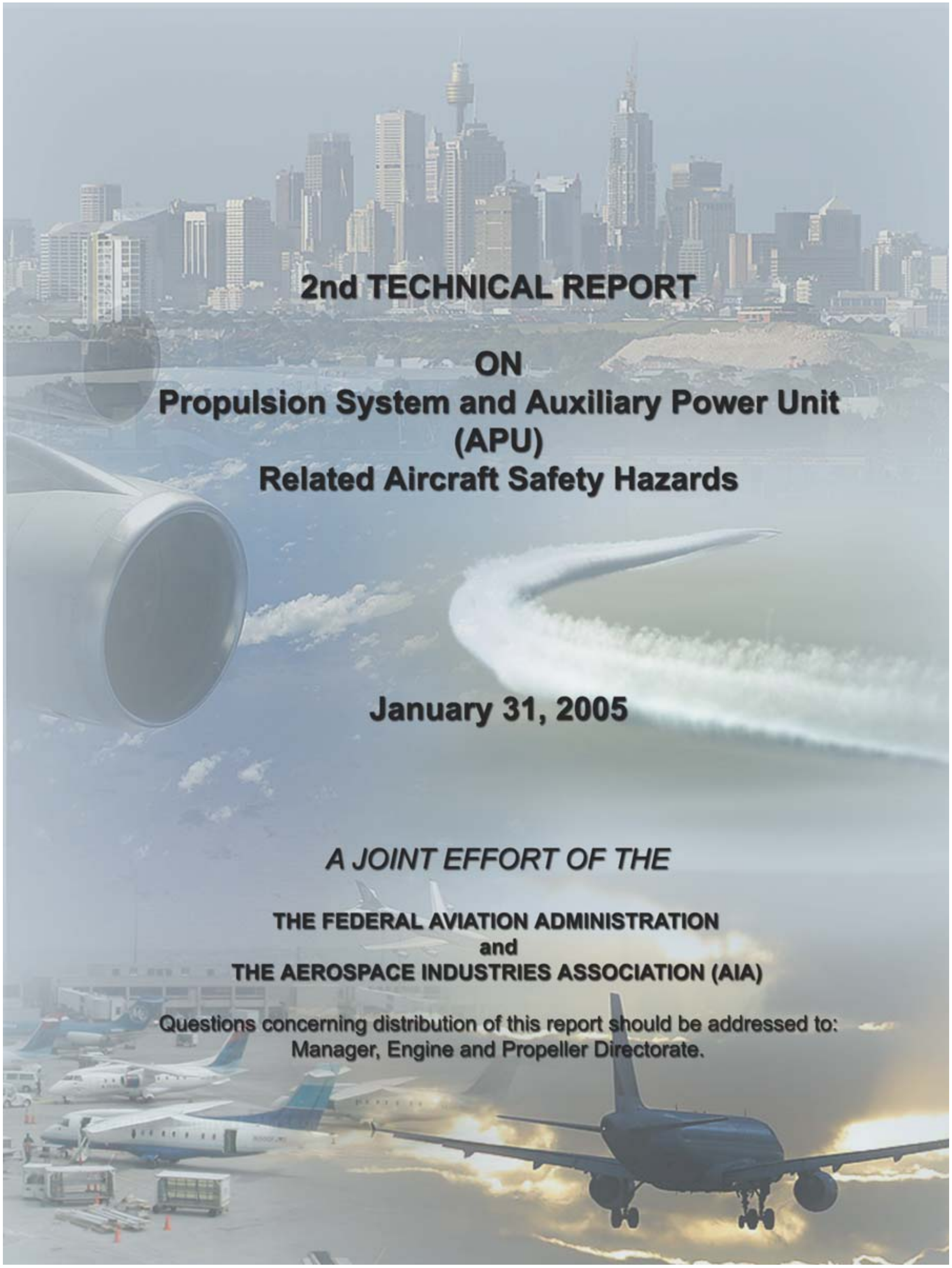

2nd TECHNICAL REPORT

ON
Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards

January 31, 2005

A JOINT EFFORT OF THE

THE FEDERAL AVIATION ADMINISTRATION
and
THE AEROSPACE INDUSTRIES ASSOCIATION (AIA)

Questions concerning distribution of this report should be addressed to:
Manager, Engine and Propeller Directorate.

CONTENTS

I. FOREWORD

The material presented in this "Second CAAM Report" has been developed by experts from industry and the FAA under the auspices of the Aerospace Industries Association (AIA) Propulsion Committee (PC). At the request of the FAA, the AIA PC sanctioned the reconvening of the Continued Airworthiness Assessment Methodologies (CAAM) Committee to update the database of safety-significant propulsion system and APU historical malfunctions and to expand the scope of the database to render it more useful to the FAA's Transport Airplane Directorate.

This report contains the following material:

1. Standardized definitions of safety-significant propulsion system and auxiliary power unit (APU) malfunctions, and rationale for definition changes from the first report;
2. Standardized definitions of propulsion system and APU-related aircraft hazard levels based on the consequences to the aircraft, passengers and crew, and rationale for definition changes from the first report;
3. Data on safety-significant event quantities, hazard ratios, rates and generic summaries for severe and serious events during the period 1992 through 2000; and
4. Pareto prioritization of safety-significant propulsion system and APU malfunctions.
5. Data analysis and conclusions will be provided as an addendum to this report at a later date.

The material presented is not separable and should be considered in its entirety. The safety-significant events were gathered and analyzed based on the malfunction and aircraft hazard level definitions. These definitions are fundamental keys to understanding the data presented and they are unique to this activity. The material presented in the first CAAM report has proved extremely valuable in addressing propulsion-related safety concerns; this second report attempts to address questions and open issues generated by over 15 years use of the first report.

It should be noted that differences in the participating organizations and in event classification norms between the CAAM1 and CAAM2 groups may introduce variation in reported event rates.

It is likely that further opportunities for clarification or improvement of consistency will be identified during the use of the data presented in this report. The users are encouraged to provide comments or suggestions to this effect, which may be used during further updates of the CAAM database.

II. BACKGROUND

In 1993, the Aerospace Industries Association (AIA) provided the Federal Aviation Administration (FAA) with a study aimed at the development of more effective methods to identify, prioritize and resolve safety-related problems occurring on commercial aircraft engines. This initial Continued Airworthiness Assessment Methodologies (CAAM) study covered a variety of propulsion system and auxiliary power unit (APU) events, presenting historical data on event frequency and severity at the airplane level. The information was used by the FAA Engine and Propeller Directorate to help identify and prioritize responses to individual engine, propeller and APU safety concerns. It also proved vital to the development of effective safety initiatives in the propulsion community.

Between 1994 and 2002, the FAA developed a common process, for use by both the Engine & Propeller Directorate and the Transport Airplane Directorate, to assess propulsion safety concerns in service, and to determine what corrective action each concern might merit. This common process, based in part on the CAAM study, was formalized in AC39.xx. It became apparent during the disposition of public comments to the draft AC39.xx (1999 version, eventually published as AC39-8) that the CAAM database needed to be updated to support full use of the AC, and that the spectrum of events addressed needed to be expanded, to address the safety concerns of FAA TAD. An AIA group was tasked with this update in 2001, and collected the data presented in this report.

This report provides historical safety data that document propulsion system and APU-related aircraft safety hazards, for the time-period 1992 to 2000 inclusive. Due to the availability of credible data, the scope is limited to the propulsion systems (including APUs) of western-built transport category airplanes. The event characterization (hazard level) used follows the general practice of the first CAAM report, except in those cases where use of the hazard levels over a decade had disclosed major anomalies and inconsistencies. The CAAM hazard levels are listed in Appendix 1 of this report; with documented rationale for any changes from the hazard level definitions used in the first report.

Nine years of engine, propeller and APU events are analyzed and grouped by event cause (i.e., uncontainment, fire, etc.) and hazard level. Data is presented on safety-significant event quantities, hazard ratios, rates and generic summaries for severe and serious events. The causes are also ranked, in terms of their contribution to the overall propulsion-related accident rate.

III. SCOPE

The data collection for level 3 and higher events covered the time period 1992-2000 inclusive. Data collection for some of the extremely numerous events, such as flammable fluid leaks or false indications, was limited in some cases to a one-year sample and the event incidence over ten years was then extrapolated.

The fleet covered was western-built transport category airplanes in commercial use. A complete categorical listing of airplane types is provided in Appendix 5. It should be recognized that data reporting is most complete from the fleets of major commercial operators; some of the smaller airplanes listed in Appendix 5 may not have had a single event reported to a CAAM committee member. Reporting of turboprop information was especially spotty. Reporting of events on out-of-production airplanes was also problematic. Additionally, there was incomplete participation by several manufacturers.

Military airplanes, even those certified with commercial type-certificates, were excluded on the grounds that the operational environment of military aircraft was not typical of the commercial fleet.

IV. DISCUSSION

1. The data contained in the initial CAAM report have been used by the FAA's Engine and Propeller Directorate since 1994, and have become an important part of the safety management process. This report updates that data to cover the time period 1992 – 2000 and expands the scope of data collected to optimize its usage by the FAA's Transport Airplane Directorate. The report refines and includes the relevant definitions and descriptions integral to the analyses.

2. The conclusions/recommendations developed are as follows:

a. The data should be used to prioritize safety-related industry studies, research and regulatory development activities.

b. The data continue to demonstrate the importance of human factors in propulsion-related flight-safety, especially in the turboprop fleet, and the need for early industry consideration of how these issues can best be addressed. Additionally, reduction of multiple-engine powerloss events, focusing upon the turboprop fleet and also upon fuel exhaustion, deserves early industry attention.

c. The data will be beneficial to safety professionals within industry in placing the various propulsion system and APU-related flight-safety issues into proper context and in guiding decision making related to potential hazards associated with the defined propulsion system and APU malfunctions.

d. Further refinement and development of this second report should continue and user comments and recommendations for enhancements should be solicited. A third report should be prepared within ten years. Preparation of the third report may benefit from consideration of the Lessons Learned presented in Note 7.

e. The process of collecting data to provide context for in-service events should be considered for the entire aircraft.

f. Work should be undertaken to harmonize the implementation of Continued Airworthiness between the FAA and foreign authorities.

g. A follow-on study should be conducted to identify the role of maintenance error in the data collected. It is generally recommended that follow-on studies, addressing a topic in more detail, precede any decision to take regulatory action based on this report.

3. Hazard ratios (conditional probabilities) were generally not calculated for events with no occurrences in the numerator (i.e., no events at the designated hazard level or above.) There should be no assumption that hazard ratios in those instances are 0. See AC39-8 (CAAM AC), Appendix 3, for a discussion of methods for estimating the hazard ratio.

4. The data in this report are organized into the following categories:

a. Turboprop,
b. Low bypass ratio (LBPR) turbofan engines, and
c. High bypass ratio (HBPR) turbofan engines.

For uncontainments and multi-engine events, the HBPR data was also organized by generation. Several of the uncontainments could not be characterized by generation because of lack of information.

5. Where appropriate, non-revenue service events have been included to add information applicable to the calculation of hazard ratios. These events are not counted in the rates per flight summarized in the Paretos below and in Figures 65 - 67.

6. Much of the information in this Report was included, without details, in AC39-8 (CAAM AC), Appendix 8. That AC was issued on September 9, 2003. In the time since the AC was issued and this Report was prepared, additional information was provided that either added new events or revised the information (especially, the reported severity) of certain events. Future revisions of AC39-8 will be adjusted to reflect the additional data.

7. For easy reference, the Pareto of all hazard level 4 and 5 events is presented here, together with the fleet exposure for 1992 through 2000. More detailed analysis is available in Appendix 3, Propulsion System and APU-Related Safety Hazards.

PARETO OF ALL HAZARD LEVEL 4 & 5 EVENTS
REVENUE SERVICE 1992 THROUGH 2000

MALFUNCTIONS		NUMBER EVENTS	RATE PER A/C FLIGHT
PSM+ICR		21	1.29E-7
MULTI-ENGINE POWERLOSS – FUEL-RELATED		13	0.80E-7
Fuel contamination	3		
Fuel mismanagement	1		
Fuel exhaustion	9		
MULTI-ENGINE POWERLOSS – NON-FUEL		10	0.62E-7
Environmental	4		
Maintenance	3		
Other	3		
REVERSER/BETA – IN-FLIGHT DEPLOY		5	0.31E-7
UNCONTAINED - ALL		5	0.31E-7
ENGINE SEPARATION		4	0.25E-7
PROPELLER CREW ERROR		3	1.18E-7
CREW ERROR		3	0.18E-7
REVERSER/BETA – FAILURE TO DEPLOY		3	0.18E-7
PROPELLER SEPARATION/DEBRIS		2	0.79E-7
FUEL TANK RUPTURE/EXPLOSION		2	0.12E-7
PROPELLER PSM+ICR		1	0.40E-7
FALSE/MISLEADING INDICATION		1	0.06E-7
APU - ALL		0	-
UNDER-COWL FIRE		0	-
CASE RUPTURE		0	-
COWL SEPARATION		0	-
CASE BURNTHROUGH		0	-
COMPARTMENT OVERHEAT/AIR LEAK		0	-
FLAMMABLE FLUID LEAK		0	-
PROPULSION SYSTEM FUMES		0	-
OVERSPEED		0	-
TAILPIPE FIRE		0	-
AUTOFEATHER/PITCH LOCK		0	-
TOTAL		**63**	

Note 1. It is recognized that not all of the events that have occurred during the time period 1992-2000 on the applicable fleet were known to the CAAM team, although it is believed that all of the most severe events (i.e., levels 4 and 5) were captured. The reason for this is that participation in this 2nd CAAM update was less comprehensive than desired. Furthermore, the CAAM committee recognizes that not all events may make their way into the reporting organizations' databases. As a result, the data presented here may not represent a completely comprehensive dataset for the less severe events. Therefore, the

hazard ratios developed in this document may be more severe than in actuality; conversely, if rates are developed for lower-level events, these may underestimate the true occurrence rate. As a result, the hazard ratios developed in this document may be conservative; conversely, if rates are developed for lower-level events, these may underestimate the true occurrence rate.

Note 2. The expansion of the data collection to cover a much broader range of events has inevitably created overlap within the event categorization. A single event might be counted as a fuel leak, as an IFSD, and as a fire. On no account should the reader sum events or calculate rates and then sum them; this would likely overstate the total number of events or the overall event rate. Where total event counts and total event rates are presented in this Report, this has been taken into account.

Note 3. This database provides data to supplement engineering judgment. The user is cautioned to make every effort to confirm that the data is indeed applicable to the individual situation being considered by the user, with due regard to installation effects, type-specific architecture and other technical considerations.

Note 4. An attempt was made to collect data on type of operation (passenger, non-revenue, cargo, etc.), but it became apparent that this data was unavailable for the majority of lower-level events. There was some limited success with the collection of data on the flight phase in which the event occurred.

Note 5. A conscious decision was made not to attempt to collect data on maintenance errors. The committee considered that maintenance error was a causal factor, and that the focus of the CAAM database was in collecting events and their airplane-level effects, not their causes. If maintenance error was involved in a level 3 or higher event, it was so noted in the narrative.

FLEET EXPOSURE DURING CAAM STUDIES

	TURBOPROP		**JET/LOW BYPASS PRESSURE RATIO (LBPR)**	
TIME PERIOD	**1982 - 1991**	**1992 - 2000**	**1982 - 1991**	**1992 - 2000**
ENGINE HOURS		43.6E6	19.4E7	10.6E7
ENGINE CYCLES		50.6E6	24.3E7	13.9E7
AIRPLANE FLIGHTS	78.3E7	25.3E6	8.1E7	4.5E7

	ALL HIGH BYPASS PRESSURE RATIO (HBPR)		1ST GENERATION HIGH BYPASS RATIO		2ND GENERATION HIGH BYPASS RATIO	
TIME PERIOD	**1982 - 1991**	**1992 - 2000**	**1982 - 1991**	**1992 - 2000**	**1982 - 1991**	**1992 - 2000**
ENGINE HOURS	23.1E7	51.4E7	15.3E7	11E7	7.8E7	40.2E7
ENGINE CYCLES	9.3E7	22.8E7	4.5E7	3E7	4.9E7	19.8E7
AIRPLANE FLIGHTS	3.9E7	10.1E7	1.4E7	0.9E7	2.3E7	9.2E7

Note 6. In this context, 2nd generation high-bypass turbofans are considered to be as defined in the SAE report AIR4770. This includes the following: ALF502, LF507, AE3007, CFE738, TFE731-20/40/60, CF6-80A, CF6-80C and later CF6 models, CFM56-2, CFM56-3 and later CFM56 models, GE90, V2500, PW2000, PW4000, RB211-535C, RB211-524B4 and later RB211 models, RR Tay and Trent.

Note 7. The following Lessons Learned should be considered while scoping and executing data collection for a third report:

- The expansion of the report scope from the events covered in CAAM1 imposed a considerable burden upon the data-collection process and significantly delayed publication of the report. It is recommended that further expansions in any updates be carefully scrutinized for feasibility. Furthermore, where no higher-level events have occurred and sufficient data has been collected on low-level events to demonstrate a very low hazard ratio, updates may not be deemed necessary.
- Data was not collected on unintended reverser deploy on the ground. There may be other event scenarios where the potential for a Catastrophic outcome is evident, but no such outcome has occurred as yet. Collection of data on the number of lower-level events of this nature may be considered in future activities, with due regard given to the capability of the data-collection system to observe and record such an event.

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Thanks are also due to Helynne Jette of Bombardier, Sergio Carvalho of Embraer, and Mick Sanders of Rolls-Royce.

V. APPENDICES

Appendix 1

Standardized Aircraft Event Hazard Levels and Definitions

This appendix outlines the definitions of propulsion system and auxiliary power unit (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. Although level 1 and level 2 are not controlled in the regulatory requirements for Continued Airworthiness, it is recognized that some manufacturers have found it useful to discriminate between level 1 events and level 2 events; thus, the level 1 and level 2 definitions are presented here. This presentation does not imply that FAA Transport Airplane Directorate concurs with these definitions. These definitions do not necessarily align with FAR 25.

It is important to emphasize that all event classification is based on what actually occurred rather than what might have occurred. It is inappropriate to inflate the hazard level for an event in the name of conservatism; such a practice is likely to lead to confusion and dissension, and a reduction in the ability to differentiate between the risks posed by different unsafe conditions.

LEVEL 0 – CONSEQUENCES WITH NO SAFETY EFFECT.

a. In-flight shutdown of a single engine with no airplane-level effect other than loss of thrust and associated services, above an altitude of 3000 feet.

b. Casing uncontained engine failure, contained within the nacelle.

c. Malfunctions or failures that result in smoke and/or fumes that have no effect on crew or passengers beyond their notice of the event. The production of smoke or fumes as a consequence of some failures or malfunctions is an expected condition for which the airplane is designed and crew procedures are established and no unsafe condition exists.

LEVEL 1 - MINOR CONSEQUENCES.

a. Uncontained nacelle damage confined to affected nacelle/APU area.

b. Uncommanded power increase, or decrease, at an airspeed above V1 and occurring at an altitude below 3,000 feet (includes in-flight shutdowns (IFSD) below 3,000 feet).[1]

[1] The concern regarding such power changes is pilot workload. Power changes affecting controllability are considered to be more severe.

c. 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.

d. Separation of propeller/components which cause no other damage.

e. Uncommanded propeller feather.

f. Propulsion system (engine or propeller) malfunctions resulting in severe vibration. In this context, high vibration is a load and frequency spectrum which exceeds the level demonstrated for compliance with §§ 33.23, 25.361, or 25.903(c) or their equivalent (e.g., engine malfunctions resulting in an imbalance exceeding the level of imbalance demonstrated under § 33.94 or its equivalent).

LEVEL 2 - SIGNIFICANT CONSEQUENCES.

a. Nicks, dents and small penetrations in any aircraft principal structural element[2].

b. Slow depressurization.

c. Controlled fires (i.e., inside fire zones[3]). Tailpipe fires that do not impinge upon aircraft structure, or present an ignition source to co-located flammable material, are considered level 2 also.

d. (1) Flammable fluid leaks that present a fire concern[4]. Specifically fuel leaks in the presence of an ignition source and of sufficient magnitude to produce a large fire.

d. (2) Fuel leaks that present a range concern for the airplane.

e. Minor injuries.

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[2] The previous definition related to "aircraft primary structure". There was considerable debate over what was considered primary structure.

[3] The previous definition stated that controlled fires were those which were extinguished by normal on-board fire extinguishing equipment. This led to the classification of a number of events as uncontrolled fires, which did not appear to the committee to meet the intent of the definition. For instance, fires which could easily have been extinguished by the onboard system had the pilot chosen to use it, small fires which were immediately extinguished by ground crew so that the pilot had no opportunity to use the onboard system, and fires which due to their location were not extinguishable by the onboard system but nevertheless presented no threat to the aircraft (such as grass fires) – all of these were categorized as "uncontrolled" according to the previous definition. The CAAM committee concluded that a better definition of the term "controlled" was whether the fire had impinged upon, or could have impinged upon, the remainder of the airplane.

[4] It is recognized that the words "present a concern" initially appear inconsistent with the philosophy of deciding hazard levels according to what actually happened. The qualifiers for 2.d. were found to be necessary to eliminate those fuel leaks that were so small that, although outside maintenance manual limits, they had no airplane-level effect. Further consideration confirms that the severity level for 2.d. is based on the actual fuel leak, not on the potential consequence of uncontrolled fire or fuel exhaustion.

f. Multiple propulsion system or APU malfunctions, or related events, where one engine remains shutdown but continued safe flight at an altitude 1,000 feet above terrain along the intended route is possible. This carries with it an assumption that the aircraft is at least under partial power for any length of time longer than transient events (see note associated with level 3.e.)

g. Any high-speed takeoff abort (usually 100 knots or greater).

h. Separation of propulsion system, inlet, reverser blocker door, translating sleeve or similar substantial pieces of aerodynamic surface without level 3. Separations on the ground in the process of cycling the reverser are excluded (i.e., low speed, post-thrust reversal.)

i. Partial in-flight reverser deployment or propeller pitch change malfunction without level 3 consequences.

j. Malfunctions or failures that result in smoke or toxic fumes that cause minor impairment or minor injuries to crew and/or passengers.[5]

LEVEL 3 - SERIOUS CONSEQUENCES.

a. Substantial damage to the aircraft or second unrelated system.

(1) "Substantial damage[6]" in this context means damage or structural failure that adversely affects the limit loads capability of a primary structural element, the performance or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected components. (Typically not considered “substantial damage” are engine failure damage limited to the engine or mount system, bent fairings or cowlings, dented skin, small puncture holes in the skin or fabric, or damage to landing gear associated with runway departures, wheel, tires, flaps, engine accessories on the failed engine, brakes or wing tips).

(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.

(3) Small penetrations of aircraft fuel lines or aircraft fuel tanks, where the combined penetration areas exceed two square inches[7]. Assistance of the airframe manufacturer should be sought when questions arise.

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[5] A level 2 event may result in an emergency being declared to initiate ATC priority sequencing. This does not inherently imply that the event was a level 3.
[6] This definition departs somewhat from the NTSB definition. Clarification was found advisable by the team after some difficulties in using the NTSB definition.
[7] The concern is exhaustion of fuel reserves.

(4) Damage to a second engine (cross-engine debris) which results in a significant loss of thrust or an operational problem requiring pilot action to reduce power. Minor damage which was not observed by the crew during flight and which did not affect the ability of the engine to continue safe operation for the rest of the flight is excluded, being considered a level 2 event.

b. Uncontrolled fires – which escape the fire zone and impinge flames onto the wing or fuselage, or act as ignition sources for flammable material anticipated to be present outside the fire zone.

c. Rapid depressurization of the cabin.

d. Permanent loss of thrust or power greater than one propulsion system.

e. Temporary or permanent inability to climb and fly 1000 feet above terrain (increased threat from terrain, inclement weather, etc.) along the intended route.
Note: For multiple-engine events that resulted in temporary total powerloss, the following criteria were considered to place an event within level 3.e.: occurrence below 10,000 feet AGL or the loss of more than 5,000 feet altitude (as in situations wherein the airplane must descend to a suitable altitude prior to attempting restart). Consideration of transitory events of total powerloss below 10,000 feet should consider length of transient vs. closeness to the ground as part of this evaluation.

f. Any temporary or permanent impairment of aircraft controllability caused by propulsion system malfunction, thrust reverser in-flight deployment, propeller control malfunction, or propulsion system malfunction coupled with aircraft control system malfunction, abnormal aircraft vibration, or crew error.

g. Malfunctions or failures that result in smoke or other fumes on the flight deck that result in a serious impairment. Serious impairment includes the loss of crew's ability to see flight deck instrumentation or perform expected flight duties. Purely psychological aspects of the concern of odors, etc, are not to be included; nor are concerns about long-term exposure.

LEVEL 4 - SEVERE CONSEQUENCES.

a. Forced landing. Forced landing is defined as the inability to continue flight where imminent landing is obvious but aircraft controllability is not necessarily lost (e.g., total powerloss due to fuel exhaustion will result in a "forced landing"). 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 they will perform the landing.[8] However, off-airport landings are almost always forced landings.

[8] Where it is unclear whether the landing was forced, it may be helpful to consider whether the pilot had any alternative to landing at the closest airport .

b. Actual loss of aircraft (as opposed to economic) while occupants were on board[9].

c. Serious injuries or fatalities.[10]

LEVEL 5 - CATASTROPHIC CONSEQUENCES.

Catastrophic outcome[11]. An occurrence resulting in multiple fatalities, usually with the loss of the airplane.

GENERAL NOTES APPLICABLE TO ALL EVENT HAZARD LEVELS.

a. The severity of aircraft damage is based on the consequences and damage that actually occurred.

b. Injuries resulting from an emergency evacuation rather than from the event that caused the evacuation are not considered in evaluating the severity of the event. It is recognized that emergency evacuations by means of the slides can result in injuries, without regard to the kind of event precipitating the evacuation.

c. It is recognized that there is some overlap between the definitions of hazard levels and the characterization of events, particularly for the lower hazard levels (for example, uncontrolled fire). Efforts were made to develop more objective hazard level definitions, rather than defining by example; these efforts were not successful.

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[9] Hull losses where the airplane could have been repaired, but repair would not have been cost effective, are excluded. Additionally, hull losses that occurred well after the event because appropriate action was not taken to further mitigate damage (i.e., fire breaking out because no fire equipment was available) are not considered hull losses for the purposes of this threat evaluation. Some degree of judgment may be required in determining whether the hull loss qualifies for inclusion.

[10] In this context, serious injuries are intended as injuries of a life-threatening nature. This is different from the NTSB definition, which would include most simple fractures.

[11] Extension of the use of the CAAM database to the entire propulsion system was associated with a desire to discriminate between the kind of events that resulted in a small number of serious injuries or fatalities, and those that resulted in serious injuries or fatalities to most or all of the airplane occupants. This was felt to be a useful discriminator by Transport Airplane Directorate. CAAM Level 4, as defined in the original report, was therefore split into two levels, level 4 and level 5.

Appendix 2

Definitions

1. PURPOSE. This appendix outlines the major propulsion system malfunction definitions and the aircraft hazard matrix, as developed by the Aerospace Industries Association (AIA) Committee on Continued Airworthiness Assessment Methodologies (CAAM), PC342.

2. MISCELLANEOUS.

a. Hazard level. Levels of threat, as defined by their effect on the airplane, passengers and crew. Appendix 1 provides a definition of these established hazard levels.

b. Hazard ratio. The conditional probability that a particular powerplant installation failure mode will result in an event of a specific hazard level.

3. SINGLE PROPULSION SYSTEM EVENT.

a. Uncontained. A significant safety event that initiates from an uncontained release of debris from a rotating component malfunction (blade, disk, spacer, impeller, drum/spool). In order to be categorized as uncontained, the debris must pass completely through the nacelle envelope. Parts that puncture the nacelle skin but do not escape or pass completely through are considered contained. Fragments that pass out of the inlet or exhaust opening without passing through any structure are not judged to be "uncontained." Starter and gearbox uncontainments are specifically excluded.

b. Engine overspeed. Engine acceleration to a rotor speed above that sanctioned in the type-certificate datasheet.

c. Case rupture. A significant safety event that initiates from a sudden rupture of a high-pressure vessel or case with the resultant release of high-pressure gases into the under-cowl cavity. Case ruptures resulting from uncontained release of debris from a rotating component malfunction are excluded. Case ruptures include those events that propagate from fatigue-type cracks as well as ruptures related to secondary malfunctions (e.g., flame impingement). See 3.d. below.

d. Case burnthrough. Case burnthrough is defined as a local case penetration that initiates from local overtemperature of the case external wall due to an internal engine malfunction (e.g., fuel nozzle leakage, internal bearing compartment fires, titanium fires). Burnthroughs are distinguished from ruptures by their lack of an explosive release of high-pressure gas. A common cause of case burnthrough is localized penetration due to fuel nozzle malfunction. Events involving accessory component cases also contribute to this category; for example, sump fires that propagate internally and result in burnthrough of piping or that initiate gearbox fires. The key aspect, whether in the primary gas path or accessories, is that fire initiates from an internal malfunction and proceeds to burn through a case, tube or gearbox to reach external regions.

e. Under-cowl fire. A safety-significant propulsion system fire-related event involving combustion external to the engine casings. Under-cowl fires are those that occur within the nacelle and on the engine side of the strut or installation fire barrier/wall. Internal pylon fires, including events where fuel leaks from the pylon and initiates a fire under the cowl, are to be excluded. Under-cowl may be within fire zones or flammable fluid zones. Tailpipe fires, and hot air leaks resulting in fire warnings, without combustion, are excluded from the definition and documented separately. Fires that remain internal to the engine casing are excluded[12].

f. Flammable fluid leak. Leak of fuel, oil or hydraulic fluid into the pylon or dry bay, or under the engine cowls, which could credibly lead to a fire.[13] Leaks collected from shrouds and components and drained directly overboard by a dedicated drain were excluded from those leaks under consideration due to their lack of being fire safety concerns. Drips and seeps were also excluded. In-tank leakage was excluded.

g. Compartment overheat/air leak. High-pressure or temperature air leaks due to casing or high-pressure /temperature air duct system malfunctions within the nacelle or in the pylon.

h. Engine separation. Separation of the engine, with or without the strut/pylon. Events resulting from ground contact are excluded.

i. Cowl separation. Separation of nacelle components such as inlets, cowls, thrust reversers, exhaust nozzles, tail plugs, etc. Separation of relatively small sections of skin, blow-out panels or other small pieces that are unlikely to hazard continued safe flight and landing are excluded. Events resulting from ground contact are excluded.

j. Propulsion system malfunction and inappropriate crew response (PSM+ICR). A significant safety event initiating from a single propulsion system malfunction (excluding propeller system), which, by itself, does not hazard the aircraft, but is compounded by inappropriate crew response (i.e., crew did not execute checklist/normal flying duties). A typical example of PSM+ICR is an IFSD followed by inappropriate crew response that caused the aircraft to crash. Not counted are cases of gross error negligence (such as

[12] Interest was expressed in collecting information on internal engine fires, since they might result in shaft or disk failures. However, since data was already being collected on uncontained events–regardless of the originating failure leading to the uncontainment–this approach was not pursued.

[13] Attempts were made to categorize the leaks by the location of the leak, the nature of the leaked fluid, the pressure of the leakage source and the magnitude of the leakage rate. The level of detail in the event records resulted in only partial success in this effort. Efforts to reach consensus on the quantity of leakage presenting a fuel exhaustion concern were unsuccessful; data in this category was therefore not presented.

deciding to take off with an engine known to be inoperative). See the AIA/AECMA Project Report on PSM+ICR (November, 1998) for additional examples.

k. Crew error. A significant safety event caused by a propulsion system malfunction or improper operation that was caused by an inappropriate crew action, excluding sabotage, gross negligence and suicide. Not counted are events where inappropriate crew action causes a propulsion system malfunction through very indirect means such as flying the airplane into the ground or running the airplane into equipment on the taxiway/runway.

l. Reverser/beta malfunction – in-flight deploy. A significant safety event wherein a thrust reverser deploys in-flight, or a propeller enters beta mode in-flight (exclusive of design intent).

m. Reverser/beta malfunction – failure to deploy. A significant safety event resulting from the failure of a thrust reverser to deploy or a propeller to enter beta mode when commanded.

n. Fuel tank rupture/explosion. A burst failure of a fuel tank or explosion within a fuel tank.

o. Tailpipe fire. Fire within the tailpipe, where visible sustained flames exit the tailpipe. Engine surge/stall and hot starts resulting in a "glow" are excluded, as are events resulting from deicing fluid ingestion[14].

p. False/misleading indication. Indication that was appreciably different from reality, to the point where an indication difference was noticed by the pilot or subsequent investigation. [15] This included parameters that were higher than actuality, lower than actuality or completely absent, and also discrete warnings or alerts that were falsely present or absent[16]. Individual EICAS messages were excluded since these were very type-specific and numerous.

4. MULTIPLE-ENGINE POWERLOSS EVENT.[17]

a. Environmental. A significant safety event initiating from essentially simultaneous power loss from multiple propulsion systems for an environmental cause (e.g., bird, ice, rain, hail, or volcanic ash ingestion).

[14] Due to the limited volume of deicing fluid available for combustion.
[15] Undetected false /misleading indications were not reported, since data was unavailable.
[16] No initial assumptions were made over whether a false indication would in fact be misleading. Individual EICAS messages (as opposed to mandated indications) were excluded.
[17] Transient events are included if they were perceptible to the flight crew.

b. Maintenance. A significant safety event initiating from multiple propulsion system powerloss from clearly improper maintenance (e.g., failure to restore oil system integrity after inspection).

c. Other/unknown. A significant safety event initiating from multiple propulsion system powerloss for reasons other than those characterized elsewhere, or where the initiating event(s) are unknown. This includes unrelated events of engine powerloss within the same flight.

d. Fuel contamination. A significant safety event initiating from power loss from multiple propulsion systems from fuel contamination. Sequential power loss and recovery is excluded.

e. Fuel mismanagement. A significant safety event initiating from power loss from multiple propulsion systems from improper management of the airplane fuel system (e.g tank crossfeed). Sequential power loss and recovery is excluded.

f. Fuel exhaustion. A significant safety event initiating from power loss from multiple propulsion systems from complete exhaustion of the airplane fuel reserves. Sequential power loss and recovery is excluded.

5. APU SYSTEM EVENT.

A significant APU-related safety event as follows:

a. Uncontained. An uncontained rotating component malfunction that allows debris to exit through the APU containment casings.

b. Axial uncontained. Major rotating components that exit the APU containment casings in an axial direction (i.,e., without penetrating the case).

c. Overspeed. Acceleration of a rotor beyond the speed sanctioned in the Type Certificate Data Sheet.

d. Fire. Combustion external to the APU casings. Tailpipe fire data and hot air leaks resulting in fire warnings, without combustion, are excluded from the definition and documented separately.

e. Tailpipe fire. Fires within the tailpipe and exiting the tailpipe, where flames are visible. Hot starts resulting in a "glow" are excluded.

f. Compartment overheat. High-temperature air leaks due to casing high-pressure/temperature air duct system malfunctions within the APU.

6. PROPELLER SYSTEM EVENT. An event that initiates from a malfunction or misuse of the propeller system as follows:

a. Propeller separation/debris release. Separation of single or multiple blades, or large piece thereof, due to blade or hub malfunction. Note that events occurring after groundstrike are included for their information on their threat to the aircraft or its occupants.

b. Autofeather/pitch lock. Propeller system malfunction leading to inability to control the propeller. Control hunting is excluded as a normal product behavior.

c. Propeller system malfunction plus inappropriate crew response (Propeller PSM+ICR). A significant safety event initiating from a propeller system malfunction which, by itself, does not hazard the aircraft, passengers, or crew, but is compounded by inappropriate crew response.

d. Crew error. A significant safety event caused by a propeller system malfunction or improper operation that was caused by an inappropriate crew action, excluding sabotage, gross negligence and suicide (e.g., operation in beta mode in violation of operating instructions). Not included are events where inappropriate crew action causes a propeller system malfunction through very indirect means such as flying the airplane into the ground or running the airplane into equipment on the taxiway/runway.

7. PROPULSION SYSTEM FUME EVENT. Significant smoke and/or fumes on the flight deck or cabin that are generated by the propulsion system.

Appendix 3

Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards (1992 through 2000)

UNCONTAINED BLADE – 1992-2000
TURBOPROP AND JET/LOW BYPASS

FIGURE 1. UNCONTAINED BLADE – TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY MODULE								
FAN					6	1	0	1
Platforms					1	0	0	0
LPC	0	0	0	0	1	0	0	0
IPC	0	0	0	0	0	0	0	0
HPC	0	0	0	0	2	0	0	0
HPT	0	0	0	0	2	0	0	0
IPT	1	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	0	0	0	0	9	0	0	0
TOTAL	**1**	**0**	**0**	**0**	**21**	**1**	**0**	**1**

UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 1
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 1
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 2
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 22

FIGURE 2. HAZARD RATIOS FOR UNCONTAINED BLADE TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP			JET/ LOW BYPASS		
HAZARD LEVEL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL
HAZARD RATIO BY MODULE						
FAN				2/6= .333	1/6= .333	1/6= .333
Platforms				0/1= *	0/1= *	0/1= *
LPC	0/0= *	0/0= *	0/0= *	0/1= *	0/1= *	0/1= *
IPC	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
HPC	0/0= *	0/0= *	0/0= *	0/2= *	0/2= *	0/2= *
HPT	0/0= *	0/0= *	0/0= *	0/2= *	0/2= *	0/2= *
IPT	0/1= *	0/1= *	0/1= *	0/0= *	0/0= *	0/0= *
LPT/PT	0/0= *	0/0= *	0/0= *	0/9= *	0/9= *	0/9= *
ALL BLADES	0/1= *	0/1= *	0/1= *	2/21= .10	1/21= .05	1/21= .05

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – Uncontained blade – Hazard level 4 or 5.

Engine Type	**Event Summary**
Low Bypass	Bird ingestion, fan debris holed fuel tank (installed between 2 fuselage-mounted engines); airplane fire; all 10 occupants killed (hazard level 5.)

Event summaries – Uncontained blade – Hazard level 3.

Engine Type	**Event Summary**
Low Bypass	Bird ingestion 10 feet off ground; No. 3 uncontained; cross-debris destroyed No. 4 and cut several hydraulic lines and control cables. Extensive damage (hazard level 3.a.) **Event also included in Multiple-engine powerloss – non-fuel, Fig. 49.**

UNCONTAINED BLADE – 1992-2000
1ST AND 2ND GENERATION HIGH BYPASS

FIGURE 3. UNCONTAINED BLADE – HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS BY MODULE												
FAN	39	1	0	0	16*	1	0	0	17*	0	0	0
Platforms	1	0	0	0	1	0	0	0	0	0	0	0
LPC	0	0	0	0	0	0	0	0	0	0	0	0
IPC	0	0	0	0	0	0	0	0	0	0	0	0
HPC	0	0	0	0	0	0	0	0	0	0	0	0
HPT	2	0	0	0	1	0	0	0	1	0	0	0
IPT	0	0	0	0	0	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	56	1	0	0	41†	1	0	0	13†	0	0	0
TOTAL	98	2	0	0	59	2	0	0	31	0	0	0

* 6 FAN BLADES UNKNOWN GENERATION.
† 2 LPT BLADES UNKNOWN GENERATION.

UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 2
UNCONTAINED BLADE TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 98

FIGURE 4. HAZARD RATIOS FOR UNCONTAINED BLADE HIGH BYPASS TOTAL AND BY GENERATION

ENGINE TYPE	**ALL HIGH BYPASS**			**1ST GENERATION**			**2ND GENERATION**		
HAZARD LEVEL	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**
HAZARD RATIO BY MODULE									
FAN	1/39 = .03	0/39 = *	0/39 = *	1/16 = .06	0/16 = *	0/16 = *	0/17 = *	0/17 = *	0/17 = *
Platforms	0/1 = *	0/1 = *	0/1 = *	0/1 = *	0/1 = *	0/1 = *	0/0 = *	0/0 = *	0/0 = *
LPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
IPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
HPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
HPT	0/2 = *	0/2 = *	0/2 = *	0/1 = *	0/1 = *	0/1 = *	0/1 = *	0/1 = *	0/1 = *
IPT	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
LPT/POWER TURBINE (PT)	1/56 = .02	0/56 = *	0/56 = *	1/41 = .02	0/41 = *	0/41 = *	0/13 = *	0/13 = *	0/13 = *
ALL BLADES	2/98 = .02	0/98 < .01	0/98 < .01	2/59 = .03	0/59 = *	0/59 = *	0/31 = *	0/31 = *	0/31 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

NOTE: 6 FAN BLADES UNKNOWN GENERATION.
2 LPT BLADES UNKNOWN GENERATION.

Event summaries – Uncontained blade – Hazard level 4 or 5.

No events.

Event summaries – Uncontained blade – Hazard level 3.

Engine Type	**Event Summary**
High Bypass	Number 1 engine fan blade fracture; inlet cowl penetrated forward of A flange. Engine IFSD; debris crossed over and penetrated No. 2 engine pylon hydraulic reservoir, causing loss of fluid (hazard level 3.a.) 1st generation.
	Number 1 engine LPT nozzle spinning and uncontainment at takeoff rotation. Nicks and dents, small punctures to wing underside; FOD to No. 3 engine requiring power reduction. Neither engine shutdown; positive rate of climb (hazard level 3.a.) 1st generation.

UNCONTAINED DISK[18] – 1992-2000 TURBOPROP AND JET/LOW BYPASS

FIGURE 5. UNCONTAINED DISK – TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY MODULE								
FAN					2	1	1	0
LPC	1	0	0	0	0	0	0	0
IPC	0	0	0	0	0	0	0	0
HPC	0	0	0	0	4	2	1	0
HPT	3	0	1	0	0	0	0	0
IPT	0	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	2	0	0	0	0	0	0	0
TOTAL	**6**	**0**	**1**	**0**	**6**	**3**	**2**	**0**

UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 3
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 6
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 12

FIGURE 6. HAZARD RATIOS FOR UNCONTAINED DISK TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP			JET/ LOW BYPASS		
HAZARD LEVEL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL
HAZARD RATIO BY MODULE						
FAN				2/2= 1.0	1/2 = .50	0/2 = *
LPC	0/1= *	0/1= *	0/1= *	0/0= *	0/0= *	0/0= *
IPC	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
HPC	0/0= *	0/0= *	0/0= *	3/4 = .75	1/4 = .25	0/4= *
HPT	1/3= .33	1/3= .33	0/3= *	0/0= *	0/0= *	0/0= *
IPT	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
LPT/PT	0/2= *	0/2= *	0/2= *	0/0= *	0/0= *	0/0= *
ALL DISKS	1/6 = .17	1/6 = .17	0/6 = *	5/6 = .83	2/6 = .33	0/6 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

[18] Includes disks, spools, hubs, impellers.

Event summaries – Uncontained disk – Hazard level 4 or 5.

Engine Type	Event Summary
Turboprop	Uncontained HPT failure and fire just after lift-off. The pilot landed immediately on the remaining runway length. The aircraft overran the end of the runway, breaking off the nose landing gear and deforming the fuselage. Hull loss (hazard level 4.b.)
Low Bypass	Fan hub fracture during takeoff roll, liberating the hub. Accompanying fan blade fragments penetrated the fuselage (passenger cabin). Two fatalities (hazard level 4.c., 3.a.)
	High-pressure compressor disk fragment fractured during takeoff roll. Disk fragment penetrated through fuel line in fuselage. Aircraft destroyed by the internal fuselage fire. One injury (hazard level 4.b., 4.c.)

Event summaries – Uncontained disk – Hazard level 3.

Engine Type	Event Summary
Low Bypass	Fan hub fractured during takeoff after liftoff, releasing 2 and 4 adjacent fan blades. Engine was fuselage-mounted. Substantial damage to the fuselage at the engine installation; fire continued after discharge of both bottles (hazard level 3.a., 3.b.)
	Ninth stage compressor disk segment uncontained; debris penetrated left wing and cut hydraulic lines (hazard level 3.a.)
	During takeoff; uncontained HPC impeller failure; debris caused significant damage to the airframe, including penetration of the fuselage aft of the main rear bulkhead. Fan/LPC assembly released, overtaking the aircraft and coming to rest in a field. Engine had to be shutdown via the firewall shutoff valve (hazard level 3.a.)

UNCONTAINED DISK – 1992-2000
1ST AND 2ND GENERATION HIGH BYPASS

FIGURE 7. UNCONTAINED DISK – HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS BY MODULE												
FAN	1	0	1	0	1	0	1	0	0	0	0	0
LPC	0	0	0	0	0	0	0	0	0	0	0	0
IPC	1	1	0	0	1	1	0	0	0	0	0	0
HPC	8	2	0	0	5	1	0	0	3	1	0	0
HPT	5	2	0	0	2	1	0	0	3	1	0	0
IPT	0	0	0	0	0	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	12	2	0	0	9*	2	0	0	0*	0	0	0
TOTAL	27	7	1	0	18	5	1	0	6	2	0	0

* 3 LPT DISKS UNKNOWN GENERATION.

UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 1
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 8
UNCONTAINED DISK TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 27

FIGURE 8. HAZARD RATIOS FOR UNCONTAINED DISK HIGH BYPASS TOTAL AND BY GENERATION

ENGINE TYPE	ALL HIGH BYPASS			1ST GENERATION			2ND GENERATION		
HAZARD LEVEL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL
HAZARD RATIO BY MODULE									
FAN	1/1 = 1.0	1/1 = 1.0	0/1 = *	1/1 = 1.0	1/1 = 1.0	0/1 = *	0/0 = *	0/0 = *	0/0 = *
LPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
IPC	1/1 = 1.0	0/1 = *	0/1 = *	1/1 = 1.0	0/1 = *	0/1 = *	0/0 = *	0/0 = *	0/0 = *
HPC	2/8 = .25	0/8 = *	0/8 = *	1/5 = .20	0/5 = *	0/5 = *	1/3 = .33	0/3 = *	0/3 = *
HPT	2/5 = .20	0/5 = *	0/5 = *	1/2 = .50	0/2 = *	0/2 = *	1/3 = .33	0/3 = *	0/3 = *
IPT	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
LPT/POWER TURBINE (PT)	2/12 = .17	0/12 = *	0/12 = *	2/9 = .22	0/9 = *	0/9 = *	0/0 = *	0/0 = *	0/0 = *
ALL DISKS	8/27 = .30	1/27 = .04	0/27 = *	6/18 = .33	1/18 = .06	0/18 = *	2/6 = .33	0/6 = *	0/6 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

NOTE: 6 LPT DISKS UNKNOWN GENERATION.

Event summaries – Uncontained disk – Hazard level 4 or 5.

Engine Type	**Event Summary**
High Bypass	Uncontained fan disk failure on takeoff roll. Takeoff aborted; fire to empennage. Hull loss (hazard level 4.b.) 1st generation.

Event summaries – Uncontained disk – Hazard level 3.

Engine Type	Event Summary
High Bypass	HPC spool fracture. Fuel tank punctured; core and fan cowls separated; small, transient under-cowl hydraulic fluid fire. Minor fan blade damage to opposite engine, not affecting thrust (hazard level 3.a.) 1st generation.
	No. 3 uncontained high compressor disk failure during takeoff roll; crew rejected takeoff due to firewarning. Debris bounced off runway and struck No. 1 engine, causing damage, fire, engine firewarning and uncommanded shutdown (hazard level 3.a., 3.d.) **Event also included in Multiple-engine powerloss – non-fuel, Fig. 51.** 1st generation.
	Number 3 engine uncontained HPT failure during climb. Debris cut fuel line and started fire. Small debris also impacted the No. 4 engine. Fire being blown onto wing leading edge was extinguished by fuel shutoff; ground crew extinguished remaining small fire on engine. (hazard level 3.a., 3.b.) 1st generation.
	LPT disk failure causing holes in lower and upper wing leading edge and loss of engine indications on adjacent engine, which was shutdown by crew (hazard level 3.a., 3.d.) **Event also included under Multiple-engine powerloss – non-fuel, Fig. 51.** 1st generation.
	During climb, LPT uncontained failure that severed hydraulic lines in the equipment bay and separated the bay door. After landing, the crew did not have sufficient control to stay on the taxiway, and the airplane came to rest in the grass (hazard level 3.a.) 1st generation.
	HPC spool fracture during low-speed takeoff; severed fuel line on engine and fire detector loops, causing uncontrolled fire, which was extinguished by ground crew (hazard level 3.b.) 2nd generation.
	Ground run. HPT disk fracture; 1/3 disk penetrated front spar/fuel tank structure, causing uncontrolled fuel fire around engine. Heat damage to lower wing surface panels; dents to fuselage (hazard level 3.a., 3.b.) 2nd generation.

UNCONTAINED - OTHER[19] – 1992-2000
TURBOPROP, JET and LOW BYPASS

FIGURE 9. UNCONTAINED - OTHER – TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS BY MODULE								
FAN					0	0	0	0
LPC	0	0	0	0	0	0	0	0
IPC	0	0	0	0	0	0	0	0
HPC	0	0	0	0	0	0	0	0
HPT	1	0	0	0	0	0	0	0
IPT	0	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	0	0	0	0	0	0	0	0
UNKNOWN	1	0	0	0	0	0	0	0
TOTAL	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 0
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 2

[19] Includes spinners, cooling plates, spacers, air seals

FIGURE 10. HAZARD RATIOS FOR UNCONTAINED - OTHER TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP			JET/ LOW BYPASS		
HAZARD LEVEL	**(3+4+5) /ALL**	**(4+5) /ALL**	**5 /ALL**	**(3+4+5) /ALL**	**(4+5) /ALL**	**5 /ALL**
HAZARD RATIO BY MODULE						
FAN				0/0= *	0/0= *	0/0= *
LPC	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
IPC	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
HPC	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
HPT	0/1= *	0/1= *	0/1= *	0/0= *	0/0= *	0/0= *
IPT	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
LPT/PT	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *	0/0= *
UNKNOWN	0/1= *	0/1= *	0/1= *	0/0= *	0/0= *	0/0= *
ALL OTHER	0/2 = *	0/2 = *	0/2 = *	0/0= *	0/0= *	0/0= *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

<u>Event summaries – Uncontained - other - Hazard level 3, 4 or 5.</u>

No events.

UNCONTAINED - OTHER – 1992-2000
HIGH BYPASS AND 2ND GENERATION HIGH BYPASS

FIGURE 11. UNCONTAINED - OTHER – HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY MODULE												
FAN	2	1	0	0	1*	1	0	0	0*	0	0	0
LPC	0	0	0	0	0	0	0	0	0	0	0	0
IPC	0	0	0	0	0	0	0	0	0	0	0	0
HPC	1	0	0	0	0†	0	0	0	0†	0	0	0
HPT	3	0	0	0	2	0	0	0	1	0	0	0
IPT	0	0	0	0	0	0	0	0	0	0	0	0
LPT/POWER TURBINE (PT)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	6	1	0	0	3	1	0	0	1	0	0	0

* 1 FAN SPINNER UNKOWN GENERATION.
† 1 HPC SPACER UNKNOWN GENERATION.

UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 1
UNCONTAINED OTHER TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 6

FIGURE 12. HAZARD RATIOS FOR UNCONTAINED - OTHER HIGH BYPASS TOTAL AND BY GENERATION

ENGINE TYPE	ALL HIGH BYPASS			1ST GENERATION			2ND GENERATION		
HAZARD LEVEL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL
HAZARD RATIO BY MODULE									
FAN	1/2 = .50	0/2 = *	0/2 = *	1/1 = 1.0	0/1 = *	0/1 = *	0/0 = *	0/0 = *	0/0 = *
LPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
IPC	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
HPC	0/1 = *	0/1 = *	0/1 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
HPT	0/3 = *	0/3 = *	0/3 = *	0/2 = *	0/2 = *	0/2 = *	0/1 = *	0/1 = *	0/1 = *
IPT	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
LPT/POWER TURBINE (PT)	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
ALL OTHER	1/6 = .17	0/6 = *	0/6 = *	1/3 = .33	0/3 = *	0/3 = *	0/1 = *	0/1 = *	0/1 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

NOTE: 1 FAN SPINNER UNKOWN GENERATION.
1 HPC SPACER UNKNOWN GENERATION.

Event summaries – Uncontained - other – Hazard level 4 or 5.

No events.

Event summaries – Uncontained - other – Hazard level 3.

Engine Type	Event Summary
High Bypass	Number 2 engine fan spinner cap fractured; penetrated inlet cowl forward of "A" flange. Debris ingested by No. 1 engine. Both engines surged, had exceedances, and were IFSD. **Event also included under Multiple-engine pwerloss – non-fuel, Fig. 51.** 1st generation. Spinner failure resulted from improper repair.

UNCONTAINED - ALL PARTS – 1992-2000 ANALYSIS

FIGURE 13. UNCONTAINED - ALL – TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
TOTAL	9	0	1	0	27	4	2	1

FIGURE 14. UNCONTAINED - ALL – HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
TOTAL	131	10	1	0	80*	8	1	0	38*	2	0	0

* 13 PARTS UNKNOWN GENERATION.

The relationship between first and second generation uncontainment rates is addressed below, in Figure 66 and following material.

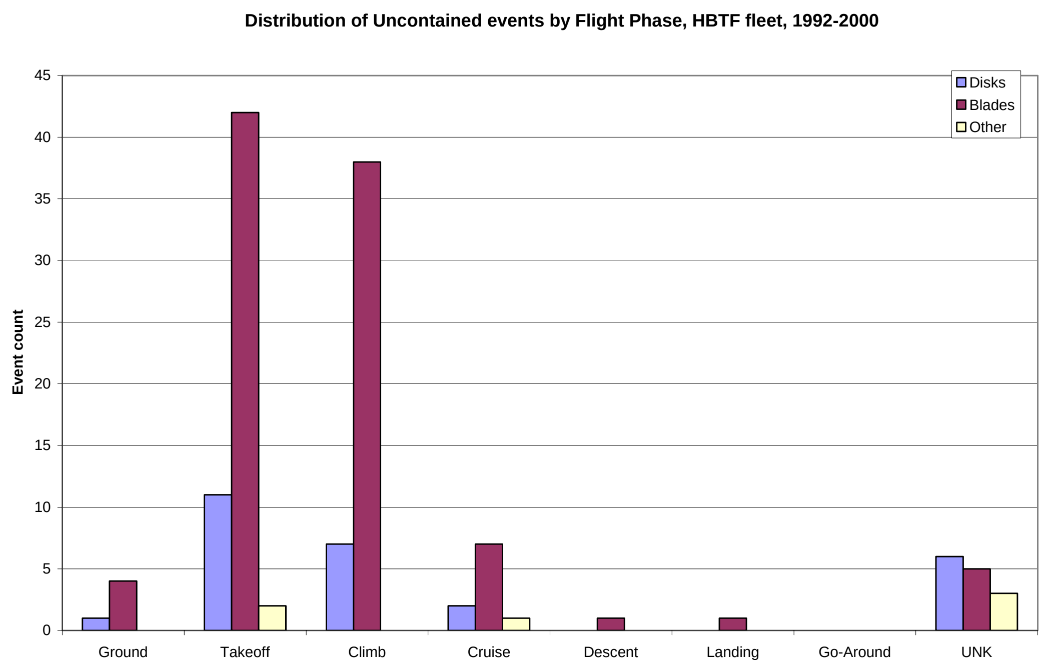


FIGURE 15. UNCONTAINED - ALL – HIGH BYPASS DISTRIBUTION BY FLIGHT PHASE – 1992 THROUGH 2000

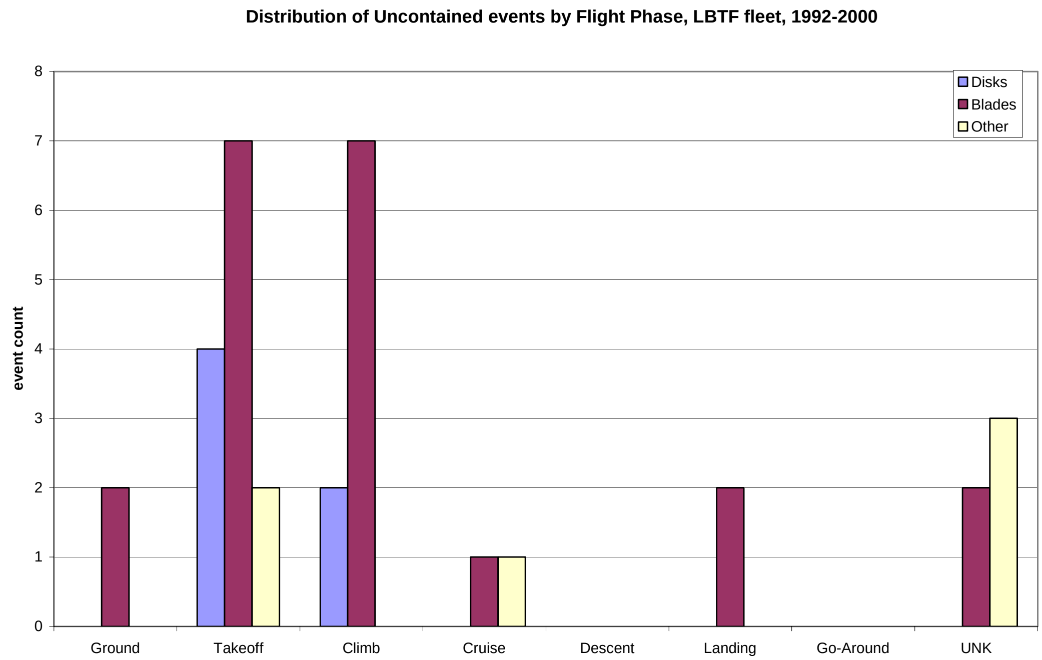


FIGURE 16. UNCONTAINED - ALL – LOW BYPASS DISTRIBUTION BY FLIGHT PHASE – 1992 THROUGH 2000

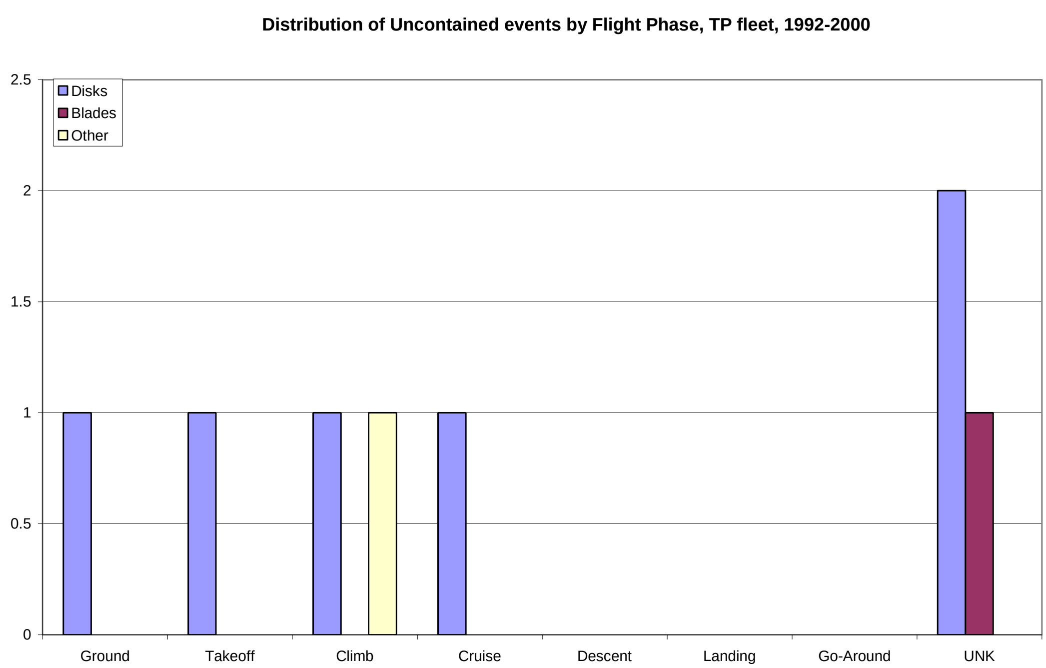


FIGURE 17. UNCONTAINED - ALL – TURBOPROP DISTRIBUTION BY FLIGHT PHASE – 1992 THROUGH 2000

ENGINE OVERSPEED

FIGURE 18. ENGINE OVERSPEED - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				TURBOFAN			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS TOTAL					449	0	0	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 449

FIGURE 19. HAZARD RATIOS FOR ENGINE OVERSPEED

ENGINE TYPE	TURBOPROP	TURBOFAN
LVL.5/ALL		0/449 = <.002
LVL.4+5/ALL		0/449 = <.002
LVL.3+4+5/ALL		0/449 = <.002

None of the 403 events resulting from control system failures propagated to uncontainment; they were generally minor exceedances, less than 120% redline. Overspeeds resulting from torque path failures (46 events) reached higher speeds and 50% of these were uncontained. All overspeeds were less than level 3 in severity.

Event summaries – Engine overspeed - Hazard level 3, 4 or 5.

No events.

CASE RUPTURE

FIGURE 20. CASE RUPTURE - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	0	0	0	0	6	0	0	0	7	0	0	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 13

FIGURE 21. HAZARD RATIOS FOR CASE RUPTURE

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL 5/ALL	0/0 = *	0/6 = *	0/7 = *
LVL (4+5)/ALL	0/0 = *	0/6 = *	0/7 = *
LVL(3+4+5)/ALL	0/0 = *	0/6 = *	0/7 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries - Case rupture - Hazard level 3, 4 or 5.

No events.

CASE BURNTHROUGH

FIGURE 22. CASE BURNTHROUGH - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	3	1	0	0	3	0	0	0	27	1	0	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 33

FIGURE 23. HAZARD LEVEL FOR CASE BURNTHROUGH

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL 5/ALL	0/3 = *	0/3 = *	0/27 = *
LVL (4+5)/ALL	0/3 = *	0/3 = *	0/27 = *
LVL(3+4+5)/ALL	1/3 = 0.333	0/3 = *	1/27 = 0.037

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Many case burnthroughs were detected during routine maintenance activity because the volume of hot air released was insufficient to cause a fire detector or overheat loop indication.

Event summaries - Case burnthrough - Hazard level 4 or 5.

No events.

Event summaries - Case burnthrough - Hazard level 3.

Engine Type	Event Summary
Turboprop	Rear inlet case burnt through. Aircraft wiring and pneumatic systems were damaged (hazard level 3.a., 3.b.)

High Bypass	Fuel nozzle burnthrough impinged on adjacent primary fuel manifold. Major secondary fuel leak and undercowl fire, consumed 15% of core cowl in flight. Core cowls opened and wrapped upward around the pylon, upper fire shoulder between fire zone and airplane was no longer in place. (hazard level 3.b.) **Event also included in Under-cowl fire, Fig. 24.**

UNDER-COWL FIRE

FIGURE 24. UNDER-COWL FIRE - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	20	4	0	0	11	0	0	0	87	4	0	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 8
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 118

FIGURE 25. HAZARD RATIOS FOR UNDER-COWL FIRE

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL 5/ALL	0/20 = *	0/11 = *	0/87 = *
LVL (4+5)/ALL	0/20 = *	0/11 = *	0/87 = *
LVL(3+4+5)/ALL	5/20 = 0.25	0/11 = *	4/87 = 0.05

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

The relationship between undercowl fire and leaks is analyzed in Appendix 7. It should be noted that undercowl fires resulting from flammable fluid leakage onto hot surfaces in the nacelle were primarily observed at low altitudes (below 10,000 ft), where surface temperatures were highest (from high takeoff/climb power settings) and ambient pressure was high. All of the level 3 fires occurred below 10,000 ft.

Event summaries – Under-cowl fire – Hazard level 4 or 5.

No events.

Event summaries – Under-cowl fire – Hazard level 3.

Engine Type	Event Summary
Turboprop	In-flight fire from fuel leaking from fuel heater damaged engine and nacelle (hazard level 3.b.) **Event also included in Fuel leak (primary cause), Fig 28.**

Fire during landing from leaking fuel heater cover caused substantial damage to the fuselage (hazard level 3.a., 3.b.) **Event also included in Fuel leak (primary cause), Fig 28.**

During taxiing, the tower reported fire emanating from the nacelle. Fire crew dispatched to extinguish the fire. Extensive damage to the landing gear and fuselage; skin cracked, permitting flames to enter the cabin and burn seats and overhead bins (hazard level 3.a., 3.b.)

During landing, bang and firewarning from No. 1 engine. Aircraft stopped on the runway and passengers were evacuated without injury. Burning fuel pooled on the runway below the engine; wind blew flames under the aircraft's fuselage, causing substantial damage before the fire could be extinguished (hazard level 3.a., 3.b.) **Event also included in Fuel leak (primary cause), Fig 28.**

High Bypass

Fire after landing from pylon fuel leak. Fire extinguished by ground crew (hazard level 3.b **Event also included in Fuel leak (primary cause), Fig 28.**

Fuel leak due to improperly installed AGB component Fire warning during climb at 4000 feet; fuel was shut off at the HP shutoff valve, but the low-pressure fuel system remained pressurized. Fire continued to burn for 16 minutes until the airplane landed and the fire handles were pulled and the engine foamed. Core cowls opened and wrapped upward around the pylon, upper fire shoulder between fire zone and airplane was no longer in place. Wing panels were scorched and delaminated (hazard level 3.b.) **Event also included in Fuel leak (primary cause), Fig. 28.**

Fuel nozzle burnthrough impinged on adjacent primary fuel manifold. Major secondary fuel leak and undercowl fire, consumed 15% of core cowl in flight (3.b.) **Event also included in Case burnthrough (primary cause), Fig. 22.**

Test flight. During reverse thrust, the tower indicated fire from the No. 3 engine. Fuel leak in pylon from hose nut near firewall. Fire bottles discharged, but fire extinguished by ground crew (hazard level 3.b.) **Event also included in Fuel leak (primary cause), Fig 28.**

OIL/HYDRAULIC FLUID LEAK

FIGURE 26. OIL/HYDRAULIC FLUID LEAK - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				TURBOFAN			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS TOTAL*	463	0	0	0	1876	0	0	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY SIGNIFICANTLY UNDERREPORTED.

NOTE: DOES NOT INCLUDE MULTI-ENGINE OIL LEAKS DUE TO MAINTENANCE ERROR.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 2339

FIGURE 27. HAZARD LEVEL FOR OIL/HYDRAULIC FLUID LEAK

ENGINE TYPE	TURBOPROP	TURBOFAN
LVL.5/ALL	0/463 = <.002	0/1876 = <.001
LVL.4+5/ALL	0/463 = <.002	0/1876 = <.001
LVL.3+4+5/ALL	0/463 = <.002	0/1876 = <.001

* HAZARD RATIO LIKELY CONSERVATIVE DUE TO UNDER-REPORTING.

<u>Event summaries – Oil/hydraulic fluid leak - Hazard level 3, 4 or 5.</u>

No events.

FUEL LEAK

FIGURE 28. FUEL LEAK - 1992 THROUGH 2000

ENGINE TYPE	**TURBOPROP**				**TURBOFAN**			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS TOTAL	72*	3	0	0	2765	12	0	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY SIGNIFICANTLY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 15
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 2837

FIGURE 29. HAZARD RATIOS FOR FUEL LEAK

ENGINE TYPE	**TURBOPROP**	**TURBOFAN**
LVL.5/ALL	0/72 = *	0/2765 = <.001
LVL.4+5/ALL	0/72 = *	0/2765 = <.001
LVL.3+4+5/ALL	3/72 = .04†	12/2765 = .004

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.
† HAZARD RATIO LIKELY CONSERVATIVE DUE TO UNDER-REPORTING.

The relationship between undercowl fire and leaks is analyzed in Appendix 7. It should be noted that the actual number of leaks is far greater than that reported; most manufacturers did not report data in this category. Due to the resources required in collecting such a large number of events, those manufacturers who did contribute data were permitted to do so for a shorter time period such as one year, and to extrapolate to estimate the total number of leaks over the nine-year period.

<u>**Event summaries – Fuel leak – Hazard level 4 or 5.**</u>

No events.

<u>Event summaries – Fuel leak – Hazard level 3.</u>

Engine Type	Event Summary
Turboprop	During landing, bang and firewarning from No. 1 engine. Aircraft stopped on the runway and passengers were evacuated without injury. Burning fuel pooled on the runway below the engine; wind blew flames under the aircraft's fuselage, causing substantial damage before the fire could be extinguished (hazard level 3.a., 3.b.) **Event also included in Under-cowl fire, Fig 24.**
	In-flight fire from fuel leaking from fuel heater damaged engine and nacelle (hazard level 3.b.) **Event also included in Under-cowl fire, Fig 24.**
	Fire during landing from leaking fuel heater cover caused substantial damage to the fuselage (hazard level 3.a., 3.b.) **Event also included in Under-cowl fire, Fig 24.**
Turbofan	Fire during taxi in No.1 engine strut area. Fuel leak in front spar coupling. Fire bottles discharged, but fire extinguished with help of ground equipment (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)
	2 events. Fuel leak led to fire after post-flight engine shutdown. Fire extinguished by ground crew (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)
	Fuel leak at front spar coupling caused fire during reverse thrust. Fire extinguished by ground crew (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)
	Number 3 pylon fire following post-flight engine shutdown. Fire bottles discharged with no effect; blowout doors blown out. Fire caused by leaking fuel from fuel flow transmitter and plugged pylon drain line. Fire extinguished through blowout panel area by ground crew (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)
	Number 3 engine firewarning after landing. Both bottles discharged but did not extinguish fire; emergency evacuation, no reported injuries. Fire from leak in fuel supply line. Ground crew extinguished fire (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)

Fuel leak due to improperly installed AGB component Fire warning during climb at 4000 feet; fuel was shut off at the HP shutoff valve, but the low-pressure fuel system remained pressurized. Fire continued to burn for 16 minutes until the airplane landed and the fire handles were pulled and the engine foamed. Core cowls opened and wrapped upward around the pylon, upper fire shoulder between fire zone and airplane was no longer in place. Wing panels were scorched and delaminated (hazard level 3.b.) **Event also included in Under-cowl fire, Fig 24.**

Fire after landing from pylon fuel leak. Fire extinguished by ground crew (hazard level 3.b.) **Event also included in Under-cowl fire, Fig 24.**

While parked at the gate as the engines spooled down, loud explosion and fire and the rear of No. 4 engine. Fuel leak from loose coupling. Fire extinguished by ground crew; fuel continued streaming from the weep holes on both sides of the strut (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)

Fire in No. 4 strut area during parking. Fuel leaked into turbine cooling system and ignited; fire extinguished by ground crew (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)

Non-revenue flight. Number 4 engine caught fire from fuel leak after landing; airplane stopped on taxiway. Fire bottles discharged, but fire extinguished by ground crew (hazard level 3.b.) (Fire initiated external to cowling; not counted as undercowl fire.)

Test flight. During reverse thrust, the tower indicated fire from the No. 3 engine. Fuel leak in pylon from hose nut near firewall. Fire bottles discharged, but fire extinguished by ground crew (hazard level 3.b **Event also included in Under-cowl fire, Fig 24.**

COMPARTMENT OVERHEAT/AIR LEAK

FIGURE 30. COMPARTMENT OVERHEAT/AIR LEAK - 1992 THROUGH 2000

ENGINE TYPE	ALL ENGINES			
HAZARD LEVEL	ALL	3	4	5
NUMBER EVENTS TOTAL	978	0	0	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 978

FIGURE 31. HAZARD RATIOS FOR COMPARTMENT OVERHEAT/AIR LEAK

ENGINE TYPE	ALL ENGINES
LVL.5/ALL	0/978 = <.001
LVL.4+5/ALL	0/978 = <.001
LVL.3+4+5/ALL	0/978 = <.001

Event summaries – Compartment overheat/air leak - Hazard level 3, 4 or 5.

No events.

ENGINE SEPARATION

FIGURE 32. ENGINE SEPARATION - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP[20]				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	2	0	0	0	6	1	2	1	3	2	0	1

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 4
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 7
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 11

FIGURE 33. HAZARD RATIOS FOR ENGINE SEPARATION

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL.5/ALL	0/2 = *	1/6 = 0.167	1/3 = 0.333
LVL.4+5/ALL	0/2 = *	3/6 = 0.500	1/3 = 0.333
LVL.3+4+5/ ALL	0/2 = *	4/6 = 0.667	3/3 = 1.000

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

The occurrence of events is more prevalent during cargo operations, and during the takeoff, climb and reverse-thrust flight phases.

Event summaries – Engine separation - Hazard level 4 or 5.

Engine Type	**Event Summary**
Low Bypass	In-flight separation of right-hand engine, pylon and wing panel. Control lost; crash (hazard level 5.)
	Number 3 engine separation in turbulence, followed by #4. Airplane roll and dive; crew recovered after 5000 feet lost altitude; used variable thrust to maintain control. Airplane veered off the runway during landing and was destroyed by fire from ignition of leaking fuel as the plane slowed (hazard level 4.b., 3.f.)

[20] The level 4 engine separation event reported in AC39-8, Appendix 8, was determined to be a non-turbine, non-transport category airplane.

	Number 3 engine separation in turbulence. Airplane landed long and departed the runway offside. Hull loss (hazard level 4.b.)
High Bypass	Separation of #3 strut and engine; knocked off #4 engine. Loss of control; crash into apartment complex. All fatal on board; multiple fatalities on the ground (hazard level 5.)

Event summaries – Engine separation - Hazard level 3.

Engine Type	Event Summary
Low Bypass	Number 1 engine separation in severe turbulence. Diversion; 14 feet of wing leading edge missing, due to separation and damage to #4 pylon, likely due to turbulence (hazard level 3.a.)
High Bypass	During reverse thrust, the #1 engine and strut rotated downward and dragged on the runway. Sparks ignited fuel; fire began and damaged flaps, leading edge, and aft fairing. Maintenance-related, as the fuse pin retainers had not been reinstalled after a recent inspection during C-check. (hazard level 3.a., 3.b.)
	Number 2 engine separation in severe turbulence. Substantial damage to wing leading edge (hazard level 3.a., 3.f.)

COWL SEPARATION

FIGURE 34. COWL SEPARATION - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	3*	0	0	0	27	1	0	0	117	1	0	0

* THE EVENT COUNT FOR ALL EVENTS MAY BE INCOMPLETE.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 147

FIGURE 35. HAZARD RATIOS FOR COWL SEPARATION

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL.5/ALL	0/3 = *	0/27 = *	0/117 <= 0.01
LVL.4+5/ALL	0/3 = *	0/27 = *	0/117 <= 0.01
LVL.3+4+5/ ALL	0/3 = *	1/27 = 0.04	1/117 = 0.01

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – Cowl separation - Hazard level 4 or 5.

No events.

Event summaries – Cowl separation - Hazard level 3.

Engine Type	Event Summary
Low Bypass	Loud bang and flight control column shudder at 37,000 feet, followed by a rapid depressurization. Event caused by both sides of the No. 2 engine fan cowl departing the aircraft during flight and impacting the fuselage. Two holes in the fuselage; two impact areas on the leading edge of the left horizontal stabilizer, one large area close to the stabilizer root and a small area outboard (hazard level 3.a., 3.c.)

High Bypass	Fan cowl separated (latches not secured), causing broken fuselage frame and depressurization at 5,000'. Two holes, each 2 sq.ft., in fuselage skin aft of overwing exit. Wing leading edge impacted by large segment of cowl structure (hazard level 3.a., 3.c.)

PROPULSION SYSTEM MALFUNCTION PLUS INAPPROPRIATE CREW RESPONSE (PSM+ICR)

FIGURE 36. PSM+ICR - 1992 THROUGH 2000

ENGINE TYPE	**TURBOPROP**				**JET/LBPR**				**HBPR**			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS	*	1†	3	8	*	3†	3	2	*	2†	1	4

* TOTAL EVENTS UNKNOWN.
† LEVEL 3 EVENTS LIKELY UNDER-REPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 14
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 21
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 27
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= *

Event summaries – PSM+ICR - Hazard level 4 or 5.

Engine Type	**Event Summary**
Turboprop	False low oil p indication, engine throttled to idle and ATB. Executed missed approach in high drag configuration. 3 fatalities of 24 on board; hull loss (hazard level 5.) **Event also included in False/misleading indication, Fig. 47.**
	After takeoff, the aircraft climbed to 30 feet before suddenly rolling to the right and crashing. The right engine was not delivering power on impact; the left propeller control was found seized in the feather position and the left propeller blades in the near-feather position. The forward fuel tank, which provides fuel to the right engine, was found to be heavily contaminated with water, an emulsifying agent, and bacterial growth. The fuel from the airport fuel truck and the main underground tank contained the same mixture. Pilot apparently feathered the left engine after right engine powerloss (hazard level 5.) **Event also included in Multiple-engine powerloss – fuel-related, Fig. 53.**
	Negative torque system light, misinterpreted as engine failure (no actual malfunction); engine retarded to flight idle, propeller not feathered, incorrect rudder input. Loss of control; crash (hazard level 5.)

During approach, apparent left engine IFSD. Because of the flight regime, the propeller did not autofeather. Control lost during attempted go-around and crashed short of the runway. Investigation showed that engine was not powered but also revealed no anomalies of any engine components (hazard level 5.)

Reported left engine failure shortly after takeoff. Pilot requested permission to return, but aircraft crashed in fields some 200m short of the runway (hazard level 5.).

During initial climb, engine powerloss and propeller autofeather. The aircraft subsequently rolled and crashed (hazard level 5.)

Single engine power loss during cruise; pilot failed to maintain Vmcg, hull loss, fatal (hazard level 5.)

Engine failure on takeoff. T/O aborted, runway departure, airplane fire. 16 fatal (hazard level 5.)

Engine IFSD on approach, attempted go-round; landed in rice paddy; no fatalities (hazard level 4.a.)

Oil cap not replaced after servicing. Right engine IFSD after takeoff; pilot elected to go around during approach due to traffic on the runway, but did not retract flaps. Forced landing, hull loss (hazard level 4.a., 4.b.)

During cruise, #1 engine IFSD due to a loss of oil pressure. Crew unable to maintain height on the remaining engine. Just before impact, #2 IFSD by pilot in an attempt to maintain directional control. Aircraft reportedly near maximum gross weight. Hull loss (hazard level 4.a., 4.b.)

Low Bypass

Contained engine failure during final approach. Loss of control during go-around; aircraft impacted ground and broke into three sections. Hull loss; fatal (hazard level 5.)

During takeoff, firewarning on No. 3 engine (possibly false warning due to cowl loss). Aircraft failed to gain altitude and crashed into house. Suspect power mismanagement on other engines. Fatal to all on board and many on the ground (hazard level 5.) **Event also included in Event also included in Multiple-engine powerloss – non-fuel, Fig. 49.**

During climb, No. 1 engine surge due to fractured fan blade (contained). Inlet cowl separated from engine; air turnback. Aircraft landed long, skidded offside runway and ran into a wall. Hull loss, no injuries (hazard level 4.b.)

Engine overthrust and high EGT during takeoff roll. Crew rejected takeoff 6 knots below V1. Airplane departed offside the runway; both main gear and the right engine separated. Fire around the empennage, right wing and inside the fuselage; spread and destroyed aircraft. No injuries (hazard level 4.b.)

Loud bang and vibration in flight; pilot throttled back both engines and both flamed out. A successful unpowered landing was made. One engine had fractured blade; other engine operated successfully on the ground (hazard level 4.a.) **Event also included in Multiple-engine powerloss – non-fuel, Fig. 49.**

High Bypass

During descent after level off for approach, RH thrust lever stuck near idle position and did not respond to autothrottle command causing asymmetric thrust with airplane banking right. Flight crew control wheel was input was to the right opposite to that which the autopilot was holding. Airplane lost control and impacted mountain. (hazard level 5)

During climb after takeoff, the number one engine thrust began to retard slowly towards idle thrust, without pilot input. At approximately 4500 feet altitude, the asymmetric thrust resulted in the aircraft being in a severe bank. Pilot's initial attempt to compensate included control inputs in the opposite direction required to recover (crew had earlier experience in aircraft with alternative indicator depiction); airplane rolled and crashed (hazard level 5.)

During takeoff after rotation, No. 3 engine failure (powerloss and thud). Crew rejected takeoff at 9 feet AGL; airplane overran runway, colliding with obstacles. The center fuel tank was damaged by landing gear collapse, causing fuel to ignite from friction sparks. Airplane severely damaged by fire; 3 fatalities attributed to direct impact by the landing gear (hazard level 5.)

Engine failure during descent from FL390 to FL370. Crew requested emergency landing at nearest airfield. On final, near the approach end of the runway, the airplane was observed to bank sharply to the left. The left wing tip tank struck the ground, followed by the fuselage. The airplane came to rest in the grass to the left of the runway. There were post-impact fires on both sides of the

	fuselage, which were extinguished by airport crews on standby due to the declared emergency. Both crew fatal; the three passengers exited through an opening at the front of the cabin (hazard level 5.)
	Airplane landed long at night and reverse was commanded on only one engine. Aircraft went offside runway; came back on to it but overran by 200 meters and came to rest among houses. Hull loss; two serious injuries on board; three fatal on ground (hazard level 4.b., 4.c.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41.**

Event summaries – PSM+ICR - Hazard level 3.

Engine Type	**Event Summary**
Turboprop	Right engine uncontrolled torque increase during approach. Pilot elected to continue landing; touchdown at 139 KIAS. Pilot attempted to stop the airplane using the parking brake. All main tires burst; overrun; propeller blade release causing fuselage damage (hazard level 3.a., 3.f.) **Event also included in Propeller separation, Fig. 59.**
Low Bypass	Rejected takeoff following engine powerloss. Aircraft overran runway, crashed through a wall and on to an adjacent street. (Economic) hull loss; minor evacuation injuries (hazard level 3.a.)
	Rejected takeoff because of EPR discrepancy between indicators. Aircraft overran by 40 meters; nose gear collapsed into EE bay, causing substantial damage (hazard level 3.a.)
	Rejected takeoff at 80 knots due to low EPR on No. 2 engine. Airplane veered off left-hand side of the runway into a ditch. Significant damage to engine, nose gear and fuselage in the nose gear area (hazard level 3.a.)
High Bypass	Number 1 engine surge during takeoff (loud band with powerloss) just after nose wheel liftoff. Crew rejected, and the airplane overran the end of the runway. Significant damage to the aircraft (hazard level 3.a.)
	Engine surge shortly after takeoff; misidentified as tire or gear problem. Pilot failed to maintain directional and airspeed control; recovered (hazard level 3.f.)

HAZARD RATIOS FOR PSM+ICR

Hazard ratios for PSM+ICR after turbofan IFSD or significant powerloss are provided in Figure 37 below. These hazard ratios are conservative, as only IFSDs were used in the denominator, not all powerloss events. Throttle split or overboost events are not included, due to lack of data on occurrence rate. Level 3+ hazard ratios are not calculated because of suspected significant under-reporting of level 3 PSM+ICR events.

IFSD data was not available for the turboprop fleet.

FIGURE 37. EFFECT OF FLIGHT PHASE ON PSM+ICR HAZARD RATIO – TURBOFANS - 1992 THROUGH 2000

ENGINE TYPE	ALL TURBOFANS				
HAZARD LEVEL	**IFSDs[21]**	**Level 4 PSM+ICR Events**	**Level 4+ Hazard Ratio**	**Level 5 PSM+ICR Events**	**Level 5 Hazard Ratio**
Takeoff	992	0	.002	2	.002
Climb	3957	0	<.0003	0	<.0003
Cruise	6226	1	.0002	0	<.0002
Descent	1525	0	<.0007	0	<.0007
Landing/Go-around	128	0	.008	1	.008
ICR unrelated to flight phase of PSM		1		1	
TOTAL	12,829	2	.0005	4	.0003

[21] IFSDs estimated based on sampling.

CREW ERROR

FIGURE 38. CREW ERROR - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	*	0†	0	1	*	2†	2	0	*	3†	0	0

* TOTAL EVENTS UNKNOWN.
† LEVEL 3 EVENTS LIKELY UNDER-REPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 1
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 3
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 8
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= *

Event summaries – Crew error - Hazard level 4 or 5.

Engine Type	Event Summary
Turboprop	Crew did not deploy anti-icing in known icing conditions; dual engine flameout. Ditched; fatal (hazard level 5.) **Event also included in Multiple-engine powerloss – non-fuel, Fig. 49.**
Low Bypass	Rejected takeoff after rotation for perceived low power. Hull loss; minor injuries to all 12 occupants (hazard level 4.b.)
	Pilot elected to takeoff with a known inoperative engine. Following liftoff, the aircraft was seen to rock back and forth, climbing to only 5 or 10 feet before settling back down on the runway with undercarriage retracted. The aircraft subsequently departed the runway and slid for some 1,600 meters before stopping. Additionally, though the aircraft had a minimum crew requirement of two, consisting of pilot and copilot; the copilot seat was occupied by a private pilot-rated passenger who did not hold a multi-engine rating. Forced landing, hull loss (hazard level 4.a., 4.b.)

Event summaries – Crew error - Hazard level 3.

Engine Type	Event Summary
Low Bypass	Pilot reported engine non-response to throttle on multiple engines. Aircraft stalled and lost control; loss of 8400 feet in 39 seconds before recovery. Investigation revealed no powerplant problems; suspected mode awareness issue (hazard level 3.e., 3.f.) **Event also included under Multiple-engine powerloss – non-fuel, Fig. 49.**
	The landing took place at night, on a wet runway with strong cross-winds. Engine #1 thrust level was not at idle upon touchdown, disabling the automatic braking system. Subsequent inadvertent advance of thrust lever resulted in thrust asymmetry and off-runway excursion. Nose gear was torn off and electronics bay severely damaged as the airplane crossed a rainwater collector tank. Economic hull loss (hazard level 3a)
High Bypass	Improper engine operation resulted in engine tailpipe fire and aircraft damage (hazard level 3.a., 3.b.) **Event also included in Tailpipe fire, Fig. 45.**
	Crew attempted landing with autothrottle in missed-approach phase, physically holding thrust levers at idle. After touchdown, three of four engines produced reverse thrust as commanded while one went to high forward thrust (pilot's hand slipped, autothrottle still trying to execute a missed approach). Airplane departed side of runway into shallow lagoon, substantial damage. (hazard level 3a)
	Crew shut down both engines during climb at 4000 feet; the intention was to retract landing gear, but crew set master engine levers 1 and 2 to "off" instead. The crew training simulator, in which the captain had recently been trained, had a gear warning horn malfunction that required cycling the engine cut-off switch to resolve. APU started, dual engine start performed and descent arrested at 1000 feet (hazard level 3.e.) **Event also included in Multiple-engine powerloss – non-fuel, Fig. 51.**

HAZARD RATIOS FOR CREW ERROR

Preparation of Hazard Ratios for crew error was not possible given the unknown incidence of lower-level events.

REVERSER/BETA MALFUNCTION – IN-FLIGHT DEPLOY

FIGURE 39. REVERSER/BETA MALFUNCTION – IN-FLIGHT DEPLOY 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	5*	1	2	2	3	0	0	0	13	2	0	1

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 3
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 5
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 8
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 21

FIGURE 40. HAZARD RATIOS FOR REVERSER/BETA - IN-FLIGHT DEPLOY

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL.5/ALL	2/5 = †	0/3 = *	1/13 = .08
LVL.4+5/ALL	4/5 = †	0/3 = *	1/13 = .08
LVL.3+4+5/ALL	5/5 = †	0/3 = *	3/13 = .23

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.
† HAZARD RATIO NOT CALCULATED DUE TO INCOMPLETE REPORTING.

<u>Event Summaries – Reverser/beta malfunction - in-flight deploy - Hazard level 4 or 5.</u>

Engine Type	**Event Summary**
Turboprop	Two engine overspeed after propeller beta mode selected in flight. Hull loss; fatal (hazard level 5.) **Event also included in Propeller crew error (primary cause), Fig. 59.**
	Crashed on approach after inadvertent activation of power lever(s) into beta range accompanied by failure of beta lockout for undetermined reason(s). No survivors (hazard level 5.)

	Dual-engine overspeed due to operation of propellers in beta range inflight. Unpowered landing (on-airport) and runway overrun. No injuries (hazard level 4.a.) **Event also included in Propeller crew error (primary cause), Fig. 59.**
	Propeller flat pitch selected during the final stage of approach. Descent rate rapidly increased, as did engine speed. Crash landing; hull loss, no fatalities (hazard level 4.b.) **Event also included in Propeller crew error (primary cause), Fig. 59.**
High Bypass	Thrust reverser deployed during takeoff; aircraft loss of control and crash. Fatal to all on board and two on the ground (hazard level 5.)

Event Summaries – Reverser/beta malfunction - in-flight deploy - Hazard level 3.

Engine Type	**Event Summary**
Turboprop	Two engine overspeed after propeller beta mode selected in flight. Successful single engine landing. No injuries (hazard level 3.f.) **Event also included in Propeller crew error (primary cause), Fig. 59.**
High Bypass	During descent, caution message for No. 1 thrust reverser accompanied by buffet and aircraft yaw to the left. The crew disconnected the auto-throttle system, retarded both throttles to idle and disconnected the auto-pilot. Shortly thereafter, buffeting stopped, and all systems appeared normal. Crew elected to shut down the No. 1 engine to avoid a possible recurrence. The airplane landed without further incident (hazard level 3.f.)
	Thrust reverser deployment during climb caused a deep bank. Control was recovered; uneventful single-engine landing (hazard level 3.f.)

REVERSER/BETA MALFUNCTION – FAILURE TO DEPLOY

FIGURE 41. REVERSER/BETA MALFUNCTION – FAILURE TO DEPLOY 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	8*	5	1	0	†	†	0	0	784	0	2	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY SIGNIFICANTLY UNDERREPORTED.
† NO DATA REPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 3
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 8
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 792

FIGURE 42. HAZARD RATIOS FOR REVERSER/BETA - FAILURE TO DEPLOY

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL.5/ALL	0/8 = *	†	0/784 = *
LVL.4+5/ALL	1/8 = †	†	2/784 = .003
LVL.3+4+5/ALL	5/8 = †	†	2/784 = .003

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.
† HAZARD RATIO NOT CALCULATED DUE TO INCOMPLETE REPORTING.

No level 3 or higher events were reported in connection with unstow in flight, being slow to deploy, inadvertent stow or being slow to stow after reverse (and lower-level data were not reported for these events).

Event Summaries – Reverser/beta malfunction - failure to deploy - Hazard level 4 or 5.

Engine Type	**Event Summary**
Turboprop	On landing, beta selected on both engines, but did not deploy on right one. Pilot recognized beta light, but engines left at 100% RPM. Offside runway and down an embankment; hull loss (level 4.b., 3.f.) **Event also included in Propeller PSM+ICR (primary cause), Fig. 59.**

High Bypass	One reverser failed to deploy, airplane aquaplaned and overran runway into Lake Victoria, hull loss (hazard level 4.b.)
	Airplane landed long at night and reverse was commanded on only one engine. Aircraft went offside runway; came back on to it but overran by 200 meters and came to rest among houses. Hull loss; two serious injuries on board; three fatal on ground (hazard level 4.b., 4.c.) **Event also included in PSM+ICR (primary cause), Fig. 36**

Event Summaries – Reverser/beta malfunction - failure to deploy - Hazard level 3.

Engine Type	**Event Summary**
Turboprop	No reverse on right engine; runway departure into 4-ft. ditch at 70 kts, gear collapse and FOD to props. One failed at hub, pieces penetrated fuselage (8" tear). No injuries (hazard level 3.a., 3.f.) **Event also included in Propeller separation and Propeller PSM+ICR (primary cause), both Fig. 59.**
	Right propeller pitchlocked due to inadequate oil pressure. Full reverse selected on landing. Runway departure, significant aircraft damage, minor injuries (hazard level 3.a, 3.f.) **Event also included in Propeller autofeather/pitch lock and Propeller PSM+ICR (primary cause), both Fig. 59.**
	Unable to reverse one propeller during landing. Runway departure, significant aircraft damage (hazard level 3.a.,3.f.) **Event also included in Propeller PSM+ICR (primary cause), Fig. 59.**
	During landing, left propeller did not go into fine pitch. Runway departure down a steep slope, where the nose landing gear was torn off (hazard level 3.f.) **Event also included in Propeller PSM+ICR (primary cause), Fig. 59.**
	Unable to reverse one propeller during landing. Runway departure, damage limited to propeller and engine, no injuries (hazard level 3.f.) **Event also included in Propeller PSM+ICR (primary cause), Fig. 59.**

FUEL TANK RUPTURE/EXPLOSION

FIGURE 43. FUEL TANK RUPTURE/EXPLOSION - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS	0	0	0	0	1	0	0	1	1	0	0	1

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 2
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 2

FIGURE 44. HAZARD RATIOS FOR FUEL TANK RUPTURE/EXPLOSION

ENGINE TYPE	TURBOPROP	LOW BYPASS	HIGH BYPASS
LVL.5/ALL	0/0 = *	1/1 = 1.0	1/1 = 1.0
LVL.4+5/ALL	0/0 = *	1/1 = 1.0	1/1 = 1.0
LVL.3+4+5/ALL	0/0 = *	1/1 = 1.0	1/1 = 1.0

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – Fuel tank rupture/explosion – Hazard level 4 or 5.

Engine Type	Event Summary
Jet/Low Bypass	On takeoff, FOD caused tire failure, which in turn caused fuel tank rupture. Severe fire and fuel starvation. Crash; all fatal (hazard level 5.)
High Bypass	During climb, center fuel tank explosion. Airplane broke apart; all fatal (hazard level 5.)

Event summaries – Fuel tank rupture/explosion – Hazard level 3.

No events.

TAILPIPE FIRE

FIGURE 45. TAILPIPE FIRE - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				TURBOFAN			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS TOTAL	11*	4	0	0	218	1	0	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY SIGNIFICANTLY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 5
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 229

FIGURE 46. HAZARD RATIOS FOR TAILPIPE FIRE

ENGINE TYPE	TURBOPROP	TURBOFAN
LVL.5/ALL	0/11 = †	0/218 = *
LVL.4+5/ALL	0/11 = †	0/218 = *
LVL.3+4+5/ALL	4/11 = †	1/218 = .005

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.
† HAZARD RATIO NOT CALCULATED DUE TO INCOMPLETE REPORTING.

The majority of tailpipe fires occur when the engine is below idle speed (start-up or shut down).

Event summaries – Tailpipe fire - Hazard level 4 or 5.

No events.

Event summaries – Tailpipe fire - Hazard level 3.

Engine Type	Event Summary
Turboprop	**3 events.** Fire in exhaust pipe due to excessive friction at thermal blankets, with titanium dust and organic residue causing a pyrophoric reaction and metal fire. Fire self-extinguished when lower metal temperatures were reached (hazard level 3.b.)

During initial climb, the right engine failed, but remained at idle. Oil over-servicing produced internal engine fire fed by overheated air/oil mix out the breather pipe causing an afterburning effect out the tailpipe. Additionally, the aft fuel drain was not capped, causing fuel to drain rearward and under the engine and possibly be ignited by the hot exhaust pipe. The engine was shutdown, but the fire progressed into the right hydraulic system reservoir, causing the loss of both hydraulic systems. The aircraft diverted, but overran during landing, causing significant damage (hazard level 3.a., 3.b.)

Turbofan	Improper engine operation resulted in engine tailpipe fire and aircraft damage (hazard level 3.a., 3.b.) **Event also included in Crew error (primary cause), Fig. 38.**

FALSE/MISLEADING INDICATION

FIGURE 47. FALSE/MISLEADING INDICATION - 1992 THROUGH 2000

ENGINE TYPE	**TURBOPROP**				**TURBOFAN**			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS TOTAL	268*	0	0	1	9000	0	0	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY SIGNIFICANTLY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 1
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 1
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 1
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 9268

FIGURE 48. HAZARD RATIOS FOR FALSE/MISLEADING INDICATION

ENGINE TYPE	TURBOPROP	TURBOFAN
LVL.5/ALL	1/268 = .004*	0/9000 = <.0001
LVL.4+5/ALL	1/268 = .004*	0/9000 = <.0001
LVL.3+4+5/ALL	1/268 = .004*	0/9000 = <.0001

* HAZARD RATIO LIKELY CONSERVATIVE DUE TO INCOMPLETE REPORTING.

Since the incidence of serious outcomes from false or misleading indications is so rare, it was not possible to determine the effect of factors such as flight phase or type of operation. The false indications reported included: N1, N2, EPR, EGT, fuel flow, oil pressure, temperature and quantity, fuel filter and oil filter impending bypass, vibration, reverser unlock and fire warnings. In some instances, the false indication occurred on all engines. No instances were reported of parameters being switched between engines.

Note: It is believed that there is considerable under-reporting of false indications. Hazard ratios are likely to be even lower than calculated.

Event summaries – False/misleading indication - Hazard level 4 or 5.

Engine Type	Event Summary
Turboprop	False low oil p indication, engine throttled to idle and ATB. Executed missed approach in high drag configuration. Three fatalities of 24 on board; hull loss (hazard level 5.) **Outcome resulted from inappropriate crew response rather than falseness of indication; event also included in PSM+ICR (primary cause), Fig. 36.**

Event summaries – False/misleading indication - Hazard level 3.

No events.

MULTIPLE-ENGINE POWERLOSS – NON-FUEL TURBOPROP AND JET/LOW BYPASS

FIGURE 49. MULTIPLE-ENGINE POWERLOSS – NON-FUEL – TURBOPROP AND JET/LOW BYPASS – 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY CONDITION								
Environmental	12	3	1	2	8	4	0	1
Maintenance	0	0	0	0	0	0	0	0
Other/unknown	1	0	1	0	11	8	1	1
NUMBER EVENTS TOTAL	13	3	2	2	19	12	1	2

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 4
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 7
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 22
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 32

FIGURE 50. HAZARD RATIOS FOR MULTIPLE-ENGINE POWERLOSS – NON-FUEL - TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP			JET/ LOW BYPASS		
HAZARD LEVEL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL
HAZARD RATIO BY CONDITION						
Environmental	6/12 = .50	3/12 = .25	2/12 = .17	5/8 = .63	1/8 = .13	1/8 = .13
Maintenance	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *	0/0 = *
Other/unknown	1/1 = 1.0	1/1 = 1.0	0/1 = *	10/11 = .91	2/11 = .18	1/11 = .09
Total	7/13 = .54	4/13 = .31	2/13 = .15	15/19 = .79	3/19 = .16	2/19 = .11

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

<u>Event summaries – Multiple engine powerloss – non-fuel - Hazard level 4 or 5.</u>

<u>Engine Type</u>	**<u>Event Summary</u>**
ENVIRONMENTAL	
Turboprop	Crew did not deploy anti-icing in known icing conditions; dual engine flameout. Ditched; fatal (hazard level 5.) **Event also included in Crew error (primary cause), Fig. 38.**
	Multiple engine shutdown as the result of severe icing in excess of original inlet certification basis. Incomplete performance of emergency procedures reduced probability of restarting (hazard level 5.)
	During approach, both engines flamed out. Suspect ice build up on unheated propeller spinners during a previous rejected approach into a different airport. Ice then likely broke away during the descent, and was ingested into the engines. Forced landing (hazard level 4.a.)
Jet/Low Bypass	Dual engine flameout after lightning strike. Battery exhausted during repeated high altitude start attempts. Crash landing, 2 fatalities; 2 injuries (hazard level 5.)
OTHER/UNKNOWN	
Turboprop	Both engines failed for unknown reason, causing the crew to carry out a forced landing short of the runway (hazard level 4.a.)
Jet/Low Bypass	During takeoff, firewarning on No. 3 engine (possibly false warning due to cowl loss). Aircraft failed to gain altitude and crashed into house. Suspect power mismanagement on other engines. Fatal to all on board and many on the ground (hazard level 5.) **Event also included in PSM+ICR (primary cause), Fig. 36.**
	Loud bang and vibration during flight; pilot throttled back both engines and both flamed out. A successful unpowered landing was made. One engine had fractured blade; other engine operated successfully on the ground (hazard level 4.a.) **Event also included under PSM+ICR (primary cause), Fig. 36.**

Event summaries – Multiple engine powerloss – non-fuel - Hazard level 3.

Engine Type	**Event Summary**
ENVIRONMENTAL	
Turboprop	Dual engine stalls as airplane climbed through temperature inversion. Power fluctuations persisted for ~30 seconds while maintaining 700 feet AGL. Powered landing, no injuries (hazard level 3.e.)
	2 events. Multi-engine flameout in icing; recovered (hazard level 3.e.)
Jet/Low Bypass	Multi-engine Birdstrike. One engine IFSD and the other damaged producing part power (hazard level 3.d.)
	During approach, the aircraft encountered a large flock of snow geese. Right engine rolled back and would not respond to throttle; left engine repeated surges. Safe landing; both engines severely damaged, but producing part power (hazard level 3.d.)
	Both engines surged during rotation due to wing ice ingestion. Throttles retarded to clear surges; air turnback (hazard level 3.e.)
	Both engines flamed out in turbulence at 41,000 feet; restarted at 26,000 feet (hazard level 3.e.)
OTHER/UNKNOWN	
Jet/Low Bypass	**6 events.** Dual engine flameout at high altitude for unidentified reason; engines relit at lower altitude (hazard level 3.e.)
	Pilot reported engine non-response to throttle on multiple engines. Aircraft stalled and lost control; loss of 8400 feet in 39 seconds before recovery. Investigation revealed no powerplant problems; suspected mode awareness issue (hazard level 3.e., 3.f.) **Event also included under Crew error (primary cause), Fig. 38.**
	Bird ingestion 10 feet off ground; No. 3 uncontained; cross-debris destroyed No. 4 and cut several hydraulic lines and control cables. Extensive damage (hazard level 3.a.) **Event also included in Uncontained blade (primary cause), Fig. 1.**

MULTIPLE ENGINE POWERLOSS – NON-FUEL 1ST AND 2ND GENERATION HIGH BYPASS

FIGURE 51. MULTIPLE-ENGINE POWERLOSS – NON-FUEL - HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY CONDITION												
Environmental	36	5	0	0	17	4	0	0	19	1	0	0
Maintenance	7	2	3	0	4	2	1	0	3	0	2	0
Other/unknown	27	7	0	0	19	6	0	0	8	1	0	0
TOTAL	70	14	3	0	40	12	1	0	30	2	2	0

* THE EVENT COUNT FOR ALL EVENTS IS LIKELY UNDERREPORTED.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 3
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 17
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 70

FIGURE 52. HAZARD RATIOS FOR MULTIPLE ENGINE POWERLOSS NON-FUEL - HIGH BYPASS TOTAL AND BY GENERATION

ENGINE TYPE	ALL HIGH BYPASS			1ST GENERATION			2ND GENERATION		
HAZARD LEVEL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL	3+4+5 /ALL	4+5 /ALL	5 /ALL
HAZARD RATIO BY CONDITION									
Environmental	5/36 = .14	0/36 = *	0/36 = *	4/17 = .24	0/17 = *	0/17 = *	1/19 = .05	0/19 = *	0/19 = *
Maintenance	5/7 = .71	3/7 = .43	0/7 = *	3/4 = .75	1/4 = .25	0/4 = *	2/3 = .67	2/3 = .67	0/3 = *
Other/unknown	7/27 = .26	0/27 = *	0/27 = *	6/19 = .32	0/19 = *	0/19 = *	1/8 = .13	0/8 = *	0/8 = *
TOTAL	17/70 = .24	3/70 = .04	0/70 < .01	13/40 = .33	1/40 = .03	0/40 = *	4/30 = .13	2/30 = .07	0/30 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – Multiple engine powerloss - non-fuel – Hazard level 4 or 5.

Engine Type	Event Summary
MAINTENANCE	
High Bypass	Four-engine oil loss due to maintenance (failure to reinstall O-rings); 1 left running; forced landing (hazard level 4.a.) 1st generation.
	Dual engine rapid oil loss at FL150 due to borescope crank pad cover left off both engines after borescope previous night. Emergency powered landing at closest airport; considered imminent forced landing (hazard level 4.a.) 2nd generation.
	Air turnback after low oil level and pressure warning on both engines. Both engines were completely out of oil; considered forced landing (hazard level 4.a.) 2nd generation.

Event summaries – Multiple engine powerloss – non-fuel - Hazard level 3.

Engine Type	Event Summary
ENVIRONMENTAL	
High Bypass	At FL310 to avoid icing, with anti-ice bleed on, aircraft encountered a hot cell. Stability bleeds opened, and all four engines went sub-idle. At FL160, No. 1 and No. 3 restarted, but would not accelerate. At FL120, all engines began to slowly accelerate; normal operation at FL100. All engines were found to have ice damage, but it is unknown whether that occurred prior to the rollbacks or concurrent with them (causing them) or occurred during descent from ice accretion (hazard level 3.e.) 1st generation.
	During cruise, aircraft encountered heavy turbulence in clouds. Icing during descent; anti-ice not used. Number 1 flamed out at FL310; No. 2 flamed out during attempted cross-bleed air start. Air-driven generator deployed; APU-assisted start; engines stabilized at FL050. Crew did not follow emergency checklist and lacked aircraft systems knowledge and flight in icing conditions (hazard level 3.e.) 1st generation
	Four-engine rollback in icing; recovered and normal landing (hazard level 3.e.) 1st generation.

Multi-engine birdstrike. Number 2 IFSD and No. 1 damaged and at reduced thrust (hazard level 3.d.) 1st generation.

Ice accretion and shed caused dual-engine flameout at 18,000 feet. Successful windmill restarts on both engines at 12,000 feet (hazard level 3.e.) 2nd generation.

MAINTENANCE

High Bypass At the top of climb, No. 4 engine had an indication of high vibration and the engine was shutdown. The flight was aborted and aircraft turned back to departure airport. During descent, No. 1 engine had an indication of high vibration and it was also shutdown. Aircraft made an uneventful two-engine landing (hazard level 3.d.) 1st generation.

Vibration indication on No. 1 engine; crew shut down engine. Two minutes later, No. 4 engine vibration indication and that engine was also shut down. Aircraft diverted, dumped excess fuel and landed uneventfully (hazard level 3.d.) 1st generation.

OTHER/UNKNOWN

High Bypass **2 events.** Multiple engine shutdown due to unrelated causes (hazard level 3.d.) 1st generation.

Dual-engine loss of power response at FL370. Number 2 engine power recovered at FL120; diversion; No. 1 engine recovered during approach. Unknown cause; both engines operated successfully on the ground (hazard level 3.e.) 1st generation.

LPT disk failure causing holes in lower and upper wing leading edge and loss of engine indications on adjacent engine, which was shutdown by crew (hazard level 3.a., 3.d.) **Event also included under Uncontained disk (primary cause), Fig. 7.** 1st generation.

Number 2 engine fan spinner cap fractured; penetrated inlet cowl forward of "A" flange. Debris ingested by No. 1 engine. Both engines surged, had exceedances, and were IFSD by the crew. **Event also included under Uncontained - other (primary cause), Fig. 11.** 1st generation. Spinner failure resulted from improper repair.

No. 3 uncontained high compressor disk failure during takeoff roll; crew rejected takeoff due to firewarning. Debris bounced off runway and struck No. 1 engine, causing damage, fire, engine firewarning and uncommanded shutdown (hazard level 3.a.) **Event also included in Uncontained disk (primary cause), Fig. 7.** 1st generation.

Crew shut down both engines during climb at 4000 feet; the intention was to retract landing gear, but crew set master engine levers 1 and 2 to "off" instead. The crew training simulator, in which the captain had recently been trained, had a gear warning horn malfunction that required cycling the engine cut-off switch to resolve. APU started, dual-engine start performed and descent arrested at 1000 feet (hazard level 3.e.) **Event also included in Crew error (primary cause), Fig. 38.** 2nd generation.

MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED[22] TURBOPROP AND JET/LOW BYPASS

FIGURE 53. MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED – TURBOPROP AND JET/LOW BYPASS - 1992 THROUGH 2000

ENGINE TYPE	TURBOPROP				JET/ LOW BYPASS			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5
NUMBER EVENTS BY CONDITION								
Contamination	*	0	0	2	1†	0	0	0
Mismanagement	*	0	1	0	2†	0	1	0
Exhaustion	5	0	4	1	4	0	2	2
TOTAL	5	0	5	3	7	0	3	2

* THE EVENT COUNT FOR ALL EVENTS IS UNKNOWN.
† SUSPECTED UNDER-REPORTING.

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 5
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 13
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 13
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= *

FIGURE 54. HAZARD RATIOS FOR MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED - TURBOPROP AND JET/LOW BYPASS

ENGINE TYPE	TURBOPROP			JET/ LOW BYPASS		
HAZARD LEVEL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL	(3+4+5) /ALL	(4+5) /ALL	5 /ALL
HAZARD RATIO BY CONDITION						
Contamination	†	†	†	0/1 = *	0/1 = *	0/1 = *
Mismanagement	†	†	†	1/2 = .50‡	1/2 = .50‡	0/2 = *
Exhaustion	5/5 = 1.0	5/5 = 1.0	1/5 = .17	4/4 = 1.0	4/4 = 1.0	2/4 = .50
Total	†	†	†	5/7 = .29	5/7 = .29	2/7 = .29

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.
† HAZARD RATIO NOT CALCULATED DUE TO INCOMPLETE REPORTING.
‡ HAZARD RATIO LIKELY CONSERVATIVE DUE TO SUSPECTED UNDER-REPORTING.

[22] Note that these include only those cases that led to multiple-engine effects.

Event summaries – Multiple-engine powerloss – fuel-related - Hazard level 4 or 5.

Engine Type	Event Summary
CONTAMINATION	
Turboprop	After takeoff, the aircraft climbed to 30 feet before suddenly rolling to the right and crashing. The right engine was not delivering power on impact; the left propeller control was found seized in the feather position and the left propeller blades in the near-feather position. The forward fuel tank, which provides fuel to the right engine, was found to be heavily contaminated with water, an emulsifying agent, and bacterial growth. The fuel from the airport fuel truck and the main underground tank contained the same mixture. Pilot apparently feathered the left engine after right engine powerloss (hazard level 5.) **Event also reported under PSM+ICR (primary cause), Fig. 36**.
	Multiple engine problems shortly after takeoff. Fuel reportedly contaminated with water. Fatal crash (hazard level 5.)
MISMANAGEMENT	
Turboprop	**Ferry flight.** During cruise at 12,000 feet, pilot declared an emergency and reported fuel transfer problems. Aircraft ditched, but occupants were rescued (hazard level 4.a., 4.b.)
Jet/Low Bypass	Fuel system icing (tank transfer). Both engines flamed out at 22,000 feet. Unpowered on-airport landing, no injuries (hazard level 4.a.)
EXHAUSTION	
Turboprop	Aircraft crashed after running out of fuel (hazard level 5.)
	Forced landing shortly after takeoff caused by engine shutdowns due to fuel exhaustion. Fuel had reportedly been stolen (hazard level 4.a.)
	Forced landing after aircraft ran out of fuel. Crew had deviated from planned route and got lost (hazard level 4.a.)
	During descent, both engines lost power. Pilot subsequently carried out a forced landing. Rear tank was empty, but forward tank had 225 lb. of fuel (hazard level 4.a.)

Ferry flight. Pilot ditched aircraft after running out of fuel. Pilot was rescued (hazard level 4.a., 4.b.)

Jet/Low Bypass

During fly-by to ascertain status of landing gear, aircraft ran out of fuel and crashed. Fatal to 2 of 6 onboard, hull loss (hazard level 5.)

After being unable to make a planned refueling stop, and making multiple missed approaches, the aircraft ran out of fuel and impacted the ground approximately 1.5 miles from the runway. Five fatalities and injuries to the other 34 onboard, hull loss (hazard level 5.)

Aircraft experienced navigation problems; during diversion, fuel exhausted at 28,000 feet and 6 miles from the airport. Aircraft landed short of the runway; minor injuries (hazard level 4.a.)

Test flight. Both engines lost power due to fuel exhaustion; pilot subsequently carried out a forced landing on a road. Aircraft sustained only minor damage. Report that fuel gauges were inaccurate (hazard level 4.a.)

Event summaries – Multiple-engine powerloss – fuel-related - Hazard level 3.

No Events.

MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED 1ST AND 2ND GENERATION HIGH BYPASS

FIGURE 55. MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED – HIGH BYPASS TOTAL AND BY GENERATION – 1992 THROUGH 2000

ENGINE TYPE	ALL HIGH BYPASS				1ST GENERATION				2ND GENERATION			
HAZARD LEVEL	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**	**ALL**	**3**	**4**	**5**
NUMBER EVENTS BY CONDITION												
Contamination	4	0	1	0	1	0	0	0	3	0	1	0
Mismanagement	14	1	0	0	12	0	0	0	2	1	0	0
Exhaustion	2	0	2	0	1	0	1	0	1	0	1	0
TOTAL	20	1	3	0	14	0	1	0	6	1	2	0

TOTAL NUMBER EVENTS HAZARD LEVEL 5	= 0
TOTAL NUMBER EVENTS HAZARD LEVEL 4+5	= 3
TOTAL NUMBER EVENTS HAZARD LEVEL 3+4+5	= 4
TOTAL NUMBER EVENTS HAZARD LEVEL ALL	= 20

FIGURE 56. HAZARD RATIOS FOR MULTIPLE-ENGINE POWERLOSS – FUEL-RELATED - HIGH BYPASS TOTAL AND BY GENERATION

ENGINE TYPE	ALL HIGH BYPASS			1ST GENERATION			2ND GENERATION		
HAZARD LEVEL	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**	**3+4+5 /ALL**	**4+5 /ALL**	**5 /ALL**
HAZARD RATIO BY CONDITION									
Contamination	1/4 = .25	1/4 = .25	0/4 = *	0/1 = *	0/1 = *	0/1 = *	1/3 = .33	1/3 = .33	0/3 = *
Mismanagement	1/14 = .07	0/14 = *	0/14 = *	0/12 = *	0/12 = *	0/12 = *	1/2 = .50	0/2 = *	0/2 = *
Exhaustion	2/2 = 1.0	2/2 = 1.0	0/2 = *	1/1 = 1.0	1/1 = 1.0	0/1 = *	1/1 = 1.0	1/1 = 1.0	0/1 = *
TOTAL	4/20 = .20	3//20 = .15	0/20 = *	1/14 = .07	1/14 = .07	0/14 = *	3/6 = .50	2/6 = .33	0/6 = *

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – Multiple-engine powerloss – fuel-related - Hazard level 4 or 5.

Engine Type **Event Summary**

CONTAMINATION

High Bypass Dual engine flameout at FL370 due to severe fuel contamination (water). Unpowered off-airport landing (hazard level 4.a.) 2nd generation.

EXHAUSTION

High Bypass Complete fuel exhaustion during weather-related diversion in high-drag configuration (flaps unable to retract). Forced off-airport landing (hazard level 4.a.) 1st generation.

Crew unable to retract landing gear after takeoff; diversion in high drag configuration led to complete fuel exhaustion. Unpowered on-airport landing (hazard level 4.a.) 2nd generation.

Event summaries – Multiple-engine powerloss – fuel-related - Hazard level 3.

Engine Type **Event Summary**

MISMANAGEMENT

High Bypass **Flight test**. During enroute descent, aircraft experienced sudden total loss of power on all engines. Engine flameout was the result of temporary fuel starvation after suction feed operation. All engines were restarted after 21,000 ft altitude loss, and aircraft landed without further incident (hazard level 3.e.) 2nd generation

APU EVENTS

FIGURE 57. APU-RELATED AIRCRAFT HAZARD MATRIX 1992 THROUGH 2000

HAZARD LEVEL	ALL	3	4	5
APU SYSTEM MALFUNCTION	**NUMBER EVENTS**			
UNCONTAINED	47	0	0	0
AXIAL UNCONTAINED	15	0	0	0
OVERSPEED*	63	0	0	0
FIRE*	45	6	0	0
TAILPIPE FIRE*	28	1	0	0
COMPARTMENT OVERHEAT*	242	0	0	0
TOTAL EVENTS		**7**	**0**	**0**

* THE EVENT COUNT FOR ALL EVENTS MAY BE INCOMPLETE.
† NO EVENTS REPORTED - MAY BE INCOMPLETE

NOTE: APU FUME EVENTS REPORTED UNDER PROPULSION SYSTEM FUMES, BELOW

FIGURE 58. HAZARD RATIOS FOR APU

APU EVENT	UNCONT	AXIAL UNCONT	OVER-SPEED	FIRES	TAILPIPE FIRES	COMP. OVERHEAT
LVL.5/ ALL	0/47 = *	0/15 = *	0/63 = *	0/45 = *	0/28 = *	0/242 = <.004
LVL.4+5/ ALL	0/47 = *	0/15 = *	0/63 = *	0/45 = *	0/28 = *	0/242 = <.004
LVL.3+4+5/ ALL	0/47 = *	0/15 = *	0/63 = *	6/45 = .133	1/28 = .036	0/242 = <.004

* HAZARD RATIO NOT CALCULATED. SEE PARA. 3 IN SECTION IV, DISCUSSION.

Event summaries – APU - Hazard level 4 or 5.

No events.

Event summaries – APU - Hazard level 3.

Malfunction	**Event Summary**
Fire	Fire bottles did not discharge, resulting in minor damage to fuselage (hazard level 3.b.)
	Fumes and fire during start resulting in burnt oil tank (hazard level 3.b.)
	APU caught fire in flight during start; crew unable to extinguish it (hazard level 3.b.)
	Explosion and fire after start. Aircraft damage; fire extinguished by ground crew (hazard level 3.a., 3.b.)
	Fire suppression system unable to extinguish flames; fire department called. Minor damage to aircraft (hazard level 3.b.)
	On approach, firewarning light illuminated. Extinguishers deployed; however fire had to be extinguished by ground crew. Substantial damage to rear fuselage (hazard level 3.a., 3.b.)
Tailpipe fire	Blade shift event caused tailpipe fire and resulting vibration led to oil ingestion, uncontrolled fire assumed (hazard level 3.b.)

Notes on APU Overspeed.

1. Control system failures caused 49 of the 63 reported overspeeds. None resulted in uncontainment.
2. Torque path failures caused 10 of the 63 reported overspeeds. None resulted in uncontainment.
3. De-ice fluid ingestion caused the 4 of the 63 reported overspeeds. One event resulted in uncontainment (of less than level 3 severity).

PROPELLER EVENTS

FIGURE 59. PROPELLER SYSTEM-RELATED AIRCRAFT HAZARD MATRIX 1992 THROUGH 2000

HAZARD LEVEL	**ALL**	**3**	**4**	**5**
PROPELLER SYSTEM MALFUNCTION	**NUMBER EVENTS**			
PROPELLER SEPARATION/DEBRIS RELEASE	84	17	1	1
AUTOFEATHER/PITCH LOCK	75	1	0	0
PSM+ICR	*	5	1	0
CREW ERROR	*	2	2	1
TOTAL EVENTS		25†	4	2

* LOWER-LEVEL EVENTS NOT REPORTED.
† DUPLICATE CLASSIFICATION OF SOME EVENTS.

NOTE: ADDITIONAL PROPELLER SYSTEM EVENTS ARE REPORTED IN FIGURE 39, IN-FLIGHT BETA, AND FIGURE 41, FAILURE TO ENTER BETA.

FIGURE 60. HAZARD RATIOS FOR PROPELLER

PROPELLER SYSTEM EVENT	**PROPELLER SEPARATION/ DEBRIS RELEASE**	**AUTOFEATHER/ PITCH LOCK**	**PSM+ICR**	**CREW ERROR**
LVL.5/ALL	1/84 = .012	0/75 = < .013	*	*
LVL.4+5/ALL	2/84 = .024	0/75 = < .013	*	*
LVL.3+4+5/ALL	19/84 = .226	1/75 = .013	*	*

* PREPARATION OF HAZARD RATIO NOT POSSIBLE GIVEN THE UNKNOWN INCIDENCE OF LOWER-LEVEL EVENTS.

Event summaries – Propeller - Hazard level 4 or 5.

Malfunction	**Event Summary**
Propeller separation/ debris release	Left propeller blade separation during climbout. Gearbox/propeller laterally displaced, causing significant drag. The crew was unable to maintain altitude; forced landing in an open field. Aircraft was destroyed by impact and post-crash fire; multiple fatalities (hazard level 5.)

	Aircraft hit two deer on landing. Propeller blade separated and penetrated fuselage, seriously injuring one passenger (hazard level 4.c., 3.a.)
PSM+ICR	On landing, beta selected on both engines, but did not deploy on right one. Pilot recognized beta light, but engines left at 100% RPM. Offside runway and down an embankment; hull loss (level 4.b., 3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41.**
Crew Error	Two engine overspeed after propeller beta mode selected in flight. Hull loss; fatal (hazard level 5.) **Event also included in Reverser/beta malfunction - in-flight deploy, Fig. 39.**
	Dual-engine overspeed due to operation of propellers in beta range inflight. Unpowered landing (on-airport) and runway overrun. No injuries (hazard level 4.a.) **Event also included in Reverser/beta malfunction - in-flight deploy, Fig. 39.**
	Propeller flat pitch selected during the final stage of approach. Descent rate rapidly increased, as did engine speed. Crash landing; hull loss, no fatalities (hazard level 4.b.) **Event also included in Reverser/beta malfunction - in-flight deploy, Fig. 39.**

Event summaries – Propeller - Hazard level 3.

Malfunction	**Event Summary**
Propeller separation/ debris release	Inflight fracture of propeller blade and separation of propeller from engine. Penetration of fuselage and cabin; minor injuries (hazard level 3.a., 3.c.)
	Propeller blade debris released inflight. Fuselage penetration; minor injuries (hazard level 3.a.)
	2 events. Propeller blade debris released inflight. Fuselage penetration; no injuries (hazard level 3.a.)
	One propeller blade separated during run-up at takeoff, causing damage to the engine mounts, nacelle, fuselage, wing and flap (hazard level 3.a.)

No reverse on right engine; runway departure into 4-ft. ditch at 70 kts, gear collapse and FOD to props. One failed at hub, pieces penetrated fuselage (8" tear). No injuries (hazard level 3.a.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41, and Propeller PSM+ICR (primary cause), below.**

Propeller blade debris released from no. 1 propeller bounced off the runway and damaged multiple blades on the No. 2 propeller (hazard level 3.a.)

Propeller blade release during runway overrun causing fuselage damage (hazard level 3.a.) **Event also included in engine PSM+ICR (primary cause), Fig. 36.**

Propeller blade release after contact with snowbank. Fuselage penetration (hazard level 3.a.)

Propeller blade fracture following deer strike; fuselage penetration (hazard level 3.a.)

Propeller blade fracture following landing gear collapse; fuselage penetration (hazard level 3.a.)

Stall warning during takeoff; crew rejected. Aircraft contacted the runway and veered into a snow bank. All 8 blades from both engines separated; three from the right engine penetrated the fuselage. Minor injuries (hazard level 3.a.)

During landing with the landing gear retracted, the propellers struck the ground and the landing was aborted. Damage to the No. 3 propeller caused the engine to be torn from its mounts. Parts of the No. 3 propeller struck the fuselage and also damaged the No 4 engine. Both the No. 2 and No. 4 propellers were also damaged during the ground strike. The aircraft was unable to climb, but landed safely after second approach. Damage resulted in what is believed to be an economic hull loss (hazard level 3.a., 3.e.)

Tug drove into rotating propeller; two blades separated and damaged the aircraft (hazard level 3.a.)

Propeller blade fracture following collision with ground power unit. Debris caused fuselage damage (hazard level 3.a.)

Training flight. Propeller debris (counterweight and arm) release during flight. Fuselage punctured (hazard level 3.a.)

	Engine test run. Aircraft jumped its chocks, causing propeller impact with tractor. Blade separation caused severe damage to the fuselage (hazard level 3.a.)
Autofeather/Pitch Lock	Right propeller pitch was locked due to inadequate oil pressure. Full reverse selected on landing. Runway departure, significant aircraft damage, minor injuries (hazard level 3.a., 3.f.**) Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41, and Propeller PSM+ICR (primary cause), below.**
PSM+ICR	No reverse on right engine; runway departure into 4-ft. ditch at 70 kts, gear collapse and FOD to props. One failed at hub, pieces penetrated fuselage (8" tear). No injuries (hazard level 3.a., 3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41, and Propeller Separation, above.**
	Right propeller pitch locked due to inadequate oil pressure. Full reverse selected on landing. Runway departure, significant aircraft damage, minor injuries (hazard level 3.a, 3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41, and Propeller autofeather/pitch lock, above.**
	Unable to reverse one propeller during landing. Runway departure, significant aircraft damage (hazard level 3.a.,3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41.**
	During landing, left propeller did not go into fine pitch. Runway departure down a steep slope, where the nose landing gear was torn off (hazard level 3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41.**
	Unable to reverse one propeller during landing. Runway departure, damage limited to propeller and engine, no injuries (hazard level 3.f.) **Event also included in Reverser/beta malfunction - failure to deploy, Fig. 41.**
Crew Error	Two engine overspeed after propeller beta mode selected in flight. Successful single engine landing. No injuries (hazard level 3.f.) **Event also included in Reverser/beta malfunction - in-flight deploy, Fig. 39.**
	Pilot input with nose gear still in the air caused differential engine beta. Airplane lost control; nose gear collapse after impact with runway lighting. (hazard levels 3.a., 3.f.)

PROPULSION SYSTEM FUME EVENTS

FIGURE 61. PROPULSION SYSTEM FUMES AIRCRAFT HAZARD MATRIX 1992 THROUGH 2000

HAZARD LEVEL	ALL	3	4	5
SYSTEM	**NUMBER EVENTS**			
APU*	3199	1	0	0
ENGINE*	1161	2	0	0
TOTAL EVENTS	4360	3	0	0

* THE EVENT COUNT FOR ALL EVENTS MAY BE INCOMPLETE.

FIGURE 62. HAZARD RATIOS FOR PROPULSION SYSTEM FUMES

ENGINE TYPE	APU	TURBINE ENGINES	ALL PROPULSION SYSTEM
LVL.5/ALL	0/3199 < 0.001	0/1161 < 0.001	0/4360 < 0.001
LVL.4+5/ALL	0/3199 < 0.001	0/1161 < 0.001	0/4360 < 0.001
LVL.3+4+5/ALL	1/3199 < 0.001	2/1161 = 0.002	3/4360 < 0.001

The events documented were limited to those where fumes generated either by the engine or APU were clearly present; effect severity was based on the immediate and obvious effects on the crew and passengers. Events with an undetermined relationship between engine or APU behavior and crew well-being were not included.

Event summaries – Fumes - Hazard level 4 or 5.

No events.

Event summaries – Fumes - Hazard level 3.

System	Event Summary
APU	After landing, cabin filled with smoke; visibility severely limited; injuries during evacuation unrelated to base event (hazard level 3.g.)
Engine	Smoke in the cabin and cockpit. After emergency landing, 4 passengers were treated for smoke inhalation (hazard level 3.g.) Turboprop.

Aircraft cruising at 28K feet when haze filled the cockpit and then the cabin. Flight crew indicated that haze was dense enough to obscure the primary instruments. No. 1 engine uncommanded shutdown; haze cleared (hazard level 3.g.) Turbofan.

FIGURE 63. AIRCRAFT HAZARD EVENT COUNT MATRIX - SUMMARY REVENUE SERVICE 1992 THROUGH 2000 EXCLUDING APU-RELATED AND FUME EVENTS

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR				ALL			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
MALFUNCTION TYPE	EVENT COUNTS															
UNCONTAINED SUBTOTAL	9	0	1	0	27	4	2	1	130	9	1	0	166	13	4	1
Blade	1	0	0	0	21	1	0	1	98	2	0	0	120	3	0	1
Disk, Spool, etc.	6	0	1	0	6	3	2	0	26	6	1	0	38	9	4	0
Other	2	0	0	0	0	0	0	0	6	1	0	0	8	1	0	0
ENGINE OVERSPEED	*	*	*	*	†	0	0	0	†	0	0	0	449	0	0	0
CASE RUPTURE	0	0	0	0	6	0	0	0	7	0	0	0	13	0	0	0
CASE BURNTHROUGH	3	1	0	0	3	0	0	0	27	1	0	0	33	2	0	0
UNDER-COWL FIRE	20	4	0	0	11	0	0	0	86	3	0	0	117	7	0	0
FLAMMABLE FLUID LEAK SUBTOTAL	535‡	3	0	0	†	2	0	0	†	8	0	0	5174	13	0	0
Oil/Hydraulic Leak	463‡	0	0	0	†	0	0	0	†	0	0	0	2339	0	0	0
Fuel Leak	72‡	3	0	0	†	2	0	0	†	8	0	0	2835	13	0	0
COMPARTMENT OVERHEAT/AIR LEAK	†	0	0	0	†	0	0	0	†	0	0	0	978	0	0	0
ENGINE SEPARATION	2	0	0	0	6	1	2	1	3	2	0	1	11	3	2	2
COWL SEPARATION	3‡	0	0	0	27	1	0	0	117	1	0	0	147	2	0	0
PSM+ICR	*	1‡	3	8	*	3‡	3	2	*	2‡	1	4	*	6‡	7	14
CREW ERROR	*	0‡	0	1	*	2‡	2	0	*	3‡	0	0	*	5‡	2	1
REVERSER/BETA - INFLIGHT DEPLOY	5‡	1	2	2	3	0	0	0	13	2	0	1	21	3	2	3
REVERSER/BETA FAILURE TO DEPLOY	8‡	5	1	0	*	*	0	0	784	0	2	0	792	5	3	0

FIGURE 63. Continued

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR				ALL			
HAZARD LEVEL	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5	ALL	3	4	5
MALFUNCTION TYPE	EVENT COUNTS (continued)															
FUEL TANK RUPTURE	0	0	0	0	1	0	0	1	1	0	0	1	2	0	0	2
TAILPIPE FIRE	11‡	4	0	0	†	0	0	0	†	1	0	0	229	5	0	0
FALSE/MISLEADING INDICATION	268	0	0	1	†	0	0	0	†	0	0	0	9268	0	0	1
MULTI-ENG – NON-FUEL SUBTOTAL	**13**	**3**	**2**	**2**	**19**	**12**	**1**	**2**	**70**	**14**	**3**	**0**	**102**	**29**	**6**	**4**
Environmental	12	3	1	2	8	4	0	1	36	5	0	0	56	12	1	3
Maintenance	0	0	0	0	0	0	0	0	7	2	3	0	7	2	3	0
Other/Unknown	1	0	1	0	11	8	1	1	27	7	0	0	39	15	2	1
MULTI-ENG - FUEL SUBTOTAL	*****	**0**	**3**	**3**	**6**	**0**	**2**	**2**	**19**	**0**	**3**	**0**	**29**	**0**	**8**	**5**
Fuel Contamination	*	0	0	2	1	0	0	0	4	0	1	0	5	0	1	2
Fuel Mismanagement	*	0	0	0	2	0	1	0	13	0	0	0	15	0	1	0
Fuel Exhaustion	4	0	3	1	3	0	1	2	2	0	2	0	9	0	6	3
PROPELLER SYSTEM SUBTOTAL	**159**	**25**	**4**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**159**	**25**	**4**	**2**
Blade Separation/Debris	82	15	1	1									82	15	1	1
Autofeather/Pitch Lock	75	1	0	0									75	1	0	0
Propeller PSM+ICR	*	5	1	0									*	5	1	0
Propeller Crew Error	*	2	2	1									*	2	2	1
GRAND TOTAL	*****	**33**	**13**	**15**	*****	**23**	**11**	**8**	*****	**38**	**9**	**7**	*****	**94**	**33**	**30**

* EVENTS NOT REPORTED.
† EVENTS NOT SEPARATED BY THIS ENGINE TYPE.
‡ SUSPECTED UNDER-REPORTING.

NOTE: TOTALS HAVE REMOVED THE EFFECT OF DUPLICATE AND NON-REVENUE EVENTS.

FIGURE 64. AIRCRAFT HAZARD RATIO MATRIX - SUMMARY 1992 THROUGH 2000 EXCLUDING APU-RELATED AND FUME EVENTS

ENGINE TYPE	TURBOPROP			JET/LBPR			HBPR		
HAZARD RATIO	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL
MALFUNCTION	HAZARD RATIOS								
UNCONTAINED									
Blade	-	-	-	0.1	0.05	0.05	0.02	<0.01	<0.01
Disk, spool, etc.	0.17	0.17	-	0.83	0.33	-	0.3	0.04	-
Other	-	-	-	-	-	-	0.17	-	-
ENGINE OVERSPEED	-	-	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
CASE RUPTURE	-	-	-	-	-	-	-	-	-
CASE BURNTHROUGH	0.33	-	-	-	-	-	0.037	-	-
UNDER-COWL FIRE	0.25	-	-	-	-	-	0.05	-	-
FLAMMABLE FLUID LEAK									
Oil/Hydraulic Leak	<0.002	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Fuel Leak	0.04	-	-	0.004	<0.001	<0.001	0.004	<0.001	<0.001
COMPARMENT OVERHEAT/AIR LEAK	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ENGINE SEPARATION	-	-	-	0.667	0.5	0.167	1	0.33	0.33
COWL SEPARATION	-	-	-	0.04	-	-	0.01	<0.01	<0.01
PSM+ICR	*	*	*	*	*	*	*	*	*
CREW ERROR	*	*	*	*	*	*	*	*	*
REVERSER/BETA – INFLIGHT DEPLOY	*	*	*	-	-	-	0.23	0.08	0.08
REVERSER/BETA - FAILURE TO DEPLOY	*	*	*	*	*	*	0.003	0.003	-

FIGURE 64. Continued

ENGINE TYPE	TURBOPROP			JET/LBPR			HBPR		
HAZARD RATIO	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL	(3+4+5)/ ALL	(4+5)/ ALL	5/ ALL
MALFUNCTION	HAZARD RATIOS								
FUEL TANK RUPTURE	-	-	-	1	1	1	1	1	1
TAILPIPE FIRE				0.005	-	-	0.005	-	-
FALSE/MISLEADING INDICATION	0.004	0.004	0.004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
MULTI-ENG – NON-FUEL SUBTOTAL	0.54	0.31	0.15	0.79	0.16	0.11	0.24	0.04	<0.01
Environmental	0.5	0.25	0.17	0.63	0.13	0.13	0.14	-	-
Maintenance	-	-	-	-	-	-	0.71	0.43	
Other/Unknown	1	1		0.91	0.18	0.09	0.26	-	-
MULTI-ENG – FUEL SUBTOTAL				0.29	0.29	0.29	0.2	0.15	-
Fuel Contamination	-	-	-	-	-	-	0.25	0.25	
Fuel Mismanagement	-	-	-	0.5	0.5	-	0.07	-	-
Fuel Exhaustion	1	1	0.17	1	1	0.5	1	1	-
PROPELLER SYSTEM SUBTOTAL	*	*	*						
Blade Separation/Debris	0.226	0.024	0.012	†	†	†	†	†	†
Autofeather/Pitch Lock	0.013	<0.01	<0.01	†	†	†	†	†	†
Propeller PSM+ICR	*	*	*	†	†	†	†	†	†
Propeller Crew Error	*	*	*	†	†	†	†	†	†

* HAZARD RATIOS NOT CALCULATED DUE TO NON-REPORTING OF BASE EVENTS.
† NOT APPLICABLE.
‡ HAZARD RATIOS CONSERVATIVE DUE TO SUSPECTED UNDER-REPORTING.

FIGURE 65. AIRCRAFT EVENT RATES MATRIX - SUMMARY 1992 THROUGH 2000 EXCLUDING APU-RELATED AND FUME EVENTS RATES GIVEN PER 100 MILLION AIRPLANE DEPARTURES

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	ALL	3+4+5	4+5	5	ALL	3+4+5	4+5	5	ALL	3+4+5	4+5	5
MALFUNCTION TYPE	EVENT RATES											
UNCONTAINED SUBTOTAL	36	4	4	0	59	15	6	2	129	10	1	-
Blade	4	-	-	-	46	4	2	2	97	2	-	-
Disk, Spool, etc.	24	4	4	-	13	11	4	-	26	7	1	-
Other	8	-	-	-	0	-	-	-	6	1	-	-
ENGINE OVERSPEED	*	-	-	-	†	-	-	-	†	-	-	-
CASE RUPTURE	0	-	-	-	13	-	-	-	7	-	-	-
CASE BURNTHROUGH	12	4	-	-	7	-	-	-	27	1	-	-
UNDER-COWL FIRE	79	16	-	-	24	-	-	-	85	3	-	-
FLAMMABLE FLUID LEAK SUBTOTAL	2115	12	-	-	*	4	-	-	*	8	-	-
Oil/Hydraulic Leak	1830	-	-	-	*	-	-	-	*	-	-	-
Fuel Leak	284	12	-	-	*	4	-	-	*	8	-	-
COMPARMENT OVERHEAT/AIR LEAK	*	-	-	-	*	-	-	-	*	-	-	-
ENGINE SEPARATION	8	-	-	-	13	9	6	2	3	3	1	1
COWL SEPARATION	12	-	-	-	59	2	-	-	115	1	-	-
PSM+ICR	*	47	43	32	*	18	11	4	*	7	5	4
CREW ERROR	*	4	4	4	*	7	4	-	*	*	-	-
REVERSER/BETA – INFLIGHT DEPLOY	*	20	16	8	7	-	-	-	13	3	1	1
REVERSER/BETA - FAILURE TO DEPLOY	*	24	4	-	*	*	-	-	776	2	2	-

FIGURE 65. Continued

ENGINE TYPE	TURBOPROP				JET/LBPR				HBPR			
HAZARD LEVEL	**ALL**	**3+4+5**	**4+5**	**5**	**ALL**	**3+4+5**	**4+5**	**5**	**ALL**	**3+4+5**	**4+5**	**5**
MALFUNCTION TYPE	**EVENT RATES**											
FUEL TANK RUPTURE	-	-	-	-	2	2	2	2	1	1	1	1
TAILPIPE FIRE	*	16	-	-	*	-	-	-	*	1	-	-
FALSE/MISLEADING INDICATION	1059	4	4	4	*	-	-	-	8911	-	-	-
MULTI-ENG – NON-FUEL SUBTOTAL	51	28	16	8	42	33	6	4	69	17	3	0
Environmental	47	24	12	8	18	11	2	2	36	5	-	-
Maintenance	-	-	-	-	-	-	-	-	7	5	3	-
Other/Unknown	4	4	4	-	24	22	4	2	27	7	-	-
MULTI-ENG - FUEL SUBTOTAL	20	20	20	12	13	9	9	4	19	3	3	
Fuel Contamination	*	8	8	8	2	-	-	-	4	1	1	-
Fuel Mismanagement	*	-	-	-	4	2	2	-	13	-	-	-
Fuel Exhaustion	16	16	16	4	7	7	7	4	2	2	2	-
PROPELLER SYSTEM SUBTOTAL	620	122	24	8								
Blade Separation/Debris	324	67	8	4								
Autofeather/Pitch Lock	296	4	-	-								
Propeller PSM+ICR	*	24	4	-								
Propeller Crew Error	*	20	12	4								
GRAND TOTAL	*	241	111	59	*****	**93**	**42**	**18**	*****	**53**	**16**	**7**

* RATES NOT CALCULATED DUE TO UNDER-REPORTING/NON-REPORTING OF BASE OR LEVEL 3 EVENTS.

NOTE: TOTALS HAVE REMOVED THE EFFECT OF DUPLICATE EVENTS.

FIGURE 66. AIRCRAFT EVENT RATES MATRIX – COMPARISON OF FIRST AND SECOND GENERATION HBPR REVENUE SERVICE 1992 THROUGH 2000 SELECTED EVENT TYPES RATES GIVEN PER 100 MILLION AIRPLANE DEPARTURES

ENGINE TYPE	FIRST GENERATION HBPR				SECOND GENERATION HBPR			
HAZARD LEVEL	**ALL**	**3+4+5**	**4+5**	**5**	**ALL**	**3+4+5**	**4+5**	**5**
MALFUNCTION TYPE	**EVENT RATES**							
UNCONTAINED								
Blade	656	22	-	-	34	-	-	-
Disk, spool, etc.	200	67	11	-	6	1	-	-
Other	33	11	-	-	1	-	-	-
MULTI-ENGINE								
Environmental	189	44	-	-	21	1	-	-
Maintenance	44	33	11	-	3	2	2	-
Other/Unknown	211	67	-	-	9	1	-	-
Fuel Contamination	11	-	-	-	3	1	1	-
Fuel Mismanagement	133	-	-	-	1	-	-	-
Fuel Exhaustion	11	11	11	-	1	1	1	-

FIGURE 67. AIRCRAFT EVENT RATES MATRIX - SUMMARY COMPARISON WITH CAAM1 (*GIVEN IN PARENTHESES*) EXCLUDING APU-RELATED AND FUME EVENTS AND EVENTS NOT COLLECTED FOR CAAM1 REVENUE SERVICE; RATES GIVEN PER 100 MILLION AIRPLANE DEPARTURES

ENGINE TYPE	**TURBOPROP**			**JET/LBPR**			**HBPR**		
HAZARD LEVEL	**ALL**	**3+4**	**3+4+5**	**ALL**	**3+4+5**	**4+5**	**ALL**	**3+4+5**	**4+5**
MALFUNCTION TYPE	**EVENT RATES**								
UNCONTAINED SUBTOTAL	36 (*64*)	4 (*6*)	4 (*3*)	59 (*120*)	15 (*25*)	6 (*4*)	129 (*349*)	10 (33)	1 (*8*)
Blade	4 (*22*)	- (*1*)	- (*1*)	47 (*86*)	4 (*11*)	2	97 (*277*)	2 (*3*)	-
Disk, Spool, etc.	24 (*38*)	4 (*5*)	4 (*5*)	13 (*26*)	11 (*12*)	4 (*4*)	26 (*46*)	7 (*23*)	1 (*8*)
Other	8 (*37*)	-	-	- (*7*)	-	-	6 (*25*)	1 (*8*)	-
CASE RUPTURE	(*15*)	-	-	13 (*26*)	- (*5*)	- (*3*)	7 (*25*)	- (*5*)	-
CASE BURNTHROUGH	12 (77)	4 (*1*)	-	7 (*7*)	-	-	27 *(113)*	1 (-)	-
UNDER-COWL FIRE	79 (*22*)	16 (*4*)	- (*1*)	24 (*22*)	- (*1*)	-	85 *(226)*	3 (*8*)	-
COMPARMENT OVERHEAT/AIR LEAK	*	-	-	*	-	-	*	-	-
ENGINE SEPARATION	*	-	-	13 (*2.5*)	9	6	3 (*5*)	3 (*5*)	1 (*5*)
COWL SEPARATION	*	-	-	59 (*34*)	2	-	115 (*200*)	1 (3)	-
PSM+ICR	*	47 (*23*)	43 (*18*)	*	18 (*9*)	11 (*6*)	*	7	5 (*5*)
CREW ERROR	*	4 (*6*)	4 (*6*)	*	7 (*1*)	4	*	* (*8*)	- (*3*)
REVERSER	*	44	20	7 (*18*)	* (*3*)	- (*1*)	789 (*51*)	5 (*15*)	3 (*3*)
MULTI-ENG SUBTOTAL	71	48 (*28*)	36 (*22*)	55 (*43*)	42 (*16*)	15 (*6*)	88 (*264*)	20 (*63*)	6 (*10*)
GRAND TOTAL (all causes including those not listed here)	*	**241 (*74*)**	**111 (*53*)**	*	**93 (*61*)**	**42 (*21*)**	*	**53 (*167*)**	**16 (*33*)**

* RATES NOT CALCULATED DUE TO UNDER-REPORTING/NON-REPORTING OF BASE OR LEVEL 3 EVENTS.

NOTES: GRAND TOTAL INCLUDES ALL LEVEL 3 AND 4 EVENTS, INCLUDING THOSE NOT COLLECTED IN CAAM1.
GRAND TOTAL REMOVES THE EFFECT OF DUPLICATE EVENTS.
BASE-LEVEL AND LEVEL 3 EVENTS SHOULD BE COMPARED WITH CAUTION, SINCE THE EXTENT OF REPORTING AND LEVEL 3 DEFINITIONS VARIED BETWEEN THE TWO CAAM STUDIES.

<u>Relationship to previous CAAM data</u>

Note that the total number of uncontained blade failures is significantly down from CAAM1 (120 vs. 195), as is the total number of level 3+ blade uncontainments (4 vs. 11) and also the uncontained blade rate for each sub-fleet.

Note that the total number of uncontained disk failures **is** significantly down from CAAM1 (38 vs. 69), as is the total number of level 3+ disk uncontainments (12 vs. 23) and also the uncontained disk rate for each sub-fleet.

Note the low hazard ratio for blades, as was also observed in CAAM1. Second generation HBTF blade rates appear much lower than first generation HBTF rates.

Observe the total number of uncontained blade failures is significantly down from CAAM1 (120 vs 195), as is the total number of level 3+ blade uncontainments(4 vs. 11) and also the uncontained blade rate for each sub-fleet.

Observe the total number of uncontained disk failures significantly down from CAAM1 (38 vs 69) , as is the total number of level 3+ disk uncontainments (12 vs. 23) and also the uncontained disk rate for each sub-fleet.

Observe the low hazard ratio for blades, as also observed in CAAM1.

Second generation HBTF blade rates appear much lower than first generation HBTF rates .

The number of case rupture and case burnthrough events is significantly fewer for each sub-fleet compared to CAAM1. This also translates to a lower overall rate for each sub- fleet.

For undercowl fire, the numbers of events and the hazard ratios are very similar to those observed in the first CAAM study, even though the definition of “uncontrolled fire” was made more restrictive for the second study. The rates show some improvement for the high bypass turbofan fleet, and some deterioration for the turboprop fleet.

The data continues to show, as in the first CAAM report, that the likelihood of a propulsion system high pressure air leak or compartment overheat leading to a serious event at the airplane level is controlled to a very low level.

The number of cowl separation events has increased since the first study, primarily in the high bypass turbofan fleet. It should be recognized that the event definition has been expanded to include ground events as well as flight events, which would be expected to drive the number up. The hazard ratio remains low.

The number of engine separation events, number of serious events and low bypass fleet event rate have all increased since the first CAAM report. It should be noted that the first report intent was only to document in-flight events, while the scope has been broadened to intentionally include on-ground events for CAAM2. The lower hazard ratio observed for CAAM2 reflects the inclusion of the less serious on-ground events

The number of PSM+ICR events is relatively constant compared to the first CAAM study. Interventions have been introduced in the late 1990s to address this issue, it is recommended that follow-on work be initiated to check the effectiveness of these interventions and take further action as needed.

There was some reduction in the number and severity of crew error events compared to the first CAAM report.

There was an increase in the number of reverser severe events compared to the first CAAM report, but it should be recognized that the first report did not include turboprop in-flight beta malfunction, which accounts for most of the level 4 and 5 events. The number of severe events associated specifically with thrust reversers was halved.

It should be recognized that the definition for a level 3 multi-engine power loss event was expanded for the CAAM update, to include events engine power was completely lost for a sufficient time that the airplane lost 5000 feet of altitude. In the previous study, many of these events would have been classified as less serious than level 3. There was also more data collected from the turboprop fleet than for the first report, and the power losses were grouped differently. Caution should be used in comparing numbers of base events and level 3 events between CAAM1 and CAAM2. Nonetheless, the high bypass turbofan fleet had fewer multiple engine power loss events for environmental causes than in the first report

It should be noted that the hazard ratio from APU uncontainment remains undefined, since no level 3 or higher events have resulted in either of the CAAM studies. Fire remains the most significant issue for APUs.

FIGURE 68. PARETO OF ALL HAZARD LEVEL 4 AND 5 EVENTS REVENUE SERVICE 1992 THROUGH 2000

MALFUNCTIONS		NUMBER EVENTS	RATE PER A/C FLIGHT
PSM+ICR		21	1.29E-7
MULTI-ENGINE POWERLOSS – FUEL-RELATED		13	0.80E-7
Fuel exhaustion	9		
Fuel contamination	3		
Fuel mismanagement	1		
MULTI-ENGINE POWERLOSS – NON-FUEL		10	0.62E-7
Environmental	4		
Maintenance	3		
Other	3		
REVERSER/BETA – IN-FLIGHT DEPLOY		5	0.31E-7
UNCONTAINED - ALL		5	0.31E-7
ENGINE SEPARATION		4	0.25E-7
PROPELLER CREW ERROR		3	1.18E-7
CREW ERROR		3	0.18E-7
REVERSER/BETA – FAILURE TO DEPLOY		3	0.18E-7
PROPELLER SEPARATION/DEBRIS		2	0.79E-7
FUEL TANK RUPTURE/EXPLOSION		2	0.12E-7
PROPELLER PSM+ICR		1	0.40E-7
FALSE/MISLEADING INDICATION		1	0.06E-7
APU - ALL		0	-
UNDER-COWL FIRE		0	-
CASE RUPTURE		0	-
COWL SEPARATION		0	-
CASE BURNTHROUGH		0	-
COMPARTMENT OVERHEAT/AIR LEAK		0	-
FLAMMABLE FLUID LEAK		0	-
PROPULSION SYSTEM FUMES		0	-
ENGINE OVERSPEED		0	-
TAILPIPE FIRE		0	-
AUTOFEATHER/PITCH LOCK		0	-
TOTAL		**63**	

FIGURE 69. PARETO OF ALL HAZARD LEVEL 3, 4 & 5 EVENTS REVENUE SERVICE 1992 THROUGH 2000

MALFUNCTIONS		NUMBER EVENTS	RATE PER 100 MILLION A/C FLIGHTS
MULTI-ENGINE POWERLOSS NON-FUEL		39	24.0
Other	18		
Environmental	16		
Maintenance	5		
PSM+ICR		27	16.6
UNCONTAINED - ALL		18	11.1
PROPELLER SEPARATION/DEBRIS		17	67.2
MULTI-ENGINE POWERLOSS - FUEL-RELATED		13	8.0
Fuel exhaustion	9		
Fuel contamination	3		
Fuel mismanagement	1		
FLAMMABLE FLUID LEAK		13	8.0
REVERSER/BETA - FAILURE TO DEPLOY		8	4.9
REVERSER/BETA – IN-FLIGHT DEPLOY		8	4.9
CREW ERROR		8	4.9
UNDER-COWL FIRE		7	4.3
APU - ALL		7	-
ENGINE SEPARATION		7	4.3
PROPELLER PSM+ICR		6	23.7
TAILPIPE FIRE		5	3.1
PROPELLER CREW ERROR		5	19.7
PROPULSION SYSTEM FUMES		3	-
CASE BURNTHROUGH		2	1.2
COWL SEPARATION		2	1.2
FUEL TANK RUPTURE/EXPLOSION		2	1.2
AUTOFEATHER/PITCH LOCK		1	3.9
FALSE/MISLEADING INDICATION		1	0.6
ENGINE OVERSPEED		0	-
CASE RUPTURE		0	-
COMPARMENT OVERHEAT/AIR LEAK		0	-
TOTAL		**157**	

Appendix 4

Hazards to Persons Being Overflown

Concern has frequently been expressed regarding the potential for pieces of the propulsion system to fall from the aircraft and potentially injure persons on the ground. Large or dense pieces may depart the aircraft in the event of an engine or other propulsion system failure in flight, and it is physically credible that they could seriously injure someone on the ground as they fall. However, historically there have been no serious injuries from falling pieces as long as the airplane itself remained intact (impact of an entire airplane with one or multiple buildings is clearly a different scenario).

The service record of substantial pieces of propulsion systems departing the airplane in flight is given in the body of the report. It shows that none of these 158 large and dense items has struck or seriously injured an overflown individual. Nor have any of the pieces of uncontained rotor, departing the airplane without striking it, injured an overflown individual. (167 events involving multiple pieces)

Moreover, in the course of internal engine failures, substantial quantities (tens or hundreds of pieces) of metal debris may be generated, ranging in size from a fraction of an ounce to several pounds, which depart the engine via the exhaust nozzle and fall to the ground: none of these pieces have seriously injured an overflown individual. Manufacturers records, although necessarily incomplete, suggest that such metal debris has been released on many thousand occasions over the last nine years. It should be recognized that many of these smaller pieces have a relatively low terminal velocity and are not energetic enough to cause impact damage; and a case is actually recorded of an individual being struck – but not injured, until the individual picked up the hot part which had fallen to the ground. It should also be recognized that buildings will shield those people indoors from all but the heaviest and densest pieces, and that even the heaviest pieces would not present a threat to individuals on the lower floors of multi-story buildings.

Service experience, then would suggest a hazard ratio of injury to persons being overflown of 1/3000 for small pieces (estimated) – weighing 1 lb or less, as an arbitrary break-point – and a hazard ratio of 1/325 for large, dense pieces weighing up to several hundred pounds. A mathematical analysis follows, which demonstrates the physical basis for the benign service experience, and provides some better focus on the hazard ratios.

Statistical Analysis: Assumptions

- Population density for an urban area ranges from 1673 persons/km^2 (Kansas City) to 28,405 persons/km^2 (Hong Kong); an average of the 86 largest cities is 3300 persons/km^2.

- Average exposed area per person estimated as 2ft^2 (standing); 4ft^2 (sitting) and 12ft^2 (lying).

- Persons indoors are shielded from small debris but not from large, dense debris (neglects benign shielding effect of multi-story buildings).

- Time average exposed area per person – based on being indoors lying down at night (8 hours/day) and being indoors sitting for eight hours/day, outdoors standing for eight hours/day:
  Exposure to large debris - .33*12 + .33*4 +.33*2 = 8ft^2
  Exposure to small debris - .33*0 + .33 *0 + .33 *2 = 0.7 ft^2

Fraction of urban area overflown which is occupied by persons not shielded:
= time average exposed area * persons/kilometer^2
Conditional probability of being struck by small debris: 2.3E-4
Conditional probability of being struck by large debris: 2.6E-3

This analysis shows that the likelihood of being struck by falling debris[23] is significantly lower than other hazard ratios calculated in the body of the report; which addresses level 4 threats to persons occupying the airplane. It may provide additional perspective to consider a similar threat from another source; several hundred meteorites normally strike the land or sea each year; this presents a similar order of magnitude of risk to that posed by propulsion components hitting persons overflown.

[23] Various simplifying, conservative assumptions have been made in the course of this analysis. No credit is taken for the lower population density during flight over rural areas and ocean, or the fact that more flight occur during the day, when the average exposed are per person is significantly lower for large pieces of debris.

Appendix 5

Fleet Included in the Data-Collection Process

TURBOJETS/ TURBOFANS

A300
A310
A320
A330
A340
Aerospatiale Corvette
BAe125
BAe146
Beech 400 Beechjet
Boeing 707
Boeing 717
Boeing 727
Boeing 737
Boeing 747
Boeing 757
Boeing 767
Boeing 777
Canadair 600/601 Challenger
Canadair RJ
Cessna Citation
Concorde
Dassauult Falcon
DC10
DC8
DC9
Embraer ERJ 135
Embraer ERJ 145
Fokker 100
Fokker 70
Fokker F28
Gulfstream GII, III, IV
Hawker Siddely BAe 125
L1011
Learjet
MD11
MD80
MD90
Caravelle
BAC111
Trident

TURBOPROPS

ATR 72
ATR 42
BAe ATP
BAe Jetstream 41
BE99
CASA/IPTN C-212
CASA C295
CASA/IPTN CN-235
Convair 580
DHC 6
DHC-7
DHC-8
Dornier Do328
Embraer EMB-120
FH227
Fokker 50
Fokker F27
Grumman Gulfstream I
Hawker Siddeley HS748
Lockheed 100
Lockheed 188 Electra
Saab 2000
Saab SF340
Shorts 330
Shorts 360
Swearingen SA 226
Swearingen SA 227
Vickers Viscount

Appendix 6

Thrust Excursions (High Bypass Fleet)

Thrust excursions. Perceptible uncommanded thrust changes, including IFSD (either engine initiated or pilot commanded), power loss of a lesser degree than IFSD, failure to respond to the throttle, errant thrust direction changes including reverser uncommanded behaviors, uncommanded thrust increase, unstable fluctuating response such that pilot response is deemed necessary, inability to shut down, perceptible and audible stall/surge[24].

Data was collected for the high bypass fleet on the following:

- IFSDs (presented in Appendix 3)
- Uncommanded thrust increase (by 10% or more)
- Inability to reduce power by throttle (above idle)
- Inability to shut down
- Perceptible and audible stall/surge

The following factors were considered relevant to high thrust/surge events, and attempts were made to collect data[25]:

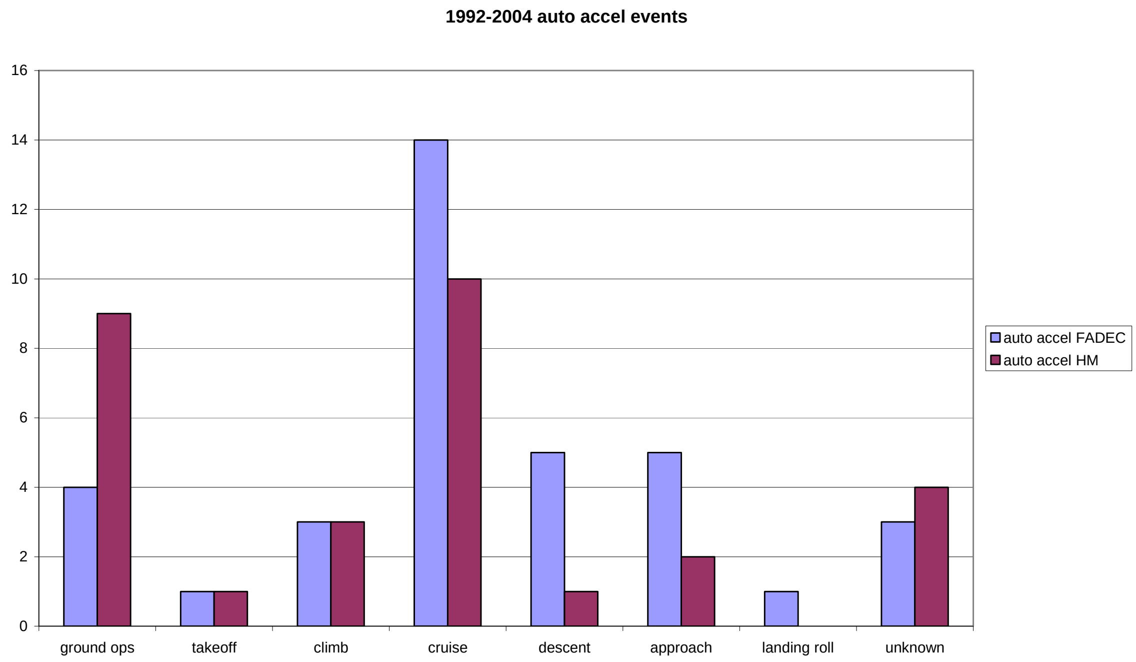
- Flight Phase
- Type of engine control (Hydromechanical vs electronic)
- Airspeed (for ground events). Airspeed was only available for two RTO events, no studies were possible.
- Centerline vs. wing installation. Only a small number of events involved tail-installations, the event outcome appeared equally benign for both wing and tail engines.

Transient overshoots when setting power were excluded, since there were such a large number of these events reported, without adverse effect, that the event appeared to be within the range of normal operations.

[24] It is noted that some of these present a continuum of severity. There is considerable overlap between these sub-categories cited.

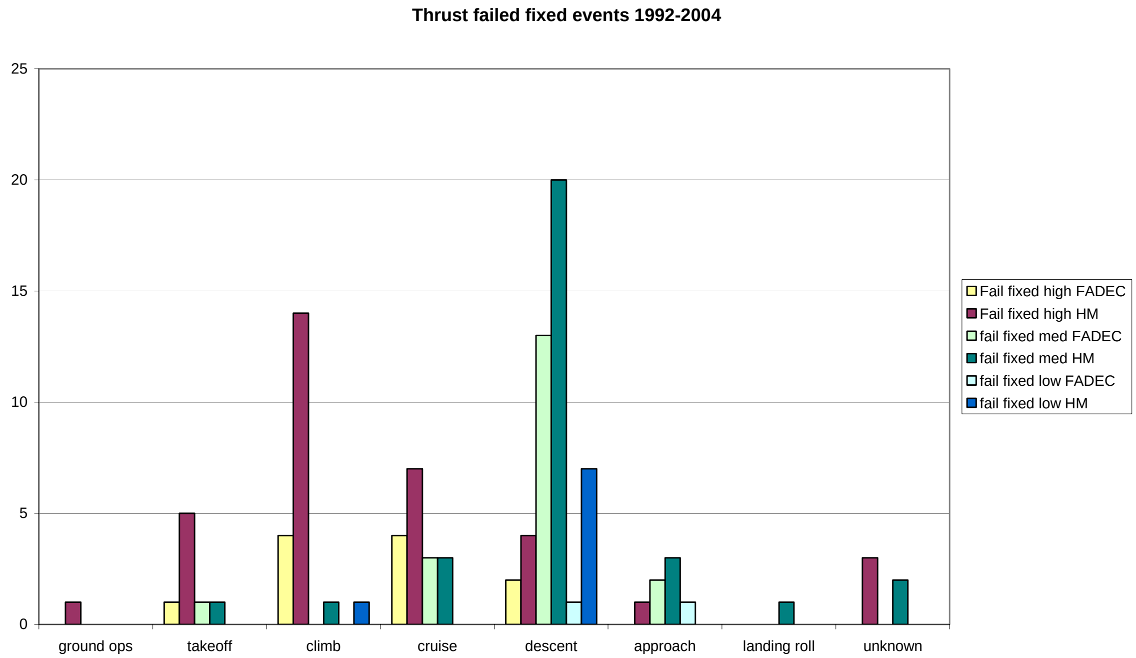
[25] Data of any kind was only available from a subset of manufacturers, and it was evident that events were substantially under-reported since many reports mentioned multiple event occurrences; this may therefore be regarded as a sample.

Uncommanded Thrust Increase



No level 3, 4 or 5 events were observed in the high bypass fleet as a result of an auto-accel or “thrust runaway”.

Power failed fixed



No level 3, 4 or 5 events were observed in the high bypass fleet as a result of thrust failing to a fixed setting.

Inability to shut down

120 instances of inability to shut down were reported, involving delays in shutdown from 10 seconds to 4 minutes.
One event occurred in flight, the remainder occurred on the ground during the normal shutdown process.
One event involved an inability to shut down using the fire handle (no fire was present, the crew used the fire handle as a means to speed up the shut down.)
None of the events were level 3, 4 or 5.

Perceptible and audible stall/surge

1200 events of perceptible stall/surge were reported. The distribution by flight phase is shown in Table Y, below.

Flight phase	twin hbtf	tri hbtf	quad hbtf	**fleet**
t/o below V1	104	42	48	194
t/o above V1	85	25	29	139
climb	203	62	91	356
cruise	80	30	60	170
descent	69	21	36	126
landing	28	15	34	77
taxi	88	19	31	138
all phases	657	214	329	1200

One multi-engine IFSD likely involved surge and resulted in a level 5 event (inability to restart engines, also reported in Multi-engine – environmental).
Two of the single engine events resulted in level 3 outcomes, (reported in PSM+ICR).

Appendix 7

Relationship Between Flammable Fluid Leaks And Fires

It was considered desirable to explore the relationship between flammable fluid leaks and fires. An attempt was made to collect data on leaks and on fires that identified the following significant parameters:

- Flammable fluid involved in the leak or fire
  - -jet fuel
  - -oil
  - -Skydrol
- Location of the fire
  - -within a designated fire zone
  - -within the nacelle but not in a designated fire zone
  - -within the pylon
  - -within wing leading edge
  - -within wing trailing edge
  - -from wing fuel tank surface
  - -within pressurized fuselage
    - etc
- Leakage source pressure
- Leakage quantity with respect to drainage rate

The detail of leak reports was generally insufficient to support the desired study, the majority of manufacturers providing little or no data.

In particular, leakage rate with respect to drainage rate was frequently not known or not recorded, since cowls were not opened until after the leak stopped and since the act of opening the cowls would change the situation with respect to pooled fluid, if such were to exist. Furthermore, it was not generally possible to establish the state of atomization of a leak – whether it was a drip, jet or spray – since the engine was generally shut down before the cowls were opened. In some cases, it could be established whether the source of the leak was high or low pressure fluid, but where a tortuous path was required for the leak to reach the undercowl space, the physical form of the leak (drip, jet or spray) might not be determined by the pressure far upstream.

A follow-on study dedicated to the details of leaks and fires may produce more definite results, if this is considered desirable.

OBSERVED HIGH BYPASS RATIO TURBOFAN LEAKS

<table>
<tr><td colspan="14">Total leaks 3411</td></tr>
<tr><td colspan="14"></td></tr>
<tr><td colspan="7">Designated fire zone</td><td colspan="3">Wing mounted pylon</td><td>Wing leading edge</td><td colspan="2">Wing tank surface</td><td>Unprx fuselage</td></tr>
<tr><td colspan="7">3374</td><td colspan="3">14</td><td>1</td><td colspan="2">20</td><td>2</td></tr>
<tr><td colspan="4">JetA</td><td>Oil</td><td colspan="2">Skydrol</td><td>Jet A</td><td colspan="2">Skydrol</td><td>Jet A</td><td colspan="2">Jet A</td><td>Jet A</td></tr>
<tr><td colspan="4">1770</td><td>1405</td><td colspan="2">199</td><td>8</td><td colspan="2">6</td><td>1</td><td colspan="2">20</td><td>2</td></tr>
<tr><td colspan="2">Low P</td><td colspan="2">High P</td><td>Low P</td><td>Low P</td><td>High P</td><td>Low P</td><td>Low P</td><td>High P</td><td>Low P</td><td colspan="2">Low P</td><td>Low P</td></tr>
<tr><td colspan="2">1692</td><td colspan="2">49</td><td>1405</td><td>18</td><td>181</td><td>8</td><td>1</td><td>5</td><td>1</td><td colspan="2">20</td><td>2</td></tr>
<tr><td>slow</td><td>fast</td><td>slow</td><td>fast</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>slow</td><td>fast</td><td>fast</td></tr>
<tr><td>1663</td><td>29</td><td>12</td><td>37</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>19</td><td>1</td><td>2</td></tr>
</table>

OBSERVED HIGH BYPASS RATIO TURBOFAN FIRES

<table>
<tr><td colspan="8">Total fires 86</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td colspan="3">Designated fire zone</td><td colspan="2">Wing mounted pylon</td><td>Wing leading edge</td><td>Wing tank surface</td><td>Unprx fuselage</td></tr>
<tr><td colspan="3">77</td><td colspan="2">1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Jet A</td><td>Oil/metal/other</td><td>Skydrol</td><td>Jet A</td><td>Skydrol</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>49</td><td>23</td><td>5</td><td>1</td><td>0</td></tr>
</table>

Note: Classified fires do not sum to the total because event detail was insufficient, or classification scheme was ambiguous, in some cases. There was generally insufficient event detail available to determine pressure of leak source or drainage rate.