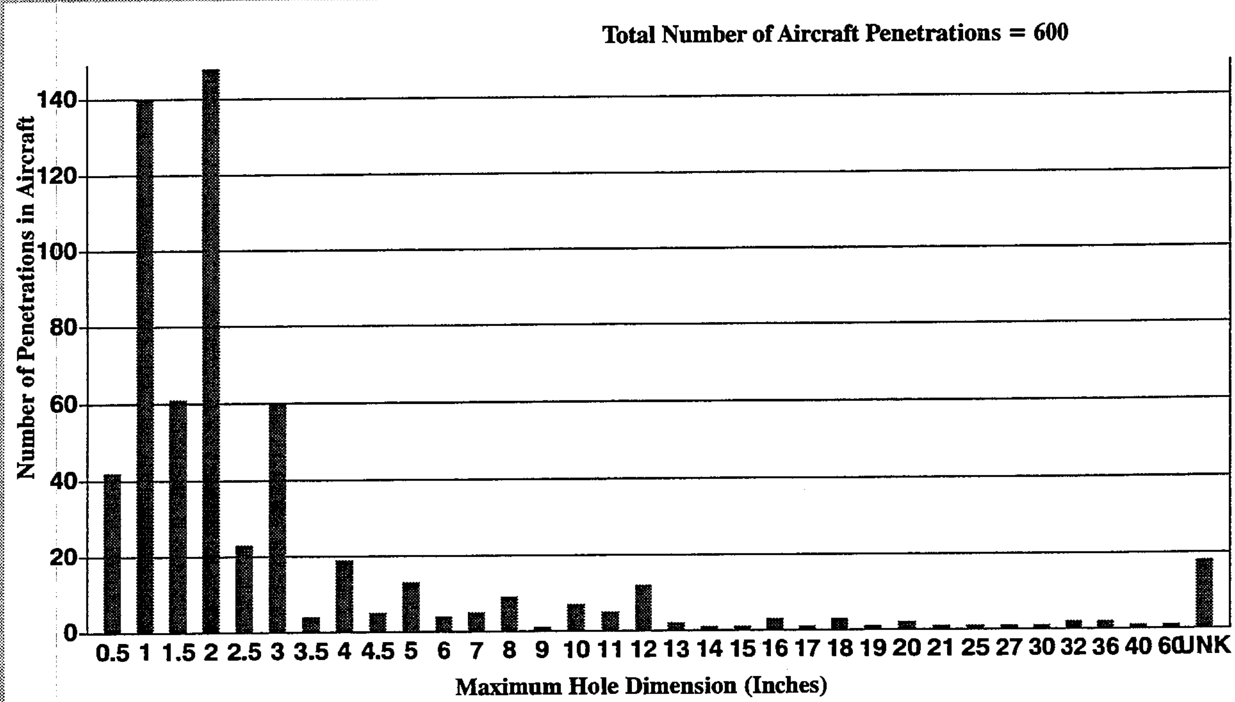


FIGURE 4. Size Distribution of Penetrations (Maximum Dimension)

474 holes (81.44%) had maximum dimensions of 3 inches or less. 515 holes (88.49%) had maximum dimensions of 5 inches or less. 67 holes (11.17%) had maximum dimensions of more than 5 inches. The cumulative percent of holes documented by increasing hole size is shown in figure 5.

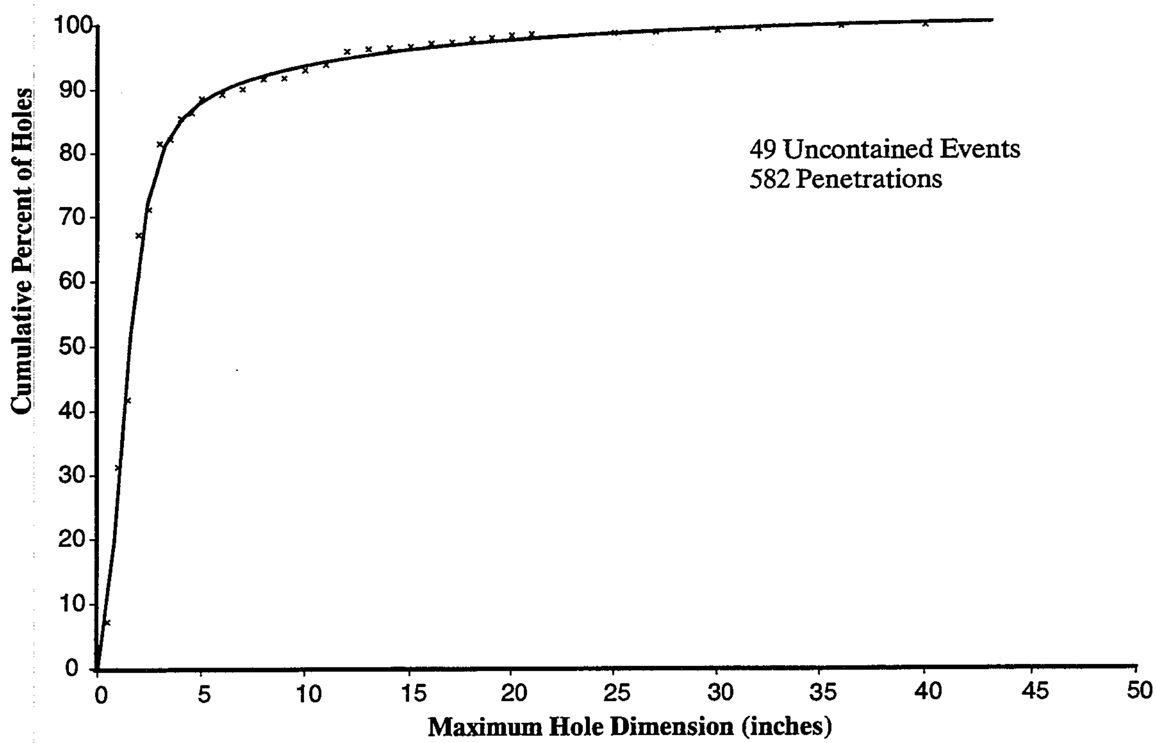


FIGURE 5. Cumulative Size Distribution of Penetrations (Maximum Dimension)

The penetration with the largest maximum dimension was a tangential slice in the fuselage by a disk rim segment (described in section 4.2.2), which opened up a hole approximately 5 inches by 60 inches. The smallest documented holes for the purposes of this study measured approximately $^1/_2$ inch by $^1/_2$ inch (some were even smaller). There were 42 penetrations of approximately this size and smaller. The sizes of the fragments which caused these penetrations are unknown.

4.2.2 DISK FRAGMENTS – MAXIMUM DIMENSIONS

Of the 582 penetrations documented, 25 penetrations (4.3%) were caused by disk or disk rim fragments. The largest penetration was a 5 inch by 60 inch hole, which was a tangential strike on the fuselage (event 4, hole 5). The disk segment which caused this hole was estimated by the engine manufacturer to be approximately 12 inches long and 3 inches wide, weighing about 10 pounds. Three of the documented disk penetrations resulted in holes with maximum dimensions of 5 inches or smaller. The average maximum dimension of all holes caused by the penetration of a disk fragment is 17.9 inches, as noted in Figure 6, which shows the distribution of hole sizes caused by disk fragments, using the maximum hole dimension for each event.

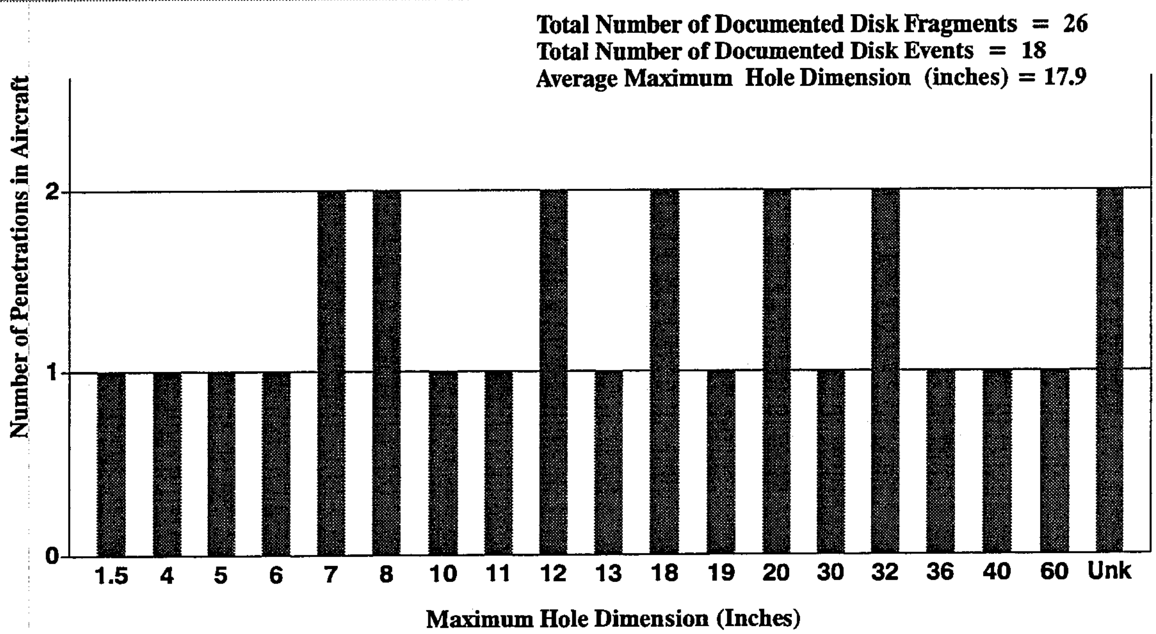


FIGURE 6. Size Distribution of Disk Penetration (Maximum Dimension)

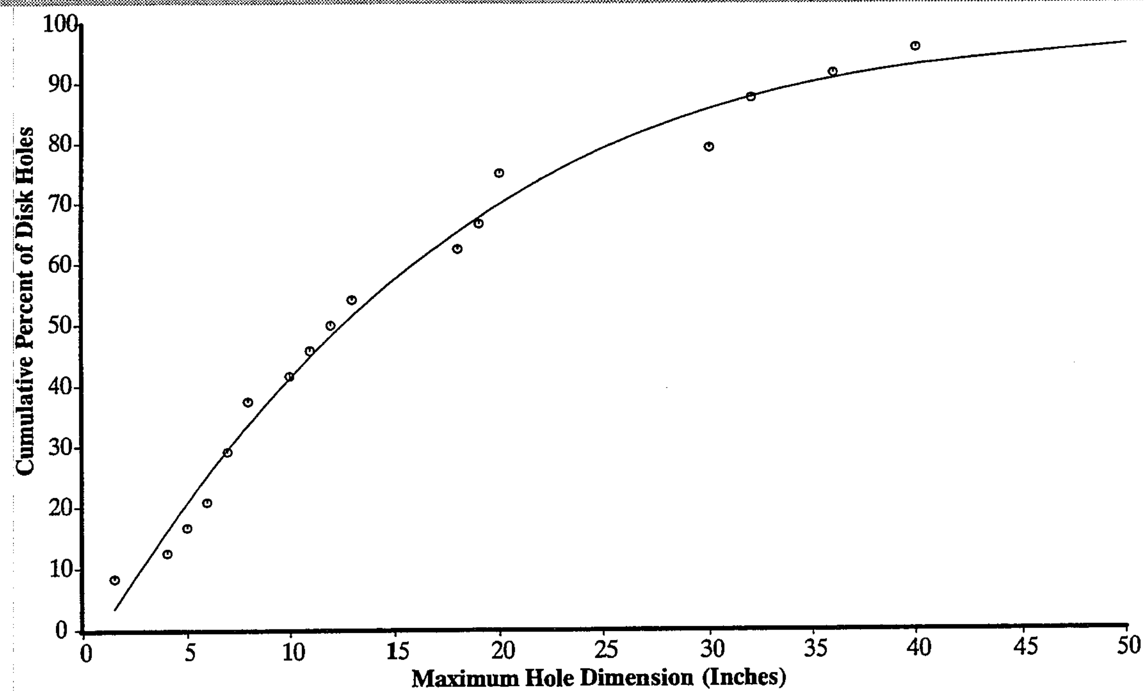


FIGURE 7. Cumulative Size Distribution of Disk Penetrations (Maximum Dimension)

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Figure 7 (previous page) shows the size distribution of disk penetrations based on the cumulative percent of holes of each size.

4.3 FRAGMENT TRAJECTORIES AS DEFINED BY PENETRATIONS

This study was initiated to provide useful data concerning uncontained turbine engine disintegration fragment trajectory and hazard mitigation requirements from historical events on all aircraft. In order to give a complete picture of the results of the analysis which has been performed, trajectory data has been separated according to multiple criteria. Hence the data may be repeated for each event as it fits into the different criteria.

Data has been separated for analysis using the following trajectory criteria:

- Trajectories are calculated as a straight line from the plane of rotor disintegration to the point of fragment impact on the aircraft (as determined by the hole).

- Events are separated into the following categories:
    1) All event trajectories and hole sizes (Section 4.3.2);
    2) Disk only event trajectories and hole sizes (Section 4.3.3);
    3) Maximum fragment trajectory spread in a single event (Section 4.3.4);
    4) Fragment trajectories and holes sizes separated by airplane model (Section 4.3.5).
    5) Fragment trajectories and holes sizes separated by engine manufacturer (Section 4.3.6).
    6) Fragment trajectories and hole sizes separated by flight phase (Section 4.3.7);
    7) Fragment trajectories and hole sizes separated by CAAM hazard level (Section 4.3.8).
    8) Fragment trajectories and hole sizes separated by low bypass ratio engine (LBR) and high bypass ratio engine (HBR) types (Section 4.3.9).

4.3.1 CURRENT AC 20–128 / ACJ 25.903(d)(1) REQUIREMENTS

The current federal requirements concerning uncontained turbine engine disintegration fragment trajectories are found in FAR 25.903(d)(1) and the associated Advisory Circular, AC 20–128. As part of this study these requirements have been examined and compared with historical experience. In order to fully understand the implications of the analysis in this study, the reader must be familiar with these regulations, which are reproduced in Appendix B.

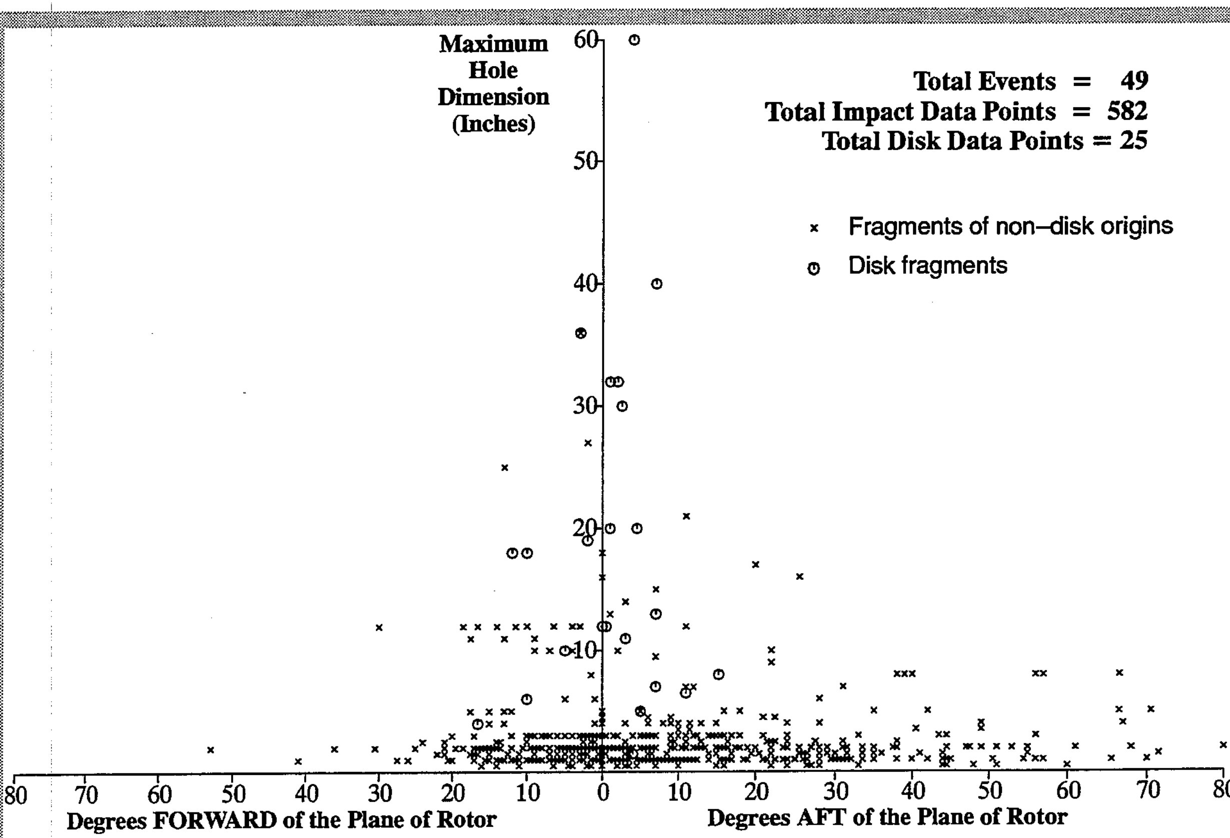


FIGURE 8. Fragment Trajectory versus Hole Size

4.3.2 FRAGMENT TRAJECTORIES – ALL PENETRATIONS

The trajectories from the plane of engine disintegration to the penetration location have been calculated for 582 holes in the 49 events. Figure 8 is a "splatter" plot of this data, showing the trajectory and size of all fragments which have been documented for this study.

In many instances, multiple data points are found at the same location on the plots. In these situations, only one symbol has been used on the plot.

The trajectories of fragments ejected by uncontained turbine engine disintegrations varies from the largest forward angle of 53.5° to the largest aft angle of 80°. The penetration at 53.5° forward angle (event 22, hole 3) was relatively small. The hole left by the fragment was in the lower cargo section of the fuselage, measuring 2 inches by 2 inches. The fragment which caused this was a part of the fan section. The penetration at 80° aft (event 9, hole 2) was also small, measuring 2 inches by 1 inch. The fragment which caused this hole was from the first stage of the low pressure turbine (LPT). It impacted the aircraft on the horizontal stabilizer lower skin.

The trajectory of the fragment which caused the largest hole (event 4, hole 5) was calculated to be 4° aft of the plane of disintegration, and resulted in a lengthy slice (60 inches by 5 inches) in the vertical tail fin of a rear–engine–mounted aircraft.

4.3.3 FRAGMENT TRAJECTORIES – DISK PENETRATIONS

The trajectories of disk fragments ejected in these events varies from 16.5° forward to 15.0° aft (figure 9).

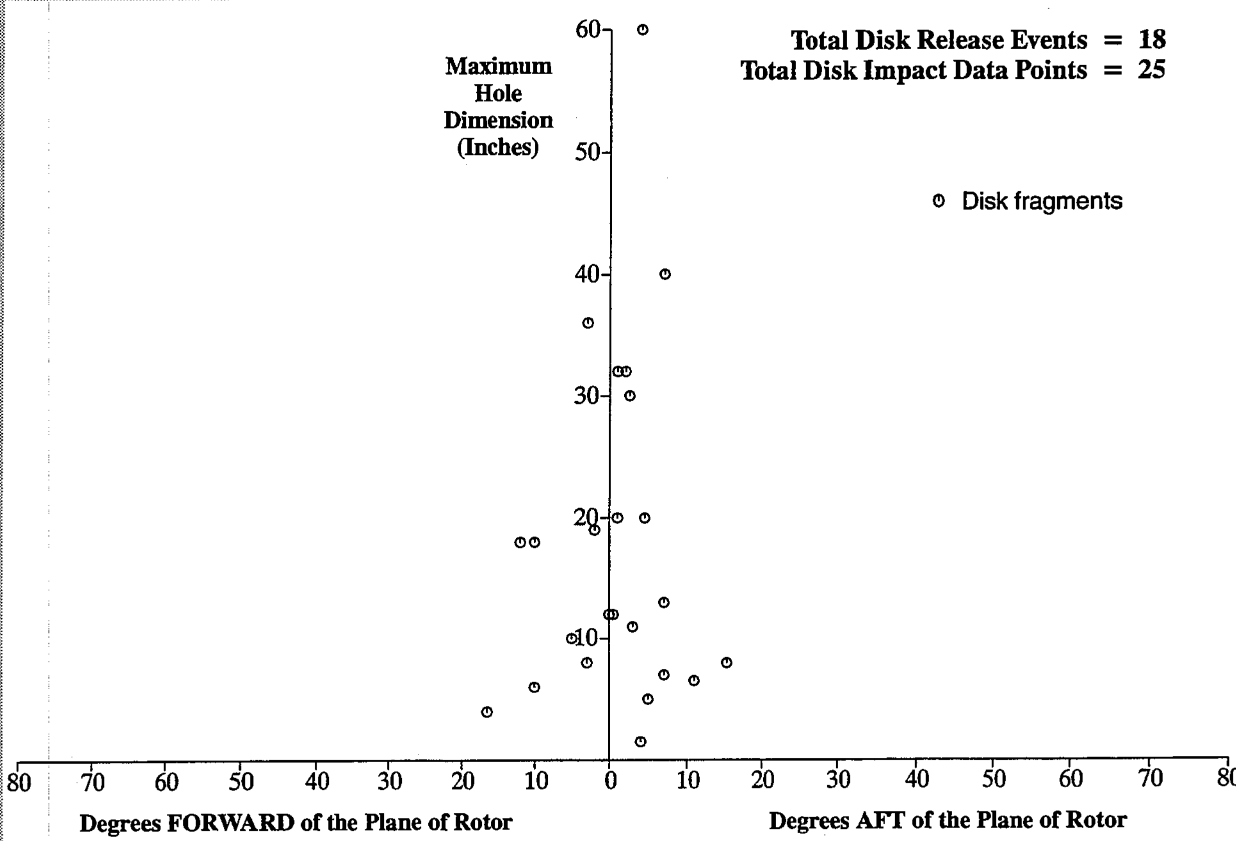


FIGURE 9. Disk Fragment Trajectory versus Hole Size

The forward–most disk penetration at 16.5° forward (event 18, hole 14) measured approximately 4 inches by 4 inches, in the vertical stabilizer of the aircraft (tail–mounted engine). The disk fragment was released from the compressor section of the engine. It is not described in detail.

Photographic evidence indicates multiple pieces of the disk rim were released in the event, measuring in size from about 2 inches in diameter to about 10 inches by 2 inches. It is not known which disk fragment caused this hole.

The furthest aft penetration by a disk fragment, at 15.0° aft (event 16, hole 3), measured 8 inches by 5 inches. The disk rim segment which caused this hole was approximately 20 inches by 2 inches in size, weighing close to 5 pounds. It was released from the high pressure turbine (HPT) section of the engine. The engine manufacturer has estimated the velocity of this fragment to be in the range of 700 feet per second.

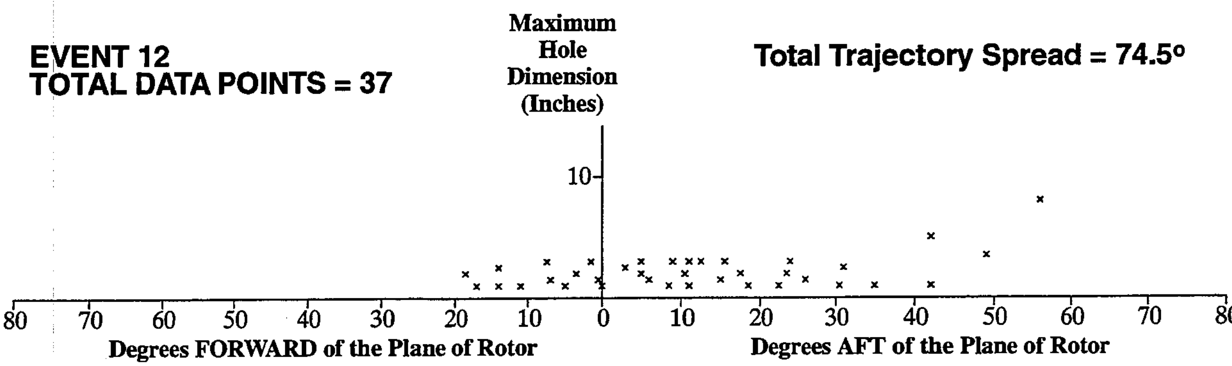


FIGURE 10. Maximum Fragment Trajectory Spread (Single Event)

4.3.4 MAXIMUM FRAGMENT TRAJECTORY SPREAD FOR A SINGLE EVENT

The largest trajectory spread of fragments in one event occurred in event 12, where fragments ejected were spread from 18.5° forward (hole 13) to 56.0° aft (hole 7) (a total debris trajectory spread of 74.5°). Figure 10 contains a graphical summary of this event data. All aircraft penetrations in this event had maximum dimensions of 4 inches or less. There were no disk fragments ejected in this event.

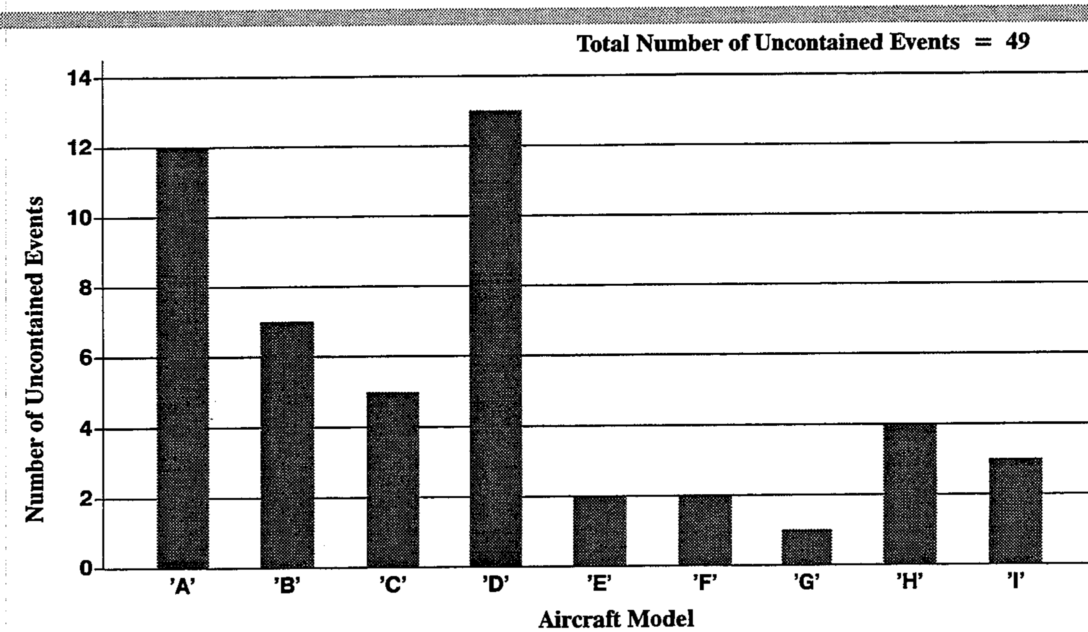


FIGURE 11. Number of Uncontained Events by Aircraft Model**

NOTE: This summary chart is not intended to convey the message that some aircraft types are more prone to uncontained disintegrations than others. It is simply a consequence of the availability and reliability of data for each aircraft model, showing the number of events on each aircraft type as documented in this study.

4.3.5 FRAGMENT TRAJECTORIES BY AIRPLANE MODEL

The historical record indicates that most aircraft models have experienced uncontained turbine engine disintegrations. In this study, 11 airplane models from four airplane manufacturers were identified in the 50 events used for analysis. The statistical breakdown of the database by aircraft model is found in Figure 11, in bar graph summary format. Specific data plotted by airplane model is contained in Figures E–1 through E–9 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

4.3.6 FRAGMENT TRAJECTORIES BY ENGINE MANUFACTURER

Data collected in this study show that uncontained turbine engine disintegrations are not limited to few engine types or even to one engine manufacturer more than others. Three engine manufacturers were identified in the 49 events used for analysis. Figure 12 (following page) contains a bar graph summary of this data. Specific data plotted by engine manufacturer is contained in Figures E–10 through E–12 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

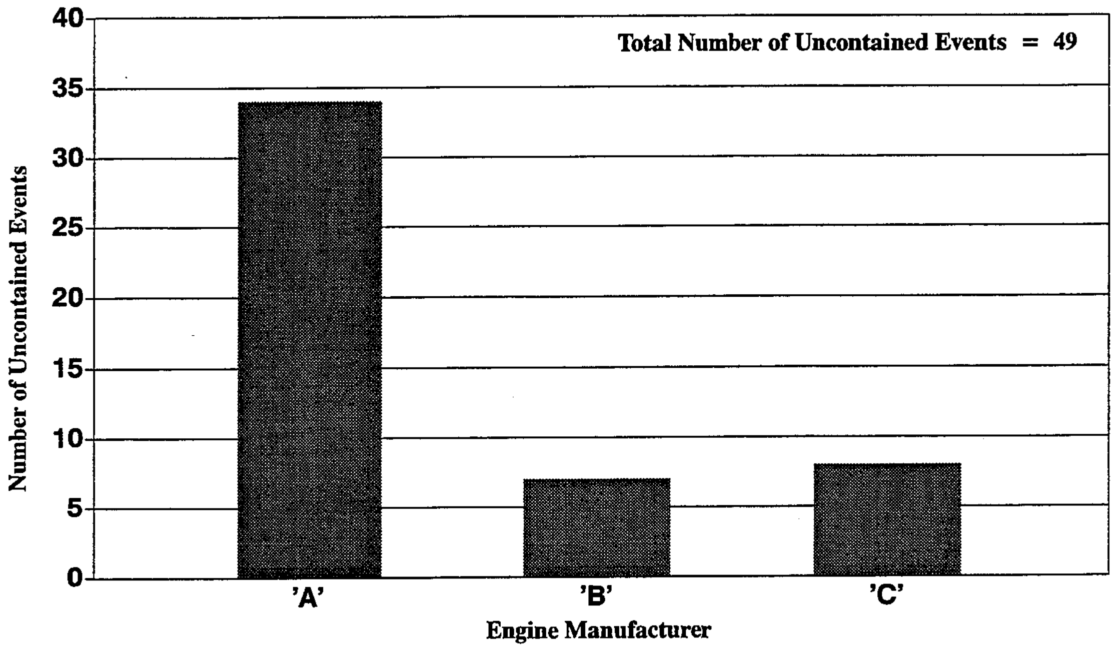


FIGURE 12. Number of Uncontained Events by Engine Manufacturer **

*****NOTE: This summary chart is not intended to convey the message that some aircraft types are more prone to uncontained disintegrations than others. It is simply a consequence of the availability and reliability of data for each aircraft model, showing the number of events on each aircraft type as documented in this study.*****

4.3.7 FRAGMENT TRAJECTORIES BY FLIGHT PHASE

The presentation of the Uncontained Turbine Engine Disintegration data from the database can be used to analyze events by flight phase. This is useful in showing the fragment trajectories and impact locations due to flight phase. Figure 13 (following page) summarizes the number of events by flight phase which have been documented in this study. Specific data plotted by flight phase is contained in Figures E–13 through E–17 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

Due to the differences in stresses in the engine at different power settings, it is quite reasonable to assume that hazardous events will occur more often when the engine is at a high power setting (such as takeoff or climb) than at lower settings (such as descent or approach). This assumption is verifiable using the events documented in this study, where 37 of the 49 documented events (75.5%) occurred while engines were at high power settings (takeoff, climb, and top of climb).

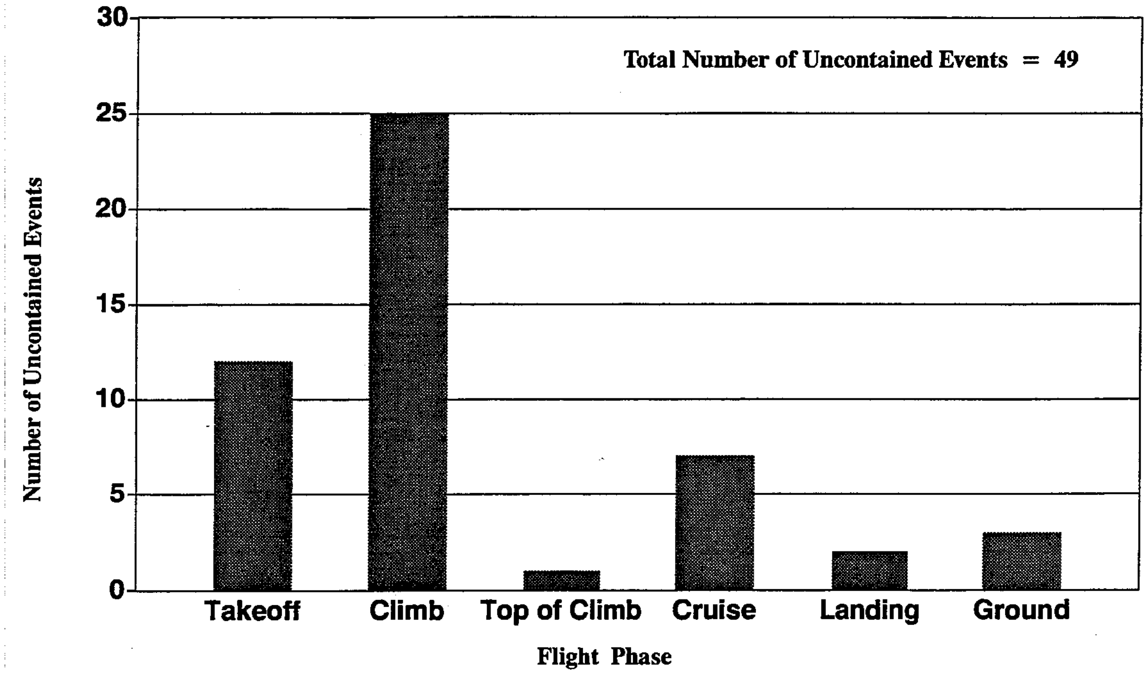


FIGURE 13. Number of Uncontained Events by Flight Phase

No events have been documented during Top of Descent (TOD), Descent, or Approach flight phases. Events which occurred on the ground were either during ground run–up testing (3 events) or during taxi (1 event).

4.3.8 FRAGMENT TRAJECTORIES BY HAZARD LEVEL

The Uncontained Turbine Engine Disintegration data in this study can also be presented based on the "hazard level" associated with each event (as defined by the Continuing Airworthiness Assessment Methodology (CAAM) team). Definitions of CAAM Hazard Levels are found in Appendix D of this report for clarification of this data presentation.

Figure 14 (following page) summarizes the number of events classified in each hazard level which have been documented in this study. Specific data plotted by CAAM hazard level is contained in Figures E–18 through E–20 in Appendix E, not included with this report but available upon request from the Propulsion Safety Advocate.

Further analysis shows the fragment trajectories and impact locations for events which are classified by CAAM hazard levels. Figure 15 (following page) repeats the data contained in the database as presented earlier in Figure 8, separated to show the trajectories and hole sizes by

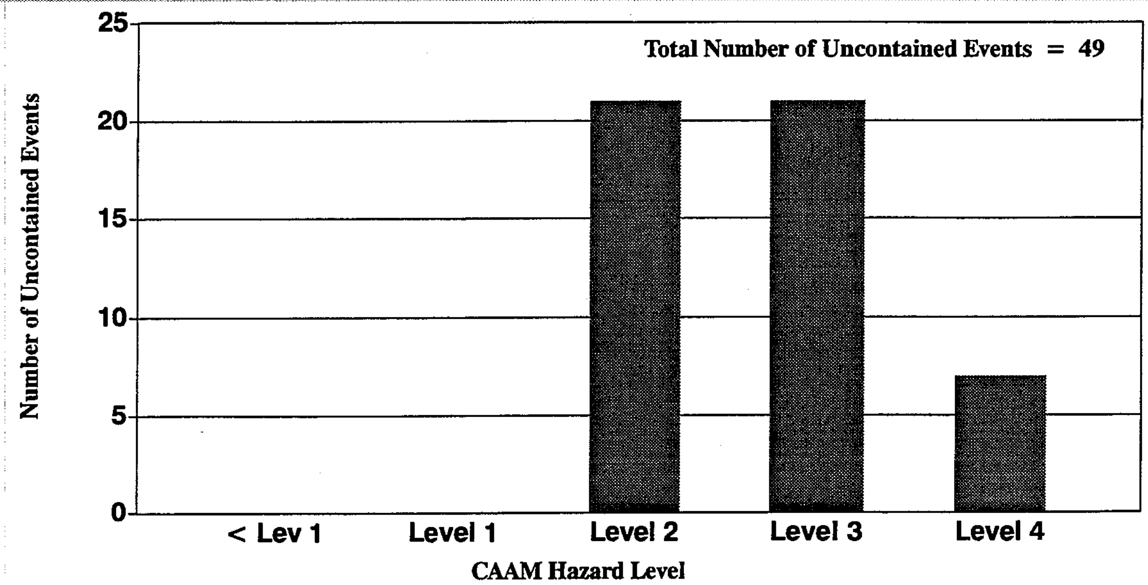


FIGURE 14. Number of Uncontained Events by CAAM Hazard Level

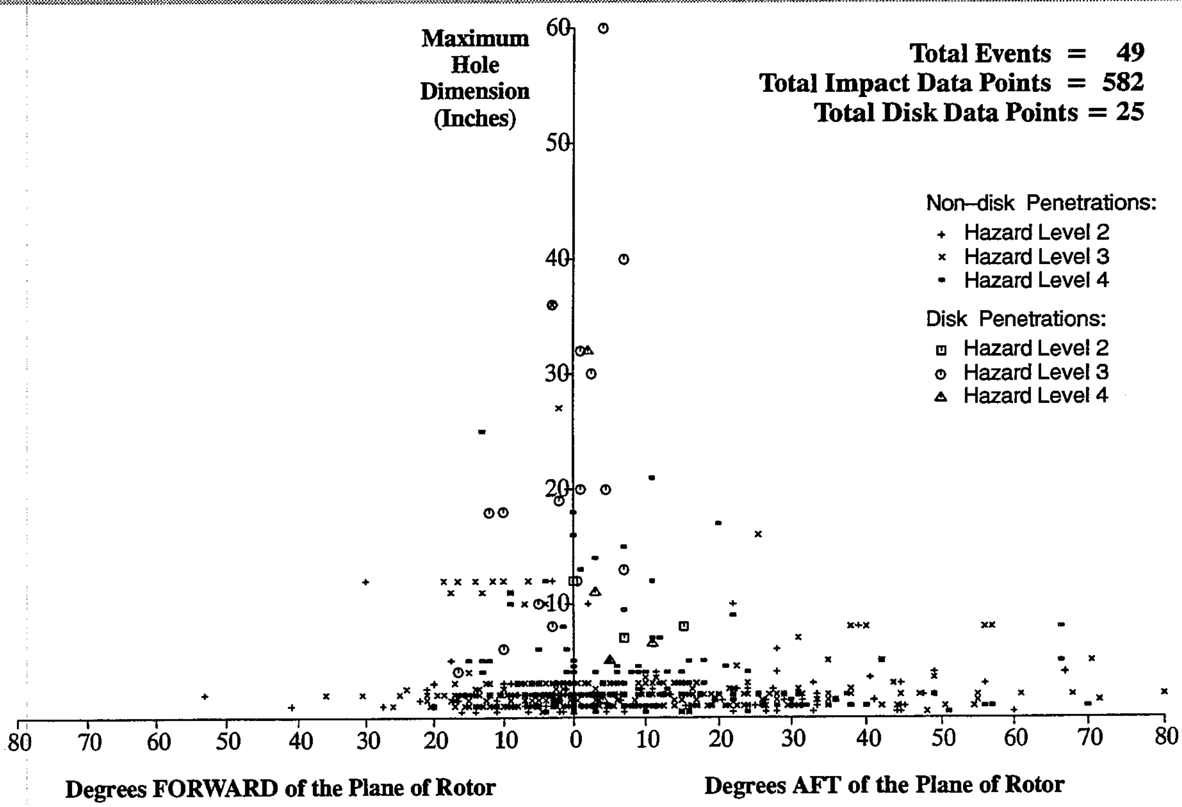


FIGURE 15. Uncontained Trajectories by CAAM Hazard Level

CAAM hazard level. The data shown in Figure 15 is contained in the Propulsion Research Uncontained Engine Disintegration Database, and can also be plotted separately to show clearly the trajectories and hole sizes for events of each specific hazard level.

4.3.9 FRAGMENT TRAJECTORIES BY RELATIVE BYPASS RATIO

Further analysis of the data in the Uncontained Turbine Engine Disintegration database can be performed based on whether the engine involved in the event was a high bypass ratio (HBR) or a low bypass ratio (LBR) engine. Information in the database shows that there were twenty–five documented events on LBR engines and twenty–four documented events on HBR engines at the time of this report.

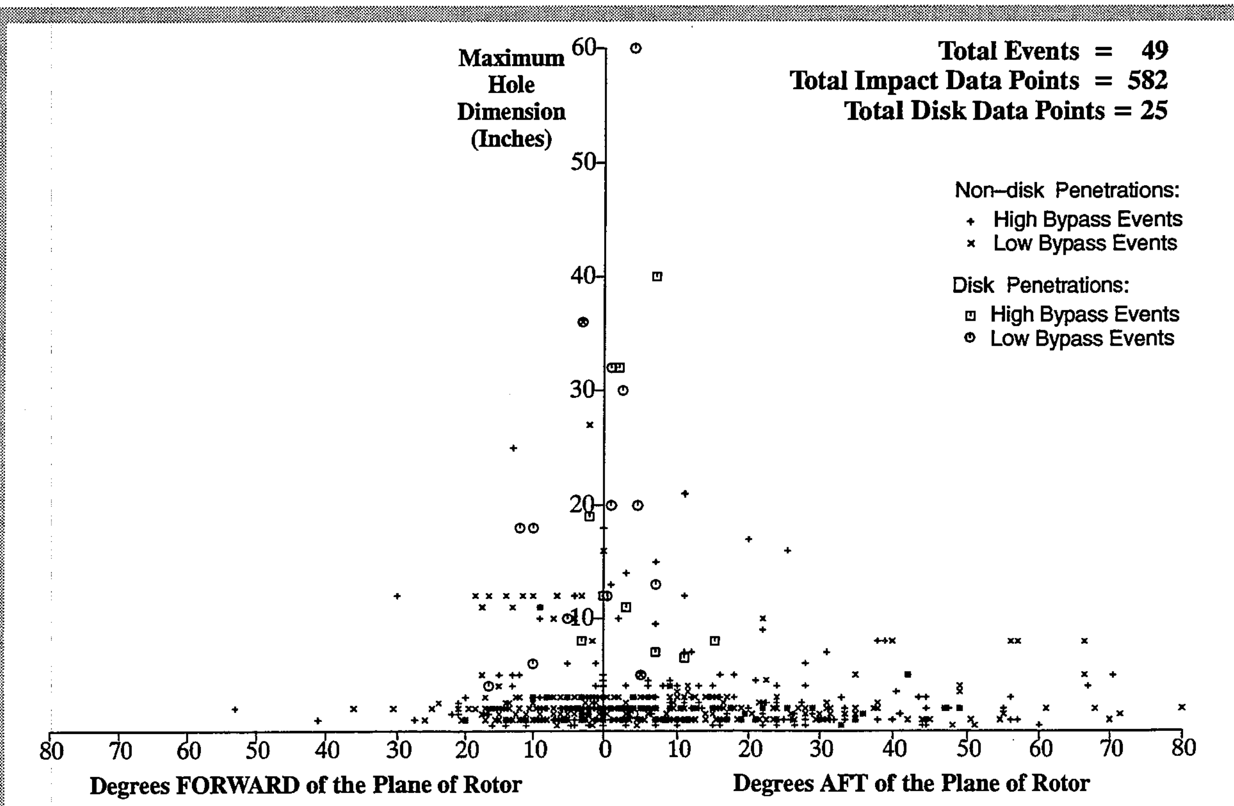


FIGURE 16. Uncontained Trajectories by Relative Bypass Ratio

Figure 16 was extracted from the Uncontained Engine Disintegration Database, once again containing the same data as Figure 8. However, in this instance the data is separated to show a comparison of the fragment trajectories along with respective hole sizes in the aircraft structure due to high bypass ratio engine events and due to low bypass ratio engine events.

4.4 FRAGMENT TRAJECTORIES OF KNOWN FRAGMENTS

Limited fragment size data is available for uncontained turbine engine disintegration events, since in most events the majority of the pieces are not recovered. In addition, even when fragments are recovered it is often difficult to determine which fragment actually caused the noted penetration. However, sufficient information has been collected to create a database containing fragment sizes from twenty eight uncontained disintegration events. In each instance, the maximum dimension of the largest known fragment has been incorporated into the report. Only the LARGEST known fragment from each event has been used in the plot. (This includes only the largest disk fragment if more than one disk fragment was released in a single event.) However, in cases where data exists in a single event for both a disk fragment and a fragment of non–disk origin, the largest fragment of each (disk and non–disk) is included.

There were a total of 36 fragments documented in these 28 events. 20 fragments were of non–disk origins, while the remaining 16 were of disk origins. Figure 17 (following page) shows the trajectories of these fragments by the actual fragment size.

The trajectories of these pieces ranged from 36° forward of the plane of rotor disintegration (event 7, fragment 6) to 56° aft of the plane of rotor disintegration (event 12, fragment 1). The two fragments shown at 66.5° aft of the plane of rotation were the result of a combustor can explosion which caused an aircraft hull loss. Because these fragments were not from a rotating part of the engine, it was decided to show these as separate data points. These data points are represented by the shaded squares in figure 17.

The largest documented fragment ejected in all events was a disk section measuring approximately 60% of the entire disk in event 39. This large fragment did not impact the aircraft, but was recovered from the area where the incident occurred. Because there is no aircraft impact location, the trajectory of this fragment is unknown. The diameter of the disk (and therefore the maximum dimension of the fragment) was 31.4 inches. Figure 17 shows this data point at 0° trajectory, 31.4 inches.

The remaining 40% of the disk in this event split into three major fragments (roughly similar in size to each other). All of these pieces impacted the aircraft in the horizontal stabilizer, and are documented in Appendix A of this report.

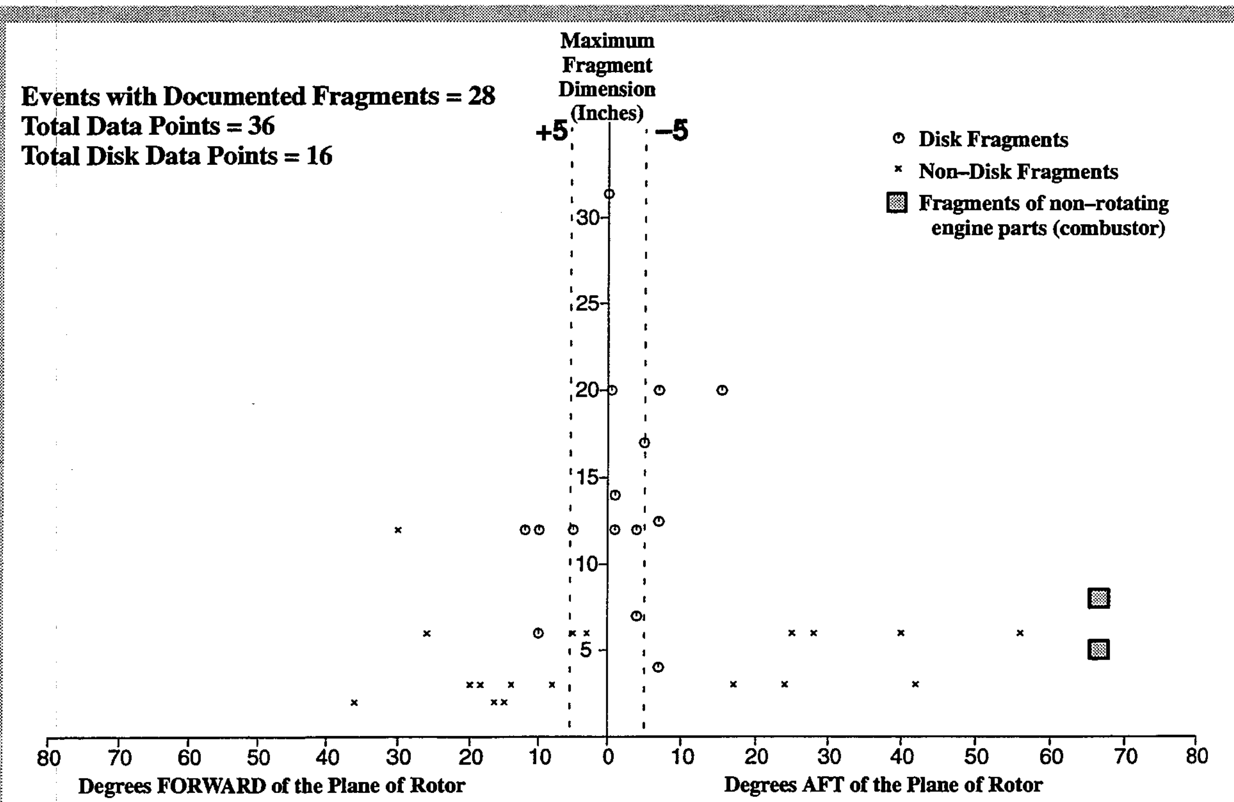


FIGURE 17. Fragment Trajectories of Known Fragments

4.5 FRAGMENT TRAJECTORIES COMPARED WITH CURRENT FAR/JAR REGULATIONS

Current regulations establish a fragment trajectory range for airframe system separation criteria which does not appear to encompass the range of fragment trajectories found in the historical record. The regulations are based on fragment trajectory predictions developed from historical data, much of which has been included in this study. However, the data in this study significantly expands the database upon which the regulations are based. The expanded database shows marked differences between predicted trajectories in the current regulations and historical fact.

Figure 18 (following page) contains a plot showing the data points which have been collected and documented in this study (duplicated from Figure 8), overlaid by dashed lines showing the current regulatory limits. A significant number of trajectory data points, both disk and non-disk, are observed in Figure 18 to lie outside the limits imposed by current regulations. This observation is

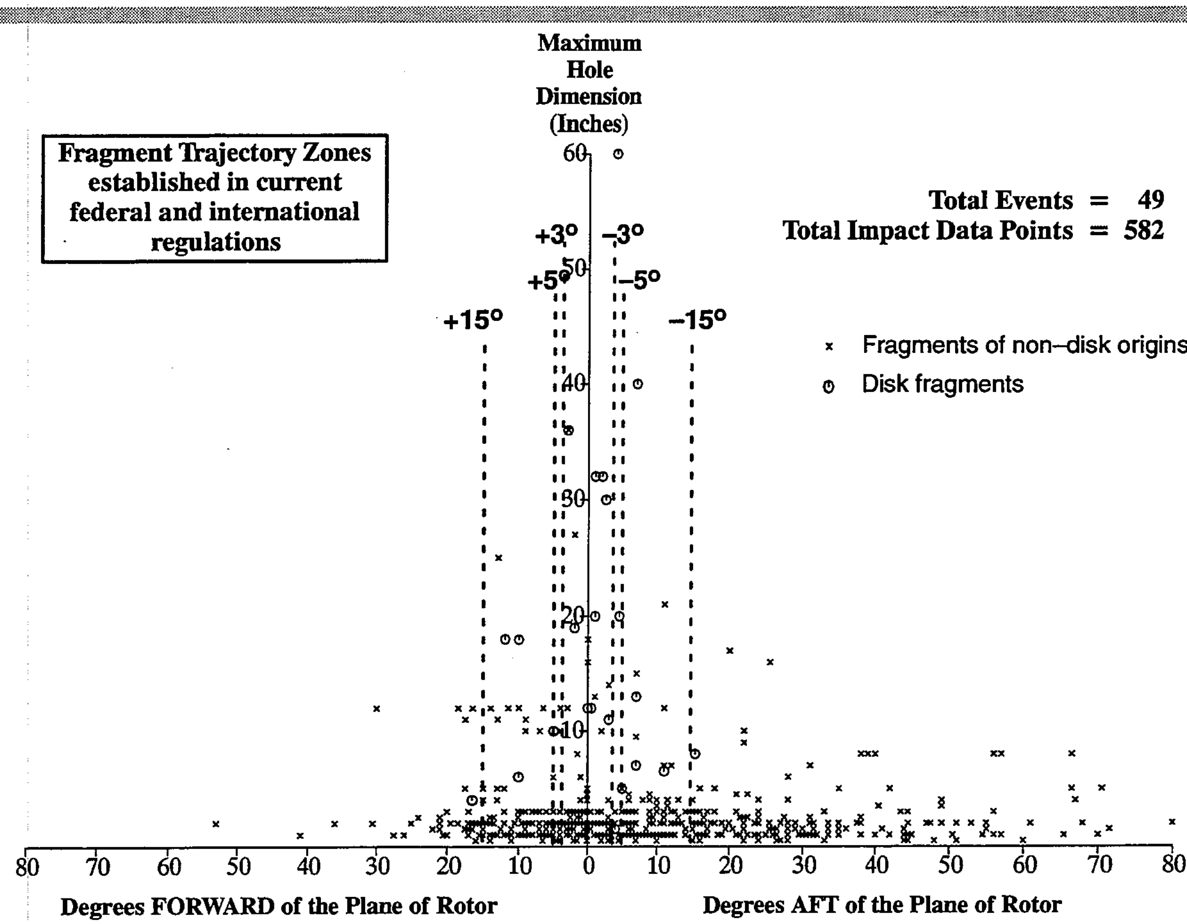


FIGURE 18. Current Trajectory Limits overlaid on Historical Trajectory Data

valid both for penetration trajectory data points *forward* of the plane of the rotor and penetration trajectory data points *aft* of the plane of the rotor.

It is readily apparent from the data shown in figure 18 that a larger number of penetrations have trajectories *AFT* of the plane of rotation than have trajectories *FORWARD* of the plane of rotation, and that the fragments which have aft trajectories generally result in greater trajectory angles than fragments ejected forward. This noticeable rearward shift is presumed to be due to windage effects (drag of released fragments in the airstream). Current regulations do not show compensation for these airstream effects evident in the historical record.

SECTION 5

CONCLUSIONS

5.0 CONCLUSIONS

The results of these studies indicate that refinement of advisory material related to mitigation of the airplane hazards from uncontained engine failures should be undertaken. Internal Boeing Company design related guidance should also be enhanced. The observations and conclusions listed below are presented in order of importance based on the judgment of the authors.

1) In general, the number of airplane damage sites increases with increasing event severity based on Industry–developed severity criteria (SAE–Ad Hoc Committee on Rotor Containment or AIA PC342 Continued Airworthiness Assessment Methodology).

2) In several of the accidents contained within this study, investigation revealed that relatively small fragments caused the critical aircraft damage.

3) The damage (tears and penetrations) sites occur at locations more widely dispersed than envisioned by AC/J 20–128 criteria for both disk and smaller fragments.

4) The majority of damage sites are relatively small, with 81.44% of penetrations 3 inches or less on the major axis.

5) The available data suggests that fragment trajectories and damage are similar for similar uncontained events, whether the engine is a low bypass or a high bypass type, and whether the engine is small or large in terms of thrust class.

6) A significantly larger number of ejected fragments have trajectories *aft* of the plane of the rotor than have trajectories *forward* of the plane of the rotor. The effects of the airstream on the ejected fragments can be used to explain this difference.

5.1 OBSERVATIONS

1) Based on the limited data set available, no conclusions should be drawn concerning differences between specific engine models or specific airplane models. Also, no conclusions should be drawn between respective engine or airframe manufacturers.

2) The data contained in this report is collected for turbojet and turbofan events only. No turboprop propulsion systems events are included.

3) A comparison of this historical record with the current regulations governing the design of commercial aircraft with respect to mitigation of hazard due to uncontained engine disintegrations shows considerable data which does not fit the assumptions made in the current regulations.

5.2 OUTSTANDING ISSUES

1) Critical missing elements in the analysis of uncontained fragments and trajectories are the fragment energy level, dimensions, and mass that caused the airplane damage. To permit more effective design of mitigation systems, additional knowledge concerning fragment characteristics (e.g., energy levels, mass, material, etc.) is needed.

2) Given that a hole occurs in an aircraft structure due to uncontained fragment penetration, there is no currently available calibrated analytical approach which would allow the fragment energy level to be established. Frequently the fragment that made the hole is not reported. A calibrated design system, acceptable to the authorities, is needed which would permit: a) Design of mitigation systems for a known fragment, and b) Calculation of energy level based on knowing the fragment origin, energy, hole dimension, material properties, and other characteristics of interest.

SECTION 6

RECOMMENDATIONS

6.0 RECOMMENDATIONS

1) The separation of critical airplane systems should consider the damage site dimension set forth in Figure 19. It is recommended that critical airplane system separation be continued beyond current regulatory boundaries in order to further minimize the potential impact of uncontained failures on continued safe flight and landing.

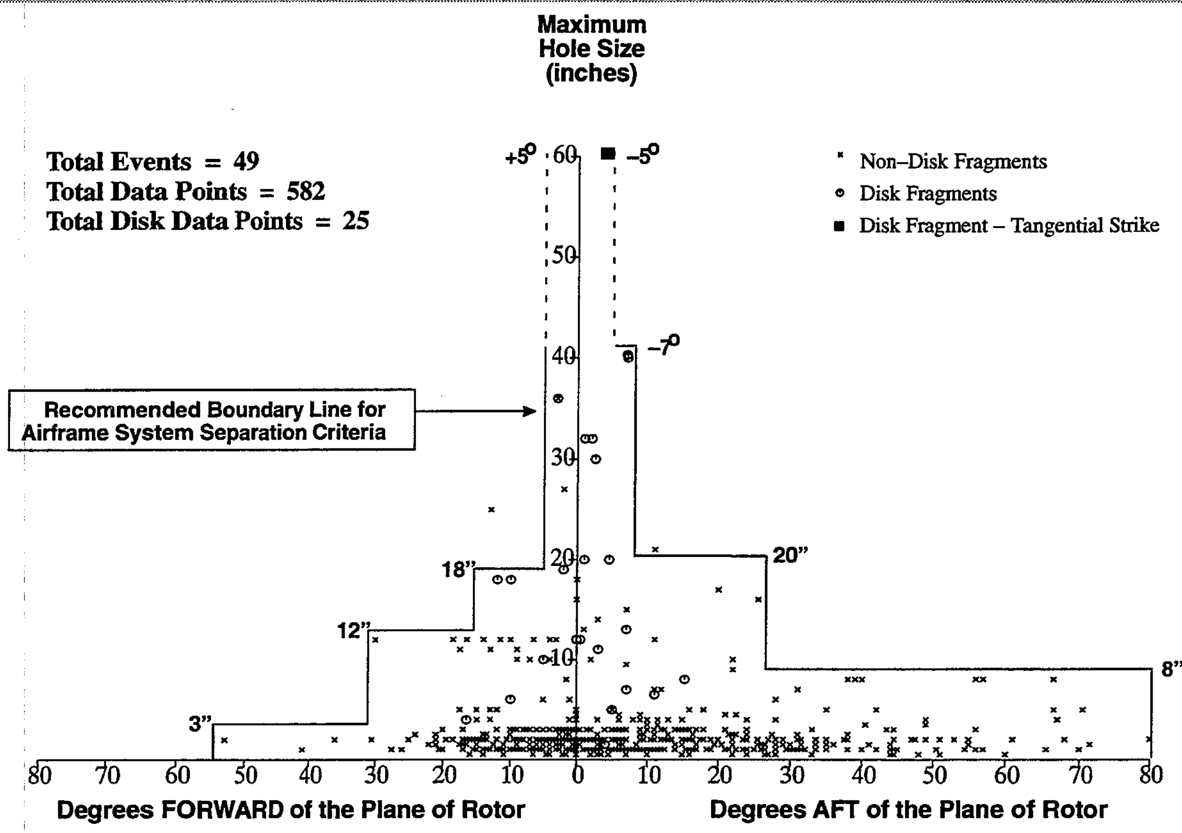


FIGURE 19. Recommended Boundary for Airframe Systems Separation Criteria Based on Penetration Sizes

2) The protection of critical systems elements, by use of existing structure elements for shielding, should be considered in the light of the multiple fragment threat.

3) The selection of advanced materials for airframe structure and/or skins should consider the relative performance of the new material versus current materials from the aspect of resisting penetration by uncontained engine fragments. A reduction in penetration resistance should be considered as a potential reduction in current aircraft safety levels.

4) Opportunities to combine functions with fragment energy reduction capabilities should be sought (e.g., passenger cabin acoustic liner material with ballistic energy reduction).

5) Engine manufacturers should be encouraged to share uncontained fragment debris information and estimates early in the airplane design phase to permit minimization of the hazard from uncontained engine failures.

6.1 AVAILABILITY OF ADDITIONAL INFORMATION

The BCAG Propulsion Safety Advocate controls the data in the Uncontained Turbine Engine Disintegration database, currently held in the Propulsion Research organization. Additional analysis may be performed using the data in this database. Requests for additional analysis must be coordinated through the Safety Advocate. Further questions concerning the information contained in this report should be addressed to the BCAG Propulsion Research Safety Advocate.

APPENDIX A

UNCONTAINED ENGINE DEBRIS TRAJECTORY DATA
INDIVIDUAL EVENT RECORDS

Appendix A – Table of Contents

1.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion–Accident**

Power Level: **EPR 1.48**
Altitude: **FL250**
Airspeed: **0.85M**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−38.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
2	Unknown					−38.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
3	Unknown					−36.0	Fuselage (low)	1.5" x 1"	Fuselage Penetration	None noted
4	Unknown					−35.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
5	Unknown					−35.0	Inboard Aileron	1.5" x 0.25"	Inboard Aileron Cut	None noted
6	Unknown					−33.5	Fuselage (low)	1.5" x 0.5"	Fuselage Penetration	None noted
7	Unknown					−31.5	Fuselage (low)	2" x 0.5"	Fuselage Penetration	None noted
8	Unknown					−31.0	Fuselage (low)	2" x 1"	Cargo Compartment Penetration	None noted
9	Unknown					−31.0	Fuselage (mid)	1" x 0.5"	Fuselage Penetration	None noted
10	Unknown					−29.5	Aft Cargo Door	1" x 1"	Cargo Door Penetration	None noted
11	Unknown					−27.0	Aft Cargo Door	2" x 0.75"	Cargo Door Slice (Penetration)	None noted
12	Unknown					−25.5	Inbd Flap Lower	2" x 1"	T.E. Flap Lower Skin Penetration	None noted
13	Unknown					−23.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
14	Unknown					−22.0	Inboard Aileron	2" x 1.5"	Inboard Aileron Penetration	None noted
15	Unknown					−22.0	Fuselage (low)	2.5" x 1"	Cargo Compartment Penetration	None noted
16	Unknown					−21.5	Inboard Aileron	1" x 1"	Inboard Aileron Penetration	None noted
17	Unknown					−21.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
18	Unknown					−19.0	Wing–to–Body Fairing	1" x 0.75"	Fairing Penetration	None noted
19	Unknown					−18.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
20	Unknown					−17.0	Wing–to–Body Fairing	3" x 1.5"	Fairing Penetration	None noted
21	Unknown					−17.0	Wing–to–Body Fairing	1" x 1"	Fairing Penetration	None noted
22	Unknown					−16.5	Wing Lower	2" x 0.5"	Wing Lower Skin Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
23	Unknown					−16.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
24	Unknown					−15.0	Wing–to–Body Fairing	3" x 1"	Fairing Penetration	None noted
25	Unknown					−15.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
26	Unknown					−14.0	Wing–to–Body Fairing	3" x 1.5"	Fairing Penetration	None noted
27	Unknown					−14.0	Wing–to–Body Fairing	1.5" x 1"	Fairing Cut	None noted
28	Unknown					−14.0	Wing–to–Body Fairing	1" x 0.5"	Fairing Penetration	None noted
29	Unknown					−12.5	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
30	Unknown					−12.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
31	Unknown					−12.0	Wing–to–Body Fairing	1" x 1"	Fairing Penetration	None noted
32	Unknown					−11.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
33	Unknown					−10.5	Wing Lower	1" x 0.25"	Wing Lower Skin Tear	None noted
34	Unknown					−9.5	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
35	Unknown					−9.5	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
36	Unknown					−9.0	MLG Door	2" x 0.25"	Main Landing Gear Door Cut	None noted
37	Unknown					−9.0	MLG Door	1" x 1"	MLG Door Penetration	None noted
38	Unknown					−7.5	MLG Door	1" x 1"	MLG Door Penetration	None noted
39	Unknown					−7.0	Fuselage (mid)	2" x 1.5"	Fuselage Penetration	Window entry; Hot Fragment burned hole in carpet
40	Unknown					−7.0	MLG Door	1" x 0.5"	MLG Door Penetration	None noted
41	Unknown					−5.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
42	Unknown					−5.0	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
43	Unknown					−5.0	MLG Door	1" x 1"	MLG Door Penetration	None noted
44	Unknown					−4.5	Wing–to–Body Fairing	1" x 0.5"	Fairing Penetration	None noted
45	Unknown					−3.5	Wing–to–Body Fairing	2" x 0.5"	Fairing Cut	None noted
46	Unknown					−3.5	MLG Door	1" x 0.75"	MLG Door Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.3 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
47	Unknown					–3.0	Wing–to–Body Fairing	2" x 1"	Fairing Penetration	None noted
48	Unknown					–3.0	MLG Door	1.5" x 1"	MLG Door Penetration	None noted
49	Unknown					–3.0	Wing Lower	0.5" x 1"	Wing Lower Skin Penetration	None noted
50	Unknown					–2.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
51	Unknown					–1.5	Wing Lower	2" x 0.25"	Wing Lower Skin Penetration	None noted
52	Unknown					–0.5	MLG Door	2" x 0.5"	Main Landing Gear Door Cut	None noted
53	Unknown					0	Wing Lower	1" x 0.75"	Wing Lower Skin Penetration	None noted
54	Unknown					9.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
55	Unknown					9.0	Fuselage (low)	1" x 1"	Fuselage Penetration	None noted
56	Unknown					9.0	Fuselage (low)	1.5" x 0.5"	Fuselage Cut	None noted
57	Unknown					8.5	Wing Lower	1" x 0.5"	Wing Lower Skin Cut	None noted
58	Unknown					8.0	Wing Lower	1" x 0.5"	Wing Lower Skin Cut	None noted
59	Unknown					7.0	Fuselage (low)	1.5" x 0.5"	Fuselage Cut	None noted
60	Unknown					6.5	MLG Door	1" x 1"	Main Landing Gear Door Cut	None noted
61	Unknown					6.0	MLG Door	1" x 0.75"	MLG Door Penetration	None noted
62	Unknown					6.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
63	Unknown					6.0	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
64	Unknown					5.5	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
65	Unknown					5.0	Wing Lower	3" x 1.5"	Wing Lower Skin Penetration	None noted
66	Unknown					5.0	MLG Door	2" x 1"	MLG Door Penetration	None noted
67	Unknown					5.0	MLG Door	1.5" x 1"	MLG Door Penetration	None noted
68	Unknown					4.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
69	Unknown					4.0	MLG Door	2" x 1"	MLG Door Penetration	None noted
70	Unknown					3.0	MLG Door	2" x 0.75"	MLG Door Penetration	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

1.4 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **LPC #2 Bearing/Hub**

SECONDARY MALFUNCTION (Rotor Stages): **2nd and 3rd Stage Tri Hub Fractures**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
71	Unknown					3.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
72	Unknown					2.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
73	Unknown					2.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
74	Unknown					1.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
75	Unknown					1.5	Fuselage (low)	1" x 1"	Fuselage Penetration	None noted
76	Unknown					1.0	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
77	Unknown					0.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
78	Unknown					0.0	Fuselage (low)	1" x 0.5"	Fuselage Penetration	None noted
79	Disk Fragment					–4.5	Wing Lower	20" x 3"	Large Cut in Lower Wing Skin	Destroyed most of Front Spar at WSTA 635
80	Disk Fragment					–2.5	Wing Lower	30" x 3"	Large Cut in Lower Wing Skin	None noted.
81	Disk Fragment					3.0	Wing Lower	36" x 2"	Large Cut in Fuel Tank Access Cover	Fuel Tank Penetration; Fuel Leak

NARRATIVE: **During cruise the #1 engine disintegrated. Probable cause was the failure of the #2 bearing, resulting in Low Pressure Turbine (LPT) disintegration. Multiple disk fragments were liberated, with three large disk segments (fragments 79, 80, and 81) contacting the aircraft wing. One of these opened a hole in the fuel tank, resulting in a fuel leak. One turbine blade fragment (fragment 39) penetrated the passenger cabin through a window, hit the interior wall on the opposite side, and fell to the floor, burning a hole in the carpet. Numerous small pieces penetrated the cargo compartment. Multiple shrapnel penetrations were found on the lower wing surface in the general area of the #1 engine. Several holes were found in the left main landing gear door. The aft portion of the wing–to–body fairing had 30 to 40 small holes ranging up to 2" in maximum dimension. Inboard aileron had several (around 10) small holes of the same general size. Additional fragment impacts were noted in files concerning multiple dents and scratches which did not penetrate the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 78 were typical blade fragments, averaging approximately 1/4 lb. in weight and measuring an average 2"x3" in size. These fragments were indicated to be 2nd and 3rd stage tri hub fracture fragments, released at an estimated average velocity of 700 ft/sec. Disk fragment sizes were not specified, but trajectories were confirmed.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

2.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **2nd, 4th, and 5th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−6.5	Fuselage (low)	3" x 1"	Fuselage Penetration	None noted
2	Unknown					−5.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
3	Unknown					−5.0	Fuselage (low)	1" x 0.5"	Fuselage Penetration	None noted
4	Unknown					−2.0	Wing Lower	3" x 0.5"	Wing Lower Skin Cut	None noted
5	Unknown					−1.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					19.5	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	None noted
7	Unknown					18.5	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
8	Unknown					17.5	Wing L.E.	11" x 3"	Wing Leading Edge Cut	None noted
9	Unknown					17.0	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	None noted
10	Unknown					17.0	Wing-to-Body Fairing	1.5" x 1"	Fairing Penetration	None noted
11	Unknown					16.5	Wing L.E.	12" x 3.5"	Wing Leading Edge Cut	None noted
12	Unknown					15.0	Wing Lower	2"x 0.5"	Wing Lower Skin Cut	None noted
13	Unknown					15.0	#2 Eng Cowl	1" x 1"	#2 Engine Cowl Penetration	None noted
14	Unknown					14.0	Wing L.E.	12" x 2.5"	Wing Leading Edge Cut	None noted
15	Unknown					13.5	Fuselage (low)	2.5" x 0.5"	Fuselage Penetration	None noted
16	Unknown					13.0	Wing L.E.	11" x 3"	Wing Leading Edge Cut	None noted
17	Unknown					11.5	Wing L.E.	12" x 4"	Wing Leading Edge Cut	None noted
18	Unknown					10.0	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
19	Unknown					9.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
20	Unknown					9.5	Wing Lower	1" x 0.25"	Wing Lower Skin Cut	None noted
21	Unknown					9.0	Wing L.E.	11" x 2"	Wing Leading Edge Cut	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

2.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **2nd, 4th, and 5th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
22	Unknown					8.5	Wing-to-Body Fairing	2" x 1"	Fairing Penetration	None noted
23	Unknown					8.5	Wing-to-Body Fairing	1" x 1"	Fairing Penetration	None noted
24	Unknown					7.0	Wing L.E.	10" x 2.5"	Wing Leading Edge Cut	None noted
25	Unknown					6.5	Wing L.E.	12" x 2"	Wing Leading Edge Cut	None noted
26	Unknown					6.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
27	Unknown					5.5	Wing Lower	1" x 0.75"	Wing Lower Skin Penetration	None noted
28	Unknown					3.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
29	Unknown					3.0	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
30	Unknown					2.0	Wing-to-Body Fairing	3" x 1.5"	Fairing Penetration	None noted
31	Unknown					1.5	Wing Lower	2.5" x 0.5"	Wing Lower Skin Cut	None noted
32	Unknown					0.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **Aircraft experienced a 3rd stage compressor failure on the #1 engine during takeoff and aborted. All blades were shed from the 2nd through 5th stages after blade fatigue failure of at least one 3rd stage blade (probably blade #24). The compressor case ruptured over about 270°. The inboard side of the #1 strut had a vertical buckle in the skin. Numerous nicks and scratches were found in the lower surface skin of the wing. The wing-to-body fairing was penetrated in several places. One puncture was found in the fuselage skin aft and below the wing trailing edge. Most of the damage was minor (dents and scratches). Ten holes were found in the wing leading edge control surface between the #1 and #2 engines. In addition some fragments were ejected through the tailpipe, resulting in trailing edge control surface damage.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 32 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average 2"x3" in size. These fragments were from compressor stages 2 through 4, and were released at an estimated average velocity of 700 ft/sec. The release of these fragments caused a "buzz saw" effect on the engine. Additionally, the engine manufacturer indicates that a stator spinner (?) fragment was released, measuring approximately 3"x20" and traveling at an estimated 200 ft/sec. No estimated weight was given, and there is no indication in the engine manufacturer's material as to whether the fragment impacted the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

3.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion–Accident**

Power Level: **Unknown**
Altitude: **FL008**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **4**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Disk/Blades/Vanes**

SECONDARY MALFUNCTION (Rotor Stages): **1st, 2nd, and 4th Stage Turbine – Blades and Vanes**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					–1.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
2	Unknown					–0.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					8.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					7.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
5	Unknown					6.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					5.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					4.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					3.5	Wing Lower	2" x 0.25"	Wing Lower Skin Cut	None noted
9	Unknown					3.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
10	Unknown					2.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
11	Unknown					2.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
12	Unknown					0.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
13	Disk Segment	8" x 14"		3rd Stg		–1.0	Wing Lower	32" x 8"	Fuel Tank Penetration	Fuel Fire

NARRATIVE: **The aircraft experienced an explosive disintegration of the 3rd stage turbine disk on the #4 engine during initial climb at about 800 feet. This disintegration resulted in the shedding of all blades and vanes from the 3rd stage. The 1st, 2nd and 4th stages disintegrated following the 3rd stage. Almost immediately a fuel fire started in the area of the #4 engine, followed by an explosion in the area of the outboard reserve fuel tank. The #4 engine and about 25 feet of the wing separated from the aircraft. The fire was extinguished inflight and an emergency landing was made at an alternate airport. No injuries were reported. The probable cause of the accident was the failure of the 3rd stage disk due to a transient loss of operating clearance between the 3rd stage disk and the inner sealing ring. At least 4 sections of turbine disk were released, with at least one fragment contacting the wing lower surface, resulting in the fuel leak and fire. The portion of the wing which separated was mostly recovered, but fire damage and impact damage combined to make it impossible to determine additional fragment impacts on this section.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 12 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average of 2"x3" in size. These fragments were from 3rd stage turbine blades and vanes, and were released at an estimated average velocity of 500 ft/sec. Fragment 13 was a disk segment as shown, released with a velocity of approximately 700 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

4.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−40.0	BSTA 1183	8" x 3"	Fuselage Penetration	Dented Hydraulic Line and Fuel Feed Line
2	Unknown					−35.0	Fuselage	5" x 4"	Fuselage Penetration	None noted
3	Unknown					−22.5	BSTA 1166	4.5" x 2"	Fuselage Cut	None noted
4	Disk Segment					5.0	BSTA 1148	10" x 7"	Fuselage Penetration	None noted
5	Disk Segment					−4.0	BSTA 1153	60" x 5"	#2 Engine Inlet Duct Penetration	FOD Damage to #2 Engine Compressor

NARRATIVE: **The #1 engine experienced an uncontained failure of the 2nd stage fan disk during takeoff, followed by failure of the #2 engine (due to FOD caused by #1 engine). The crew aborted the takeoff and successfully stopped the aircraft. No fire or injuries were reported. One large disk segment (Fragment 5) from the #1 engine penetrated the #2 engine inlet duct. Fragments entered the #2 engine, causing severe damage to the compressor section. Another large fragment (Fragment 1) severed four fuselage stringers and dented hydraulic return lines and fuel feed lines. Limited information is contained in the files concerning damage from other fragments, although it is evident that multiple fragments were released from the #1 engine during the event.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 3 were blade segments, averaging approximately 1/2 lb. in weight and measuring an average 3"x6" in size. Fragments 4 and 5 are indicated to be disk segments, each measuring 3"x12" and weighing approximately 10 lbs. All fragments shown were released from the fan 2nd stage, and according to estimates were liberated at a velocity of around 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

5.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL045**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **LP Compressor Torque Ring released – Maintenance Error**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					12.5° (est)	BSTA 835	3"x1"	Hole in Fuselage	None noted
2	Unknown					Unk*	Unk*		Not Given	None noted
3	Unknown					Unk*	Unk*		Not Given	None noted
4	Unknown					Unk*	Unk*		Not Given	None noted
5	Unknown					Unk*	Unk*		Not Given	None noted
6	Unknown					Unk*	Unk*		Not Given	None noted
7	Unknown					Unk*	Unk*		Not Given	None noted
8	Unknown					Unk*	Unk*		Not Given	None noted
9	Unknown					Unk*	Unk*		Not Given	None noted
10	Unknown					Unk*	Unk*		Not Given	None noted
11	Unknown					Unk*	Unk*		Not Given	None noted
12	Unknown					Unk*	Unk*		Not Given	None noted
13	Unknown					Unk*	Unk*		Not Given	None noted

NARRATIVE: **During climb at 4500 feet the #1 engine exploded and fire ensued. The aircraft made an emergency landing. Aircraft sustained substantial damage to the #1 engine and pylon, the underside of the left wing (mostly inboard of #1 engine), and the #2 engine pylon. Shrapnel–like penetrations were found in all the areas listed. A small hole was found in the fuselage at BSTA 835. A stator vane penetrated the #2 engine pylon and ruptured a hydraulic line. Twelve other pieces penetrated the #2 engine thrust reverser pneumatic retract line. Investigation determined that the LP compressor torque ring was not properly secured in place during overhaul. As a result, when the restraining effect of the tight fit of the ring and the three borescope inspection ports was overcome by the normal rotational forces within the compressor, the stator assembly and torque ring began to turn. At high rotational speed the torque ring bearing on the LP compressor case literally ground through the case until the case disintegrated with explosive force. No portion of the torque ring was ever found.**

Insufficient information has been found to determine the locations of the penetrations exactly at this time. No useful drawing of the airplane has been found as well. Because of these difficulties it has not been possible to calculate the trajectories of fragments ejected during the event, nor to tabulate the fragments into useful data.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

6.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **HP Compressor 7th Stage Stator Vanes**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a		

NARRATIVE: **There were no documented aircraft structural penetrations due to uncontained engine debris in this event. Uncontained fragments were released, severing a fuel line in the #3 engine pylon. The resulting fuel fire significantly damaged the aircraft empennage, and the aircraft was considered a hull loss.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **None available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

7.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **14th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown	Unk	Unk	14th Stg		−7.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown	Unk	Unk	14th Stg		−5.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown	Unk	Unk	14th Stg		−3.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					−1.5	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
5	Unknown					0.0	Fuselage (low)	2" x 0.5"	Lower Fuselage Penetration	None noted
6	Unknown					36.0	Wing Lower	2" x 0.5"	Wing Lower Skin Cut	None noted
7	Unknown					30.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
8	Unknown					24.0	Fuselage (mid)	2.5" x 1"	Fuselage Penetration	None noted
9	Unknown					21.0	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
10	Unknown					17.5	Wing Lower	1.5" x 0.25"	Wing Lower Skin Cut	None noted
11	Unknown					15.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
12	Unknown					12.0	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted
13	Unknown					9.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
14	Unknown					8.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
15	Unknown					6.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
16	Unknown					3.0	Wing Lower	2" x 0.25"	Wing Lower Skin Penetration	None noted
17	Unknown					2.0	Fuselage (low)	1.5" x 0.5"	Lower Fuselage Penetration	None noted
18	Disk Fragment					−7.0	Wing Lower	13" x 4"	Fuel Tank Penetration	Fuel Leak and Fire
19	Disk Fragment					10.0	Cabin Window	6" x 5"	Cabin Window Penetration	Window Shattered

NARRATIVE: **14th stage compressor disk fractured during takeoff roll. Fragment 18 penetrated the RH wing front spar at WSTA 250.0, causing an irregular hole in the #3 fuel tank. Fire started almost immediately. Fragment 19 penetrated the passenger cabin through a cabin window, causing injuries to passengers due to shattered glass. Shrapnel fragments from the #3 engine caused numerous dents and scratches (in addition to the holes noted) on the underside of the RH wing , on the RH side of the fuselage, and FOD to #2 engine. Crew aborted the takeoff. Substantial fire damage occurred on the right side of the aircraft in the area of the #3 engine due to fuel tank penetration by fragment 18.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 17 were typical blade segments, averaging less than 1/4 lb. in weight and measuring an average 1"x2" in size. Fragment 18 was a disk segment as shown, measuring 3"x4" and weighing about 1/2 lb. Fragment 19 was also a disk segment, measuring 12"x6" and weighing approximately 6 lbs. The engine manufacturer estimates that the velocity of all of the fragments shown was in the range of 500 ft/sec. All fragments were ejected from the compressor 14th stage.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

8.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back–Accident**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **5th Stage LP Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **LP Compressor 4/5 Spacer Ring, 5/6 Spacer Ring**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a		

NARRATIVE: **The 5th stage disk of the LP compressor on the #2 engine failed during initial climb. Engine pieces exited the engine cowling but apparently did not contact the aircraft. Pieces of the disk rim and blades penetrated the right side of the compressor case and severed the main fuel line on the #2 engine. This allowed free flow of fuel around the engine pod. The fuel ignited, the engine separated, and the aircraft returned. Fire continued to burn after landing, resulting in 5 fatalities.**

The LP compressor 5th stage disk rim had separated into at least three parts, two of which were later recovered. Both the 4/5 and the 5/6 spacers were found along the flight path near the fallen engine. There was no evidence of wing impact by fragments, but the engine itself showed considerable secondary damage. Multiple blade and vane fragments were found along the flight path, along with the main fuel feed pipe. Examination showed that the fuel feed pipe was displaced by the bursting of the LP compressor disk rim and casing on the left side of the engine. No conclusive evidence was found concerning fragment impacts on the aircraft.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

9.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL120**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Turbine Section (No Further Information)**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−57.0	Fuel Access Plate	8" x 3"	Reserve Fuel Tank Access Plate Penetration	Fuel Leak and Fire
2	Unknown					−80.0	Horizontal Stabilizer	2" x 1"	Horizontal Stabilizer Lower Skin Penetration	None noted
3	Unknown					−71.5	Outbd Aileron	1.5" x 1"	Outboard Aileron Penetration	None noted
4	Unknown					−68.0	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
5	Unknown					−61.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					−55.0	Wing Lower	1.5" x 0.5"	Wing Lower Skin Cut	None noted
7	Unknown					−54.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					−49.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					−48.0	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					−47.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **During climb at FL120 a loud bang was heard by the crew. The #4 engine turbine section had disintegrated, resulting in a fuel fire. The fire was extinguished by the extinguisher bottles. Debris from the disintegrated engine damaged the aircraft in several places, most notably in the lower wing skin near the #4 engine. One fragment penetrated the #4 access plate of the right hand reserve fuel tank. The outboard aileron was damaged by shrapnel, as was the lower skin of the right hand horizontal stabilizer. Multiple dents and scratches were found in the aircraft as well, mostly in the area of the #4 engine.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not disclosed any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

10.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **70 Kts**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					26.0	#2 Eng Cowl at BSTA 1120	1" x 1"	#2 Engine Cowl Penetration	#2 Eng S–Duct Damage
2	Unknown					25.0	Fuselage	2" x 1"	Fuselage Penetration	None noted
3	Unknown					20.5	#2 Eng Cowl	1" x 0.5"	#2 Engine Cowl Cut	None noted
4	Unknown					17.5	Fuselage	1.5" x 1"	Fuselage Cut	None noted
5	Disk Segment					12.0	Fuselage at BSTA 1152	18" x 4"	Fuselage Penetration	None noted
6	Unknown					12.0	#2 Eng Cowl	2" x 1"	#2 Engine Cowl Penetration	#2 Eng S–Duct Damage
7	Unknown					12.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
8	Unknown					9.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
9	Unknown					8.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
10	Unknown					6.0	#2 Eng Cowl	1" x 1"	#2 Engine Cowl Penetration	#2 Eng S–Duct Damage

NARRATIVE: **The 2nd stage compressor disintegrated during takeoff roll at 70 knots. The compressor departed the aircraft, releasing multiple blade shrapnel and associated debris. Several fragments contacted the #2 engine inlet duct, with at least four fragments (Fragment 1, Fragment 3, Fragment 6, and Fragment 10) penetrating the S–duct. A large hole was torn in the fuselage by Fragment 5. A fuel fire was started when the fuel control unit was severed by an undisclosed fragment. In addition the oil cooler was fractured and separated from the engine. The underside of the #3 engine strut, the aft right side of the #2 engine cowl, and the lower rudder were severely damaged by the fire. The takeoff was aborted and the fire bottles were discharged. Injuries reported were all due to emergency egress.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 4 and fragments 6 through 10 were typical blade segments, averaging approximately 1/4 lb. in weight and measuring an average 3"x6" in size. Fragment 5 was determined to be a disk segment measuring 4"x12" and weighing 10 lbs. The engine manufacturer estimates all fragments shown to have been ejected with a velocity of around 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

11.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**
Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Intershaft Bearing – LPT Drive Shaft**

SECONDARY MALFUNCTION (Rotor Stages): **LPT Stages 3 and 4 Blades**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−24.0	BSTA 1263	2" x 1'	Fuselage Penetration	None noted
2	Unknown					−22.0	BSTA 1259	2.5" x 1.5"	Fuselage Penetration	None noted
3	Unknown					−17.0		3" x 1.5"	Fuselage Cut	None noted
4	Unknown					−10.0		3" x 2"	Fuselage Penetration	None noted
5	Unknown					−5.0	BSTA 1249	5" x 2.5"	Fuselage Penetration	Damage to ventral stair and Bulkhead
6	Unknown					−1.5	BSTA 1241	3" x 2"	#2 Engine Cowl Penetration	#2 Engine Throttle Cable Severed
7	Unknown					17.0	BSTA 1223	3" x 1.5"	Fuselage Penetration	None noted
8	Unknown					14.0		2" x 2"	#2 Engine Cowl Penetration	None noted
9	Unknown					4.0		10" x 8"	Fuselage Penetration	None noted
10	Unknown					3.0	BSTA 1236	1.5" x 1"	Fuselage Penetration	#2 Engine Control Cable (?) Severed
11	Unknown					1.0		3" x 3"	#2 Engine Cowl Penetration	None noted

NARRATIVE: **The #3 engine turbine section disintegrated due to oil starvation in the #4 1/2 bearing. The bearing oil line was broken in two places. Investigation revealed that all stage 3 and 4 blades had separated and the N1 turbine shaft had fractured. The 3rd and 4th stage blade debris and shrapnel was ejected through the engine casing. Shrapnel penetrated the fuselage in several places between BSTA 1223 and BSTA 1263. The #2 engine outer case was torn and holed as well. One of the two #2 engine throttle control cables was severed by Fragment 6, and the second was damaged. Fragment 10 also severed a control cable (unspecified) to the #2 engine. Fragment 5 entered the fuselage below the #3 engine strut and damaged the aft ventral stair and the rear bulkhead. The ground air service duct was dented in several places. Debris from the disintegration also severely damaged the torque box stringers.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that all fragments were typical blade segments, averaging about 1/4 lb. and measuring an average 2"x3" in size. The engine manufacturer estimates the velocity of these blade segments to be in the range of 700 ft/sec. All fragments were released from the LPT 3rd and 4th stages.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

12.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **EPR 1.92**
Altitude: **FL330**
Airspeed: **0.84M**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Stage 1–2 Spacer**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage Fan Rotor Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−56.0	FSTA 124	8" x 5"	Vertical Stabilizer Penetration	Rudder/Elevator problems noted inflight
2	Unknown					−49.0	FSTA 10	3.5" x 3"	Vertical Stabilizer Penetration	Rudder/Elevator problems noted inflight
3	Unknown					−42.0	BSTA 1260	5" x 3"	Fuselage Penetration	None noted
4	Unknown					−42.0	BSTA 1260	1" x 1"	Cabin Window Penetration	None noted
5	Unknown					−35.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
6	Unknown					−31.0	Fuselage	2.5" x 2"	Fuselage Penetration	None noted
7	Unknown					−30.5	Fuselage	1" x 0.25"	FuselagePenetration	None noted
8	Unknown					−26.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
9	Unknown					−24.0	BSTA 1040	3" x 3"	Fuselage Penetration	None noted
10	Unknown					−23.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
11	Unknown					−22.5	BSTA 1020	1" x 1"	Cabin Window Penetration	None noted
12	Unknown					−18.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
13	Unknown					−17.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
14	Unknown					−15.5	WSTA 598	3" x 2"	Wing LE Flap Penetration	None noted
15	Unknown					−15.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
16	Unknown					−12.5	WSTA 555	3" x 2"	Wing LE Flap Penetration	None noted
17	Unknown					−11.0	WSTA 529	3" x 2"	Wing LE Flap Penetration	None noted
18	Unknown					−11.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
19	Unknown					−10.5	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
20	Unknown					−9.0	BSTA 900	3" x 2"	Fuselage Penetration	None noted
21	Unknown					−8.5	Fuselage	1" x 1"	Fuselage Penetration	None noted
22	Unknown					−6.0	BSTA 880	1.5" x 0.5"	Fuselage Penetration	None noted

(CONTINUED)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

12.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan Stage 1–2 Spacer**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage Fan Rotor Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
23	Unknown					−5.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
24	Unknown					−5.0	Fuselage	2" x 2"	Fuselage Penetration	None noted
25	Unknown					−3.0	Fuselage	2.5" x 1"	Fuselage Penetration	None noted
26	Unknown					0.0	Fuselage	1" x 0.5"	Fuselage Penetration	None noted
27	Unknown					18.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
28	Unknown					17.0	Wing LE	1"x 1"	#1 LE Flap Penetration	None noted
29	Unknown					14.0	Fuselage	2.5" x 2"	Fuselage Penetration	None noted
30	Unknown					14.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
31	Unknown					11.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
32	Unknown					7.5	Wing LE	3" x 2"	#5 LE Flap Penetration	None noted
33	Unknown					7.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
34	Unknown					5.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
35	Unknown					3.5	Fuselage	2" x 1"	Fuselage Penetration	None noted
36	Unknown					1.5	Fuselage	3" x 1.5"	Fuselage Penetration	None noted
37	Unknown					0.5	WSTA 501	1.5" x 0.5"	Crack on Front Spar Lower Rail	None noted

NARRATIVE: **The #1 engine fan section and the nose inlet cowl separated from the aircraft during cruise or inflight climb. The crew first heard a loud explosive report, followed by a lurch. A degree of lateral control difficulty ensued. Investigation revealed that the fan hub had fractured and released blades and vanes. Debris from the disintegration penetrated the wing and the fuselage. Some fragments were ejected from the exhaust nozzle of the #1 engine. Damage occurred to the vertical stabilizer (Fragments 1 and 2) and the horizontal stabilizer. Significant rudder damage was noted, but the actual locations of rudder damage were not addressed in the file information. Likewise, limited information on file makes it difficult to determine what caused the damage to the horizontal stabilizer. It has been assumed that this was due to fragments ejected through the exhaust nozzle.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that all fragments listed were typical blade segments, averaging close to 1/2 lb. in weight and measuring an average 3"x6" in size. These fragments were ejected from the fan section at a velocity close to 500 ft/sec. Additionally, the engine manufacturer notes that there was a disk segment measuring about 3"x6" and weighing approximately 1 lb. ejected from the fan section at a velocity of about 500 ft/sec. Engine manufacturer information concerning this disk segment shows that the most likely trajectory was between +3° and −5° from the fan plane of rotation, although no firm data is given.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

13.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back–Accident**
Power Level: **Unknown**
Altitude: **FL028**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **11th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−12.5	BSTA 1203	3" x 1.5"	#2 Engine Cowl Penetration	None noted
2	Unknown					−11.5	#2 Eng Cowl	3.5" x 3"	#2 Engine Cowl Penetration	None noted
3	Unknown					−10.0	Fuselage	3" x 2"	Fuselage Penetration	None noted
4	Unknown					−8.5	BSTA 1199	1.5" x 1"	#2 Engine Cowl Penetration	None noted
5	Unknown					−4.0	Fuselage	2" x 1"	Fuselage Penetration	None noted
6	Unknown					−2.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
7	Unknown					−0.5	Fuselage	3" x 1"	Fuselage Penetration	None noted
8	Unknown					15.0	BSTA 1183	4" x 2"	#2 Engine Cowl Penetration	None noted
9	Unknown					13.5	BSTA 1186	2" x 2"	#2 Engine Cowl Penetration	None noted
10	Unknown					12.5	#2 Eng Cowl	1.5" x 1"	#2 Engine Cowl Penetration	None noted
11	Unknown					10.0	Fuselage	1" x 1"	Fuselage Penetration	None noted
12	Unknown					8.0	#2 Eng Cowl	3" x 1.5"	#2 Engine Cowl Penetration	None noted
13	Unknown					4.0	Fuselage	1.5" x 1"	Fuselage Penetration	None noted
14	Unknown					3.0	#2 Eng Cowl	3" x 1"	#2 Engine Cowl Penetration	None noted
15	Disk Fragment					−1.0	BSTA 1198–1195	20" x 8"	Fuselage Penetration by Disk Segment	Wiring and Hydraulic Tubing severed; Fuel Line Dented

NARRATIVE: **The aircraft experienced disintegration of the #3 engine 11th stage compressor disk during climb. A 120° section of the disk (Fragment 15) had separated and cut through the firewall and the upper part of the strut, then continued upward and into the side of the fuselage where it severed several body stringers. The disk piece continued inboard, severing the lower web of the torque box, electrical wiring (including the wiring to both fire bottles), and denting the #2 engine fuel feed line. No control cables were damaged in the incident. Numerous blade pieces were ejected through the hole made by the disk fragment, resulting in multiple penetrations (by Fragments 1 through 14) of the fuselage and the #2 engine cowl.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer notes that fragments 1 through 14 were typical blade segments, averaging approximately 1"x2" in size and weighing in the range of 1/8 lb. Fragment 15 was a disk segment weighing about 3 lbs. and measuring 9"x12" in size. The engine manufacturer estimates that all fragments were ejected from the compressor 11th stage at velocities near 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

14.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL005**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine Disk Rim Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					–7.0	Wing Lower	0.5" x 0.5"	Fuel Tank Access Cover Penetration	Fuel Leak; No Fire
2	Unknown					–5.0	Wing Lower	1" x 0.75"	Fuel Tank Access Cover Penetration	Fuel Leak; No Fire
3	Unknown					14.0	Wing LE Lower	0.5" x 0.5"	Wing LE Lower Skin Penetration	None noted
4	Unknown					15.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
5	Disk Fragment					–7.0	Wing LE area	7" x 6"	Wing LE Penetration	Wiring and Hydraulic Lines Severed; Pneumatic Ducts Severed

NARRATIVE: **The #1 engine sustained a separation of the 2nd stage turbine disk rim during climb. The crew was alerted by a #1 engine fire warning in the cockpit. Turbine blades and disk fragments were ejected through the HP turbine case and engine cowling. Two small fragments of unspecified origin (Fragments 1 and 2) each punctured a fuel access plate in the lower wing, resulting in fuel leaks. A segment of the disk (Fragment 5) penetrated the lower wing in the leading edge area, severing electrical wiring, hydraulic fluid lines, and pneumatic ducts. Fire was contained to the pylon area and was extinguished by the firing of the bottles. The fuel leaks did not catch fire. Various control surfaces (flaps, LE devices, ailerons) were damaged to varying degrees by shrapnel. Numerous dents and gouges (more than 100) were found on the lower wing skin near the #1 engine in a trajectory which was further aft than any of the few fragments which actually penetrated the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 4 were typical blade segments, released from the turbine 2nd stage at velocities around 500 ft/sec. These fragments averaged 1/4 lb. in weight and measured an average 2"x3" in size. Fragment 5 was a disk rim segment as noted, released from the turbine 2nd stage at a velocity near 700 ft/sec. This fragment measured 20"x2" and weighed approximately 5 lbs., according to the engine manufacturer.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

15.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Landing**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Turbine Stage 2 Blade Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					17.5	BSTA 598 (?)	5" x 2"	Fuselage Penetration	None noted
2	Unknown					15.5	BSTA 606	2" x 2"	Fuselage Penetration	None noted
3	Unknown					11.0	Fuselage (low)	1.5" x 1"	Fuselage Penetration	None noted
4	Unknown					10.5	Fuselage (low)	2"x 1"	Fuselage Penetration	None noted
5	Unknown					10.0	Fuselage (low)	3" x 1.5"	Fuselage Penetration	None noted
6	Unknown					7.0	Fuselage (low)	2" x 1"	Fuselage Penetration	None noted
7	Unknown					6.0	Fuselage (low)	3" x 2"	Fuselage Penetration	None noted
8	Unknown					5.5	Fuselage (low)	2" x 2"	Fuselage Penetration	None noted
9	Unknown					2.5	Fuselage (low)	3" x 2.5"	Fuselage Penetration	None noted
10	Unknown					1.0	Fuselage (low)	2.5" x 1"	Fuselage Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #3 engine turbine section on application of reverse thrust during landing. Fragments from the engine penetrated the aircraft fuselage from forward of BSTA 600 to approximately the plane of failure, mostly just below the passenger cabin floor level. The #3 engine cowling was severely torn and holed by multiple small fragmenrs. Investigation noted that most of the debris from the disintegration did not contact the aircraft. The total number of debris impact points is unknown, with only the known impact locations used in the analysis.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

16.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Ground Test**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **0**
Hazard Level (*see Definitions*): **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−11.0	Unknown	2.5" x 2"	(See Engine Manufacturer's Update	(See Engine Manufacturer's Update)
2	Unknown					−10.5	Unknown	2" x 1"		
3	Disk Fragment					−15.0	Unknown	8" x 5"		
4	Unknown					−8.5	Unknown	1" x 1"		
5	Unknown					−7.0	Unknown	2" x 1"		
6	Unknown					−7.0	Unknown	2" x 1"		
7	Unknown					−6.5	Unknown	1.5" x 0.5"		
8	Unknown					−5.5	Unknown	2" x 2"		
9	Unknown					−3.0	Unknown	1" x 1"		
10	Unknown					−2.5	Unknown	1" x 1"		
11	Unknown					−1.0	Unknown	2" x 2"		
12	Unknown					0.0	Unknown	2" x 1"		
13	Unknown					4.5	Unknown	2" x 1"		
14	Unknown					2.5	Unknown	2" x 1"		
15	Unknown					2.0	Unknown	1.5" x 1"		
16	Unknown					−33.5	Unknown	1" x 1"		
17	Unknown					−27.5	Unknown	2.5" x 1"		
18	Unknown					−26.5	Unknown	1.5" x 0.5"		
19	Unknown					−26.0	Unknown	1" x 1"		
20	Unknown					−22.0	Unknown	2" x 1"		
21	Unknown					−22.0	Unknown	1.5" x 1"		
22	Unknown					−19.5	Unknown	1.5" x 0.5"		

(CONTINUED)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

16.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine**

SECONDARY MALFUNCTION (Rotor Stages): **Rub**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
23	Unknown					−17.5	Unknown	2" x 1"	(See Engine Manufacturer's Update)	(See Engine Manufacturer's Update)
24	Unknown					−13.5	Unknown	2" x 1"		
25	Unknown					−12.5	Unknown	2" x 2"		
26	Unknown					−11.5	Unknown	1" x 1"		
27	Unknown					−5.5	Unknown	2" x 1"		
28	Unknown					−4.0	Unknown	2" x 1"		

NARRATIVE: **NOTE: The information contained in this record was drawn from a previous study. Additional analysis was performed using the data obtained from the engine manufacturer. No further narrative information is presently available.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 and 2 were typical blade segments, measuring an average 2"x3" in size and weighing an average of 1/4 lb. These two fragments were liberated from the turbine 2nd stage at a velocity of about 500 ft/sec. Fragment 3 was a disk rim segment as noted, weighing approximately 5 lbs. and measuring about 20"x2" in size. This piece was ejected at a velocity near 700 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

17.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **100 Kts**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage Fan**

SECONDARY MALFUNCTION (Rotor Stages): **2nd Stage Fan due to 1st Stage Blade Walk**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−28.0	#4 Eng Inlet	2" x 1"	#4 Engine Inlet Penetration	None noted
2	Unknown					−25.5	#4 Eng Inlet	2" x 2"	#4 Engine Inlet Penetration	None noted
3	Unknown					−24.0	#4 Eng Inlet	1" x 1"	#4 Engine Inlet Penetration	None noted
4	Unknown					−16.5	Wing Lower	2.5" x 2"	Wing Fuel Tank Penetration	Fuel Leak – No Fire
5	Unknown					−16.0	Wing Lower	2" x 1"	Wing Fuel Tank Penetration	Fuel Leak – No Fire
6	Unknown					−10.0	Wing Lower	3.5" x 2"	Wing Lower Skin Penetration	None noted
7	Unknown					−4.5	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
8	Unknown					−2.0	Fuselage (Low)	2" x 1.5"	Fuselage Penetration	None noted
9	Unknown					16.5	Fuselage (High)	2" x 2"	Fuselage Penetration	None noted
10	Unknown					15.0	Fuselage (Mid)	2" x 1.5"	Fuselage Penetration	None noted
11	Unknown					13.0	Cabin Window	1" x 1"	Cabin Window Damage	None noted
12	Unknown					11.5	Cabin Window	1" x 1"	Cabin Window Damage	None noted
13	Unknown					7.0	Fuselage (Mid)	2" x 1"	Fuselage Penetration	None noted
14	Unknown					7.0	Wing–to–Body	3" x 1.5"	Fairing Penetration	None noted
15	Unknown					3.0	Wing–to–Body	1" x 0.5"	Fairing Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the 1st stage fan disk of the #3 engine during the takeoff roll at about 100 knots, followed by disintegration of the 2nd stage. Crew aborted the takeoff and stopped the aircraft safely. No injuries were reported. Damage to the aircraft was substantial, with fuel leaking from the #3 main fuel tank due to shrapnel holes and numerous penetrations of the fuselage. The #4 engine also received shrapnel damage around the inlet, and had extensive gouging to the fan blades. The wing–to–body fairing received multiple shrapnel damage. There was no evidence of the disk contacting the aircraft.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer notes that all fragments shown are typical blade segments, averaging approximately 1/2 lb. in weight and measuring an average 6"x3" in size. Additionally, the engine manufacturer notes that a disk segment weighing about 1 lb. and measuring 6"x3" was also liberated from the fan section, but no indication of aircraft impact was given. The engine manufacturer estimates that all pieces ejected had velocities in the range of 500 ft/sec.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

18.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **8th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **No Information Given**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−1.5	Vert. Stabilizer	2" x 2"	Stabilizer Penetration	None noted
2	Unknown					0.0	Vert. Stabilizer	1.5" x 1"	Stabilizer Penetration	None noted
3	Unknown					16.5	Vert. Stabilizer	2" x 2"	Stabilizer Penetration	None noted * The 'A' hydraulic system was lost due to fragment penetration, but no indication is given as to which fragment caused the hydraulic loss.
4	Unknown					15.0	Vert. Stabilizer	1.5" x 0.5"	Stabilizer Penetration	None noted
5	Unknown					14.5	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
6	Unknown					13.5	Vert. Stabilizer	1" x 1"	Stabilizer Penetration	None noted
7	Unknown					10.5	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
8	Unknown					9.5	Vert. Stabilizer	1" x 1"	Stabilizer Penetration	None noted
9	Unknown					6.0	Vert. Stabilizer	3" x 2"	Stabilizer Penetration	None noted
10	Unknown					3.0	Vert. Stabilizer	36" x 12"	RH side of Stabilizer Penetration	None noted
11	Unknown					2.5	Vert. Stabilizer	2.5" x 2"	RH side of Stabilizer Penetration	None noted
12	Unknown					2.0	Vert. Stabilizer	27" x 3"	RH side of Stabilizer Penetration	None noted
13	Disk Fragment					10.0	Vert. Stabilizer	18" x 10"	RH side of Stabilizer Penetration	None noted
14	Disk Fragment					16.5	Vert. Stabilizer	4" x 4"	RH side of Stabilizer Penetration	None noted

NARRATIVE: **The 8th stage compressor disk on the #2 engine disintegrated during climb. Crew noted loss of power on #2 engine followed by noise heard in the cockpit. Hydraulic system 'A' was lost. Flight diverted successfully. Investigation showed that the disk rim had separated and punched a hole in the engine cowling, progressing up the side of the vertical stabilizer, leaving two large holes. Multiple small penetrations were noted in the same area. The right hand rear spar chord and web were severed for about 18 inches. Multiple holes were also noted in the #2 engine casing.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available in files.**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 12 were typical blade segments weighing on average less than 1/4 lb. and measuring an average 1"x2" in size. The engine manufacturer notes that fragment 13 was a disk fragment measuring 6"x3" and weighing about 1 lb. Fragment 14 is not confirmed, although accompanying photograph shows multiple pieces of disk rim broken away from disk. The engine manufacturer also disputes the size of hole caused by fragment 10, although no data is given to support the dispute.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

19.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **EPR 1.93**
Altitude: **FL130**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage Compressor Rotor**

SECONDARY MALFUNCTION (Rotor Stages): **7th, 8th, 10th, 11th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−31.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown					−22.0	Wing LE Outbd	10" x 3"	Wing Outbd Slat Penetration	None noted
3	Unknown					−20.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					−16.0	Fuselage (Low)	1" x 1"	LH Drain Mast aft of Wheel Well	None noted
5	Unknown					−15.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
6	Unknown					−11.5	Wheel Well	4" x 2.5"	Wheel Well Penetration	None noted
7	Unknown					−9.5	Wheel Well	2.5" x 1"	Wheel Well Penetration	None noted
8	Unknown					−4.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
9	Unknown					−4.0	Wing Lower	3" x 1.5"	Wing Lower Skin Penetration	None noted
10	Unknown					0.0	#1 Eng Cowl	16" x 3"	Engine Cowl Penetration	None noted

* The #1 hydraulic system was lost due to fragment penetration, but no indication is given as to which fragment caused the hydraulic loss.

NARRATIVE: **The #1 engine 9th stage compressor disintegrated during climb at about 13,000 feet, releasing multiple blades and vanes as well as at least one disk fragment. This was closely followed by the disintegration of the 7th, 8th, 10, and 11th stages. The engine cowl was sawn in two around 360°. The side cowl had a 16" gash in it (Fragment 10). Other aircraft damage was noted, particularly in the area of the left hand wheel well (Fragments 6 and 7). Several fragments(fragments 1, 3, 5, 8, and 9) penetrated the lower wing skin. No indications of fuel leaks are given. A fragment or fragments penetrated the #1 hydraulic lines, causing the loss of the #1 system due to fluid loss (no indication as to which fragment or fragments caused this). The flight diverted without further incident.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

20.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL180**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **2**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					3.0	Wing Lower	12" x 8"	Wing Lower Skin Gouge with Small (3" x 0.25") Cut	None noted
2	Unknown					3.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					3.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
4	Unknown					1.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
5	Unknown					0.5	Wing Lower	3" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The #1 engine disintegrated during climb. The low pressure turbine section came apart, penetrating the bottom of the engine casing and cowl. Shrapnel damage was found in numerous places on the lower wing skin, with several penetrations along with multiple scrapes and gouges. Additional perforations were noted in the engine cowl itself. One deep gouge was noted (Fragment 1) which had left a small cut in the lower wing skin at the deepest part of the gouge. The crew initiated an air turn back and landed without further incident.**

SOURCE (*Data obtained from*): **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

21.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Turbo Compressor Duct**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
4	Unknown					−49.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
2	Unknown					−45.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					−33.0	Wing Lower	0.5" x 0.25"	Wing Lower Skin Penetration	None noted
1	Unknown					−31.5	Wing LE	4" x 4"	Wing Leading Edge Penetration	None noted
5	Unknown					−22.0	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
6	Unknown					−11.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					−6.5	Wing Lower	2" x 1.5"	Wing Lower Skin Penetration	None noted
8	Unknown					12.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					6.5	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					2.5	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The #4 engine throttle in the cockpit jumped violently during climb. The crew shutdown the #4 engine and elected to divert. Examination revealed that the turbo compressor duct had ruptured, tearing away a large piece of the cowling. Shrapnel from the explosion punctured the wing lower skin in several places, and a larger hole was found in the wing leading edge about 8 feet outboard from the #4 engine (Fragment 4). No injuries were reported. It is assumed from the evidence that many of the fragments released did not contact the aircraft, as most of the blast seemed to be directed downward and outboard from the #4 engine.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

22.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL320**
Airspeed: **0.84M**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Section**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−3.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
2	Unknown					−1.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
3	Unknown					53.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
4	Unknown					41.0	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
5	Unknown	12" x 8"				30.0	Wing LE	12" x 8"	Wing Leading Edge Penetration	None noted
6	Unknown					27.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Piece of Fan Mid Shroud					22.0	Cabin Window	1.5" x 1"	Outer Window Penetration	None noted
8	Unknown					11.0	Wing Lower	0.5" x 0.5"	Wing Lower Skin Penetration	None noted
9	Unknown					8.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
10	Unknown					3.0	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #3 engine during cruise at 32,000 feet. The engine was shutdown and the flight returned. Shrapnel from the disintegration pierced several small holes in the lower skin of the wing inboard of the #3 engine (fragments 2, 6, 8, 9, and 10) as well as three places in the fuselage below the floor line (fragments 1, 3, and 4). One fragment (fragment 7) penetrated the outer pane of the #16 window in the passenger cabin, but did not penetrate the inner pane. This fragment remained between the window panes. A large fragment (fragment 5) was found imbedded in the wing leading edge slat inboard of the #3 engine. Damage to the aircraft is listed as minor, and no injuries were reported.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

23.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL350**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Compressor Fan Stage 1 Assembly**

SECONDARY MALFUNCTION (Rotor Stages): **Drive Arm due to Fatigue**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					–5.0	BSTA 1108	2" x 2"	Fuselage Penetration	None noted
2	Unknown					–2.5	#3 Eng Cowl	2" x 1"	#3 Engine Core Cowl Penetration	#3 Engine Damage noted
3	Unknown					–2.0	#3 Eng Cowl	10" x 2"	#3 Engine Nose Cowl Penetration	#3 Engine Damage noted
4	Unknown					10.0	BSTA 983	3" x 2"	Fuselage Penetration	None noted
5	Unknown					9.0	WSTA 155	3" x 2"	Wing Leading Edge Penetration	None noted
6	Unknown					8.0	BSTA 1000	3" x 1"	Fuselage Penetration	Hydraulic Lines Damaged
7	Unknown					5.5	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
8	Unknown					5.0	Fuselage (Low)	1" x 0.5"	Fuselage Penetration	None noted
9	Unknown					2.0	Fuselage (Low)	0.5" x 0.5"	Fuselage Penetration	None noted
10	Unknown					0.5	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the #1 engine low pressure compressor fan assembly during cruise. The crew heard a loud report followed by indications of #1 engine problems. Two hydraulic systems were lost almost immediately due to fragments severing hydraulic lines (fragment 6). Debris (fragments 5 and 7) damaged the wing. Several holes were found in the fuselage (due to fragments 1, 4, 6, 8, 9, and 10). Shrapnel also damaged the #3 engine (fragments 2 and 3), causing significant damage to the engine. The #3 engine was able to continue to operate despite damage.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

24.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Ground Test**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Zero**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **2nd Stage LP Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−50.5	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
2	Unknown					−44.0	Fuselage (Low)	1" x 1"	Fuselage Penetration	None noted
3	Unknown					−38.0	Fuselage (Low)	2.5" x 2"	Fuselage Penetration	None noted
4	Unknown					−29.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
5	Unknown					−28.0	Fuselage (Low)	1.5" x 1"	Fuselage Penetration	None noted
6	Unknown					−27.0	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted
7	Unknown					−26.5	Fuselage (Low)	1" x 0.5"	Fuselage Penetration	None noted
8	Unknown					−24.0	Cabin Window	2" x 1.5"	Cabin Window Cracked	None noted
9	Unknown					−21.5	Fuselage (Low)	2.5" x 1"	Fuselage Penetration	None noted
10	Unknown					−19.5	Fuselage (Low)	1.5" x 1"	Fuselage Penetration	None noted
11	Unknown					−19.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
12	Unknown					−15.5	Fuselage (Low)	2" x 1"	Fuselage Penetration	None noted

NARRATIVE: **During a routine ground test, the #1 engine experienced an uncontained disintegration of the 2nd stage turbine disk. Segments of the disk were released, as were multiple blades and blade pieces. Parts of the disk rim and all of the blades had separated. Blade fragments contacted the fuselage in many locations with 12 penetrations noted. One cabin window was cracked by debris (fragment 8). Indications of lower wing skin penetrations were given in the associated file material, but no firm evidence (written or pictorial) has been found to substantiate this. Two large pieces of the disk were found up to 500 feet away from the aircraft in the approximate plane of the 2nd stage. Preliminary inspection showed that the disk had burst into two main pieces due to a fracture between the rim and the inside edge of the disk.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

25.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL013**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Stator Guide Vane Lug Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **3rd Stage Turbine Disk, 4th Stage Guide Vane Assembly**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−5.5	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
2	Unknown					−4.0	Wing Lower	3" x 3"	Wing Lower Skin Penetration	None noted
3	Unknown					−2.5	Wing Lower	2" x 2"	Wing Lower Skin Penetration	None noted
4	Unknown					−1.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
5	Unknown					0.0	Wing Lower	1.5" x 1"	Wing Lower Skin Penetration	None noted
6	Unknown					20.0	Wing Lower	1" x 1"	Wing Lower Skin Penetration	None noted
7	Unknown					17.0	Wing Lower	3" x 2"	Wing Lower Skin Penetration	None noted
8	Unknown					16.0	Wing Lower	2" x 1"	Wing Lower Skin Penetration	None noted
9	Unknown					15.5	Wing Lower	1" x 0.5"	Wing Lower Skin Penetration	None noted
10	Unknown					10.0	Wing Lower	2.5" x 1"	Wing Lower Skin Penetration	None noted
11	Unknown					8.0	Wing Lower	3" x 0.25"	Wing Lower Skin Cut	None noted
12	Unknown					5.0	MLG Door	2" x 1"	Main Landing Gear Door Hole	None noted
13	Unknown					3.0	#3 Eng Strut	3" x 0.5"	Sailboat Fairing Penetration	None noted
14	Unknown					0.5	#3 Eng Strut	1.5" x 1"	Sailboat Fairing Penetration	None noted
15	Disk Rim Fragment					0.5	Wing Lower	12" x 4"	Wing Lower Skin Penetration, Aft of Front Spar – Fuel Tank	Fuel Leak – No Fire

* Hydraulic system pressure loss due to fragment penetration accompanied disintegration, but no indication is given as to which fragment caused the hydraulic system loss.

NARRATIVE: **The #4 engine disintegrated shortly after takeoff during initial climb. The 3rd stage turbine stator guide vane lug failed, with subsequent aft shift of the whole stator assembly and collision with the 3rd stage turbine disk. Pieces of the the 3rd and 4th stage turbine guide vane assemblies and about 1/2 of the 3rd stage disk rim were recovered from the ground at the point of the disintegration. Substantial damage to the wing was noted, including both large and small holes. Fuel was leaking from several holes in the lower wing skin including the large hole caused by the disk fragment (fragment 15). The #3 engine sailboat fairing was punctured in two places (fragments 13 and 14). Flaps and leading edge slats were substantially damaged in the area near the #4 engine. Some debris was ejected through the tailpipe and damaged the trailing edge devices.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragments 1 through 14 were typical blade segments, released from the turbine 3rd and 4th stages at velocities near 500 ft/sec. These fragments averaged about 1/4 lb. in weight and approximately 2"x3" in size. Fragment 15, a disk rim segment, was released from the turbine 3rd stage at an approximate velocity of 700 ft/sec. This disk rim segment measured 2"x20" in size and weighed about 5 lbs.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

26.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

EVENT OMITTED FROM DATABASE PER ENGINE MANUFACTURER REQUEST

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

27.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **HP Turbine 12 Stage Inner Rotating Airseal**

SECONDARY MALFUNCTION (Rotor Stages): **LP Turbine Blades and Vanes**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−49.0	Incomplete Data	2" x 1"	Incomplete Data	Incomplete Data
2	Unknown					−44.5	Incomplete Data	3" x 1"	Incomplete Data	Incomplete Data
3	Unknown					−42.0	Incomplete Data	5" x 4"	Incomplete Data	Incomplete Data
4	Unknown					−40.5	Incomplete Data	3.5" x 1.5"	Incomplete Data	Incomplete Data
5	Unknown					−36.0	Incomplete Data	1.5" x 1"	Incomplete Data	Incomplete Data
6	Unknown					21.0	Incomplete Data	2.5" x 2"	Incomplete Data	Incomplete Data
7	Unknown					20.0	Incomplete Data	3" x 3"	Incomplete Data	Incomplete Data
8	Unknown					20.0	Incomplete Data	1" x 1"	Incomplete Data	Incomplete Data
9	Unknown					16.5	Incomplete Data	1.5" x 1"	Incomplete Data	Incomplete Data
10	Unknown					11.0	Incomplete Data	1" x 1"	Incomplete Data	Incomplete Data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **NO DETAILED INFORMATION AVAILABLE.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **No additional information available.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

28.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Landing**
Flight Effect: **None**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture due to Bird Strike**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−28.0	Incomplete data	6" x 4"	Incomplete data	Incomplete data
2	Unknown					−25.5	Incomplete data	2" x 2"	Incomplete data	Incomplete data
3	Unknown					−25.0	Incomplete data	1" x 1"	Incomplete data	Incomplete data
4	Unknown					−24.0	Incomplete data	2.5" x 2"	Incomplete data	Incomplete data
5	Unknown					−22.5	Incomplete data	2.5" x 2"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **Wing front spar web was punctured by debris, resulting in a fuel leak.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event was caused by a bird strike, resulting in fan blade fracture. The only fragment confirmed is a fan blade segment measuring 6"x6" and weighing 1.1 lb. The estimated velocity of this fragment is given as approximately 500 ft/sec. The engine manufacturer notes that this event resulted in a fuel tank rupture. Further information is available from a video referenced by the engine manufacturer.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

29.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion–Accident**

Power Level: **EPR 1.4745**
Altitude: **FL110**
Airspeed: **304 Knots**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **LP Location Bearing followed by Fan Shaft Assembly shift and disintegration**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Fan Module?					Unk	9 ft Fwd of eng Front Flange	Unk	Fuselage Penetration	Hydraulic System problems noted
2	Unknown					Unk	S–duct	36"x12"	Unknown	None noted
3	Unknown					Unk	S–duct	48"x24"	Unknown	None noted

NARRATIVE: **The #2 engine fan shaft had fractured and the fan assembly moved forward as much as 12 feet in the inlet before penetrating both sides of the inlet. A section of the LP compressor fan module was missing from the engine. As the fan module departed it cut a spiral path through the inlet and struck the left side of the fuselage about 9 feet forward of the engine's front flange. This fragment then penetrated the fuselage, leaving impact marks at the upper right hand side of the inlet. Some hydraulic systems problems resulted along with various other control difficulties.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

30.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture due to Bird Strike**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					5.0	Not Given	3" x 2"	Incomplete data	Incomplete data
2	Unknown					3.5	Not Given	2" x 2"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **NO DETAILED INFORMATION AVAILABLE. Cracks in fuselage noted but no locations given.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event was a bird ingestion event resulting in fan blade damage. The only fragment noted was approximately 1.1 lbs. and about 6"x6" in size. Estimated velocity of this fragment was 500 ft/sec. The engine manufacturer makes reference to a video for further information.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

31.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Spinner Fatigue -- FAN Stage**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
n/a	n/a					n/a	n/a	n/a	n/a	n/a

NARRATIVE: **This event did not result in significant aircraft damage. There were two significant holes in the nose cowl, but no evidence that any fragments penetrated the aircraft**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files.**
DRAWINGS/PICTURES IDENTIFICATIONS: **???**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that according to their records, this event did not result in any significant damage to the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

32.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Unknown**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **LP Turbine 5th and 6th Stage Disintegration**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−67.0	Lower Wing	4" x 3"	Incomplete data	Incomplete data
2	Unknown					−56.0	Lower Wing	3" x 3"	Incomplete data	Incomplete data
3	Unknown					−47.5	Lower Wing	2" x 2"	Incomplete data	Incomplete data
4	Unknown					−44.5	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
5	Unknown					−44.0	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
6	Unknown					−41.0	Lower Wing	1.5" x 1"	Incomplete data	Incomplete data
7	Unknown					−33.5	Lower Wing	2" x 1"	Incomplete data	Incomplete data
8	Unknown					−31.5	Lower Wing	1" x 1"	Incomplete data	Incomplete data
9	Unknown					−22.0	Lower Wing	0.5" x 0.5"	Incomplete data	Incomplete data
10	Unknown					−11.5	Lower Wing	1" x 0.25"	Incomplete data	Incomplete data
11	Unknown					−6.0	Lower Wing	2" x 2"	Incomplete data	Incomplete data
12	Unknown					−3.5	Lower Wing	2" x 1"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM AN EARLIER TRAJECTORY STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE.

NARRATIVE: **A loud bang was heard during climb. The 5th and 6th stage LPT blades and stator vanes came apart, penetrating the case and cowl. The case split open around 3/4 of its circumference. Numerous cuts and abrasions were noted on the lower wing skin.**

SOURCE *(Data obtained from)*: **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

33.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **80 Kts**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **13th Stage HP Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−9.0	Wing Lower	4" x 2"	Penetration of Fuel Tank	Fuel Leak and Fire
2	Disk Fragment	3"x17"	n/a	13th Stg		−5.0	Wing Lower	5" x 4.5"	Penetration of Wing Lower Skin	None noted

NARRATIVE: **A 13th stage HPC disk fragment (Fragment 2) fractured during the takeoff roll at 80 Knots due to high cycle fatigue. Multiple blades and vanes were released along with the disk fragment or fragments. Fragment 1 penetrated the fuel tank, allowing fuel to leak and ignite. This fragment, a relatively small piece, may have been part of the 13th stage HPC, or it may have been a piece of the casing (which exploded due to overpressure) –– the origin is uncertain. The fire was almost certainly ignited by fuel dripping onto the hot engine, and was apparently immediate. Multiple other fragments followed the same general trajectory as Fragment 2, but did not have sufficient energy to penetrate the lower wing skin. These pieces are also of uncertain origin, similar to Fragment 2. Most of these pieces were found on the runwaye. The total number of these pieces has not been specified, but it is clear that most of these did not contact the aircraft. Fire destroyed the aircraft.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

34.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Taxi**
Flight Effect: **n/a**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **n/a**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **7th Stage Compressor**

SECONDARY MALFUNCTION (Rotor Stages): **8th through 13th Stages Compressor**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Disk Segment	40% of Disk	Unk	7th Stg		−4.0	BSTA 624, WBL 172 (Wing Lower)	1.5" x 1.5"	Penetration of Fuel Tank	Fuel Leak and Fire

NARRATIVE: **During taxi, #2 engine 7th stage compressor disintegrated. A 170° segment of the disk (Fragment 1) departed. A fragment penetrated the fuel tank in the plane of the 7th stage, resulting in almost immediate fuel fire. The resulting fire consumed the aircraft, incurring fatalities. Multiple other fragments were released from the 7th stage, peppering the lower wing skin inboard of the #2 engine. These fragments apparently did not penetrate in any location. 7th stage vane fragments also contributed to these dents and scratches. The 8th through 10th stages liberated multiple blade and vane fragments, also contributing to the lower wing skin damage. The 7−8 stage spacer was also released, apparently without making contact with the aircraft. A large hole approximately 12" in diameter was found in the fuselage at BSTA 937, RBL 12. Thorough investigation of this area did not yield evidence that an engine part caused this hole, however. (The trajectory from the disintegration plane of the #2 engine has been calculated to be 58.5 degrees aft for this location. Due to the uncertainty of its origin, this hole was intentionally omitted from trajectory analysis results.)**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Available in Files**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer disputes the data shown above. They note that the disk fragment which penetrated the fuel tank was not 40% of the disk, but measured approximately 6"x2" and weighed about 1/2 lb. Estimated velocity was 500 ft/sec. It is noted that multiple fragments were released due to the disintegration of the compressor. The engine manufacturer contends that this disintegration was the result of a missile which apparently was fired at the aircraft. This missile passed through the engine causing the disintegration, and impacted the aircraft fuselage 58.5° aft of the compressor 7th stage plane of rotation leaving a large hole (note Narrative).**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

35.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **2**

PRIMARY MALFUNCTION (Rotor Stages): **Fan Blade Fracture**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)
1	Unknown					−29.0	Incomplete data	1.5" x 1"	Incomplete data	Incomplete data
2	Unknown					−28.0	Incomplete data	4" x 3"	Incomplete data	Incomplete data
3	Unknown					−28.0	Incomplete data	0.5" x 0.5"	Incomplete data	Incomplete data

DATA FOR THIS EVENT WAS TAKEN FROM A PREVIOUS STUDY. ONLY FINAL TRAJECTORY RESULTS WERE AVAILABLE, SO INFORMATION IS SKETCHY.

NARRATIVE: **INSUFFICIENT INFORMATION**

SOURCE (*Data obtained from*): **Disk Release Trajectory Study, S. Knife, 1991**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that the three fragments shown measured approximately 1/2 lb. each. No dimensions were given. Estimated velocities were in the range of 500 ft/sec. (Information remains somewhat sketchy.)**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

36.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **FL310**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **3**

PRIMARY MALFUNCTION (Rotor Stages): **7th Stage Air Cooling Duct**

SECONDARY MALFUNCTION (Rotor Stages): **1st Stage LPT Disk Disintegration due to Creep Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					-55.0	Vert. Stabilizer	2" x 1"	Stabilizer Penetration	None noted
2	Unknown					-47.0	Rear Cargo Dr	2" x 2"	Tear in lower part of cargo door	None noted
3	Unknown					-44.5	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
4	Unknown					-43.5	Fuselage (Low)	3" x 2"	Fuselage Penetration	None noted
5	Unknown					-31.0	Fuselage (Mid)	7" x 2"	Fuselage Tear	None noted
8	LPT Case Frag					-21.0	Flap (Rt Outbd)	1" x 1"	Flap skin penetration	None noted
7	Unknown					-20.0	Flap	2" x 1"	Flap skin penetration	None noted
10	Unknown					-17.0	Wing-to-Body	1.5" x 1"	Fairing Penetration	None noted
11	Unknown					-16.0	Wing-to-Body	0.5" x 0.5"	Fairing Penetration	None noted
12	Unknown					-15.0	Fuselage (Low)	0.5" x 0.5"	Fuselage Penetration	None noted
13	Unknown					-14.5	Wing-to-Body	3" x 2"	Fairing Penetration	None noted
14	Unknown					-13.0	Fuselage (Low)	2" x 2"	Fuselage Penetration	None noted
16	Disk Fragment		20% Dsk	LPT1	*See GE update	3.0	Wing	8" x 2"	Wing fuel tank penetration (all the way thru the wing)	Fuel Leak – no fire noted

NARRATIVE: **The aircraft experienced a loud noise on the #4 engine during climb, followed by a drop in all #4 engine parameters. Engine was shutdown. Crew observed a hole in the upper right hand wing between #3 and #4 engines and elected to return. There was no fire warning. Multiple small engine fragments penetrated the fuselage aft of the wing as noted. One fragment (fragment 1) penetrated the vertical stabilizer. Several small fragments impacted the wing and penetrated a fuel tank access panel and fairings between the #3 and the #4 engines. Two major pieces of disk were ejected. One piece (fragment 15) did not hit the aircraft after exiting the core cowl in a downward direction. Another piece (fragment 16) passed entirely through the wing, leaving a 2"x8" hole in the bottom of the wing (plus a 3" crack from the hole) and a much larger 50"x19" hole in the top of the wing. Other fragments caused dents and scratches without penetrating the aircraft structure. The cause of the incident was attributed to failure of the 7th stage air cooling duct which went undetected by the operator during letter check, consequent loss of cooling air to the LPT rotor forward cavity and eventual creep rupture of the LPT Stage 1 disk. Fragments 8, 9, and 15 are being excluded since these fragments did not impact the aircraft after being ejected from the engine.**

SOURCE (*Data obtained from*): **GPS Database Files – CRASH.RBF; Boeing Air Safety Files; Engine manufacturer letter to Boeing dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer information has been integrated into the data. Estimated velocity of fragment 16 was 781 ft/sec. at blade tips and 574 ft/sec. at disk rim. The engine manufacturer indicates that fragment 15 (not included) left a hole 8"x35" in the core cowl, but did not impact the aircraft.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

37.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **124 Knots**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **Combustor Explosion (No Rotor Failure noted)**

SECONDARY MALFUNCTION (Rotor Stages): **Case Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Combustor Case Fragment			Case		−70.0	Wing TE Devices	1" x 1"	Small Penetration in wing trailing edge device	None noted
2	Dome Section of Combustor Can	7" x 8"		Combstr		−66.5	Fuel Tank Access Door	8" x 7"	Penetration of Fuel Tank Access Door (by both Fragment 2 and fragment 2A)	Fuel Leak and Fire (caused by impact of both Fragment 2 and Fragment 2A, most likely simultaneously)
2A	Combustor Case Fragment	4" x 5"		Case		−66.5	Fuel Tank Access Door	(See narrative)	Same as above – contact was almost simultaneous	See fragment 2
3	Combustor Case Fragment			Case		−51.0	Wing Lower	0.5" x 0.5"	Wing lower skin penetration	None noted
4	Combustor Case Fragment			Case		−37.5	Wing Lower	2" x 1"	Wing lower skin penetration	None noted
5	Combustor Case Fragment			Case		−30.0	Wing Lower	1.5" x 1"	Wing lower skin penetration	None noted

NARRATIVE: **The #1 engine combustor case exploded during the takeoff roll due to the fracture of the #9 combustor can. The combustor case shattered into multiple pieces. One small piece about 4"x5" (Fragment 2A) was carried or ejected along the same trajectory as the combustor can dome section (Fragment 2). Metallurgical analysis shows that both Fragment 2 and Fragment 2A penetrated the fuel tank access panel, probably almost simultaneously. This impact created a hole approximately 42 square inches in size, from which fuel leaked onto the hot engine and ignited almost immediately. Fire consumed the aircraft aft sections and resulted in fatalities. Fragments 3, 4, and 5 made smaller holes in the bottom of the wing, but apparently did not cause fuel leak. Fragment 1 impacted the trailing edge flaps and left a small hole. Multiple small pieces were found in the area of the event. However, no significant information was given concerning these pieces. A section of the can was blown downward and outward, striking the inner surface of the fan case as it exited. There is no evidence as to whether this piece contacted the aircraft, and it has not been incorporated into the trajectory results. The engine cowling had broken into several pieces as a result of the multiple impact locations of debris on the inside of it.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that fragment 2 weighed about 1 lb. and fragment 2A weighed about 1/2 lb. Estimated velocity of fragment 2 was 100 ft/sec., while estimated velocity of fragment 2A was 200 ft/sec. The engine manufacturer also contends that fragment 2A did not contact the fuel tank access door, and disputes portions of the narrative.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

38.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage Fan Blade**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−33.0	Wing Lower	0.5" x 0.5"	Wing lower skin penetration	None noted
2	Unknown					16.0	Wing Lower	0.5" x 0.25"	Wing lower skin penetration	None noted

NARRATIVE: **The aircraft experienced a disintegration of the fan section during cruise and diverted. The 1st stage fan shed multiple blade fragments, many of which were contained. Several pieces exited the nacelle, but most did not contact the aircraft. Fragments 1 and 2 hit the underside of the wing and left very small holes, but no system damage was noted. Multiple pieces hit the wing lower skin in many locations, but the energy of these pieces was quite low, and none left more than minor scratches or dents. The engine was substantially damaged, with damage to fan rub strip, outlet guide vanes, reverser cowl, and side cowl. The engine nose cowl was punctured, but no firm evidence was noted as to the location at which this penetration occurred. No other aircraft damage was noted.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that this event in their records is NOT a non−contained disintegration. Indications of fragments released aft (through the fan discharge area) and forward (out the inlet) are given, but the engine manufacturer does not believe any pieces passed through the engine containment structure.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL370**
Airspeed: **270 KIAS**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					−26·0	RH Inbd Elevator	1" x 1"	Small penetration in inboard elevator trailing edge	None noted
2	Unknown					−24.0	RH Inbd Elevator	1" x 0.5"	Small penetration in inboard elevator trailing edge	None noted
3	Unknown					−16.0	RH Inbd Elevator	5" x 3"	Penetration in inboard elevator (outbd portion)	Ground Impact Damage
4	Unknown					−28.0	RH Outbd Elevator	1" x 0.75"	Cut in outboard elevator (inbd portion)	Ground Impact Damage
5	Fan Shaft Nut					−9.0	RH Stabilizer Outbd Fwd	4" x 1.5"	Cut in stabilizer upper skin (outbd area)	Fan Shaft Nut found in hole
6	Unknown					−20.0	LH Outbd Elevator	17" x 2"	Cut in outboard elevator (inbd portion)	Ground Impact Damage
7	Unknown					−9·0	LH Stabilizer Outbd	4.5" x 1"	Penetration in stabilizer upper skin (outbd area)	None noted
8	Inlet Guide Vane					−11.0	LH Stabilizer Outbd	12" x 3"	Cut in stabilizer upper skin (outbd area)	Vane found in hole
9	Unknown					−7.0	LH Stabilizer Center	15" x 2"	Penetration in stabilizer upper skin (center area)	None noted
10	Unknown					−7.0	LH Stabilizer Center	3" x 2"	Cut in stabilizer upper skin (center area)	Probably ground impact damage
11	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Penetration in stabilizer leading edge (outbd)	None noted
11A	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Small hole next to hole #11 – possible secondary damage	None noted
11B	Unknown					−2.0	LH Stabilizer Center Fwd	2" x 1"	Small hole next to hole #11 – possible secondary damage	None noted
12	Unknown					−16.0	LH Stabilizer Outbd Aft	0.5" x 0.5"	Penetration in stabilizer upper skin (outbd area)	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
13	Unknown					−18.0	LH Outbd Elevator Center	5" x 2"	Cut with 8" tear propagating from it in stabilizer at outbd elevator hinge point (center)	Ground Impact Damage
14	Unknown					−11.0	LH Stabilizer upper center	7" x 1"	Cut in LH stabilizer upper skin center area, no penetration	Probably Ground Impact Damge
15	Unknown					−10.0	LH Stabilizer upper center	4" x 3"	Skin piece gone from LH stabilizer upper skin center area	None noted
16	Unknown					−3.0	LH Stabilizer upper center	4" x 1"	Cut in LH stabilizer upper skin center area	Probably Ground Impact Damage
17	Unknown					−4.0	LH Stabilizer upper center	3" x 2"	Hole in LH stabilizer upper skin center area	None noted
18	Unknown					−1.0	LH Stabilizer upper center	13" x 6"	Large hole in LH stabilizer upper skin center area	None noted
19	Fan Blade Fragment					4.0	LH Stabilizer upper center	12" x 4"	Hole in LH stabilizer upper skin center area	Fragment found in hole
20	Fan Blade Fragment					1.0	LH Stabilizer upper center	6" x 2"	Small hole in LH stabilizer upper skin center forward area	Fragment found in hole
21	Unknown					1.0	LH Stabilizer upper center	4" x 2"	Small hole in LH stabilizer upper skin center forward area	None noted
22	Unknown					−1.0	LH Stabilizer upper center	1" x 0.5"	Small hole in LH stabilizer upper skin center area	Ground Impact Damage
22A	Unknown					−3.0	LH Stabilizer upper center	0.5" x 0.5"	Small hole in LH stabilizer upper skin center area	Ground Impact Damage
23	Fan Blade Fragment					0.0	RH Elevator upper inbd	18" x 18"	Large hole in RH inboard elevator (close to fuselage)	Fragment found in hole
24	Unknown					−6.0	RH elevator	3" x 1"	Cut in RH inboard elevator	None noted
25	Unknown					15.0	RH Stabilizer inbd forward	5" x 2"	Hole in RH stabilizer upper skin; #3 hydraulic systems in RH stabilizer severed	All hydraulic fluid lost from #3 hydraulic system
26	Unknown					13.0	RH Stabilizer inbd forward	25" x 1"	Cut in RH stabilizer inbd – close to hydraulics damage	None noted
27	Unknown					12.0	RH Stabilizer inbd forward	5" x 1"	Cut in RH stabilizer upper skin inbd forward area	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.

† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.3 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
28	Unknown					13.0	RH Stabilizer inbd center	4" x 0.5"	Cut in RH stabilizer inbd center	Ground Impact Damage
29	Unknown					13.0	RH Stabilizer inbd forward	5.0" x 2.5"	Tear in RH stabilizer inbd center	None noted
30	Unknown					9.0	RH Stabilizer inbd forward	11" x 5"	Large hole in RH stabilizer inbd center near hydraulic damage	None noted
31	Unknown					9.0	RH Stabilizer inbd forward	10" x 9"	Hole in RH stabilizer inbd center, close to fuselage	None noted
32	Unknown					−12.0	RH Stabilizer extreme outbd forward	3" x 3"	Hole in extreme outbd end of RH stabilizer – forward	Ground Impact Damage
33	Unknown					−8.0	RH Stabilizer outbd forward	1" x 0.25"	Crack and puncture hole in RH stabilizer outbd forward	None noted
34	Unknown					−8.0	RH Stabilizer outbd center	4" x 1.5"	Hole in RH stabilizer outbd center	None noted
35	Unknown					5.0	RH Stabilizer inbd forward	6" x 3"	Hole in RH stabilizer inbd forward	None noted
36	Unknown					−10.0	RH Stabilizer outbd center	0.5" x 0.5"	Cut in RH stabilizer outbd center, upper surface	None noted
37	Unknown					−15.0	RH Stabilizer outbd center	2" x 0.5"	Hole in RH stabilizer outbd center	Ground Impact Damage
38	Unknown					−22.0	RH outbd elevator center	1.5" x 0.75"	Hole in RH stabilizer outbd center	None noted
39	Unknown					−19.0	RH outbd elevator center	1" x 1"	Score in RH stabilizer outbd center surface	None noted
40	Unknown					−20.0	RH outbd elevator center	2" x 1"	Dent in RH stabilizer outbd center	None noted
41	Unknown					−16.0	RH outbd elevator forward	3" x 0.5"	Hole in RH outbd elevator surface forward portion	None noted
42	Unknown					Unk	RH inbd elevator forward	3" x 2"	Hole in RH inbd elevator forward portion	None noted
43	Unknown					Unk	RH inbd elevator forward	5" x 3.5"	Hole in RH inbd elevator forward portion	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.4 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
44	Unknown					Unk	RH inbd elevator center	1" x 0.75"	Hole in RH inbd elevator top surface	None noted
45	Unknown					Unk	RH inbd elevator center	1.5" x 0.25"	Cut in RH inbd elevator bottom surface	None noted
46	Unknown					Unk	RH inbd elevator center	0.5" x 0.25"	Hole in RH inbd elevator top surface	None noted
47	Unknown					Unk	RH inbd elevator center	0.25" x 0.25"	Hole in RH inbd elevator	None noted
48	Unknown					Unk	RH inbd elevator center	2" x 1"	Hole in RH inbd elevator	None noted
49	Unknown					−22.0	LH inbd elevator aft outer edge	9" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
50	Unknown					−15.0	LH inbd elevator outer edge	2" x 0.5"	Hole in LH inbd elevator top surface	None noted
51	Unknown					−9.0	LH Stabilizer center	4" x 0.5"	Cut in LH stabilizer	Ground Impact Damage
52	Unknown					−24.0	LH inbd elevator aft center	0.5" x 0.5"	Hole in LH inbd elevator top surface	None noted
53	Unknown					−21.0	LH inbd elevator aft center	4.5" x 3"	Hole in LH inbd elevator top surface	Ground Impact Damage
54	Unknown					−17.0	LH inbd elevator outer	0.75" x 0.5"	Hole in LH inbd elevator top surface	None noted
55	Unknown					−15.0	LH inbd elevator outer	4" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
56	Unknown					−22.0	LH inbd elevator aft center	1.5" x 1"	Hole in LH inbd elevator	None noted
57	Unknown					−18.0	LH inbd elevator center	3" x 0.5"	Cut in LH inbd elevator top surface	None noted
58	Unknown					−24.0	LH inbd elevator aft center	4" x 0.5"	Cut in LH inbd elevator	Ground Impact Damage
59	Unknown					−11.0	LH inbd elevator center	21" x 0.5"	Cut in LH inbd elevator top surface	Ground Impact Damage

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.5 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
60	Fan Blade Fragment					−3.0	LH Stabilizer center	14" x 10"	Hole in LH stabilizer top Surface	Midspan shroud found in cavity
61	Unknown					−15.0	LH inbd elevator inner	0.5" x 0.5"	Cut in LH inbd elevator top surface	None noted
62	Unknown					−6.0	LH inbd elevator inner	4" x 4"	Dent in LH inbd elevator	Believed to be ground impact damage
63	Unknown					0.0	LH inbd elevator inner forward	4.5" x 1.5"	Hole in LH inbd elevator	Ground impact damage
64	Unknown					−13.0	LH inbd elevator inner	2.5" x 1"	Cut in LH inbd elevator top surface	Ground impact damage
65	Unknown					−6.0	LH inbd elevator inner	4.5" x 0.5"	Cut in LH inbd elevator top surface	None noted
66	Unknown					−9.0	LH inbd elevator inner	2" x 2"	Cut in LH inbd elevator top surface	None noted
67	Unknown					4.0	LH inbd elevator inner forward	0.5" x 0.5"	Hole in LH inbd elevator top surface	None noted
68	Unknown					−9.0	LH inbd elevator outer forward	2.5" x 2.5"	Hole in LH inbd elevator	None noted
69	Disk Fragment					2.0	RH Stabilizer center	19" x 15" (est.)	Irregular hole in RH stabilizer just forward of the inbd elevator	Probable location of damage to Hydraulic system #1
70	Disk Fragment					−2.0	RH Stabilizer Leading Edge Outer end	32" x 16" (est.)	Hole in RH stabilizer leading edge about 3/4 of the way from fuselage to end	None noted
71	Unknown					2.0	RH Stabilizer Center	2" x 1"	Hole in RH stabilizer top surfacr	None noted
72	Unknown					0.0	RH Stabilizer Center	2" x 1"	Hole in RH stabilizer top surface	None noted
73	Unknown					6.0	RH Stabilizer Center	2" x 2"	Hole in RH stabilizer top surface	None noted
74	Unknown					5.0	RH Stabilizer Center	2" x 2"	Cut in RH stabilizer top surface	None noted
75	Unknown					3.0	LH Stabilizer center	3" x 1"	Cut in LH stabilizer top surface	None noted

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

39.6 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **Fan / Fan Disk**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
90	Unknown					−7.0	RH Stabilizer Center	2" x 2"	Hole in RH stabilizer top surface	None noted
91	Stage 2 Booster Blade					−12.0	RH Stabilizer Center	7" x 0.5"	Hole in RH stabilizer top surface	Blade found in hole
92	Disk Fragment					−3.0	RH Inbd Elevator Center	11" x 5" (est.)	Large Hole in RH inbd elevator	None noted
93	Unknown					−7.0	RH Inbd Elevator Inner	9.5" x 3.5"	Hole in RH inbd elevator	None noted
94	Fan Blade Fragment					0.0	RH Inbd Elevator Inner Forward	4" x 0.5"	Cut in RH inbd elevator top surface	Fragment found in hole

NARRATIVE: **The aircraft experienced a #2 engine fan disk failure. Multiple fragments impacted the stabilizer, leading to the loss of all three hydraulic systems that powered the flight controls. The crew declared an emergency and diverted the aircraft. Without flight controls the aircraft was controllable only to a limited degree by the use of asymmetric thrust from the wing mounted engines. Control difficulties caused the aircraft to crash upon landing, resulting in breakup of the airframe, with associated fire and multiple fatalities.**

Three large holes due to fragments were deduced to exist in the RH stabilizer (Ground Impact damage obscured many details). One hole (caused by fragment 70) was in the outboard leading edge. A second hole (caused by fragment 69) was found forward of the inboard elevator. A third large hole (caused by fragment 92) was found in the inboard elevator. Multiple holes were noted in both left and right hand stabilizer surfaces. Detailed investigation revealed that the damage caused by fragment 25 resulted in the loss of hydraulic fluid in hydraulic system 3. Hydraulic system 1 sustained damage from other fragments which led to loss of fluid in that system. Hydraulic system 2 was damaged as the fan containment ring struck the accessory gearbox and hydraulic pumps during the disk separation. None of the fragments which damaged the left hand stabilizer appeared to cause any system damage, although multiple shrapnel holes were noted. Investigators noted that the disintegration of the disk resulted in liberation of shrapnel−type debris with a trajectory pattern that exceeded the level of protection provided by design features on the aircraft.

SOURCE *(Data obtained from)*: **Boeing Air Safety Files; NTSB Accident Report; Engine manufacturer letter to Boeing dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos available**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer information concerning this event has been integrated into the record for this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

40.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort**

Power Level: **Unknown**
Altitude: **Ground**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage Compressor Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Insufficient Information**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					3.0	Fuselage (Mid)	2" x 1.25"	Fuselage Penetration	None noted
2	Unknown					1.5	Fuselage (Mid)	8" x 1"	Fuselage Penetration	None noted
3	Unknown					0.0	Fuselage (Mid)	16" x 6.5"	Fuselage Penetration	Fuel fire from severed fuel feed line

NARRATIVE: **The aircraft experienced a #3 engine fire warning during takeoff roll and crew aborted. The aircraft was brought to a stop successfully. The 9th stage compressor disk rim had separated over the entire circumference, with most of the debris exiting the engine case at about 8:00 position. Fragments penetrated the fuselage just ahead of the aft pressure bulkhead. The fuel feed line to the #3 engine was severed by exiting debris, but it is impossible to determine which fragment severed the line. Fuel fire was almost immediate, and due to conditions was quickly transferred into the cargo compartment. The aircraft was a complete hull loss. Investigators determined that crack progression from a blade root corrosion pit was the cause of the disintegration.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer indicates that the three fragments shown were all about the same size, measuring 6"x1" and weighing about 1/2 lb. The estimated velocities were approximately 700 ft/sec. No further information was given.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

41.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **1000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage LP Turbine Disk**

SECONDARY MALFUNCTION (Rotor Stages): **Cut Drive Arm / OS**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	Unknown					−70.5	Vert Stabilizer FSTA 220	5" x 3"	Vertical Stabilizer penetration	None noted
2	Unknown					−38.0	BSTA 1374.4	8" x 8"	Puncture of wing landing gear door	None noted
3	Unknown					−36.0	ILES 620.0	1.5" x 1.5"	Hole in wing leading edge flaps	None noted
4	Unknown					−25.5	ILES 626.0	16" x 11"	Tear in wing leading edge skin	None noted
5	Disk Fragment					−7.0	ILES 602.6	40" x 24"	Large hole completely through wing leading edge	Electrical wiring, pneumatic tubing severed

NARRATIVE: **The aircraft experienced a #2 engine disintegration. The uncontained fragments from the #2 engine were ejected in multiple directions. Some debris passed through the engine and was ejected aft, resulting in secondary damage to other engine sections. A large fragment of the disk (fragment 5) was released inboard of the #2 engine, passing completely through the wing leading edge. This fragment severed electrical wiring and pneumatic ducts. One fragment (fragment 1) penetrated the vertical stabilizer. A significant hole was found in the landing gear door, caused by fragment 2. Multiple dents and scratches associated with the uncontained disintegration were noted in file material. Some debris also was noted to have caused FOD in the #1 engine, although the extent of this damage is not specified.**

SOURCE *(Data obtained from)*: **Boeing Air Safety Files; C/S PROP−BN37B−C92−104**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

42.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **16,000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **Oil Leak from cracked #4 bearing pressure tube**

SECONDARY MALFUNCTION (Rotor Stages): **6th Stage LPT Disk Rupture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					+3.0	Wing LE Flap	1"x1"	Leading Edge Flap penetration	None noted
2	Unknown					−29.0	Main Landing Gear Door	2"x2"	Landing Gear Door Penetration	None noted
3	Unknown					−33.0	Inboard Canoe Fairing	3"x1"	Canoe Fairing penetration	None noted
4	Unknown					−39.0	Inboard Canoe Fairing	8"x2"	Canoe Fairing penetration and ensuing tear	None noted
5	Unknown					−30.0	#1 Engine Inlet	Unknown	Damage to #1 engine fan blades	None noted

NARRATIVE: **The airplane experienced an uncontained failure of the #2 engine during climb while passing through 16,000 feet. The crew shut down the engine and elected to continue to destination. Ground maintenance inspected the engine in the destination city and noted that the 6th stage of the LPT had ruptured, liberating all blades. Several blade fragments had impacted the aircraft, mostly inboard of the #2 engine. Penetrations were found as noted above. Multiple scratches and dents were also found. The number 1 engine had ingested at least one small metal fragment (probably more), causing damage to the #1 engine fan blades. The engine operated without incident into the destination, but the fan blades were all replaced after reaching the destination. An unscheduled stop had been made due to low oil quantity indications in the #2 engine. On the ensuing flight the 6th stage disk ruptured following an oil fire in the area of the turbine exhaust case and the #3 bearing. It was found that oil had leaked from a cracked #4 bearing pressure tube and filled the triangular compartment in the exhaust case. This oil then spilled forward into the space between the exhaust case and the LP turbine case, and auto ignition occurred.**

SOURCE *(Data obtained from)*: **Boeing Customer Service Telexes, Engine manufacturer reports**
DRAWINGS/PICTURES IDENTIFICATIONS: **photocopies of pictures available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

43.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb (TOC)**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **Unknown**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **6th Stage HPC Air Seal Rupture**

SECONDARY MALFUNCTION (Rotor Stages): **5th, 6th Stage HPC Blades Fractured, Vanes Damaged**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*

NARRATIVE: **There are no indications that any uncontained fragments impacted the aircraft structure. The aircraft did not sustain any noticeable damage. Some of the blade fragments were contained, but a number of pieces were not found inside the engine. The engine case and cowling sustained some damage, but specific details are unknown.**

SOURCE *(Data obtained from)*: **Boeing Customer Service Telexes**
DRAWINGS/PICTURES IDENTIFICATIONS: **Not available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

44.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **8000 ft**
Airspeed: **Unknown**
Hazard Level (*see Definitions*): **2**

PRIMARY MALFUNCTION (Rotor Stages): **5th Stage LPT Disk Rim Separation**

SECONDARY MALFUNCTION (Rotor Stages): **5th Stage LPT Blades Fractured**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (*Note Pictures*)	Hole Size (*Dimensions*)	Damage Description (*e.g., Penetration, Tear, Dent, Scratch, etc.*)	Effect on System(s) (*e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.*)

NARRATIVE: **The LPT disk rim separated during climb. No significant impact damage was noted on the aircraft structure. All damage was limited to the engine and the engine case/cowl.**

SOURCE (*Data obtained from*): **Boeing Customer Service Telexes**
DRAWINGS/PICTURES IDENTIFICATIONS: **Not available**

ENGINE MANUFACTURER'S UPDATE: **The engine manufacturer has not provided any additional information concerning this event.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

45.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Air Turn Back**

Power Level: **Unknown**
Altitude: **7000 ft**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **9th Stage HPC Disk Fracture due to Material Defect (Hard Alpha)**

SECONDARY MALFUNCTION (Rotor Stages): **Low Cycle Fatigue**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Unknown					0.0	Wing LE	1"x0.125"	Hole in Wing leading edge	None noted
2	Unknown					−3.0	Flap Track Canoe Fairing	1"x0.5"	Hole in Flap Track Fairing just fwd of flap. (Large gouge near)	None noted
3	Unknown					+4.0	Wing−to−Body Fairing	0.75"x0.5"	Small hole in wing−to−body fairing, just fwd and below cargo lamp	None noted
4	Unknown					−26.5	Fuselage (over Emerg Exit R5)	0.35"x0.35"	Hole 2 ft above emergency exit door R5	None noted
5	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted
6	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted
7	Unknown					−44.5	Vert. Stabilizer (3−4 ft above fuselage)	1"x0.5"	Hole in side of Vertical Stabilizer	None noted

NARRATIVE: **During climb the aircraft experienced a failure of the #4 engine. The flight returned without further incident. Ground inspection revealed that the 9th stage disk of the HP compressor had fractured, resulting in small shrapnel damage to the aircraft wing and empennage. Small debris impacted the aircraft in multiple locations, but indications are that most fragments did not penetrate. Gouges and scratches were found on the underside of the wing, the wing−to−fuselage fairing, and on the empennage. Seven holes were noted (see above). Thorough detailed inspection of recovered fragments showed the presence of a hard alpha defect in the 9th stage disk, causing the fracture.**

SOURCE *(Data obtained from)*: **Boeing Uncontained Event Reports, Engine manufacturer detailed event reports**
DRAWINGS/PICTURES IDENTIFICATIONS: **photocopies of pictures available**

ENGINE MANUFACTURER'S UPDATE: **The detail of this event in Boeing records is quite sketchy. Most of the specific information concerning fragments was gathered from engine manufacturer information. The updated information was added to the Uncontained Event database after analysis of the engine manufacturer material.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

46.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Climb**
Flight Effect: **Diversion**

Power Level: **102.5% N_2**
Altitude: **FL215**
Airspeed: **305 Kts**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **1st Stage HPT Disk Fracture due to Arc Weld Burn – Bore Face**

SECONDARY MALFUNCTION (Rotor Stages): **Stage 2 HPT Disk release, probable fracture**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1				HPT		−3.5	#1 Eng Cowl	0.5"x0.5"	Penetration of cowl	None noted
2						−3.5	#1 Eng Cowl	1"x1"	Penetration of cowl	None noted
3						−3.5	#1 Eng Nozzle	0.5"x0.5"	Hole in #1 Engine Tailpipe	None noted
4						−3.5	#1 Eng Nozzle	0.5"x0.5"	Hole in #1 Engine Tailpipe	None noted
5						−2.0	#1 Eng T/R Cowl	0.5"x0.5"	Hole in #1 Engine Thrust Reverser Cowl	None noted
6						+1.0	WSTA 255	1"x0.5"	Hole in Lower Wing Skin	Fuel Leak – No fire
7						−3.0	WSTA 344	1"x0.5"	Hole in Lower Wing Dry Bay Access Door	None noted
8						+4.5	Lower Anti−collision light lens	.125"x.125"	Small Hole in Red light lens	None noted
9						0.0	Fuselage	2"x1"	Hole in Fuselage below wing TE	None noted
10						−11.0	Fuselage	2"x2"	Hole in lower Fuselage (A/C bay)	Air Conditioning system ducting penetrated
11						−6.5	Aft Flap Actuator	1"x1"	Hole in Aft Flap Actuator housing	None noted

NARRATIVE: **During climb the crew heard a loud noise which lasted approximately four seconds. The noise was immediately followed by a thrust reverser in transit indication and momentary fire warning indication on the right hand engine. The engine was shut down and the flight diverted. The landing was without incident. During taxi to the parking area, the local tower advised the crew that fuel was leaking from the right wing. There was no fire and no injuries. Investigation revealed that the HPT 1 disk had fractured, causing the release of the HPT 2. The fan midshaft was fractured in the HPT 1 plane. Some sections of the departed stages were later located and returned to the engine manufacturer, but the majority of the HPT 2 was not recovered.**

SOURCE *(Data obtained from)*: **Boeing Uncontained Files; Engine manufacturer Incident Report; C.A. Oncina Trip – Investigation Notes; engine manufacturer letter dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Photos of Incident contained in Engine manufacturer's Report; Numerous photos available from C.A. Oncina trip**

ENGINE MANUFACTURER'S UPDATE: **Engine manufacturer indicates that there were approximately 300 dings, scratches and holes in the aircraft. Most of these were considered superficial, and only about 10 fragments actually penetrated the aircraft structure. The largest of these was a 2" square hole in the flap fairing which also punctured the air conditioning system ducting (Hole 10). The fuel leak was from a hole measuring 1"x0.5" (hole 6).**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

47.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **T/O Power (1.35 EPR)**
Altitude: **Ground**
Airspeed: **45 Kts**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **6th Stage Disk of Intermediate Compressor Stage 6–7 Rotor Shaft Assembly Rupture**

SECONDARY MALFUNCTION (Rotor Stages): **None**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description *(e.g., Penetration, Tear, Dent, Scratch, etc.)*	Effect on System(s) *(e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)*
1	70° arc of 6th stage disk	15" chord, 5" rad	~ 9 lb	6th Stg Comp.	590 fps	0.0	#3 eng cowl impact, no a/p impact	12" x 10" in #3 Cowl	Hole in #3 engine cowl, superficial unspecified damage to a/p	No effect on a/p systems
2	57° arc of 6th stage disk	10" chord, 5" rad.	~ 8 lb.	6th Stg Comp.	590 fps	0.0	#1 Eng	12" x 8" in #3 Cowl, 12" x 2" in #1 eng	Hole in #3 cowl. Fragment penetrated #1 engine nacelle and entered HP compressor	Fuel leak from severed LP Fuel Pipe (at #3 engine fragment exit location) – #3 eng fire warning, #1 engine thrust loss from damaged turbine blades

NARRATIVE: **Early in the takeoff roll, just as full power was reached, the 6th Stage disk in the #3 engine ruptured. The main fuel line to the engine was severed and fuel fire ensued. A disk segment from the #3 engine (fragment 2) penetrated the #1 engine HPT case, destroying the first stage turbine blades and causing loss of thrust from the #1 engine. (Fragment 1 did not impact the aircraft except at the #3 engine cowl.) The aircraft was stopped and airport fire personnel extinguished the fire. Preliminary inspection showed at least six radial fractures through the bolt holes used for securing the stage 6–7 rotor shaft assembly to the stage 5 disk. There was evidence of pre–existing fatigue cracks originating from corrosion pitting.**

SOURCE *(Data obtained from)*: **Boeing Field Report; Air Safety Week magazine, Engine manufacturer data**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information was received from the engine manufacturer in August 1994, including fragment description, piece sizes, masses, velocities, and trajectories as shown in table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

48.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **109%**
Altitude: **Ground**
Airspeed: **123 Kts**
Hazard Level *(see Definitions)*: **2**

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disks Released from Stages 1 & 2**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Turb Bld Frag	1"x0.5"				+3.0	Fuselage (Low)	1.25"x 1"	Puncture in lower fuselage A/C pack bay	Air Cond. system damage
2	Bld Frag	Unk				+7.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
3	Bld Frag					+5.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
4	Bld Frag					+4.0	Fuselage (Low)	1"x1"	Puncture in fwd left side of lower fuselage A/C pack air intake	Air Cond. system damage
5	Bld Frag					0.0	#2 Eng Cowl	2"x1"	Pncture in RH Eng transcowl, no passthrough	None
6	Bld Frag					+4.0	#2 Eng Cowl Door	2"x2"	Puncture in RH Eng cowl door	None
7	Bld Frag					0.0	#1 Eng Pylon	1"x1"	Pylon spar penetrated on LH side	None
8	Bld Frag					−60.0	Wing LE	0.25"x0.25"	Wing Leading Edge slat damage outbd of pylon	None
9	Bld Frag					−60.0	Wing LE	0.25"x0.25"	Wing Leading Edge slat damage outbd of pylon	None
10	Bld Frag					−60.0	Wing L Inbd Flap Fairing	0.5"x0.5"	Puncture in LH Inbd Flap Actuator fairing	None
11	Bld Frag					−60.0	Wing L Inbd Flap Fairing	0.5"x0.5"	Puncture in LH Inbd Flap Actuator fairing	None
12	Bld Frag					−60.0	Wing L #4 Flap Fairing	0.25"x0.25"	Puncture in LH #4 Flap Actuator fairing	None
13	Bld Frag					−60.0	Wing L #4 Flap Fairing	0.25"x0.25"	Puncture in LH #4 Flap Actuator fairing	None

NARRATIVE: **During the takeoff roll at 123 Kts, the aircraft experienced an uncontained disk rim fragment separation of the HPT1 disk, leading to separation of both HPT disks on the left hand engine. A successful abort was performed. There were no injuries to passengers or crew. Multiple small impacts were found in the fuselage, the #1 engine pylon underside, the wing leading edge, and the right hand engine cowling. Most impacts did not result in airplane penetrations. There was some damage to the air conditioning ducts due to penetrations by four fragments (fragments 1 through 4).**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 11 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

49.1

UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Takeoff**
Flight Effect: **Abort (RTO)**

Power Level: **118% N1**
Altitude: **Ground**
Airspeed: **95 Kts**
Hazard Level *(see Definitions)*: **4**

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disk Released from Stage 1**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	HPT Bld Dovetail	Unk				−21.0	Wing Lower	1"x1"	Fuel Tank punctured	Fuel Leak, Fire
2	HPT Bld Dovetail					−13.0	Wing Lower	4"x1"	Fuel Tank punctured	Fuel Leak, Fire
3	HPT Bld Dovetail					−12.0	Wing Lower	2"x1"	Fuel Tank punctured	Fuel Leak, Fire
4	HPT Bld Dovetail					−13.0	Wing Lower	2.5"x2"	Fuel Tank punctured	Fuel Leak, Fire
5	Unknown					−7.0	Wing Lower	1"x1"	Wing Skin punctured	None noted
6	Nozzle Guide Vane	16" long				−38.0	Wing LE	1"x1"	Electrical wire severed	None noted
7	HPT Bld Frag Support Section					−40.0	Wing LE	1"x1"	Electrical cooling fan motor destroyed	None noted
8	Unknown					−57.0	Wing LE	1"x1"	None	None
9	Unknown					−56.0	Wing LE	1"x1"	None	None
10	6" Disk Rim Segment				Rebound	−11.0	#1 Eng Pylon	6.5"x3"	Penetration of #1 Eng Pylon access door & RH wing flap fairing	None
11	Unknown				Rebound from Runway	−11.0	#1 Eng Pylon	1"x1"	Penetration of #1 Engine Pylon access door	Electrical wires severed
12	Unknown				Rebound from Runway	−10.0	#1 Eng Pylon	1"x1"	Penetration of #1 Eng Pylon access door	None
13	Turb Blade					TBD	Fuselage (Cabin)	0.5"x0.5"	Penetration of fuselage. Fragments found in pax cabin	Pressurized cabin breach
14	Turb Blade				from Runway	TBD	Fuselage (Cabin)	0.5"x0.5"	Penetration of fuselage. Fragments found in pax cabin	Pressurized cabin breach
15	Turb Blade					+14.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
16	Turb Blade					−28.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
17	Turb Blade					−32.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None

(Continued)

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

49.2 UNCONTAINED ENGINE DEBRIS ANALYSIS

PRIMARY MALFUNCTION (Rotor Stages): **HPT Disk Released from Stage 1**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
18	Turb Blade	Unk				−35.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
19	Turb Blade					−40.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None
20	Turb Blade					−40.0	Fuselage (Wheel well)	1"x1"	Penetration of unpressurized area of fuselage	None

NARRATIVE: **(Details for this event are limited.) The #2 engine experienced an uncontained disk rim fragment separation of the HPT1 disk, leading to separation of both HPT disks. The event occurred during takeoff roll at about 95 Kts. Impacts were found in the lower RH wing skin, the fuselage, and the #1 engine pylon due to fragments rebounding from the runway. The passenger cabin was penetrated with two small fragments found in the cabin area following the accident. Some wiring was cut in the LH engine pylon. Several fragments penetrated the lower wing skin into the fuel tank, resulting in a fuel leak which ignited, causing major fire damage to the external surface of the fuselage and wing.**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 18 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **Sketches provided by engine manufacturer**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

50.1 UNCONTAINED ENGINE DEBRIS ANALYSIS

Flight Phase: **Cruise**
Flight Effect: **Diversion**

Power Level: **Unknown**
Altitude: **FL290**
Airspeed: **Unknown**
Hazard Level *(see Definitions)*: **3**

PRIMARY MALFUNCTION (Rotor Stages): **Blade Separation resulting from blue ice ingestion**

SECONDARY MALFUNCTION (Rotor Stages): **None noted**

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* (Note Pictures)	Hole Size (Dimensions)	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)
1	Fan Bld Frag	Unk		Fan		+21.0	Fuselage (Cabin)	1.5"x 1"	Hole in fuselage 2 feet aft of cabin door 2R	None
3	Unknown			Fan		0.0	#1 Fan Cowl	0.5"x0.5"	Puncture of #1 Eng Cowl (no through penetration)	None

NARRATIVE: **Two #2 engine fan blades sustained transverse separations due to blue ice ingestion during cruise. One small fragment impacted the passenger cabin, creating a hole just aft of the 2R door (Fragment 1). Another fragment impacted the #1 engine transcowl, putting a small hole in the outer skin. This fragment (Fragment 3) did not actually penetrate into the #1 engine cowl. Several other fragment impacts were noted from material exiting the engine exhaust.**

SOURCE *(Data obtained from)*: **Boeing Database; Engine manufacturer's report on event; Engine manufacturer's letter dated 18 May 1995**
DRAWINGS/PICTURES IDENTIFICATIONS: **n/a**

ENGINE MANUFACTURER'S UPDATE: **Information received from engine manufacturer, including trajectories, hole sizes, and descriptions have been incorporated into the table.**

* Locations given by pictures, or location in terms of airplane coordinates. Angular location convention is Aft Looking Forward.
† Angle relative to plane of rotor. (Positive angles are FORWARD of plane of rotor; Negative angles are AFT of plane of rotor.)

APPENDIX B

FEDERAL AND INTERNATIONAL REGULATIONS
APPLICABLE TO UNCONTAINED EVENTS

Appendix B – Table of Contents

CODE OF FEDERAL REGULATIONS
Title 14 – Aeronautics and Space
Part 25.903(d)(1)

"(d) *Turbine engine installations.* For turbine engine installations –

(1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case."

ADVISORY CIRCULAR
AC 20–128
09 March 1988

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: DESIGN CONSIDERATIONS FOR MINIMIZING HAZARDS CAUSED BY UNCONTAINED TURBINE ENGINE AND AUXILIARY POWER UNIT ROTOR AND FAN BLADE FAILURES

Date: 3/9/88
Initiated by: ANM-110
AC No: 20-128
Change:

1. PURPOSE. This advisory circular (AC) sets forth a method of compliance with the requirements of §§ 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 (compressor and turbine) failure and engine fan blade failures. 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 SECTIONS. Sections 23.903(b)(1), 25.365(e)(1), 25.571(e)(2), (3), (4), 25.901(d) and 25.903(d)(1) of the FAR.

3. BACKGROUND. Although turbine engine and APU manufacturers are making efforts to reduce the probability of uncontained rotor and fan blade failures, service experience shows that uncontained compressor and turbine rotor and fan blade 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 airplane. Since it is unlikely that uncontained rotor and fan blade failures can be completely eliminated, Parts 23 and 25 require that airplane design precautions be taken to protect the airplane from such events.

a. Uncontained gas turbine engine rotor failure statistics presented in Society of Automotive Engineers (SAE) Reports AIR 1537 and AIR 4003, "Report on Aircraft Engine Containment", cover two study periods, 1962 to 1975, and 1976 to 1983, respectively. During this time period (21 years total) there were 478 incidents of noncontained engine rotor failures reported for 768.2 million engine operating hours on commercial transport airplanes. The failures were due to high cycle fatigue, low cycle fatigue, material and manufacturing defects, rubbing against static parts and foreign object damage (FOD). The major cause of FOD was bird strikes which principally affected the fan sections of the high bypass ratio engines. It is noted that since 1975 the use of this engine type has increased from about 5 percent of the fleet hours to 23 percent of the total hours.

b. The statistics in the SAE studies indicate the existence of many different failure modes not readily apparent or predictable by failure analysis methods. Because of the variety of uncontained rotor and fan blade 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 an airplane from uncontained rotor and fan blade failures. These guidelines, therefore, assume a rotor or fan blade 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. Rotor. Rotors include hubs, discs, rims, drums, seals, and spacers. 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.

b. Blade. Blades include fan, compressor and turbine blades.

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 or blade fragments from the engine 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.

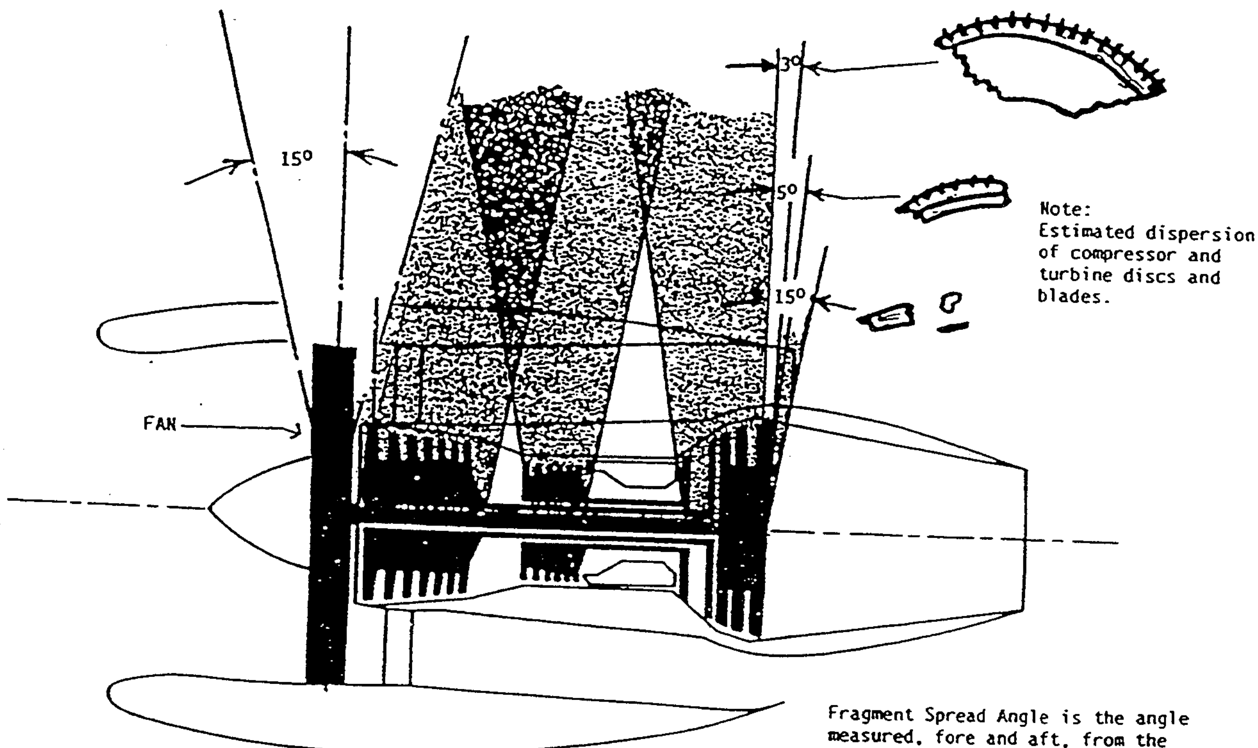
d. Critical Component. A critical component is any component (or system) whose failure would contribute to or cause a failure condition which would prevent the continued safe flight and landing of the airplane. These components should be considered on an individual basis and in relation to other components which could be damaged by the same fragment or by other fragments at the same time.

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, after any failure which has not been shown to be extremely remote.

f. Fragment Spread Angle. The fragment spread angle is the angle measured, fore and aft from the center of the plane of rotation of the disc or fan blade, initiating at the engine or APU shaft centerline. (Refer to Figure 1)

FIGURE 1

ESTIMATED PATH OF FRAGMENTS



Fragment Spread Angle is the angle measured, fore and aft, from the center of the plane of rotation of the disc or fan blade initiating at the engine or APU shaft centerline.

g. Impact Area.

(1) Rotor Failures. The impact area is that area likely to be impacted by uncontained rotor or disc rim segment fragments. Recorded observations of impact areas resulting from uncontained engine rotor failures show that heavy fragments tend to remain within a spread angle of ±3 degrees. Smaller fragments have been deflected at spread angles as much as ±15 degrees. Spread angles which should be considered in designs to minimize the hazards of uncontained rotor failures are ±3 degrees for the 1/3 disc sector with 1/3 of the blade length above the rim intact; ±5 degrees for other large fragments (3 bladed rim sector with blade root serrations); and ± 15 degrees for the smaller fragments (shrapnel).

(2) Fan Blade Failures. Service experience has shown that fan blade fragments have been contained initially by the engine but have been expelled from the plane of rotation of the fan in both the forward and aft directions. In forward trajectory failures, blade tip fragments have been expelled forward of the engine front flange and lodged in or penetrated the nacelle inlet or departed without contacting the nacelle inlet. In one aft trajectory failure incident, blade fragments lodged in the fan case wall, shearing a hydraulic line and impacting a main fuel line. The design impact area for fan blade fragments is within a spread angle of ±15 degrees.

(3) Auxiliary Power Unit. If an APU is installed which has not been shown to have rotor containment, the impact areas and spread angles identified above, along with the energy level of the uncontained fragments specified by the manufacturer, should be used. Even though rotor containment may have been demonstrated, a subjective review of the APU location and rotor failure consequences should be made to assure that the hazardous condition would not be created in the unlikely event of an uncontained APU rotor failure.

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

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

(1) The other engine(s) on the same and/or opposite wing and engine(s) mounted on the aft fuselage and in the empennage;

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

(3) Pilot compartment area (NOTE: Normally engine rotors and fans are not in line with the pilot compartment area. However, for turbine engine installations on Part 23 airplanes, satisfactory service experience relative to rotor and fan blade integrity and containment in similar engine installations can be considered in assessing the acceptability of installing engines in line with the pilot compartment area.);

(4) 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.);

(5) Essential or 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;

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

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

(8) Instrumentations essential for continued safe flight and landing.

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 have been used:

(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.

(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 or fan blade fragments.

(7) Consider the likely damage extent caused by multiple fragments (smaller fragments or shrapnel in the ± 15 degree spread angle areas).

(8) 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, as deflectors on the fluid lines have been used to minimize the likely damage and hazards.

c. External Shield and Deflectors. When shields, deflection devices or airplane structure are proposed to be used to protect systems or components, the adequacy of the protection should be shown by testing or analysis supported by test data, using the fragment energies suggested in paragraph 6.

d. Airplane Modifications. Modifications made to current certificated airplanes should not compromise the original airplane safety level relative to uncontained engine or APU rotor or fan blade failures. Examples are reengining installations, APU installations and auxiliary fuel tank installations.

6. FRAGMENT ENERGIES.

a. The energy level the designer needs to consider is that associated with the total mass in the 1/3 sector of a disk identified in paragraph 4g(1), at the critical rotating speed and translational velocity. This energy level would be the most severe in terms of catastrophic damage. Damage caused by these fragments can be minimized by the design considerations outlined in this AC.

b. Service experience primarily on high bypass engines without inlet guide vanes has shown that the engine can eject blade fragments beyond the engine case (forward and aft) even with a containment ring that remains intact. Some of the most severe incidents involved large blade tip fragments (up to 3 pounds) which spiral forward of the engine front flange. These fragments have velocities up to 900 feet per second. Another type of fragment is one that may be reingested and rebounds forward. These fragments shear and puncture at the point of impact. The fragments can weigh as much as 0.6 pounds and have velocities up to 400 feet per second. As previously noted, some occurrences have resulted in engine case penetration of basically full-sized fan blades aft of the engine containment ring.

c. The size and trajectory of the fragments vary with each particular engine design. The use of soft case containment systems, such as Kevlar, has changed the failure dynamics relative to fan blade failure events. Therefore, the engine installer should consider the engine manufacturer's data on fragment energies and trajectories in relation to the engine installation for the particular location on the airplane.

William Sullivan

Deputy Director of Airworthiness

ACJ No. 2
to
JAR 25.903(d)(1)

D1 4100 7780 REV. 6/87

ACJ No. 2 to JAR 25.903(d)(1)
Uncontained Engine Rotor Failures (Acceptable Means of Compliance and Interpretative Material)
See JAR 25.903(d)(1)

1 *Turbine Engine Installations.* Where containment of engine rotor debris has not been established, the following material provides a basis on which compliance may be shown with JAR 25.903(d)(1).

2 *Aeroplane Design Considerations*

2.1 All practical design precautions should be taken to minimise, on the basis of good engineering judgement the risk of catastrophic damage due to non-contained engine rotor debris. This should include the position of the engine with respect to critical components or regions of the aeroplane such as —

a. The other engine(s) (especially those located on the same side of the aeroplane);

b. Fuselage pressurised hull and other primary structure;

c. Flight deck region;

d. Fuel system/tanks. (Consideration should be given to spillage of fuel into the engine compartment and any other region of the aeroplane where a fire hazard could result);

e. Essential control systems, including primary flight controls, electrical systems, hydraulic systems and shut-off means;

f. Engine fire extinguisher systems; and

g. Instrumentation essential for continued safe flight.

2.2 Practical design measures to minimise the risk of catastrophic damage may include for example, location of critical components or systems outside the vulnerable areas; duplication and adequate separation of critical components of systems, and/or protection by substantial airframe structure, taking account of the possible risk of simultaneous damage caused by the release (in random directions) of single fragments; location of shut-off means so that flammable fluids can be isolated in the event of damage to the system; use of protective armour or deflection shields; precautions to ensure that flammable fluids released from damaged lines or other components are not likely to contact possible ignition sources; possible redundant design or crack stoppers to limit the dynamic propagation of tears which have been caused by debris impact.

2.3 Where protection by substantial airframe structure or by protective armour or deflection shields is claimed, the adequacy of protection should be demonstrated by tests and/or analysis based on test data, using the criteria of the engine failure model of paragraph 3.

ACJ No. 2 to JAR 25.903(d)(1) (continued)

3 *Engine Failure Model.* The safety analysis required in paragraph 4 should be made using the following engine failure model unless, for the particular engine type concerned, evidence can be produced based on operating experience or engine design features to justify a different model.

3.1 *Single One-Third Piece of Disc.* It should be assumed that the one-third piece of disc has the maximum dimension corresponding to one-third of the disc with one-third blade height and an angular spread of ±3° relative to the plane of rotation of the disc. Where energy considerations are relevant, the mass shuld 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 1.)

3.2 *Small Pieces of Debris.* It should be assumed that the small piece of debris has a maximum dimension corresponding to one-third the bladed disc radius and an angular spread of ±5° relative to the plane of the disc. 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 travelling at rim speed (see Figure 2).

3.3 *Alternative Engine Failure Model.* For the purpose of the analysis, as an alternative to the engine failure model of paragraphs 3.1 and 3.2, the use of a single one-third piece of disc having an axial spread angle of ±5° would be acceptable, provided that the objectives of paragraphs 2.1, 2.2 and 4.3 a. are satisfied.

4 *Means of Compliance – Safety Analysis*

4.1 An analysis should be made using the engine model defined in paragraph 3 to determine the critical areas of the aeroplane likely to be damaged by rotor debris and to evaluate the consequences. This should be determined in relation to the most critical flight phases.

4.1.1 A minimum delay of at least 15 seconds but in any event not more than 60 seconds should be assumed for the emergency engine shut down drill depending on the circumstances resulting from non-containment, taking into account the various phases of flight, and the fact that damage due to non-containment could result in a considerable increase in flight crew work load and delay in starting any of the emergency drills, for example, where there may be a multiplicity of warnings which require analysis of the situation by the flight crew to determine the cause.

4.1.2 Some degradation of the flight characteristics of the aeroplane or operation of a system may be permissible subject to the safe continuation of the flight. Account should be taken of the behaviour of the aeroplane under asymmetrical engine thrust or power conditions together with any possible damage to the flight control system, and of the predicted aeroplane recovery manoeuvre.

4.2 Drawings showing the trajectory paths of engine debris relative to critical areas should be provided. The analysis should include at least the following:

a. Damage to primary structure including the pressure cabin, engine mountings and airframe surfaces.

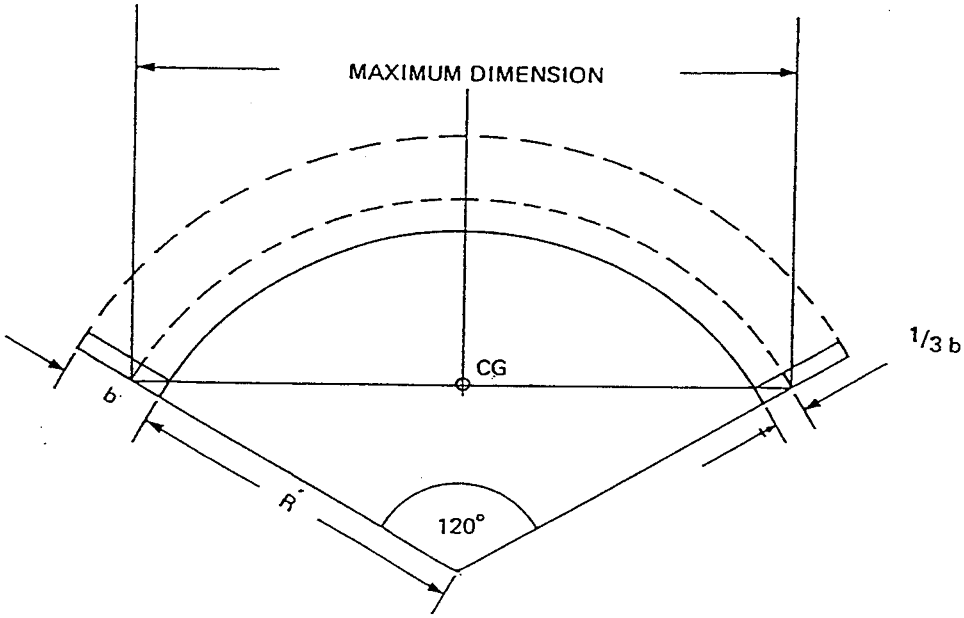
NOTE: The structural analysis should be made in accordance with ACJ 25.571.

b. Damage to any other engines (the consequences of subsequent non-containment of debris from the other engine(s), need not be considered).

c. Damage to services and equipment essential for safe flight (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.

d. Pilot incapacitance.

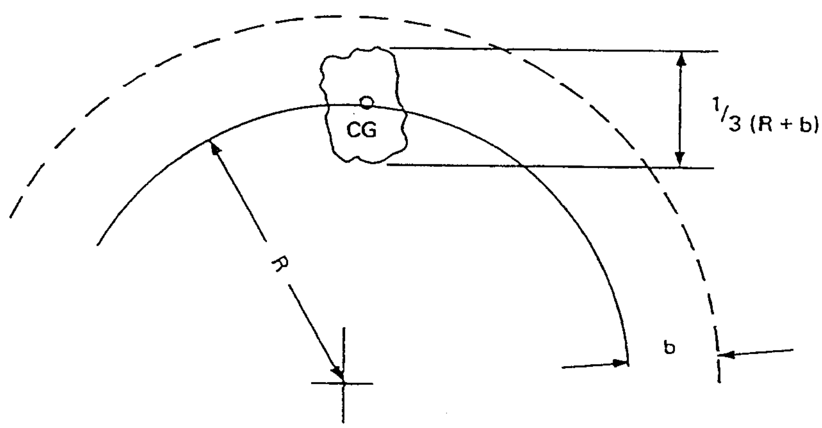
ACJ No. 2 to JAR 25.903(d)(1) (continued)



Where R = disc radius
b = blade length

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

FIGURE 1 — SINGLE ONE-THIRD DISC FRAGMENT



Where R = disc radius
b = blade length

Maximum dimension = ⅓ (R + b)

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

CG is taken to lie on the disc rim

FIGURE 2 — SMALL PIECE OF DEBRIS

e. 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 aeroplane where this could lead to a fire (or explosion).

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

g. Penetration and distortion of firewalls and cowling permitting a spread of fire.

NOTE: Consideration of the effect of damage should include degradation of the performance and handling characteristics of the aeroplane.

4.3 When all practical design precautions have been taken (see paragraph 2.1) and the safety analysis made using the engine failure model defined in paragraph 3 shows that catastrophic risk still exists for some components or systems of the aeroplane, the level of catastrophic risk should be evaluated. It is [considered that the objective of the requirement will have been met if the levels of risk stated in a, b. and c.,] as appropriate, have been achieved.

NOTE: It is accepted that due allowance should be made for the size and broad configuration of the aeroplane and that this may prevent the prescribed levels of risk being achieved.

a. *Single One-third Piece of Disc.* There is not more than a 1 in 20 chance of catastrophe resulting from the release of a single one-third piece of disc as defined in paragraph 3.1.

b. *Small Piece of Debris.* 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 3.2.

[c. *Multiple Fragments.* (Only applicable to any duplicated or multiplicated 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 centreline). There is not more than a 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 ±3° relative to the plane of the disc) causing coincidental damage to systems which are duplicated or multiplcated.

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 sub-paragraph.]

4.4 The aeroplane risk levels specified, resulting from the release of rotor debris, are the mean values obtained by averaging those for all discs on all engines of the aeroplane, assuming a typical flight. Individual discs or engines need not meet these risk levels nor need these risk levels be met for each phase of flight if either —

a. No disc shows a higher level of risk averaged throughout the flight greater than twice those stated in paragraph 4.3.

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

b. Where failures would be catastrophic in particular phases of flight only, 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 take-off. The proportional risk of engine failure during the particular phases of flight is given in SAE Paper AIR 1537 dated October 1977 'Report on Aircraft Engine Containment'. See also data contained in the CAA paper 'Engine Non-Containment —The CAA View', which includes Figure 3. This paper is published in NASA Report CP—2017, 'An Assessment of Technology for Turbo-jet Engine Rotor Failures', dated August 1977.

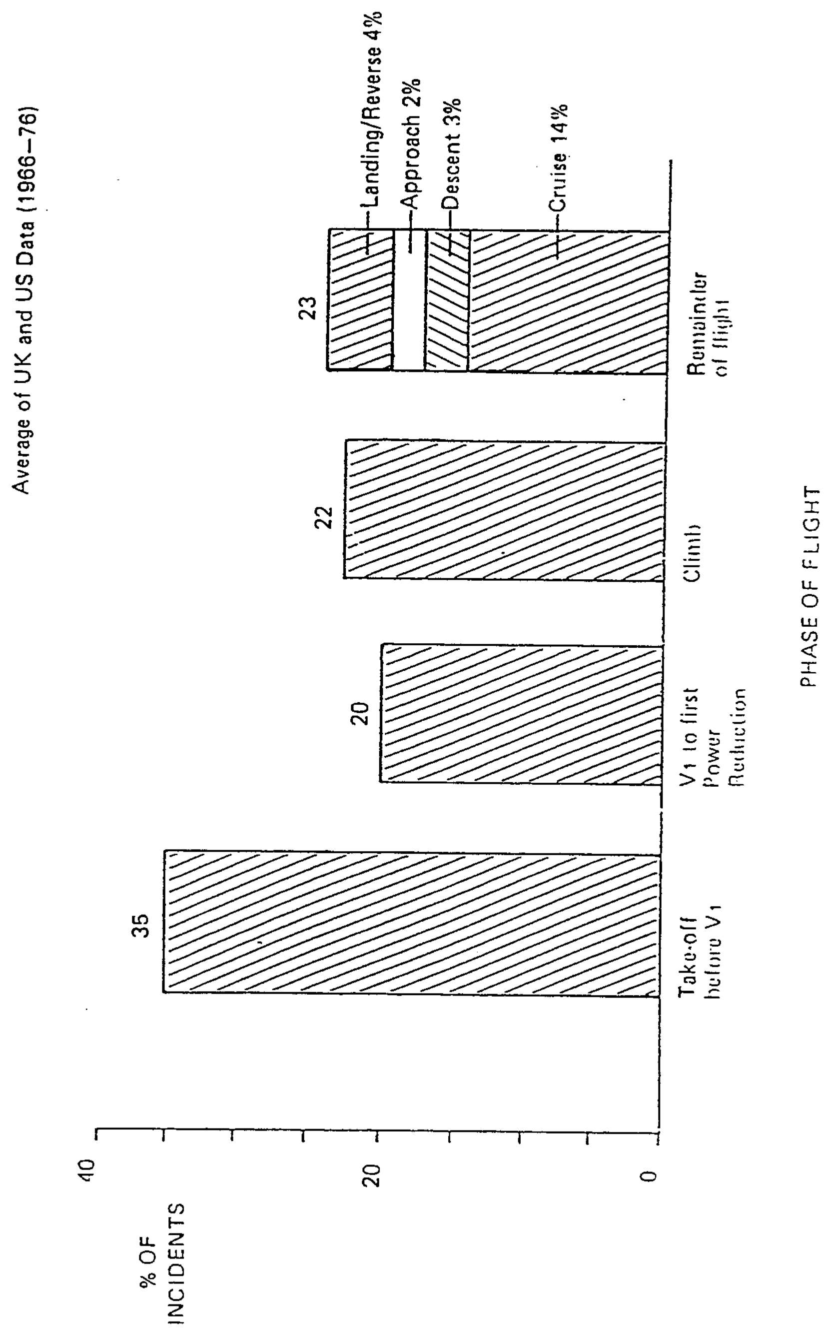


FIGURE 3 – ALL NON-CONTAINMENTS BY PHASE OF FLIGHT

APPENDIX C

UNCONTAINED ENGINE DEBRIS TRAJECTORY FIGURES

Appendix C – Table of Contents

Event#.Pg

UNCONTAINED ENGINE DEBRIS ANALYSIS

Date:
Airline:
Tail Number:

Airplane Model:
Engine Model:
Engine Position:
Eng Serial No.:

Location:
Flight Phase:
Flight Effect:

Power Level:
Altitude:
Airspeed:
Hazard Level *(see Definitions)*:

PRIMARY MALFUNCTION (Rotor Stages):

SECONDARY MALFUNCTION (Rotor Stages):

Fragment Ident. No.	Fragment Descript.	Piece Size	Piece Mass	Released From	Estimated Fragment Velocity	Trajectory (degrees)†	Impact Loc.* *(Note Pictures)*	Hole Size *(Dimensions)*	Damage Description (e.g., Penetration, Tear, Dent, Scratch, etc.)	Effect on System(s) (e.g., Fuel Leak, Fire, Hydraulic System, Flight Controls, etc.)

NARRATIVE:

SOURCE *(Data obtained from)*:
DRAWINGS/PICTURES IDENTIFICATIONS:

ENGINE MANUFACTURER'S UPDATE:

FIGURE 1. Standardized Data Entry Form for Trajectory Study

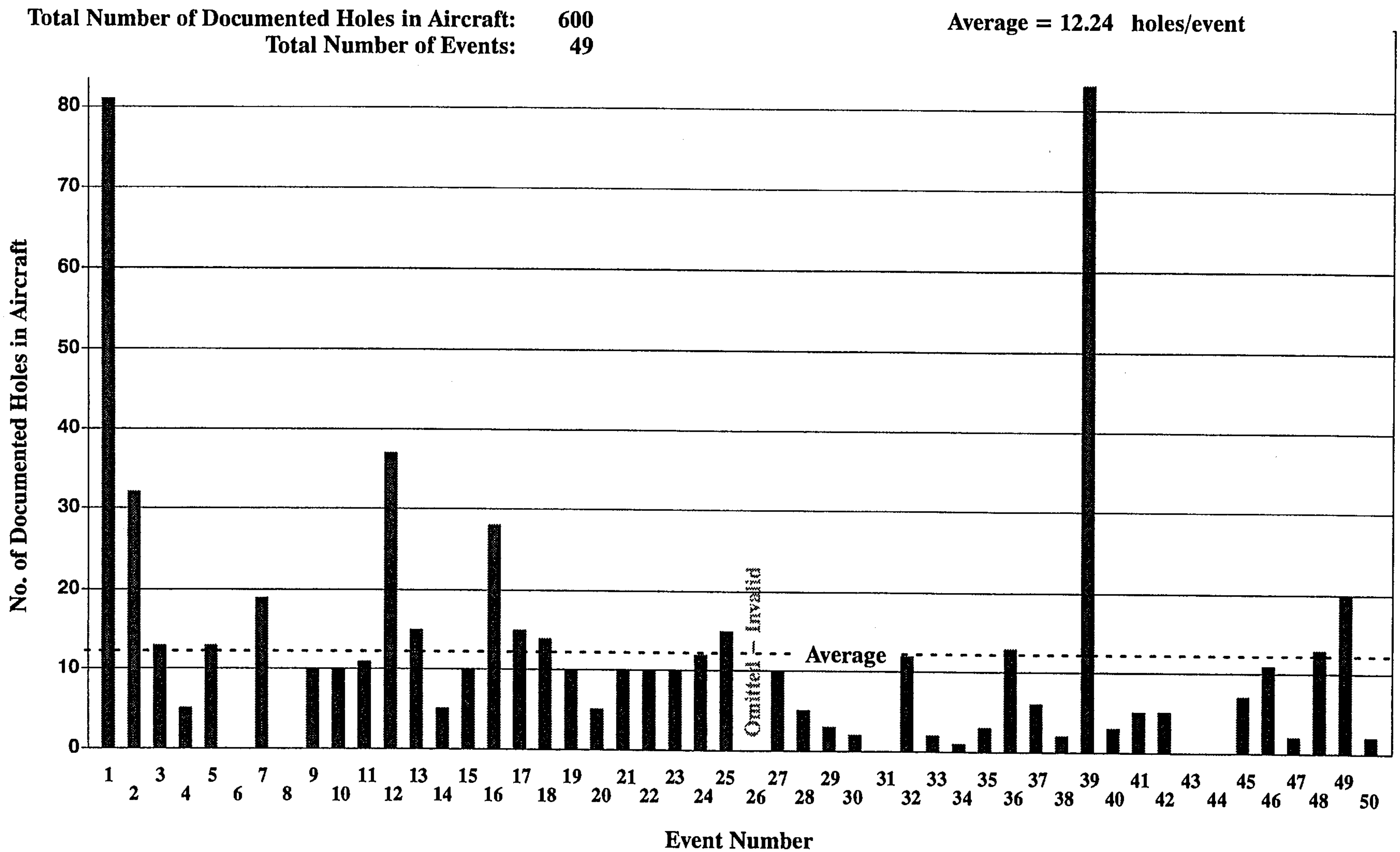


FIGURE 2. Aircraft Penetrations by Event

Number of Documented Disk Holes in Aircraft: 25
Total Number of Events: 49
Total Number of Disk Events: 18

Averages = 0.53 Disk Holes/Event
= 1.44 Disk Holes/Disk Event

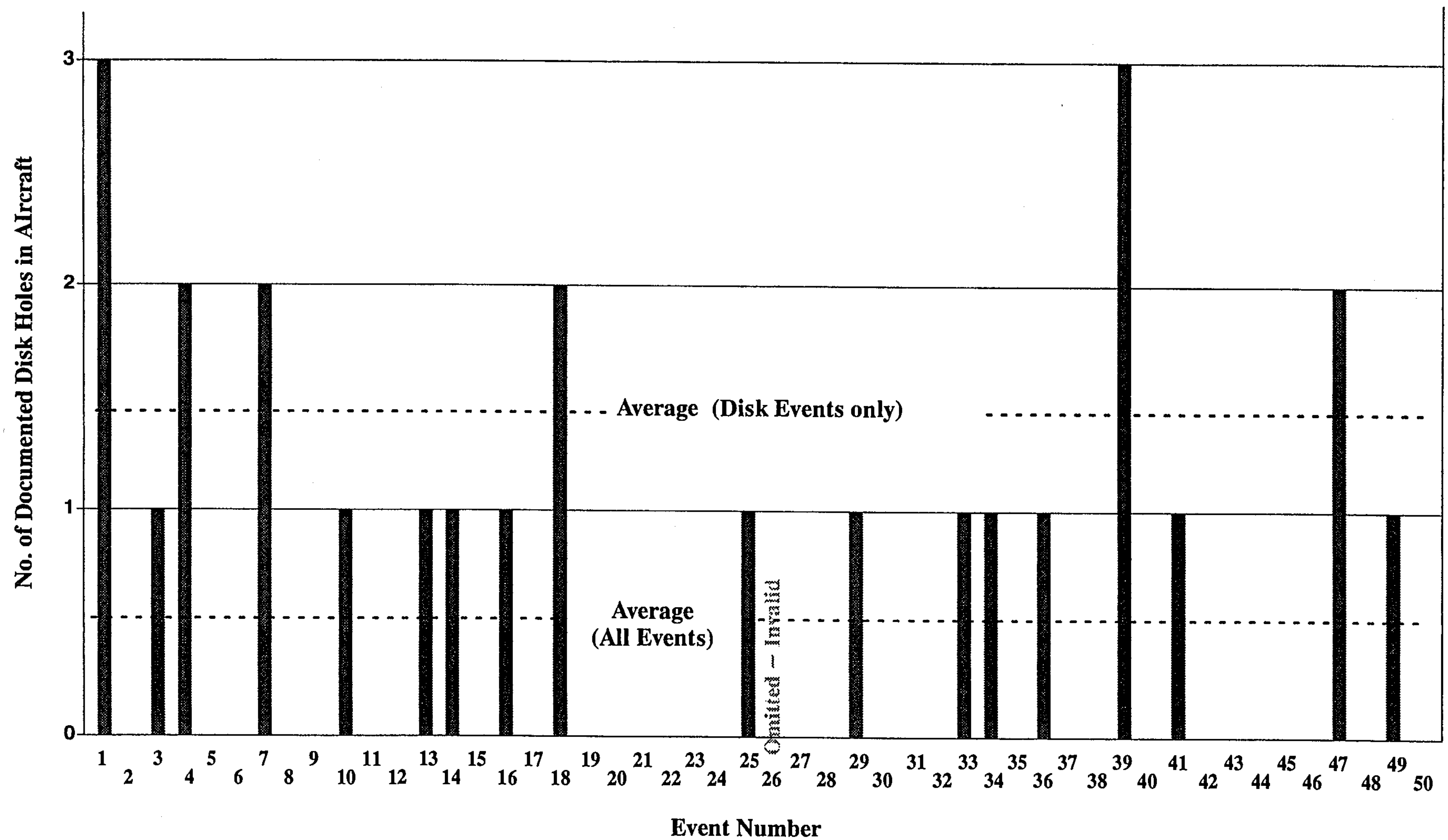


FIGURE 3. Disk Fragment Penetrations by Event

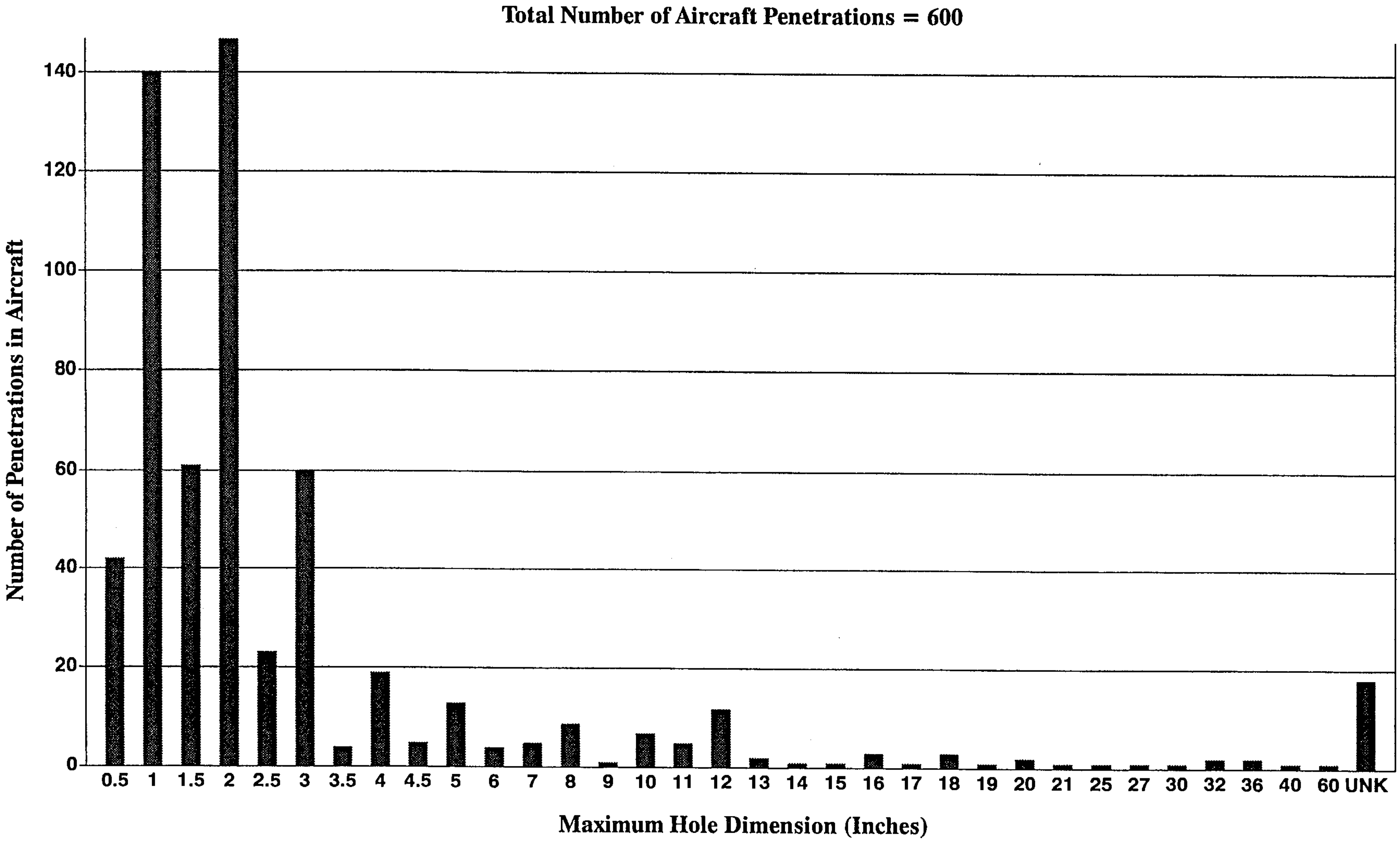


FIGURE 4. Size Distribution of Penetrations (Maximum Dimension)

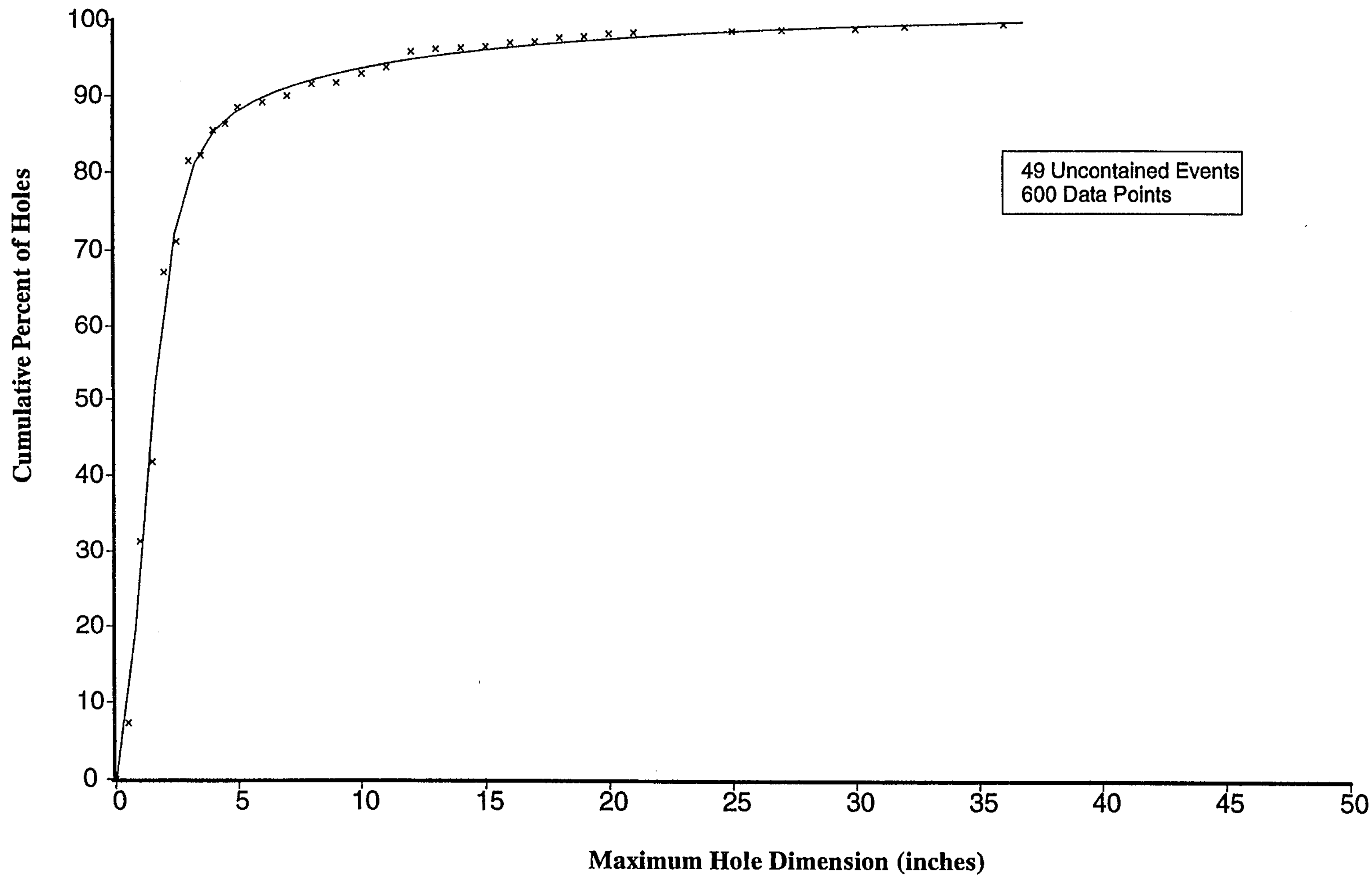


FIGURE 5. Cumulative Size Distribution of Penetrations (Maximum Dimension)

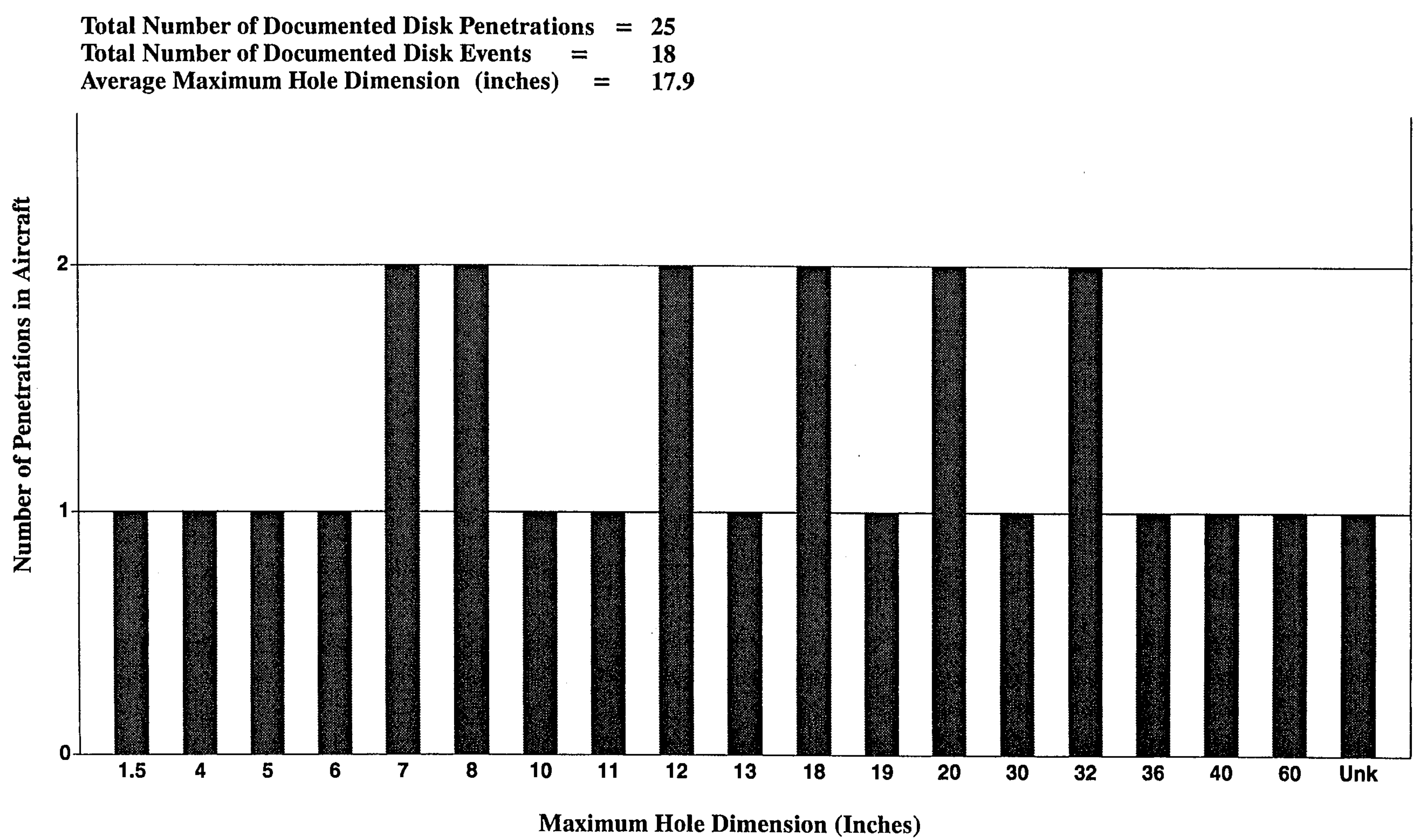


FIGURE 6. Size Distribution of Disk Penetrations (Maximum Dimension)

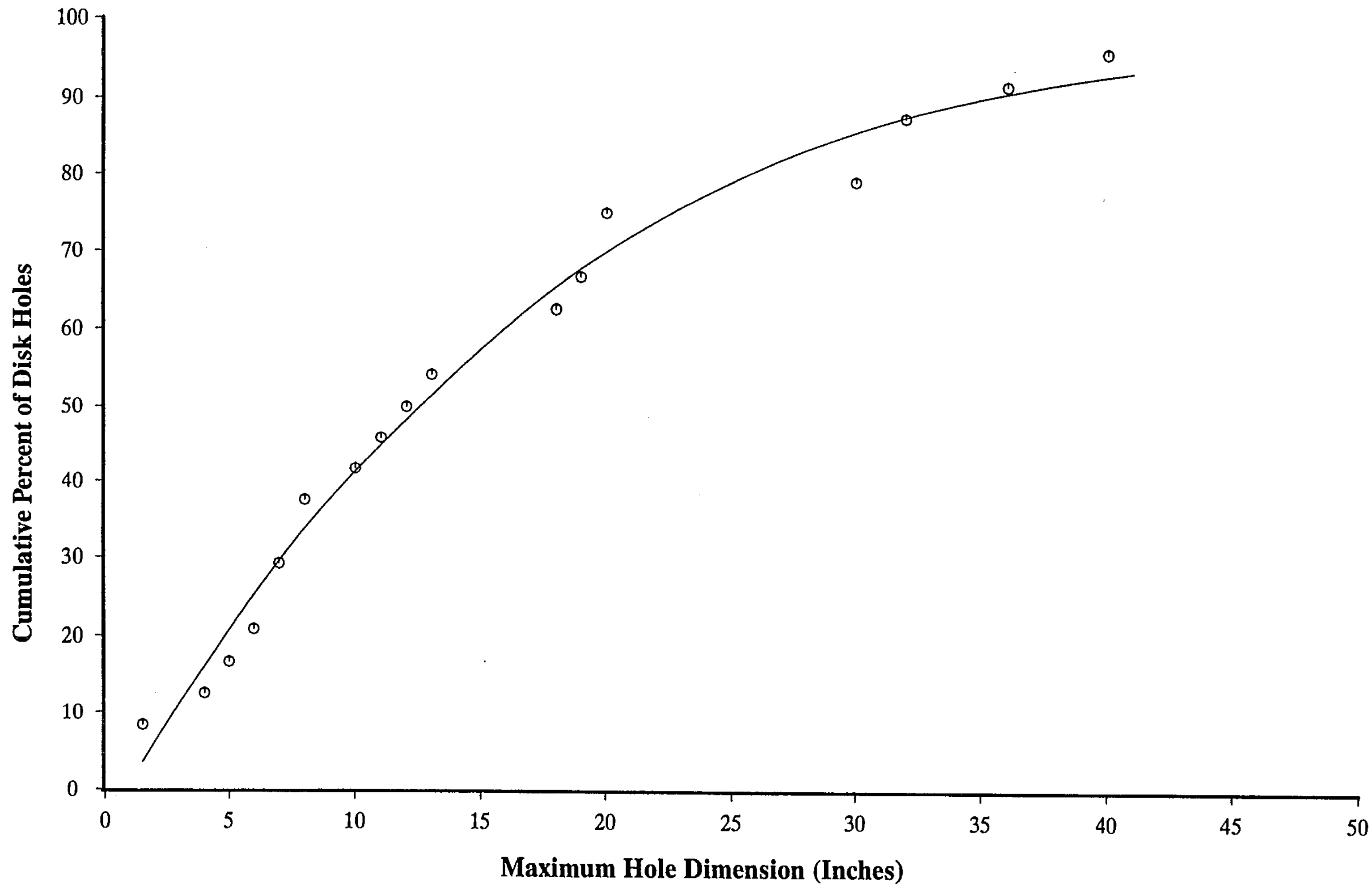


FIGURE 7. Cumulative Size Distribution of Disk Penetrations (Maximum Dimension)

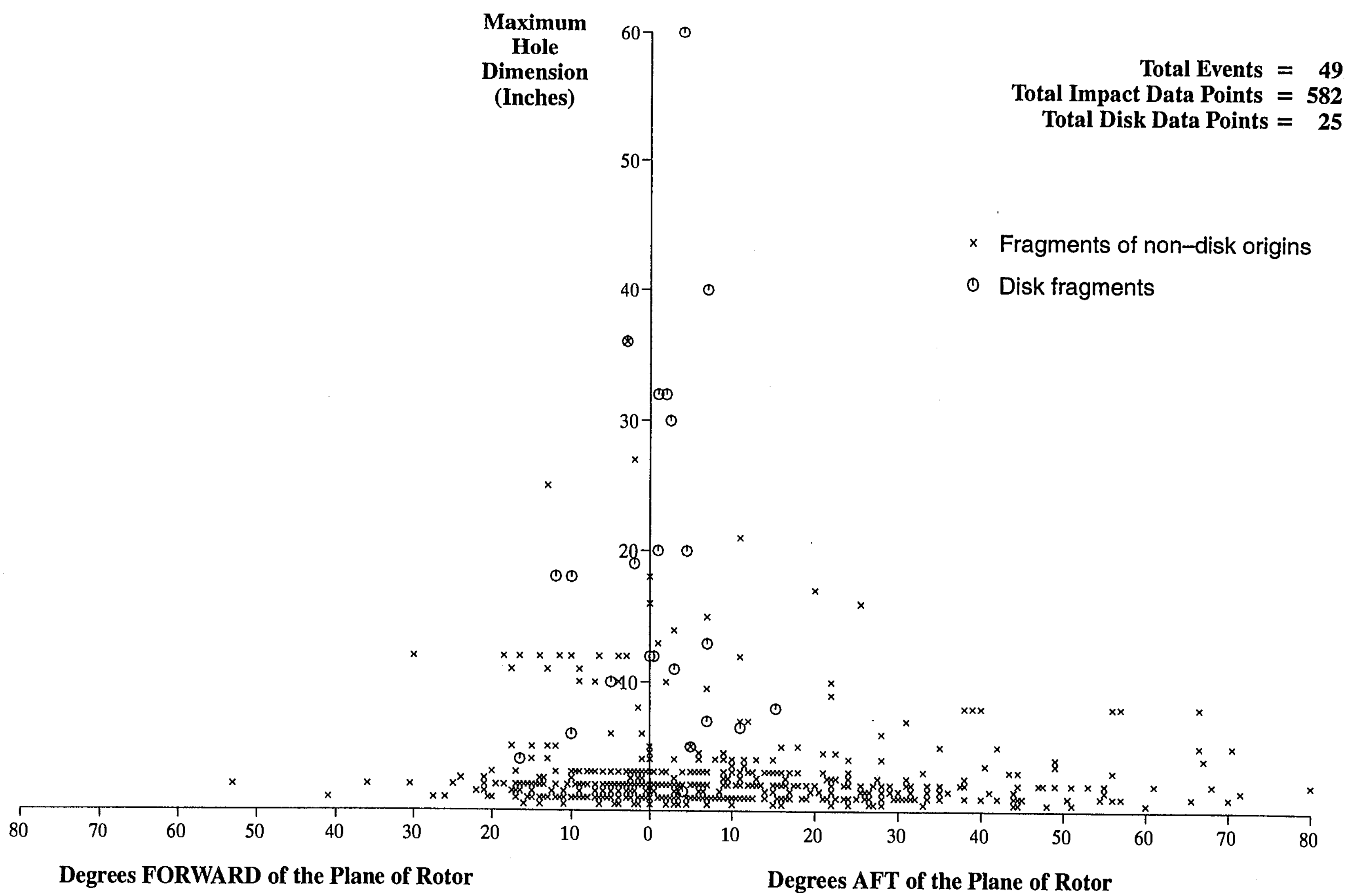


FIGURE 8. Fragment Trajectory versus Hole Size

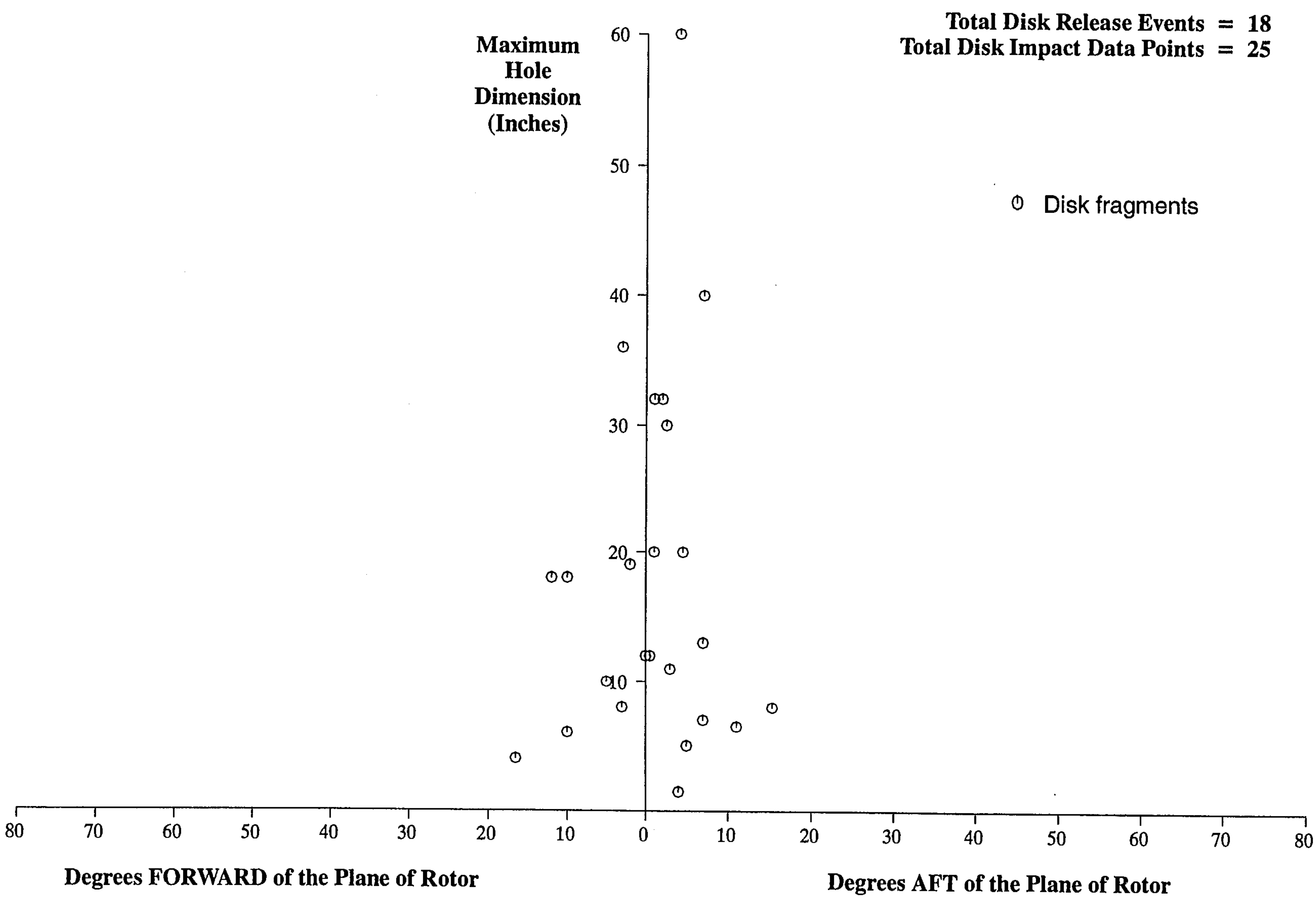


FIGURE 9. Disk Fragment Trajectory versus Hole Size

EVENT 12
TOTAL DATA POINTS = 37

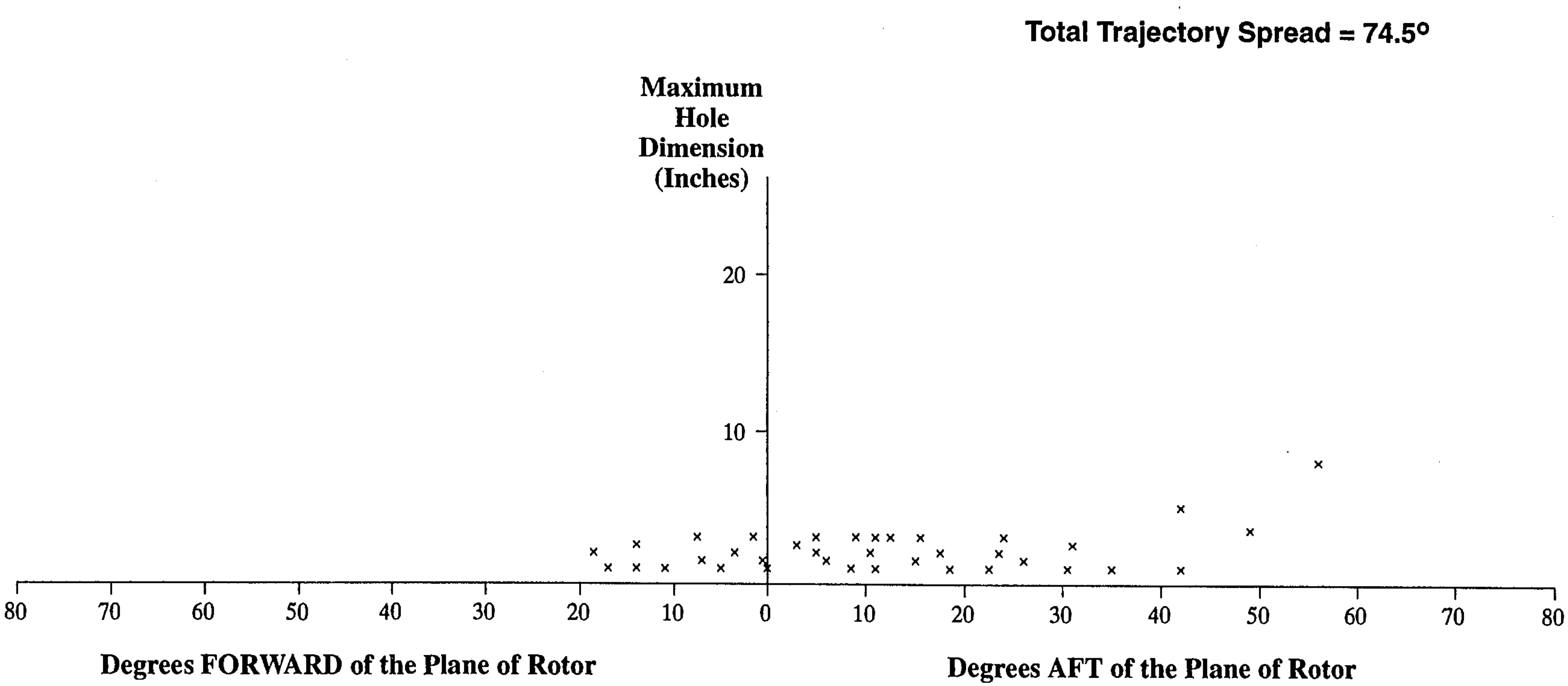


FIGURE 10. Maximum Fragment Trajectory Spread (Single Event)

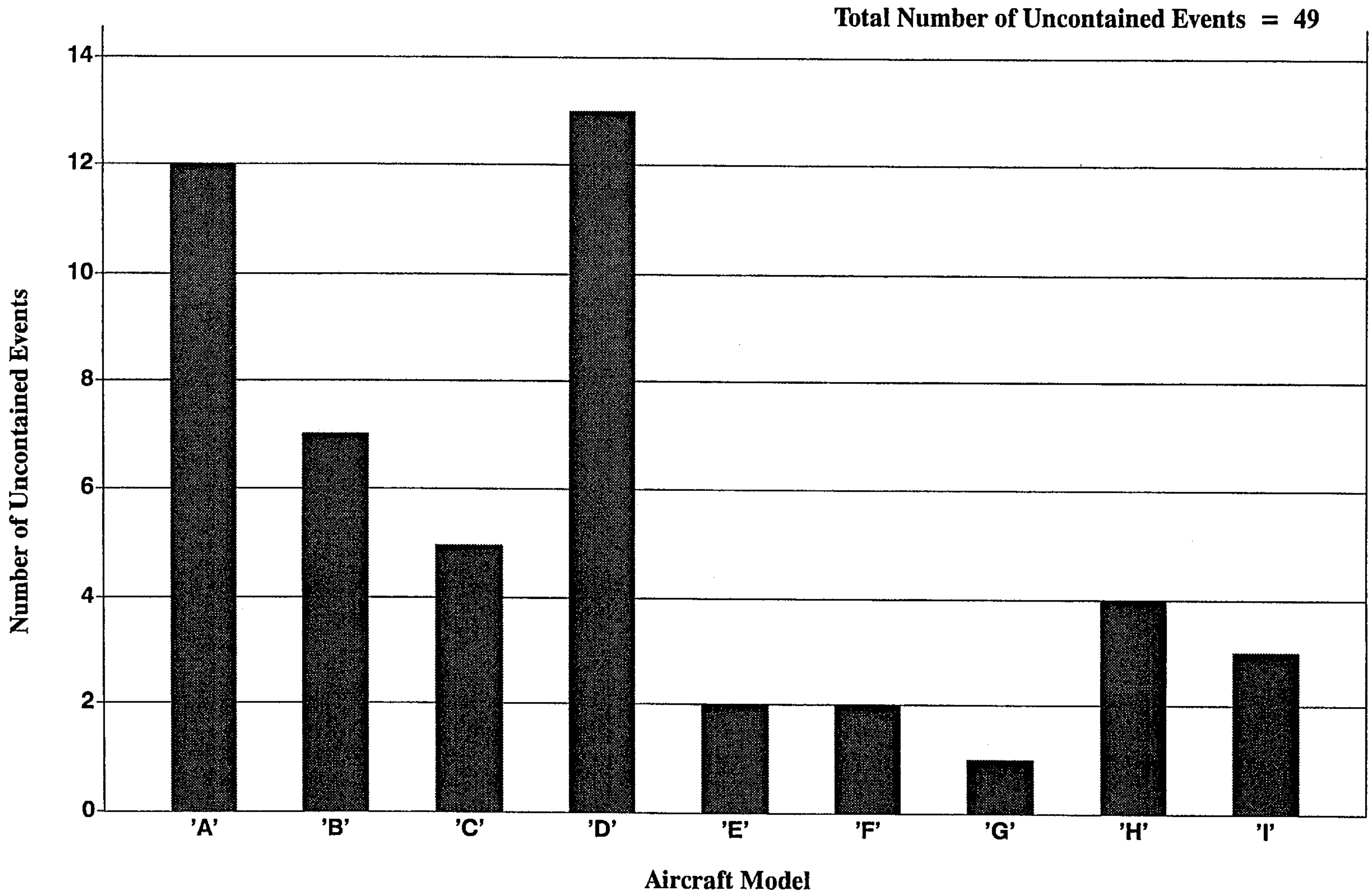


FIGURE 11. Number of Uncontained Events by Aircraft Model

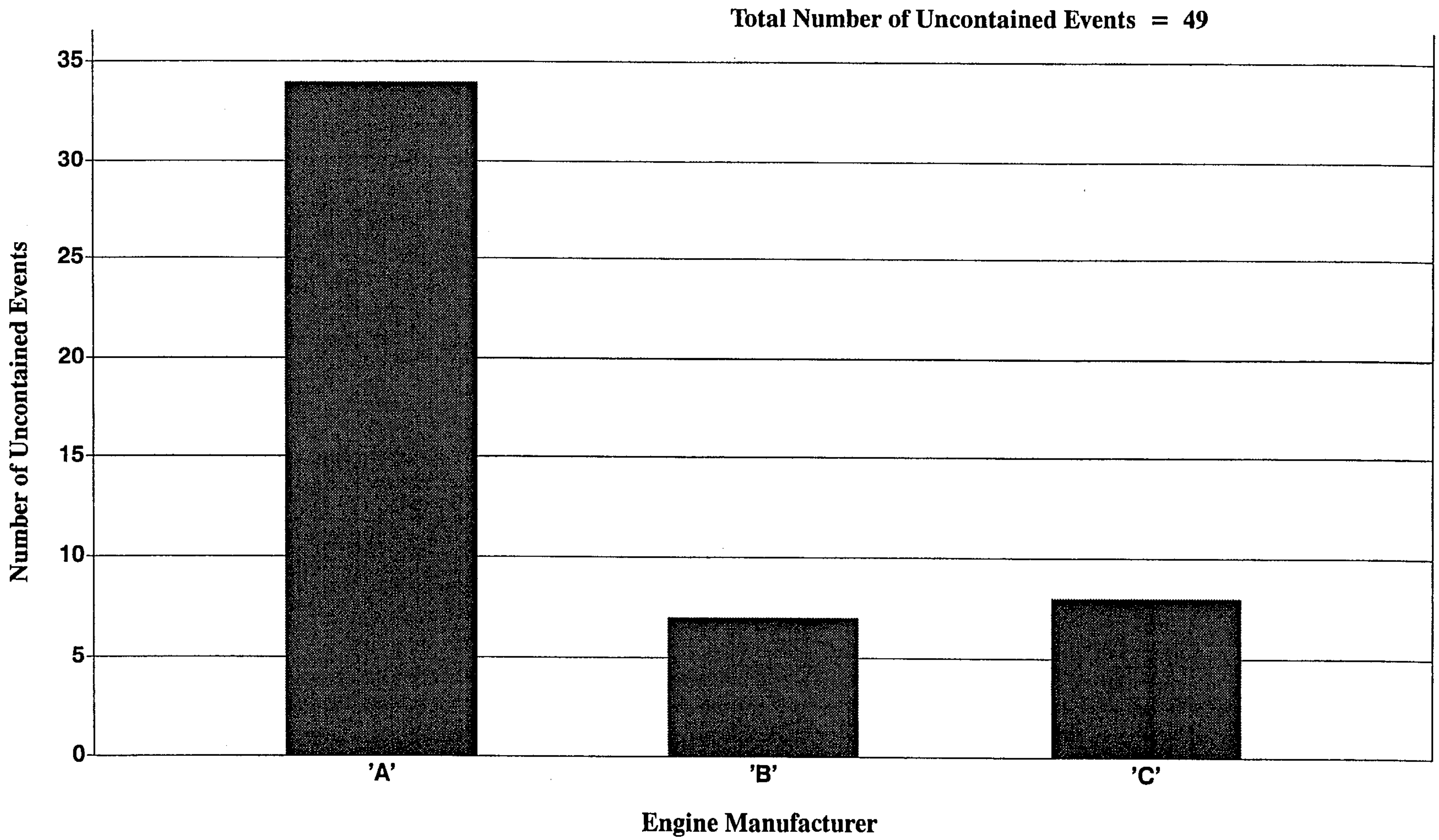


FIGURE 12. Number of Uncontained Events by Engine Manufacturer

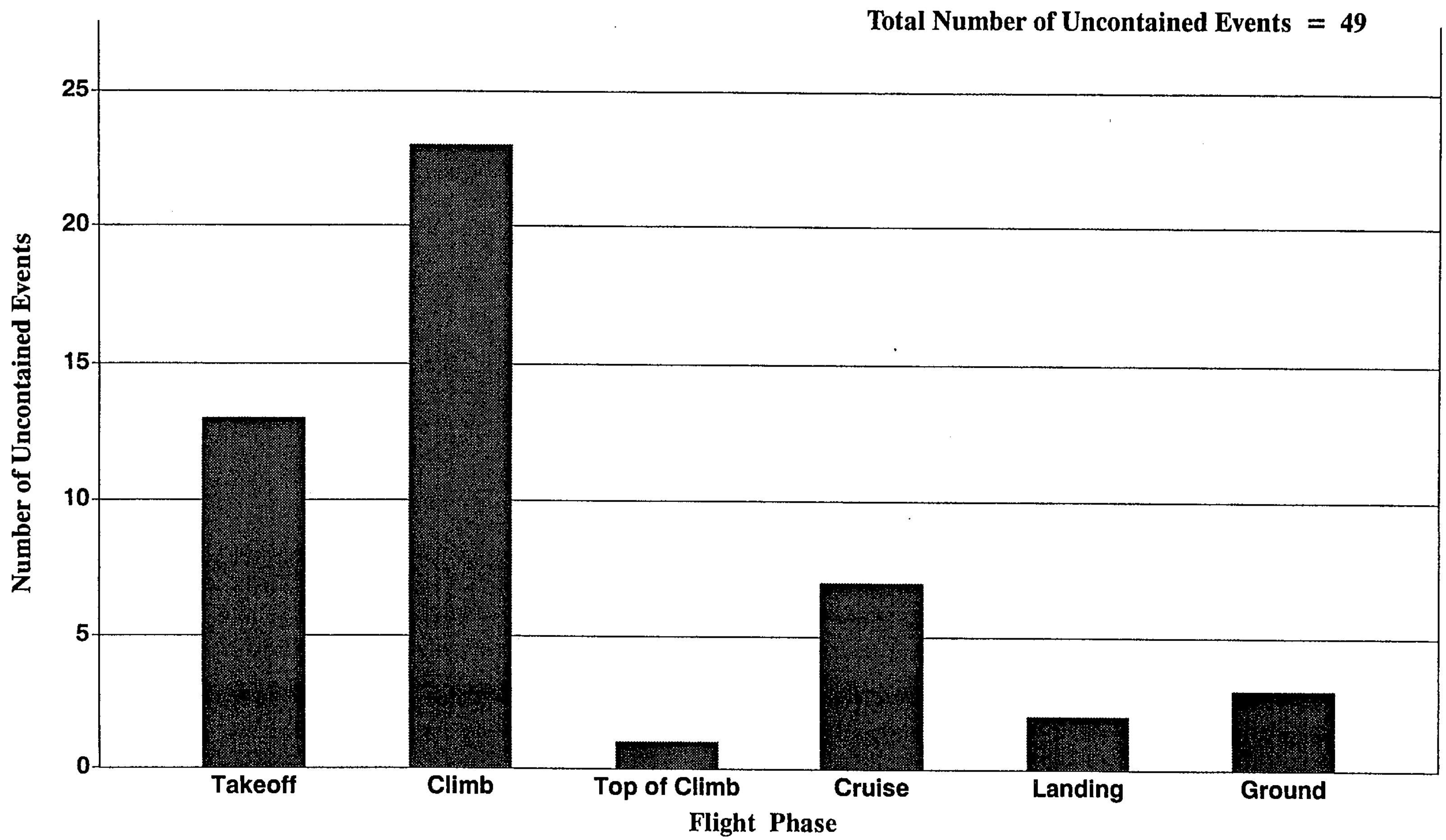


FIGURE 13. Number of Uncontained Events by Flight Phase

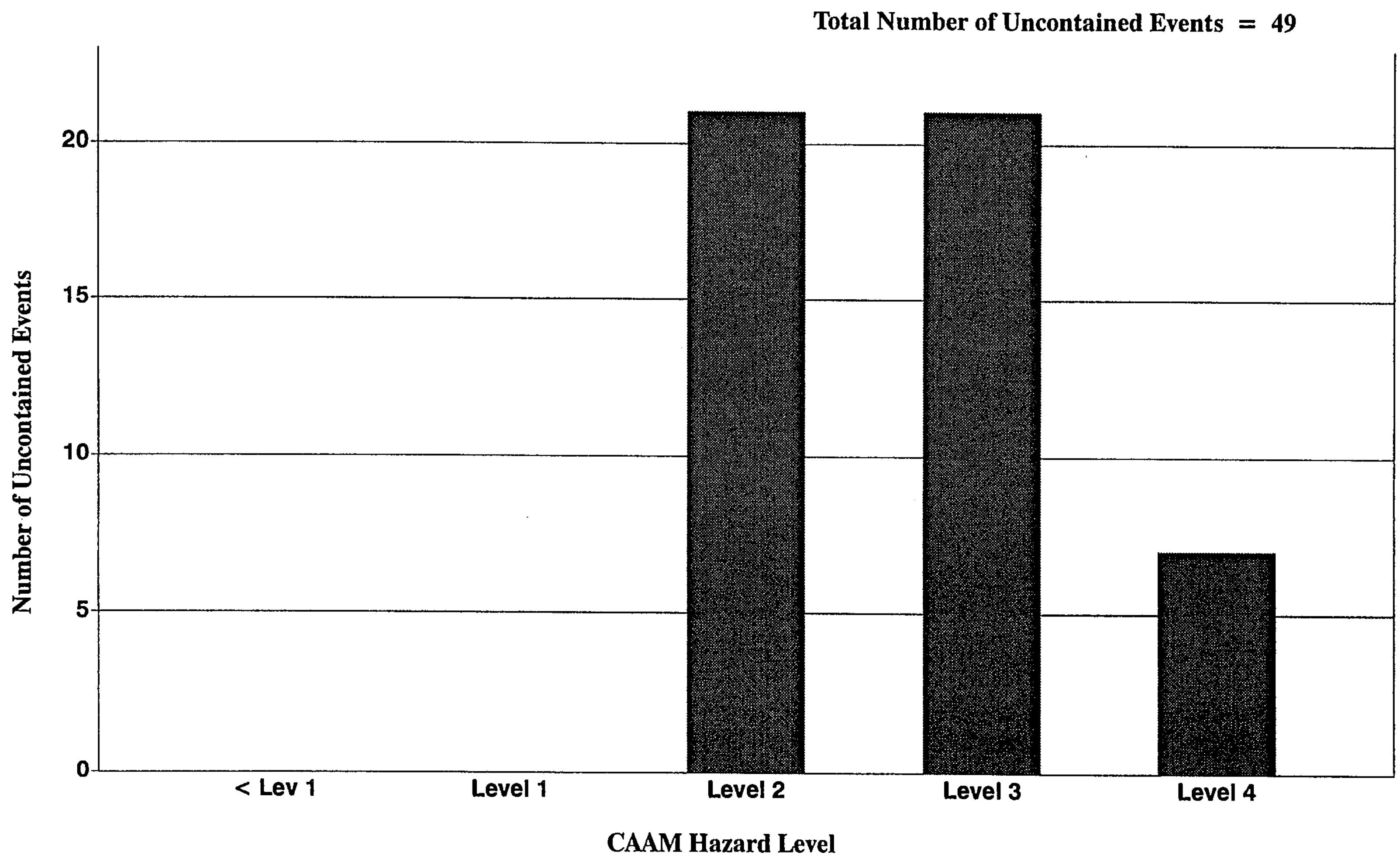


FIGURE 14. Number of Uncontained Events by CAAM Hazard Level

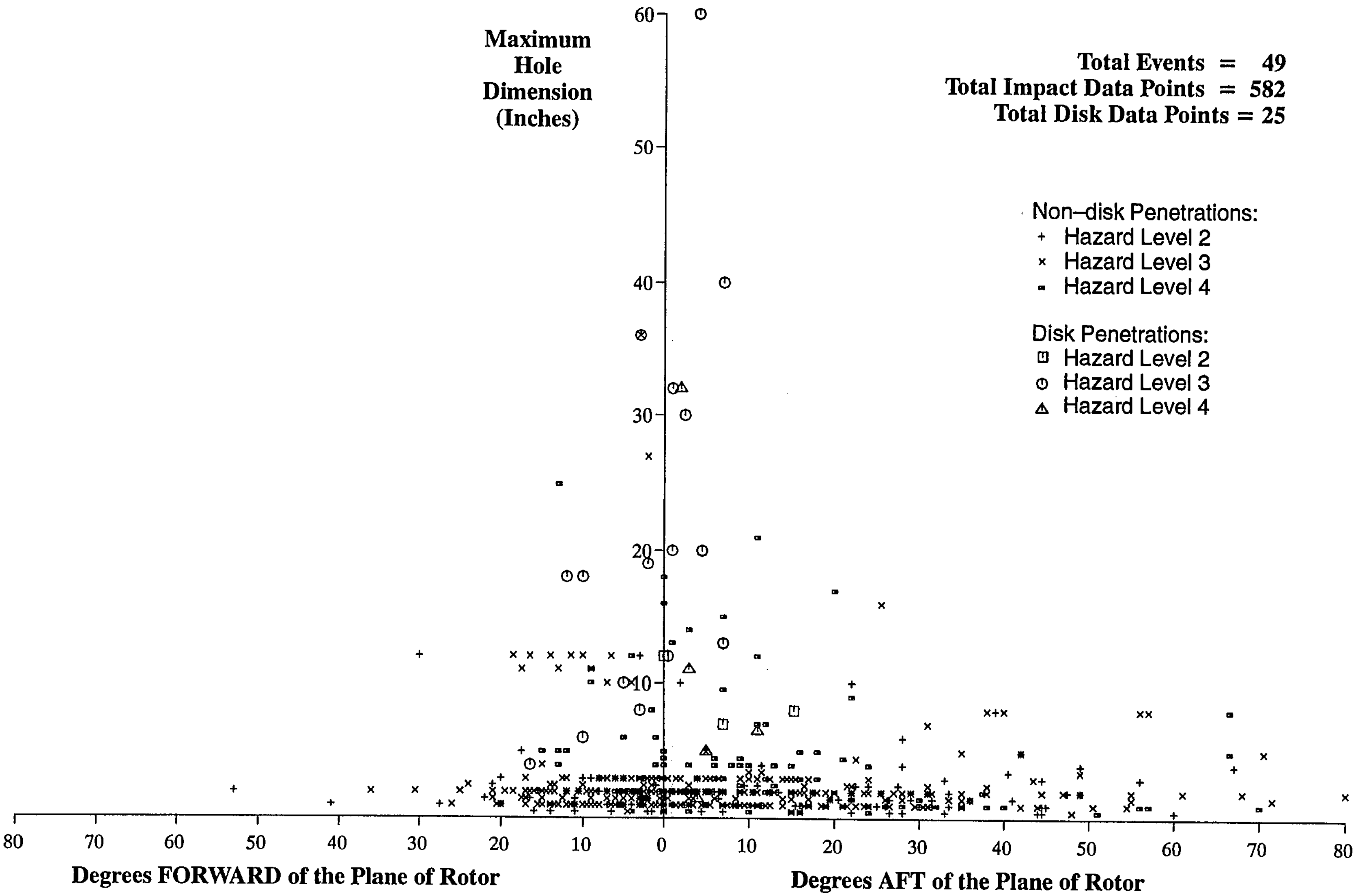


FIGURE 15. Uncontained Trajectories by CAAM Hazard Level

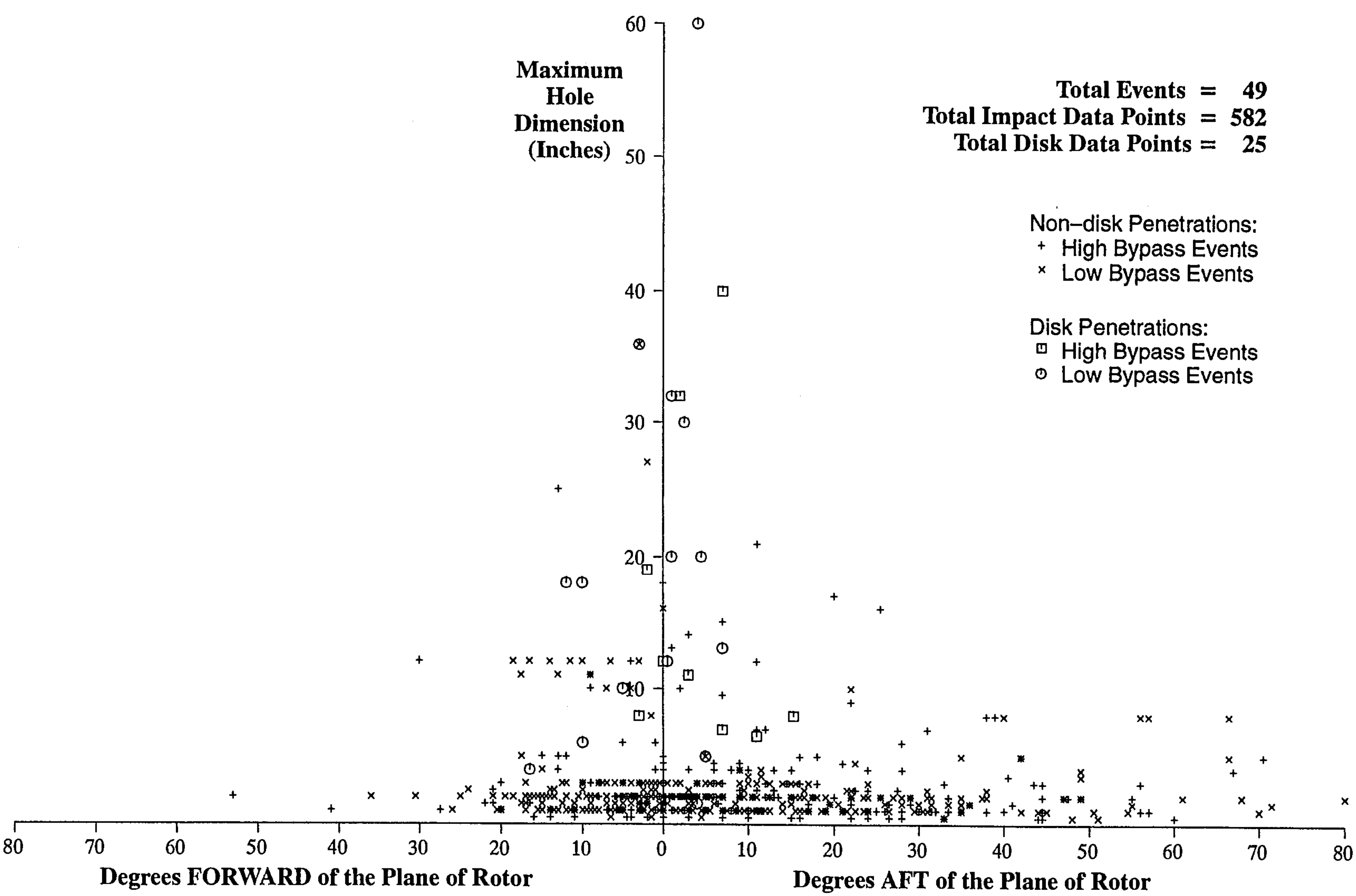


FIGURE 16. Uncontained Trajectories by Relative Bypass Ratio

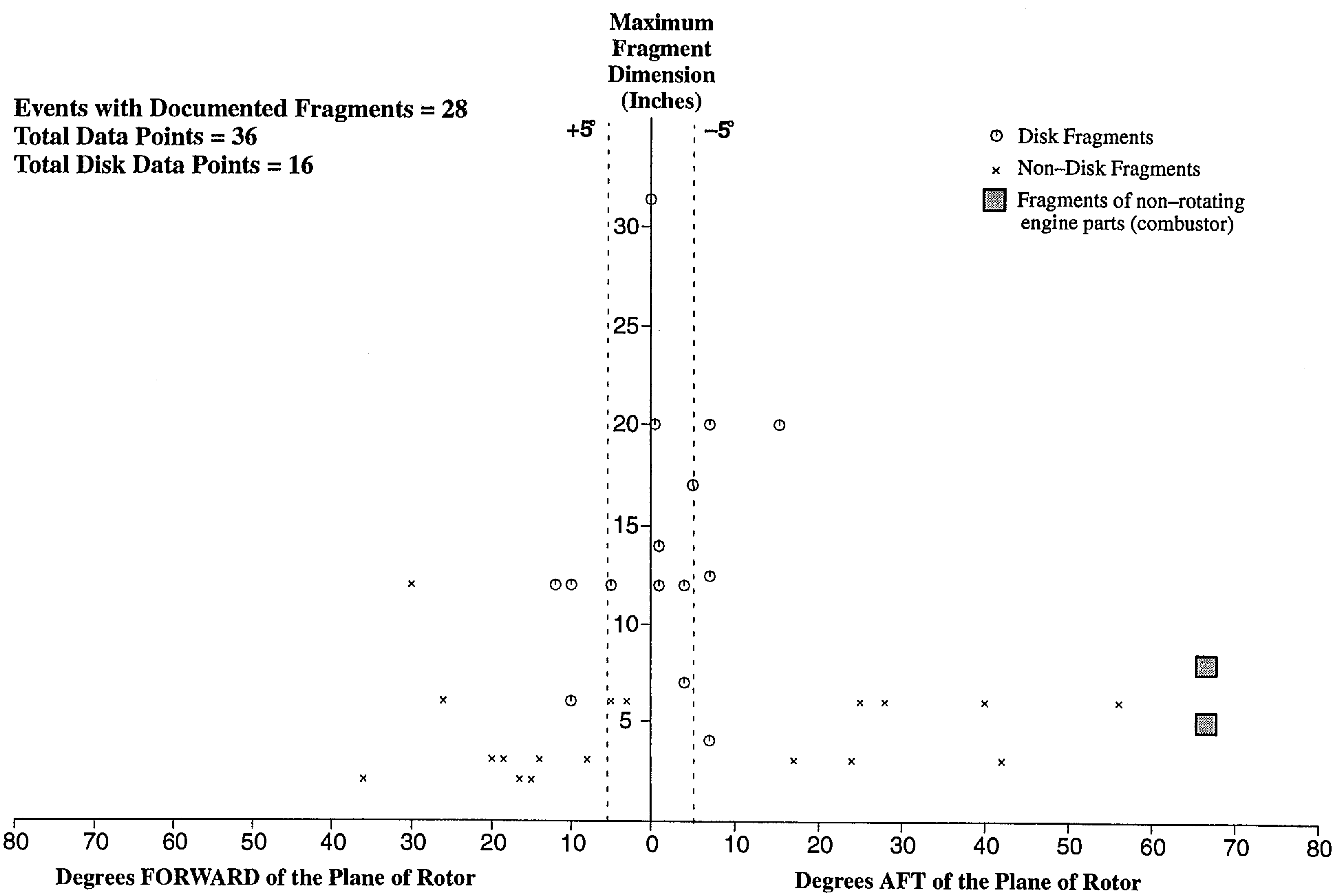


FIGURE 17. Fragment Trajectories of Known Fragments

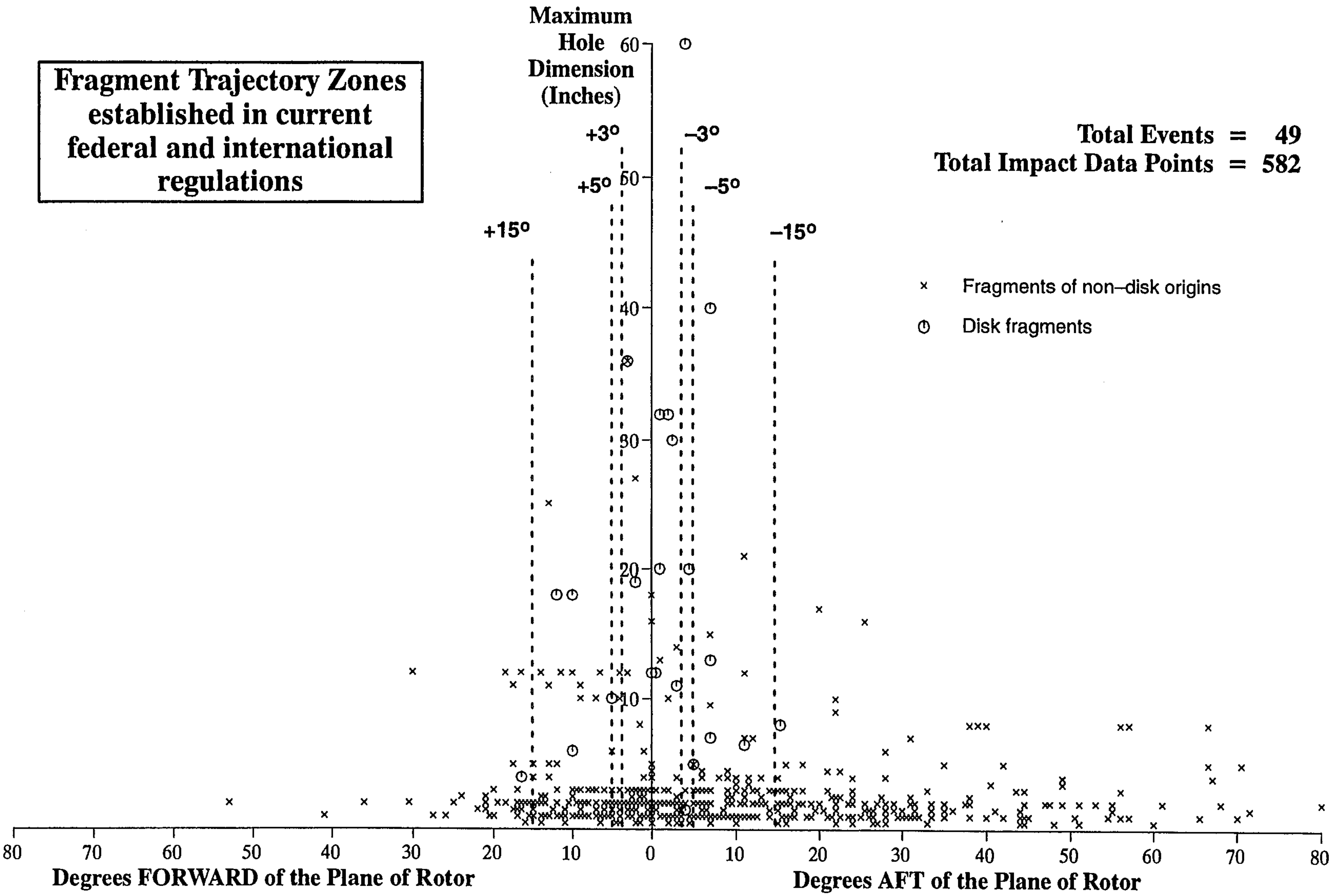


FIGURE 18. **Current Trajectory Limits overlaid on Historical Trajectory Data**

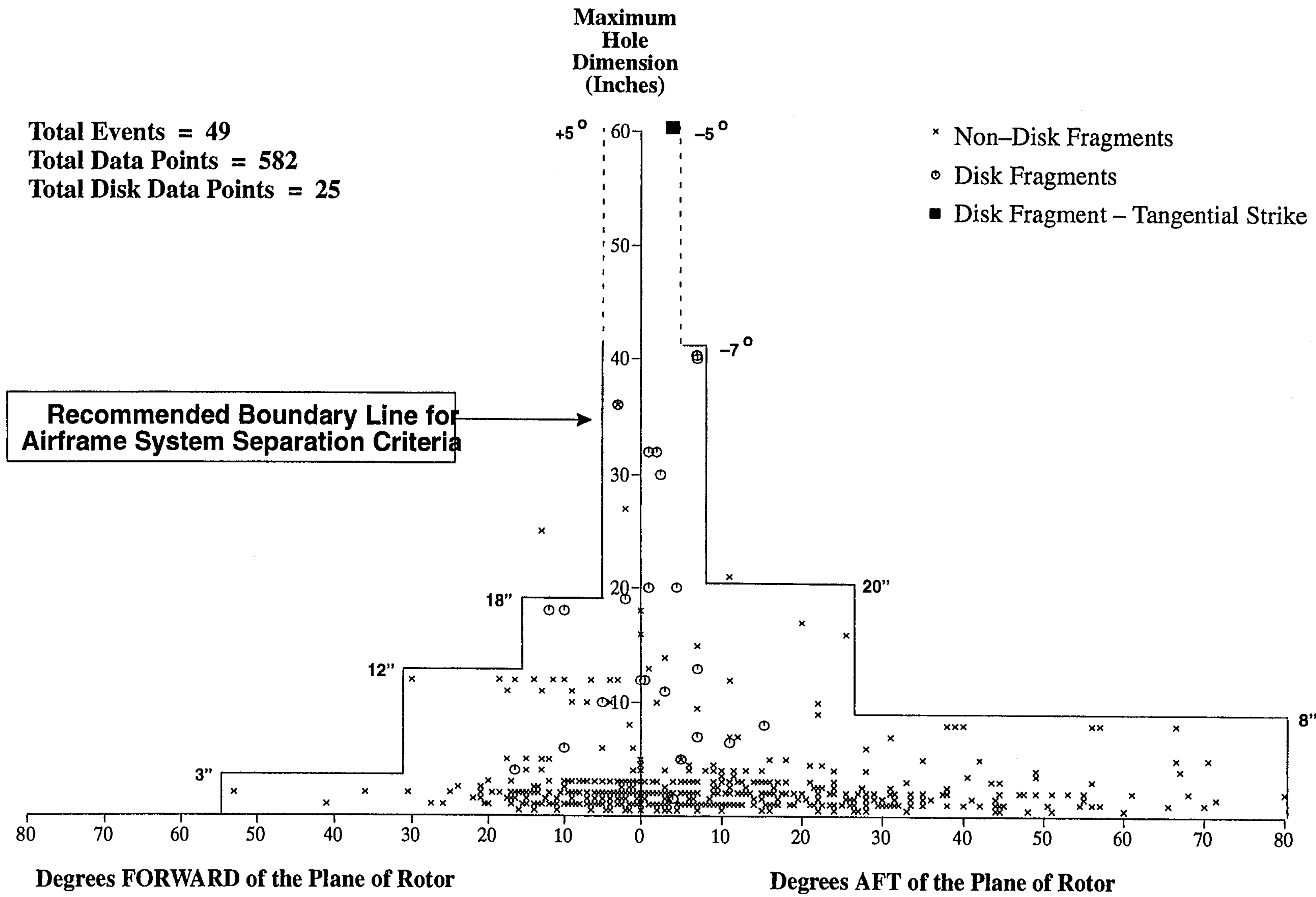


FIGURE 19. Recommended Boundary for Airframe Systems Separation Criteria Based on Penetration Sizes

APPENDIX D

HAZARD LEVEL DESCRIPTIONS

as defined by the
Continuing Airworthiness Assessment Methodology (CAAM) Team

PC342 – CAAM
STANDARDIZED AIRCRAFT HAZARD LEVELS
5/1/93

Propulsion system/APU malfunctions or related incidents, in certain cases coupled with crew error or other aircraft system malfunctions, resulting in the following consequences to the aircraft or its passengers/crew.

Level 4 – Severe Consequences

4a. Forced Landing.

Note: Forced landing is defined as the inability to continue flight due to the consequences of damage, uncontrolled fire or thrust loss where imminent landing is obvious but aircraft controllability is not necessarily lost. (i.e. Total power loss due to fuel exhaustion will result in a "forced landing". The term "emergency landing" may also be used to mean a forced landing if there is an urgent requirement to land. An air turn back or diversion due to a malfunction is not a forced landing since there is a lack of urgency and the crew has the ability to select where it will perform the landing. However, off airport landings are almost always forced landings.)

4b. Loss of Aircraft (Hull Loss)

4c. Serious Injuries or Fatalities (see NTSB Definition below)

Note: "Serious injury" means any injury that (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in the fracture of any bone (except simple fractures of fingers, toes or nose); (3) involves lacerations that cause severe hemorrhages, nerve, muscle or tendon damage; (4) involves injury to any internal organ: or (5) involves second–or–third degree burns or any burns affecting more than 5% of the body surface. In addition, "Fatal Injury" is defined as an injury that results in death within 30 days of the accident. (Egress injuries are excluded from establishing the threat category by mutual agreement of the CAAM membership).

Level 3 – Serious Consequences

(Serious Incident as defined by ICAO is "Any event involving the operation of an aircraft other than an accident where the event, or the event coupled with any other reasonably probable second event, has the direct potential to result in an accident.)

3a. Substantial damage to the aircraft or second unrelated system.

Note 1: "Substantial damage" means damage or structural failure that adversely affects the structural strength, performance or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected components. (Not considered substantial damage are engine failure damage limited to the engine, bent fairings or cowlings, dented skin, small puncture holes in the skin or fabric, damage to landing gear, wheels, tires, flaps, engine accessories, brakes or wing tips. Generally, if the aircraft can be repaired in a 48 hour period to allow a ferry flight to a repair base, the damage in not considered to be substantial.)

Note 2: Damage to a second unrelated system must impact the ability to continue safe flight and landing. Coordination and agreement between the engine/propeller/APU manufacturer and the airframe manufacturer may be required to properly categorize events related to second system damage. In general aircraft are designed to be dispatched with one part of a redundant system inoperative with no affect on flight safety. Therefore an uncontained rotor event which severed an unrelated hydraulic system line which did not significantly degrade the ability to continue safe flight should not be considered a Hazard Level 3a event.

Note 3: Small penetrations of aircraft fuel lines , or aircraft fuel tanks where the combined penetration areas exceed two square inches will be the basis for a Hazard Level 3a classification. Assistance of the airframe manufacturer should be sought when questions arise.

Note 4: Damage to a second engine (cross engine debris) which results in a significant loss of thrust or pilot action to reduce power (creates an operational problem) is a Hazard Level 3a event. Minor damage, unobserved by the crew during flight and which did not impact the ability of the engine to continue to operate safely for the rest of the flight, is Hazard Level 2.

3b. Uncontrolled fires – not extinguished by on–board aircraft systems. (Note: Internal tailpipe fires that hazard the aircraft are considered uncontrolled fires.)

3c. Rapid depressurization of the cabin.

3d. Permanent loss of thrust greater than one propulsion system.

3e. Temporary or permanent inability to climb and fly 1000 feet above terrain along the intended route. (i.e. multiple propulsion system malfunctions or single malfunctions and/or other aircraft system malfunction/crew error, which results in restricted flight capability (increased threat from terrain, inclement weather, etc.)).

3f. Any temporary or permanent impairment of aircraft controllability (includes propulsion system malfunction and/or thrust reverser in–flight deployment, propeller control malfunction, etc. May be coupled with aircraft control system malfunction or crew error).

Level 2 – Significant Consequences

2a. Nicks, dents and small penetrations in aircraft structure.

2b. Slow depressurization.

2c. Controlled fires (i.e. extinguished by on–board aircraft systems).

2d. Fuel leaks beyond normal extinguishing capabilities, i.e. if fire had resulted. (Note: "All fuel leaks resulting from aircraft fuel cell or fuel line penetrations".)

2e. Minor injuries.

2f. Multiple propulsion system/APU malfunctions, or related events, where one engine remains shutdown but continued safe flight at an altitude 1000 feet above terrain along the intended route is possible.

2g. Any high speed takeoff abort (usually 100 knots or greater).

2h. Separation of propulsion system, inlet, reverser blocker door, translating sleeve inflight without Level 3 damage consequences to the aircraft structure or systems. (Separations on the ground are excluded.)

2i. Partial inflight reverser deployment or propeller pitch change malfunction(s) which do not result in loss of aircraft control or damage to aircraft primary structure.

Level 1 – Minor Consequences

1a. Uncontained nacelle damage confined to affected nacelle/APU area.

1b. Uncommanded power increase, or decrease, at an airspeed above V1 and occurring at an altitude below 3000 feet (includes inflight shutdowns (IFSD) below 3000 feet).

1c. Multiple propulsion system malfunctions or related events, temporary in nature, where normal functioning is restored on all propulsion systems and the propulsion systems function normally for the rest of the flight. Includes common cause environmental hazard induced events.

1d. Separation of propeller/component releases which cause no other damage.

1e. Uncommanded propeller feather.

General Notes Applicable to All Hazard Levels:

(1) The severity of aircraft damage is based on the consequences and damage that actually occurred, or

(2) Damage is classified as serious aircraft damage if the event resulted in the aircraft being exposed to circumstances outside the certified limits.

(3) Uncontained event damage definitions have been modified from those used in SAE AIR 1537/4003/4770 with respect to Hazard Level 3 – secondary system damage event. The objective has been to more clearly define and separate those events which had a major impact on continued safe flight and landing from those with lesser consequences. (See notes on Hazard Level 3a.)