2021

Continued Airworthiness Assessment Methodology: Lessons Learned

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Report

Executive Summary

The Continued Airworthiness Assessment Methodology (CAAM) committee has been collecting and publishing datasets of propulsion safety-related events for the turbofan and turboprop commercial fleet for several decades. The team was tasked with surveying this safety data to:

- Identify major contributors to severe events and match these against existing safety initiatives or existing rules.,
- Document common themes and develop Lessons Learned,
- Identify where additional industry safety initiatives would have significant potential to reduce the future severity and/or frequency of severe events, based on the broad fleet data.

The team was composed of engine and airplane manufacturers and regulators. They analyzed the causes and circumstances of the most severe events (complete in flight thrust loss, hull loss, or fatalities) in the most recently published dataset (2001-2012 turbofans and turboprops, the third CAAM dataset). This was done initially by subteams based on product type; aggregation of subteam results was used to develop conclusions and recommendations. Qualitative assessment of more recent events (2013 – 2016) verified similarities to the third CAAM dataset.

Conclusions: The team found that the mature fleet risk has been driven by operational factors, particularly in the non-Part 121 fleets. These included issues with crew response to propulsion system malfunction, issues with crew operation of fully functional propulsion systems and operator maintenance practices. Older products experience the majority of the safety events. Manufacturers have taken voluntary action to address industry Lessons Learned (fuel tank leak/ exhaustion, fuel system episodic ice release, individual engine failure modes, weather radar display ambiguity) and regulators have introduced certification requirements for new products addressing technical issues (bird ingestion into the engine core, fuel quantity indication, fuel system episodic ice release).

Recommendations: The team recommends the following areas as opportunities for safety enhancement:

- Refresh and institutionalize the Propulsion System Malfunction Recognition and Response/ Engine Operation awareness packages.
- Develop awareness package for principles of propulsion system maintenance.
- Refresh Cockpit Resource Management awareness.

- Take action to reduce the bird threat near/ on airports and globally introduce wildlife control where not in place; assess the potential for bird anticipation/ monitoring at high-risk airports
- Extend battery maintenance awareness package for operations in areas of extreme weather such as inter-tropical convergence zones
- Encourage and institutionalize sharing of technical lessons learned

Introduction

Proactive aviation safety is a long-held objective of regulators and of the aviation industry as a whole. There has been extended debate over the best way to accomplish this; directing safety resources to the highest risk areas clearly reduces risk to the flying public as quickly as possible, but can be difficult to translate into a proactive approach. Responding to a known issue is clear, actionable, focused and allows a rapid risk reduction. Conversely, broad overarching initiatives can affect a much broader fleet and spectrum of issues, but may have challenges in timeliness, demonstrating effectiveness, and requiring greater resources. Considering a continuum between reactive and proactive approaches offers a path out of this dilemma, retaining a clear connection between past accidents/ serious incidents and the introduction of mitigations, while moving away from the perceived reactive mode of addressing only known issues.

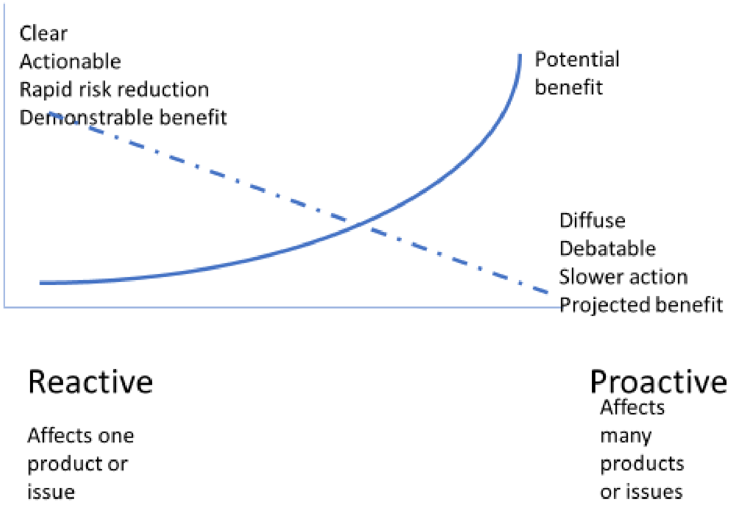


Figure 1 Continuum of Safety Initiatives

Unsafe conditions on individual propulsion systems are normally followed by mandatory corrective action for that product, managing the risk. The work of the CAAM LL committee provides an incremental step along the reactive-proactive continuum, considering actual scenarios which occurred on transport aircraft propulsion systems and developing broader mitigations which offer value across a spectrum of products. It extends the normal process of manufacturers of developing their own lessons learned to apply to their own new designs, by sharing across OEMs to accelerate the safety progress of the whole propulsion industry.

The data used has been gathered by the commercial aviation propulsion industry to more effectively manage continued operational safety and to support the regulator's assessment of safety-related issues. This process is executed by an AIA working group, the CAAM (Continued Airworthiness Assessment Methodology) committee, and the safety data is published by the FAA in the Technical Reports on Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards at https://www.faa.gov/aircraft/air_cert/design_approvals/engine_prop/engine_sp_topics/.

Although the data indicates a continuous and sustained improvement in propulsion system safety over the fleet history, the AIA tasked a review of the data to identify any opportunities for initiatives to further improve safety. The review was conducted by a team of industry stakeholders and regulators.

CAAM and CAAM Lessons Learned utility

The CAAM data and reports have provided the foundation for the Continued Operational Safety of US commercial transport propulsion for 25 years. Benefits include:

- Common understanding of which engine-level conditions present a greater or lesser aircraft-level risk, and a basis for quantitative ranking of those risks for prioritized mitigation.
- Visibility of changes with time of airplane-level propulsion risk.
- Inputs to quantitative risk assessments in support of Continued Operational Safety (COS).

Charter

The CAAM LL team was chartered to:

> Review collected data to identify key contributors to high severity events (level 3/4/5) and match these against existing safety initiatives. Document common themes and develop Lessons Learned. Identify where additional industry safety initiatives would have significant potential to reduce the future severity and/or frequency of CAAM level 3/4/5 events, based on the broad fleet data.

Specific deliverables included:

- Map major contributors to level 3/4/5 events and the current safety initiatives or existing rules which would retire risk.
- Develop Lessons Learned.
- Identify opportunities for additional high-impact industry safety initiatives

Since the team had not conducted such an analysis before, and wanted to provide recommendations in a timely fashion, it was decided to begin by analysis of the most severe (level 4/5) events. Further analysis (more recent level 4 events and potentially level 3 events) will be addressed by the CAAM standing committee.

Scope

The data used for this analysis was published in the CAAM3 report, as validated by the originating OEMs for accuracy. The data covered the time period 2001-2012 inclusive. The fleet covered was western-built transport category airplanes with high bypass or low bypass turbofans or turboprops. 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.

The event descriptions published in the CAAM3 report were augmented by the deep familiarity with event details from the manufacturers involved, to enable discussion and derivation of Lessons Learned. In some cases, very little additional detail was available (smaller aircraft not operating under Part 121, or in remote locations, with no NTSB involvement in the investigation). These events were discussed by the team and their best judgment was used to draw conclusions about the contributing factors and develop recommendations.

The data analyzed for this report was limited to that collected during the CAAM 3 effort as contained in the 3rd Technical Report On Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards. The team decided to limit the scope of its efforts to analyzing data from this report for two reasons:

(1) Events that occurred after the CAAM 3 reporting period may still be under an active independent authority-led investigation and subject to the restrictions of International Civil Aviation Organization (ICAO) Annex 13 protocols. In other words, the investigations, and by default the reliable information available from them, may be incomplete or inaccessible to the full team.

(2) An informal assessment of the events that occurred after the CAAM 3 reporting period judged that there were no systemic phenomena in these recent events that would provide additional industry level Lessons Learned, beyond what could already be developed from the CAAM 3 data set.

Team composition

The team was composed of engine and airplane manufacturers and representatives of regulatory agencies, as follows:

FAA
Transport Canada
EASA
Airbus
Boeing
Bombardier
Embraer

GE Aviation
Honeywell
Pratt & Whitney
PWC
Rolls-Royce
Safran Aircraft Engines
Textron

Process used

Three sectors were addressed; high bypass turbofans, low bypass turbofans and turboprops. A small, focused team reviewed each of the level 4 /5 events, discussing details of event progression, contributing factors, and possible systemic issues. The resulting analysis was presented to the whole group. Many of the events had already triggered corrective action at both the product level and across the industry. In some cases, an opportunity for further mitigation was actionable at the individual OEM level; and the team made appropriate recommendations to OEMs without waiting for formal industry or regulatory action.

Analysis results

Results are presented in terms of absolute number of events rather than rates. Fleet size/usage is different between product types and therefore conclusions should not be drawn about the inherent safety of a technology based on the presented number of events. Where an event was presented as contributing to multiple event types in the CAAM3 report, the team agreed which was the most meaningful event type to use, so that each event would be represented in the chart only once. For instance, a disk burst resulting in a fire leading to a hull loss was included in the “uncontained” category. Engineering judgement was used to supplement the written record for events where documentation was sparse.

Causal factors

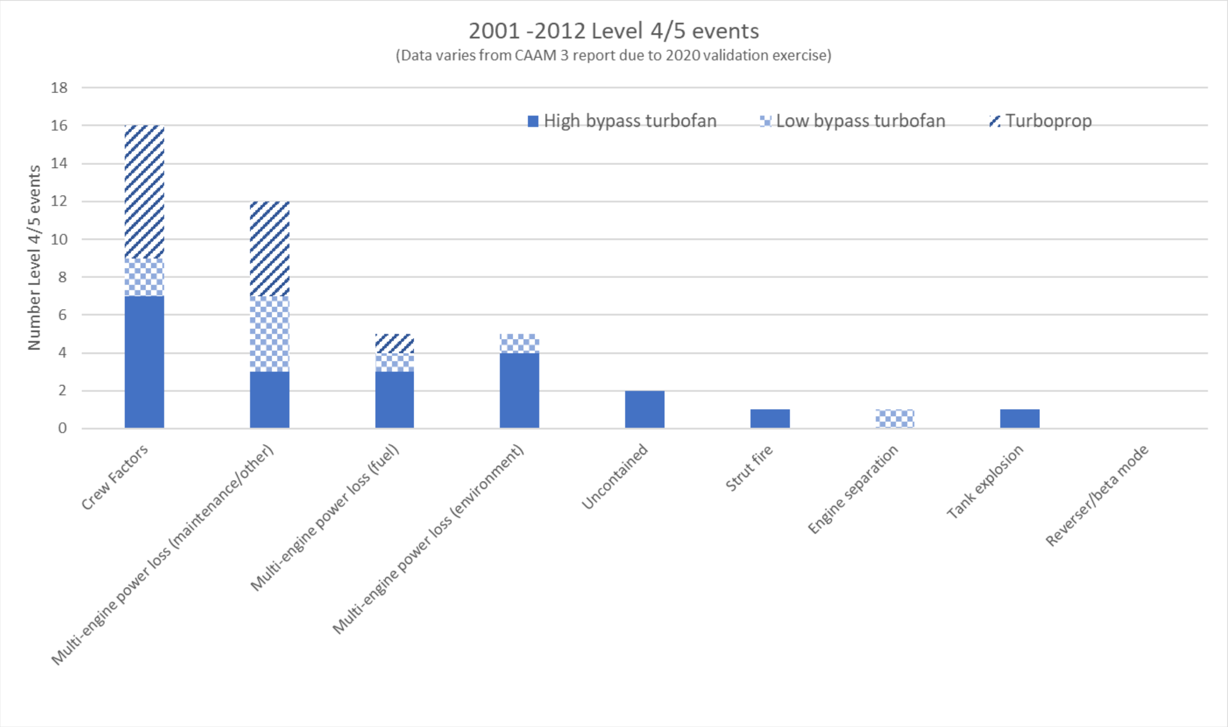


Figure 2 Event causal factors

The greatest contribution to level 4/5 events (fatality/ serious injury, hull loss, complete sustained power loss in flight) was crew factors; either crew incorrect operation of the propulsion system, or difficulties in recognizing a propulsion system malfunction and responding in accordance with standard procedures. Other key contributions were multi-engine power loss due to maintenance or other operational factors, due to fuel exhaustion or contamination, or due to environmental causes. It should be noted that the multi-engine power loss events did not always result in hull loss or fatalities.

Engine uncontained release of high energy fragments, fires, engine separation and tank explosion were smaller contributors.

Subfleet generation

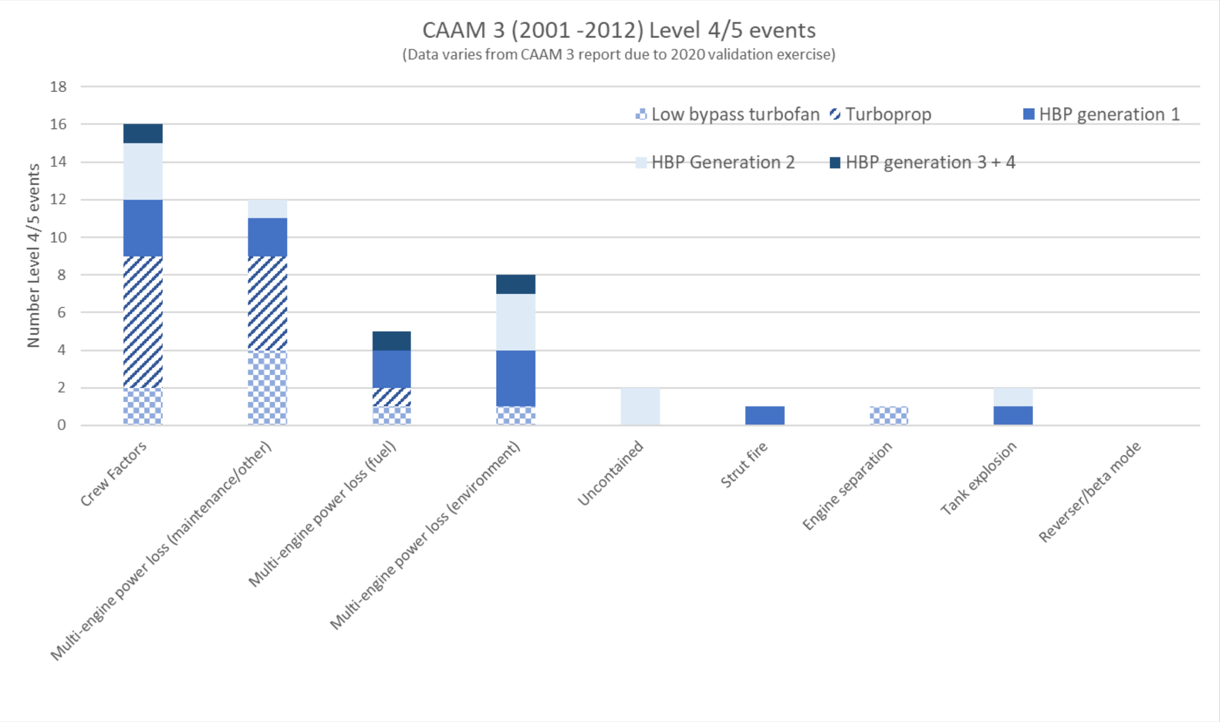


Figure 3 Distribution of events by generation

The 1st Generation High Bypass Ratio (HBPR) engines were designed in the mid-late 1960's and early 1970's. These engines were the successors to the Low Bypass Ratio (LBPR) architecture and installations that had their origins in the 1950's and 1960's. As the 1st Generation HBPR engines have matured in service the original operators of this equipment have modernized with newer 2nd/3rd/4th generation HBPR powered airplanes. These 1st Generation HBPR engines have continued in service, but have now changed ownership (in many instances multiple times) from the original operators that utilized the equipment.

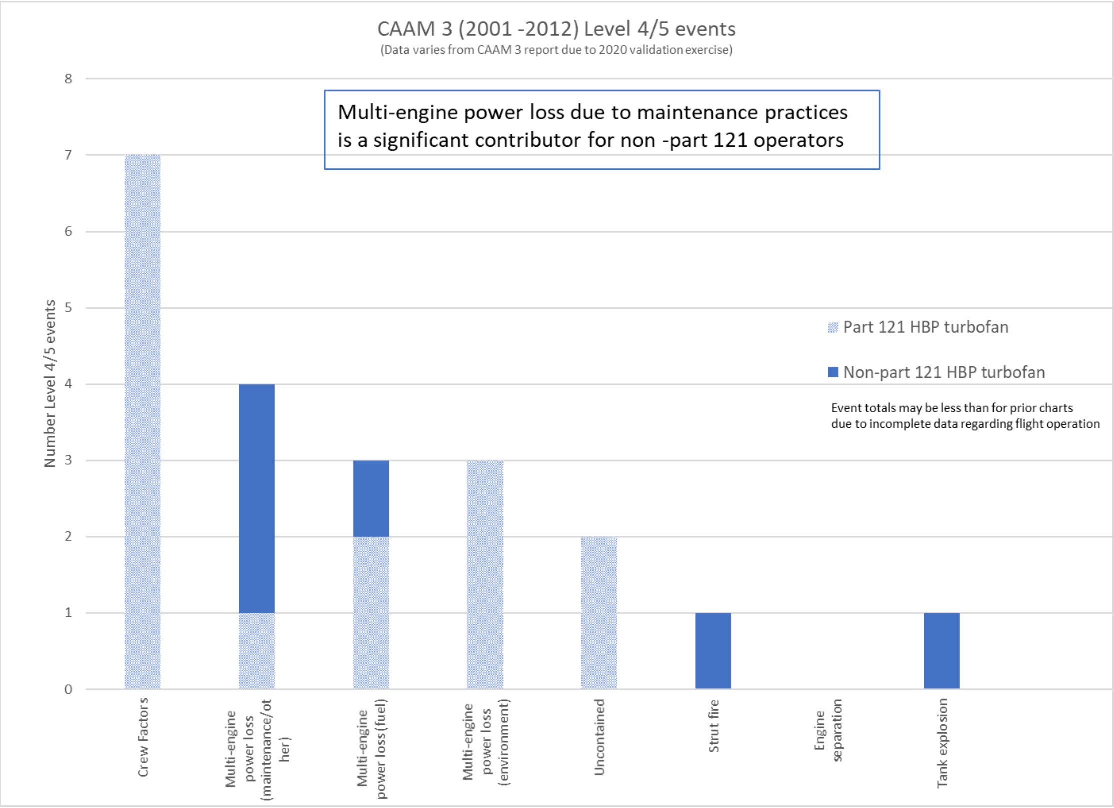
The majority of the high bypass turbofan events occurred with the earlier design products (generations 1 and 2). More recent designs (the majority of the fleet) have had relatively few of the events. The difference is attributable to the type of operations for the older vs. newer fleets and the improvements in design and manufacturing incorporated into the newer designs, including measures to eliminate specific past issues.

The HBPR 1st Generation CAAM level 4/5 events are not product specific, but rather the majority can be addressed by corrective actions that are broader in scope such as Maintenance awareness, Crew training, etc. This is also the case with the low bypass fleet. A parallel can be drawn between the fleet utilization of the low bypass and the high bypass generation 1 fleets, as low bypass equipment goes out of service and is replaced by generation 1 high bypass products. At this point in the life cycle, the HBPR 1st Generation and LBPR fleets should be treated similarly with respect to the recommended corrective actions and methods to deploy those to help further retire risk from the fleet.

Type of operation

Stratifying the data by the type of operation revealed a marked difference between Part 121 operators and other operations[1], for the events with multi-engine shutdown due to maintenance and other operational factors. This is especially notable given the large fleets and high usage of Part 121 operators. It is likely that as the older high bypass turbofan fleet transfers into less structured operations – the non-Part 121 operators and current operators of low bypass ratio turbofans - this risk area (multi-engine shutdown due to maintenance/operational considerations) will grow. The team recommends additional support be provided to low-resource or low-experience operators.

Stratifying the data by region provided no clear insights; the result is provided in Figure 7 for completeness.



Multi-engine power loss due to maintenance practices is a significant contributor for non -part 121 operators

Event totals may be less than for prior charts due to incomplete data regarding flight operation

Figure 4 High bypass turbofans; flight operating rules

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[1] "Other operations" included charter flights, private flights of transport category aircraft, ferry flights and training.

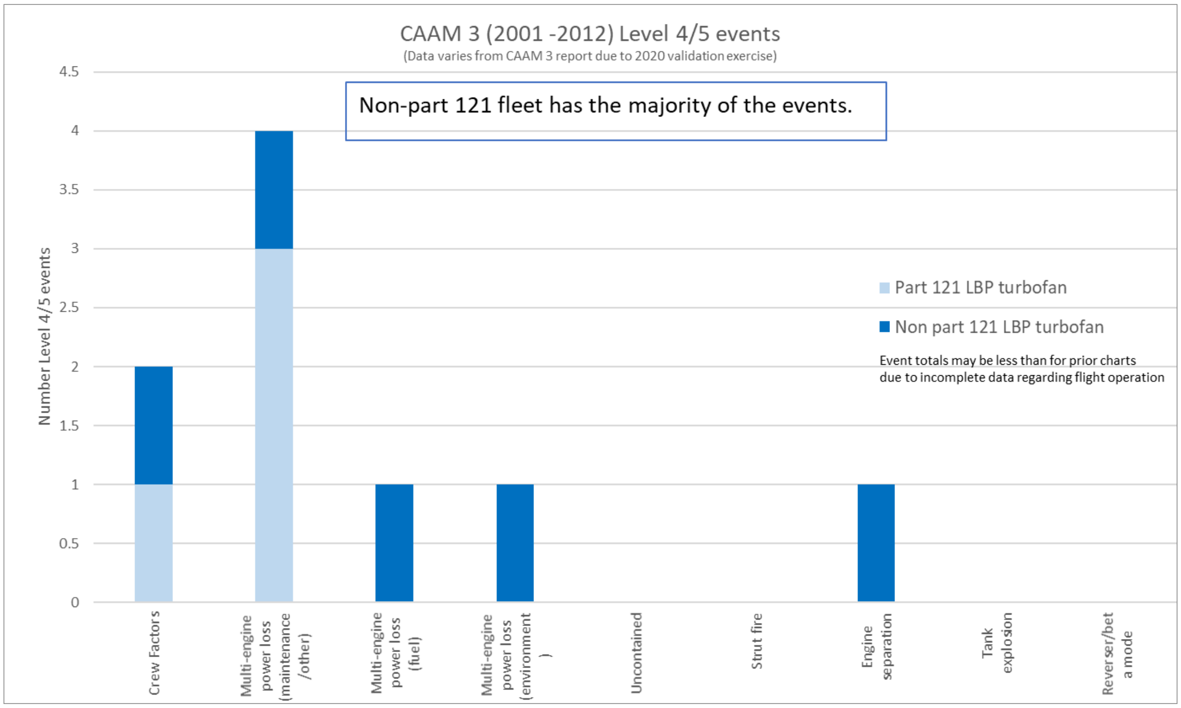

Figure 5 Low bypass turbofans: Flight operating rules

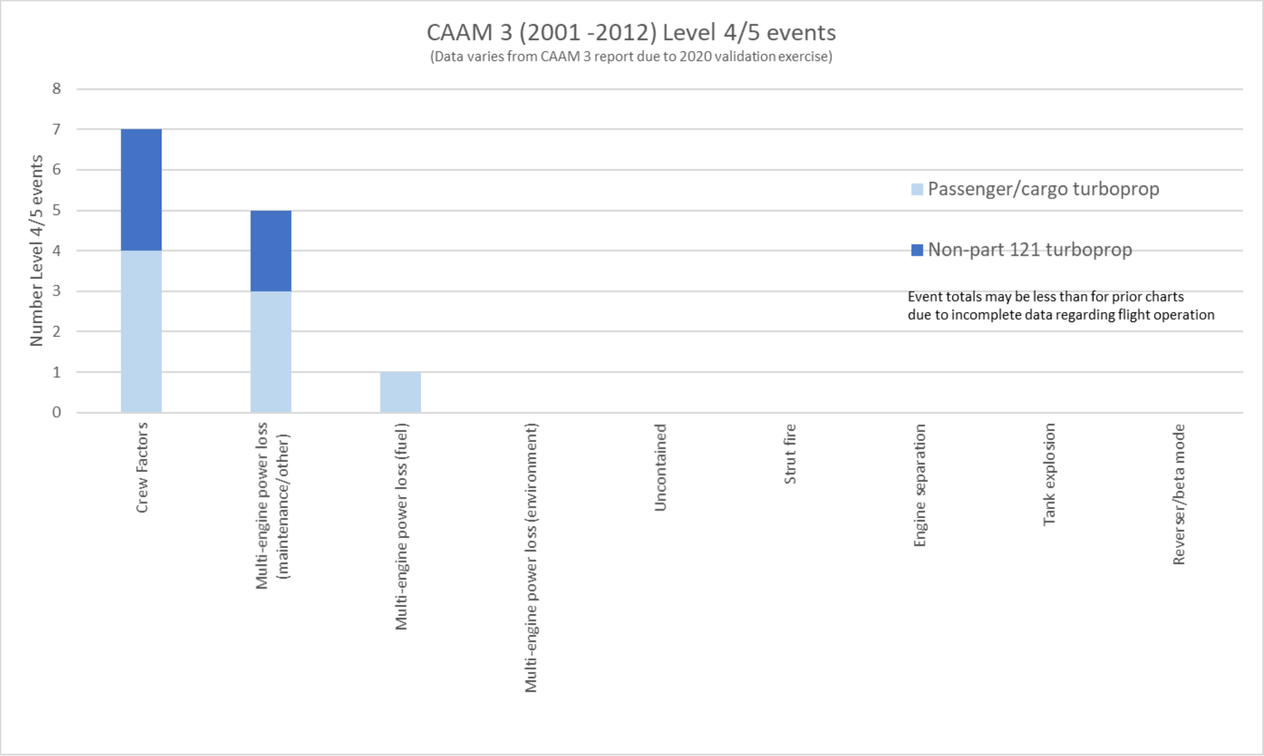

Figure 6 Turboprops; Flight operating rules

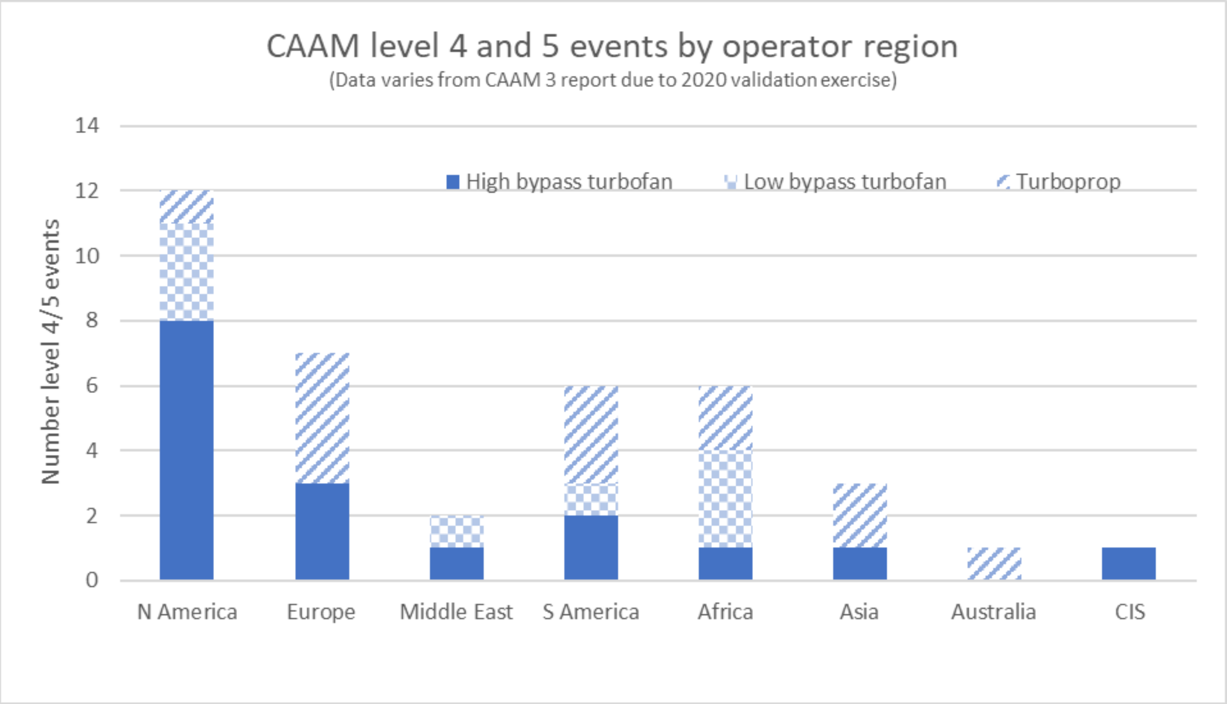

Figure 7 Regional distribution of events

Actions already taken

Many of the level 4/5 events have already received corrective action at the product level. Systemic mitigations have also been introduced, either by the regulator or the OEMs working together.

Multi-engine power loss – fuel:

- Crew procedures have been revised to address potential fuel leak as cause of a tank unbalance symptom.
- Transient excessive ice release into fuel (slushy) has been addressed across industry and in FAA issue papers and EASA CRIs or EASA CS-E amendment 5, AMC E 560(4) and AMC E 670(3).
- Low fuel alerting regulation has been introduced for new products 14 CFR 25.1535, CS 25.1305(a)(2)(iv)

Multi-engine power loss - environment:

- The effects of fan ice shed upon downstream components is being addressed by engine manufacturers.
- Bird ingestion into the engine core is being addressed by a proposed new regulation 14 CFR 33.76(e)) and is already part of published EASA CS-E amendment 5, CS-E 800(e).
- Weather radar now incorporates software which interpolates the display between high intensity cells, rather than showing saturated display (worst weather) as “clear sky”.

Fuel tank explosion

- The potential for fuel tank explosion has been addressed by the combination of the SFAR 88 review and subsequent airworthiness directives, new operational requirements, new requirements in part 26 and CS 26 and new requirements in 14 CFR 25.981 and CS 25.981 to address the risks of ignition of fuel within the tank and flammability reduction measures

Uncontained events

- The effects of abusive machining on Life Limited Parts are addressed by the Robust Manufacturing (ROMAN) initiative.
- Industry safety initiatives from Ti alloy cleanliness and quality are being extended to nickel alloys (titanium and nickel alloys are used for the high speed rotating parts of most turbofans due to their high strength, light weight (titanium) and temperature capability (nickel)).

Locked out thrust reversers

- The team discussed the industry experience with accidents involving throttle operation with locked out thrust reversers. While a uniform approach to handling throttles under these circumstances was not feasible, the discussion did lead to each OEM evaluating their susceptibility to the scenarios involved in the accidents and making changes where practical. The team recommends future airplane designs and aircraft manufacturers not involved in this initiative take these lessons into account as they contemplate their products.

Conclusions and recommendations

The propulsion system risk, for mature turbofans and turboprops, is primarily driven by operational factors. These include Propulsion System Malfunction Recognition and Response (PSMRR), crew error, and shortfalls on basic maintenance. It is notable that the maintenance/operational shortfall events were not seen for the highly structured operations of Part 121 carriers.

The CAAM LL team recommends the following actions:

- Refresh and institutionalize the Propulsion System Malfunction Recognition and Response/ Engine Operation awareness packages.
- Develop awareness package for principles of propulsion system maintenance.
- Recommend that CRM awareness be refreshed.
- Take action to reduce bird threat near/ on airports. It is recognized that some countries have excellent on-airport bird control measures, the risk of airplanes encountering birds during climb out or final approach has been challenging. The team recommends that countries with limited wildlife control on-airport consider enhancing wildlife control at their busiest or highest risk airports. The team also recommends that airports with a higher frequency of damaging birdstrikes consider measures to understand flock flight schedules. There may be potential to optimize traffic routing to avoid birds at low altitudes, and to assist in managing bird attractants.
- Extend battery maintenance awareness package for operations in areas of extreme weather such as inter-tropical convergence zones. Improved awareness of the criticality of battery maintenance will improve the likelihood of successful engine restart, in the event of an airplane encountering severe weather resulting in complete power loss.
- Encourage and institutionalize sharing of safety-related technical lessons learned in the OEM propulsion community, to the extent practicable.

Prior recommendations

The CAAM3 report made the following applicable recommendations

1. The data should be used to prioritize safety-related industry studies, research and regulatory development activities.
2. 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 power loss events, focusing upon the turboprop fleet and also upon fuel exhaustion, deserves continued industry attention.

This CAAM LL report represents an implementation of CAAM3 recommendation 1, in identifying opportunities to increase fleet safety. Specific actions recommended by the team are focused around human factors considerations and around multiple engine power loss, as recommended in CAAM3.

The AIA PSM + ICR[2] report of 1998 also recommended:

a. *The requirements of 14 CFR Parts 61 and 121 / JAR-OPS / JAR-FCL need to be enhanced for pilot training in powerplant failure recognition, the effect of powerplant failure on airplane performance and controllability, and the subsequent control of the airplane.*

b. *The regulatory authorities should establish and implement a rigorous "process" to ensure that the following occurs during the development of a pilot training program:*
   - *Identification of powerplant failure conditions that need to be trained;*
   - *Preparation of training aids (Tools & Methods);*
   - *Establishment of the appropriate means to conduct the training;*
   - *Assurance that each pilot receives the appropriate training for both malfunction recognition and proper response to it; and*
   - *Validation of training effectiveness, along with a feedback loop to improve / update training.*

PSMRR trends

One of the statistical studies conducted in support of the AIA PSMRR team addressed the statistics of high speed RTOs / RTOs above V1. The occurrence of high speed RTOs is relatively well-documented, and so these statistics provide insight into the broader subject of PSMRR.

The CAAM LL team augmented and updated this study, seeking visibility of how the incidence of PSM +RR had changed over the years, and specifically how the PSMRR training material, circulated to operators in ~2003 might have influenced behaviors. Appendix I shows the details of this study.

The results suggest that PSMRR (as measured by RTOs at/above V1) was very low between 2000 and 2010, and is now rising again. (The results have fleet growth and product reliability normalized out, to give a clearer visibility on flight crew responses). This trend is consistent with the PSMRR awareness briefings having initially had a positive effect, and the awareness being diluted over time as new flight crew members, who have not encountered the material, began flying and as flight crew who encountered the briefing retire or become less aware.

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[2] PSM+ICR (Propulsion System Malfunction +Inappropriate Crew Response; prior nomenclature) and PSMRR (Propulsion System Malfunction Recognition and Response; current nomenclature) refer to the situation where a propulsion system malfunction occurs , the airplane is controllable using ordinary piloting skills and published operating procedures, and the flight crew does not follow published procedures/ training.

The CAAM LL team therefore recommends that the flight crew briefing package be refreshed and distributed widely to operators, and that measures be considered to institutionalize flight crew awareness of the material in the briefing.

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Appendix I

Introduction

The team identified flight crew response to engine malfunctions as a safety opportunity. A refreshed crew awareness package, similar to that released ~2000, was proposed. The team wanted to know whether the effectiveness of the previous package was supported by objective evidence.

Fleet operational data collected by a major manufacturer was analyzed to assess whether the PSM RR training package had improved crew response to engine malfunctions.

Objective

Trend the conditional probability of a flight crew rejecting a takeoff above V1, given a "startling" engine symptom.

> RTO above V1 was used as a metric of inappropriate crew response to engine malfunction. The metric was selected as being clearly defined, clearly connected to safety, sufficiently frequent that trending would be possible, and likely to be reported since it would be evident to the control tower.
>
> Startling symptoms were selected as having caused a rejected takeoff above V1. Data was limited to symptoms reported as occurring in the high speed portion of the takeoff roll.

Method

Data on rejected takeoffs above V1, caused by engine symptoms, was collected for the high bypass turbofan fleet of a major manufacturer, from 1973 to 2018.

Changes in fleet reliability could affect the absolute number of RTOs above V1, by changing how often a crew experienced a startling symptom. This confounding factor was accounted for by collecting data on how often the "startling" symptom occurred during takeoff above 100 kts. A trend was plotted showing normalized event data, (calculated as #RTOs above V1/ # startling symptoms in the takeoff roll).

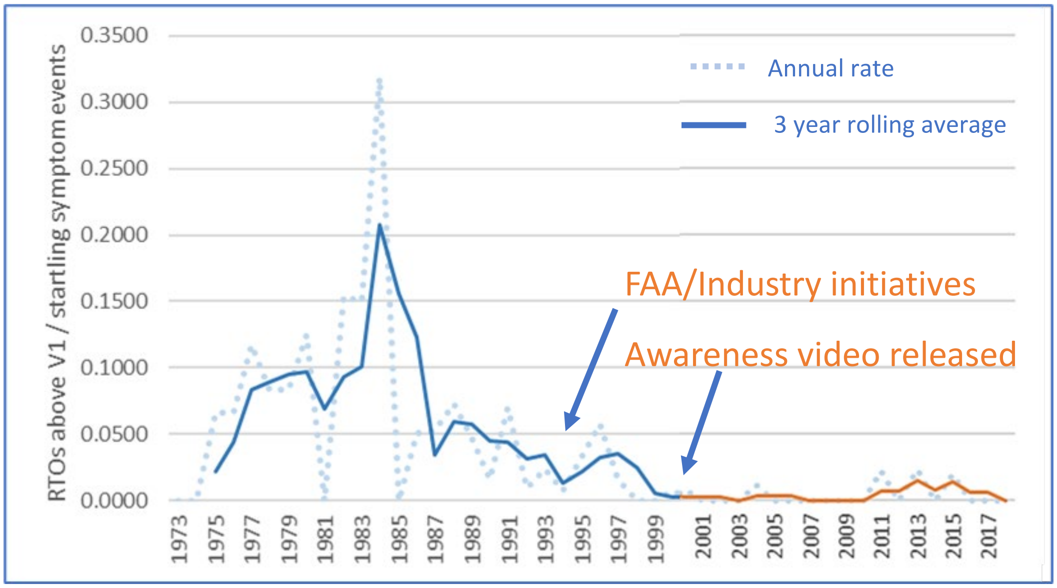
Results

The trendline for this crew response metric (3 year rolling average) dropped from a mid 1980s peak of 0.2 down to <.01 after 2000.

After 2000 metric was very low for about 10 years (average of .002), followed by a new steady level of .01.

The FAA and industry developed a takeoff safety Training Aid (release 1994), and individual operators also developed internal training material on rejecting takeoffs in the 1990s. There was widespread concern among industry and regulators regarding Propulsion System Malfunction Recognition and Response in the late 1990s, resulting in the publication of an AIA/AECMA report on the subject in 1998 (supported by operators and crew unions) and a crew awareness package release in ~2000.

The trend in Figure alpha is consistent with these 1990s FAA/ industry initiatives, including the propulsion malfunction awareness package, having had a positive effect, which reduced over time as the awareness of the flight crew was diluted (retirements and introduction of new flight crew).



Conclusion

The propulsion malfunction awareness package, and similar initiatives in the mid/late 1990s, may likely have contributed to the observed reduction in crew inappropriate response. More recent data (2010 on) shows a small upward trend in the metric, consistent with reduced awareness of the package. Refreshed awareness of the package may be beneficial.

Appendix II

Listing of level 4/5 events used for team analysis

2001-2012

Year	Product type (engine type, generation, installation, sector operation, carrier region)	Initial cause	narrative
2001	HBPR gen 2 twin, 121, S America	Uncontained	Fan blades failed leading to rapid cabin depressurization at altitude. Fan shaft/ stator fragments likely penetrated fuselage. One fatality
2001	HBPR gen 3 twin, 121, N America	Multi-engine power loss	Fuel unbalance from undercowl fuel leak. Crew diverted due to fuel shortage. Both engines flamed out due to fuel exhaustion, airplane landed at remote airport. Structural damage to airplane
2002	HBPR gen 2 twin, 121, S America	Multi-engine power loss	Fuel leak at HP fuel pump; decreasing fuel quantity at cruise. Flight diverted but crashed short of airport from fuel starvation. No fatalities.
2002	HBPR gen 2 twin, 121 Asia	Multi-engine power loss	Dual engine flameout during descent in severe weather (rain and hail). Radar display had saturated, leading crew to believe the most intense storm region was a clear spot. Relight attempted but battery was exhausted due to battery maintenance issue. Forced landing in river, one fatality.
2003	HBPR gen 1 twin, Business jet, N America	Crew error	Fuel exhaustion, landed on taxiway. Wingtip hit another plane.
2004	HBPR gen 2 twin, 121, Europe	Multi-engine power loss,	Flight descended through icing conditions with engine and airframe anti-ice systems switched on. Fan blade ice shed impacted fan duct acoustic panels, which separated and lodged in fan duct, stalling both engines. Dual power loss and forced landing short of airfield; nose gear torn off, minor injuries.
2004	HBPR gen 1 twin, 121 N America	Crew error	Dual engine stall after intentional operation outside flight envelope during ferry flight. All engine flameout, forced landing.
2005	HBPR gen 2 twin, 121 N America	Crew error	Crew did not command full reverse on landing. Airplane went off the end of the runway and through fence, colliding with car. Car passenger fatality.
2005	HBPR gen 2 twin N America	Multi-engine power loss,	Multiple engine bird ingestion (flock mourning doves) during takeoff, forced landing off runway, substantial damage.
2006	HBPR gen 2 twin, domestic scheduled passenger, Russia	Crew Error	Pilot inadvertently bumped No. 1 engine throttle forward during landing roll causing an increase in forward thrust, No. 1 engine Thrust Reverser had been locked out. Airplane departed side of runway and impacted structure and buildings.
2006	HBPR gen 1 Quad, 121 cargo, N America	PSMRR	Aborted Takeoff due to apparent No. 1 engine turbine event, no indication that engine event itself affected safety of flight. Crew reported the decision to abort was above 130 knots, airplane overran end of runway and was destroyed
2006	HBPR gen 2 twin, 121 N America	Uncontained	HPT1 disk separation during static maintenance ground run. Fragments impacted both LH and RH wing tanks causing substantial fuel leaks that burned as a pool fire under the plane, causing a hull loss.
2006	HBPR gen 2 twin, Asia	Fuel tank rupture	Center wing fuel tank explosion while parked at gate due to boost pumps left on and creating ignition source (no usable fuel in that tank). Hull loss, 1 fatality
2007	HBPR gen 2 twin, domestic scheduled passenger, S America	Crew Error	Crew left No. 2 engine at climb power resulting in an increase in forward thrust during landing roll, No. 2 engine Thrust Reverser had been locked out. Airplane overran runway end, impacted buildings
2008	HBPR gen 1 Quad 121 cargo, N America	PSMRR	Crew initiated Aborted Takeoff at 150 knots (12 knots above V1) due to No. 3 engine recoverable compressor stall after ingesting a bird. Crew had less runway available than planned due to starting

			take-off from an intersection instead of the end of the runway. Runway overrun, airplane destroyed
2008	HBPR gen 1 Quad, Non scheduled passenger, Europe/ Middle East	Pylon/strut fire	Improper assembly of main fuel line coupling (O-ring retainer not installed) at No. 3 engine strut led to fuel leak and fire during Landing Roll. Damage to engine strut and wing made airplane beyond economical repair.
2008	HBPR gen 1 Quad 121 cargo, N America	Multi engine power loss	Airplane crashed after independent events in 2 engines (No. 4 engine lost power with airplane going through V2 speed and No. 1 engine lost power at 600 feet). Airplane destroyed
2008	HBPR gen 3 twin, 121, Europe	Multi-engine power loss	Aircraft was unable to maintain altitude on approach due to dual power loss (sudden release of accreted ice blocked engine fuel systems.) Landed short of runway and collapsed all landing gear. One major injury.
2008	HBPR gen 2 twin, 121 Europe	Multi-engine power loss	Multi-engine birdstrike on short final (starlings). Crew initiated a go-round but encountered fumes, vibration, no thrust response. Hard landing and gear collapse.
2009	HBPR gen 2 Tri, 121 cargo, Africa	Crew Error	During take-off rolled crew failed to set take-off thrust. The airplane never reached the speed required to attain sufficient lift and get airborne. Airplane overran end of runway and was destroyed
2009	HBPR gen 2 twin, 121 N America	Multi-engine power loss	Multiple engine bird (Canada goose) ingestion during initial climb; multiple engine power loss, forced landing on river.
2010	HBPR gen 2 twin, private plane, Middle East	Multi-engine power loss	Airplane parked overnight in sandstorm. During takeoff, 200 ft AGL, both engines began to surge and would not climb. Returned to airport. Both HPT and LPTs had severe thermal damage due to sand clogging cooling circuits.
2003	LBPR twin, N America	Multi-engine power loss	Aircraft was critical on fuel, crashed in river when both engines flamed out.
2003	LBPR twin, scheduled domestic passenger, Africa	PSMRR + multi engine	No. 1 engine powerloss at rotation; airplane climbed to 400 feet lost speed progressively, stalled and crashed. No. 2 engine had been pulled back to idle for unexplained reasons. Crew response and coordination after engine event during critical phase of flight cited during investigation. Airplane destroyed, 102 fatalities and 1 survivor. Investigation of No. 1 engine did not yield a safety of flight issue
2008	LBPR tri, charter, S America	Multi engine power loss	Fuel exhaustion and off airport forced landing after airplane ran out of fuel during Descent to a diversion airport after multiple missed approaches to the destination airport. Airplane destroyed, no fatalities.
2008	LBPR twin, scheduled domestic passenger, Africa	PSMRR	No accident report available. Crew initiated an Aborted Takeoff around 100 knots due to a No. 1 engine power loss. No indications that engine event threatened safety of flight. Airplane overran runway into a marketplace, airplane destroyed, 3 fatalities onboard, 37 on ground. Runway had been shortened by lava flow from a volcano.
2009	LBPR quad, cargo, Africa	PSMRR	Side cowls separated from No. 4 engine during Takeoff (poorly maintained, probably not latched correctly) resulting in Pt7 line separating and giving false indication of No. 4 engine power loss. Cowl separation and indication issues themselves did not affect safety of flight. Crew could not maintain control of airplane during Air Turnback, airplane crashed and destroyed, all 6 crew fatal.
2011	LBPR tri, scheduled domestic passenger, Iran	Multi engine power loss	No report available. Engine Nos. 1 & 3 unrecoverable surge during descent 1 minute before end of Flight Data Recorder recording. Airplane destroyed with 77 fatalities, 27 survivors.
2011	LBPR quad, Part 91, N America	Engine Separation	No. 2 engine separated during Takeoff around 20 feet Above Ground Level and impacted the inlet cowl of the No. 1 engine. Resulting loss of the No. 1 engine inlet cowl had the effect of losing thrust on that engine also. Directional control could not be maintained and the Captain perceived that the airplane would not be able to Climb and decided to put it back on the ground. Airplane departed side of runway and was destroyed by post-crash fire, all 3 crew members survived. Service bulletin not performed.
2012	LBPR twin, scheduled domestic passenger, Africa	Multi engine power loss	Airplane lost power in both engines during descent and crashed into a crowded area about 2-3 miles short of the destination airport during the forced landing. Airplane destroyed with 153

			fatalities and at least 10 more on ground. Investigation could not definitively identify reason for multi-engine power loss, but appears to be common-cause related.
2001	TP twin, S America	Multi engine power loss	Aircraft lost power to both engines on approach.
2001	TP twin, ferry flight, S America	Multi-engine power loss	Multi engine flameout during ferry flight, forced landing
2001	TP twin, passenger carrying, Europe	PSMRR	Fire warning indication and IFSD. Indication continued; crew pulled fire handle on remaining engine, resulting in crash.
2001	TP twin, passenger carrying, Europe	PSM RR	In flight selection of ground beta and malfunction in anti-skid unit, bypassing protection. Asymmetric force and loss of control.
2001	TP twin, Cargo, Europe	Multi engine power loss	Dual engine flame out due to ice accumulation in inlet overnight, failure to install engine covers overnight in snow-storm, 2 fatalities
2002	TP twin Africa	Multi-engine power loss	Unspecified engine problems in flight, crashed before reaching airstrip
2003	TP twin cargo N America	PSMRR	Single engine power surge on approach causing loss of control and pilot inability to accommodate. Hull loss, no fatalities.
2004	TP twin passenger Asia	Crew response	Unspecified engine problems in flight, crashed before reaching airstrip
2005	TP twin passenger Europe	Multi engine	Fuel quantity indication unit malfunction (maintenance error); fuel exhaustion and sea ditching. 16 fatalities, 23 survivors.
2006	TP twin charter Africa	PSMRR	Engine lost power at 100 ft. Engine feathered; aircraft could not maintain altitude and crashed during attempted air return. Fire, hull loss, minor injuries
2010	TP twin training Australia	Crew response	Training flight, pilot selected flight idle during simulated engine failure in take-off training. Asymmetric forces caused loss of aircraft control. 2 fatalities
2010	TP twin passenger Asia	Multi engine power loss	Low oil p on left engine during approach. Crew decided to go around, then right engine ECU light came on, low oil pressure and self shutdown. Off-airport landing.
2011	TP twin passenger S America	PSMRR	Aircraft destroyed just after takeoff. Engine lost torque, Attempted air return, crashed during approach. 16 fatalities.