In-Flight Shutdown Study

Previous CAAM Committees have published and reviewed In-Flight Shutdown (IFSD) data as part of their work. This study will build upon what has already been published, with a summary of previous work, reporting of additional data, and an assessment of that data - including how it relates to that which was previously published.

Summary of Previously Published Material

The CAAM 1 report (Reference [1]) did not provide a definition for an IFSD and did not publish IFSD data. This report did include a Hazard Level that referenced IFSD. Specifically, Level 1 (Minor Consequences) defined:

> *Level 1.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).*

The CAAM 2 report (Reference [2]) did not provide a definition for an IFSD but did publish data as part of the Propulsions System Malfunction + Inappropriate Crew Response (PSM+ICR).

In addition to referencing IFSD in Level 1 consequences, this report also expanded reference to IFSD in the Hazard Level definitions to include Level 0 (Consequences with no Safety Effect). Note the CAAM 1 report did not include any Level 0 definitions.

> *Level 0.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.*

> *Level 1.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]

While the Level 1.b. definition remained unchanged from CAAM 1, a footnote further clarified that:

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

The IFSD data published in the CAAM 2 report (1992-2000 reporting period) was based on sampling. The results are reproduced in Figure 1 below.

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

The footnote associated with the table clarified: [21] IFSDs estimated based on sampling.

Figure 1 – CAAM 2 Report IFSD data

The CAAM 3 report (Reference [3]) also did not include a definition for IFSD but did publish data for the 2012 calendar year.

Hazard Level definitions in CAAM 3 were also modified as follows:

> *Level 0.a. In-flight shutdown of a single engine with no airplane-level effect other than loss of thrust and associated services,* ***above the standard 1500 ft. take-off/climb transition altitude as defined by § 25.111 Takeoff Path.***
>
> *Level 1.b. Uncommanded power increase, or decrease, at an airspeed above V1 and occurring at an altitude* ***below 1500 ft.*** *[1] (includes IFSDs). [2]*

Clarifying footnotes in the CAAM 3 report related to these definitions included:

> *[1] 1500 feet is the standard takeoff/climb transition altitude as defined by § 25.111.*
>
> *[2] The concern regarding such power changes is pilot workload. Power changes affecting controllability are considered to be more severe.*

The CAAM 3 report also includes the following rationale for the definition changes related to IFSDs between the CAAM 2 and CAAM 3 reports:

(Levels 0a, 1b) IFSD with no effect

The 3000 ft. altitude does not align with any version of "the critical phase of flight". CAAM intended the 1b event severity to apply to a high workload flight phase. Aligning the 1b definition with a more accepted "critical phase of flight" would make it more useful in responding to safety questions.

(Level 1b) Uncommanded power change during critical phase of flight

The intent of the definition change is to align the classification where the event severity is higher due to the high work load environment of takeoff, and final approach. See footnote 14 for additional discussion.

[14] *(Level 1b) Uncommanded power change during critical phase of flight*
The team discussed the fact that the 3000 ft. altitude does not align with any version of "the critical phase of flight". The 1b event severity was intended to apply to a high workload flight phase. Aligning the level 1b definition with a more accepted "critical phase of flight" would make it more useful in responding to safety questions. § 25.111 identifies the takeoff path as follows: "(a) The takeoff path extends from a standing start to a point in the takeoff at which the airplane is 1,500 feet above the takeoff surface, or at which the transition from the takeoff to the en route configuration is completed and VFTO is reached, whichever point is higher."

The IFSD data published in the CAAM 3 report was limited to a sample from calendar year 2012. This data is reproduced in Figure 2 below. Note that the presentation of Turboprop data in Figure 2 is for completeness only as those architectures are outside of the scope of this study.

Figure 49 is a sample of In Flight Shut Down (IFSD) events for the 2012 calendar year, broken out by Hazard Level category for both turbofan and turboprop aircraft. The tables show the comparison of events above and below 1500 feet above ground level.

FIGURE 49. IFSD SNAPSHOT BY CAAM HAZARD LEVEL 2012 DATA ONLY

TURBOFAN

CAAM Level		Description
0	302	Above 1500 feet
1	31	Below 1500 feet
2	0	
3	0	
4	0	
5	0	
Unknown	1	
Total	334	

TURBOPROP

CAAM Level		Description
0a	42	Above 1500 feet
0b	0	
0c	4	
0d	2	
1	14	Below 1500 feet
2	10	
3	0	
4	0	
5	0	
Unknown	0	
Total	72	

Figure 2 – CAAM 3 Report IFSD data

2023 CAAM Committee Data Collection

Consistent with prior reports, the Committee sampled data for a specific limited time period for the current study. Review of this data would then be used to assess if there would be a benefit to expanding to a larger time window. Calendar year 2023 was arbitrarily chosen for this data collection.
For the current effort, the Committee adopted an IFSD definition utilizing the Extended-range Twin-engine Operations Performance Standards (ETOPS) definition as contained in both Title 14 Chapter I Subchapter A Part 1 of the United States Code of Federal Regulations and Federal Aviation Administration (FAA) Advisory Circular AC120-42B:

> *In-flight shutdown (IFSD) means, for ETOPS only, when an engine ceases to function (when the airplane is airborne) and is shutdown, whether self induced, flightcrew initiated or caused by an external influence. The FAA considers IFSD for all causes: for example, flameout, internal failure, flightcrew initiated shutdown, foreign object ingestion, icing, inability to obtain or control desired thrust or power, and cycling of the start control, however briefly, even if the engine operates normally for the remainder of the flight. This definition excludes the airborne cessation of the functioning of an engine when immediately followed by an automatic engine relight and when an engine does not achieve desired thrust or power but is not shutdown.*

While this definition is specific to ETOPS, the Committee felt it was a comprehensive industry definition that could be utilized for this study, regardless of ETOPS.

As an additional clarification to this definition, the Committee established that loss of thrust or power control only (inability to modulate) is not considered an IFSD event if the engine continues to function (and is not commanded shutdown by the flight crew).

The scope of this study was airplanes powered by Generation 1 – Generation 5 High Bypass Ratio engines as listed in Table 3 below. Note that not all engines covered in the study reported an IFSD during the reporting period.

Generation	Description	Examples
Gen 1	First generation high bypass turbofan. Those designed in the late 1960s/1970s.	Includes the JT9D, JT15D series, RB211-22B and early RB211-524 models, TFE731-2/3, CF6-6, CF6-50 & CF34-3.
Gen 2	Second generation high bypass turbofan. Those designed in the 1980s with the understanding and incorporation of lessons learned from the first generation. Usage is consistent with SAE report AIR 4770 and the first and second CAAM reports.	Includes the AE3007, CFE738, CF34-8, TFE731-4 and later TFE models, CF6-80A, CF6-80C and later CF6 models, CFM56-2, CFM56-3 and CFM56-5 models, V2500, PW2000, RB211-535C, RB211-524B4 and later RB211 models, RR Tay, PW305A/B, PW306A/B, PW530A, PW535A, PW545A/B, and PW4000-94.
Gen 3	Third generation high bypass turbofan. Those designed to incorporate the lessons learned from the second generation.	Includes the GE90-94"/ 115", CFM56-7, CF34-10, PW306C/D/D1, PW307A/D, PW308 A/C, PW535B, PW545C, PW4000 100"/112" fan, PW6000, Trent 500, Trent 700, Trent 800, BR710, and BR715.
Gen 4	Fourth generation high bypass turbofan. Those designed to incorporate the Lessons Learned from the third generation.	Includes GEnx, GP7000, AS907, Trent 900, Trent 1000, PW800 series, and BR725.
Gen 5	Fifth generation high bypass turbofan. Those designed to incorporate the Lessons Learned from the fourth generation.	Includes LEAP, GE9X, Passport, Trent XWB, TEN, Trent 7000, Pearl 15 & 700, and PW1000G series.

Figure 3 – Engine families with IFSDs contained in 2023 dataset

While not all airframers participated on the Committee, IFSDs were reported for engines installed on airplanes manufactured by: Airbus, Boeing (including McDonnell Douglas product lines), Bombardier, British Aerospace (now Hawker Beechcraft), Cessna, Dassault, Embraer, Fokker, Gulfstream, Honda, and Textron.

Individual Manufacturers were requested to populate a data collection template.

With respect to CAAM Level, in the published data, there are two CAAM levels tabulated. The Committee found it useful to establish a CAAM Level that was only due to the IFSD effects in addition to the CAAM Level that may be associated with other elements of the flight. For example, an event involving a controlled Fire Zone Fire where the engine is secured below 1500 feet and the airplane safely returns would be graded a 1b for the IFSD consequences, but a 2c for the fire.

Event grading utilized CAAM 3 report definitions for Hazard Levels.

During reviews, where each individual manufacturer presented their data, the relevance of different data categorizations was discussed. Specifically, the Committee discussed the merits of segregating the data by Flight Regime, Basic/Non-Basic, and Commanded/Uncommanded events. It was decided that summarizing and reporting data by Flight Regime and Commanded/Uncommanded could provide meaningful insights and comparisons to prior work, while Basic/Non-Basic would have less utility. The rationale was that the effects of the IFSD itself would be of most relevance while the reason for the IFSD was of less relevance given the flight crew would not necessarily have awareness of the issue and thus the nature of the issue could not influence their actions.

Results

A total of 438 IFSDs were reported for this study and are tabulated in the published data set. For reference the CAAM 3 report tallied 334 IFSDs during 2012 (see Figure 3) while the CAAM 2 report estimated, based on sampling, 12,828[1] IFSDs from 1992-2000 for an average of 1,425 per year over the 9 year report period (see Figure 1). Due to lack of insight into data utilized by the CAAM 2 and 3 Committees, the present Committee did not attempt to reconcile or explain the differences in the annual IFSD totals.

Comparison to CAAM 2

Figure 4 presents a summary of the data collected in this study in a format similar to what was presented in the CAAM 2 report (see Figure 1 above).

Flight Phase	CAAM 2	2023 Event Count	CAAM 2 % (Excl. Unk)	2023 % (Excl. Unk.)
Takeoff*	992	25	8%	6%
Climb*	3957	170	31%	40%
Cruise	6226	174	49%	41%
Descent*	1525	52	12%	12%
Landing/Go-around or Descent/Landing*	128	7	1%	2%
Climb Unk. Altitude	0	3		
Unknown	0	7		
Total	12828	438		

*CAAM 2 and the 2023 data collection utilized different altitudes to define the Takeoff/Climb and Descent/Landing transition. CAAM 2 utilized 3000' while the 2023 data collection used 1500'.

Figure 4 – 2023 IFSD data by Flight Phase compared to CAAM 2

The 2023 percentage of IFSD events that occurred in specific flight phases was consistent with the CAAM 2 data for all flight phases with the exception of the Climb and Cruise phases. The number of IFSDs occurring in Climb increased by 9 percentage points from the CAAM 2 report to the 2023 data, while there was a decrease of 8 percentage points in the Cruise phase.

The Committee was not able to explain this change, in part due to lack of access to the raw data from CAAM 2. Factors that could have contributed include ambiguity in recording step climb events as

[1] Figure 1 reports a total of 12,829 IFSDs, but this total does not comport with the sum of 12,828 obtained by summing the IFSDs reported in the individual Flight Phases.

occurring during Cruise or the proportion of long haul versus short haul flights[2] in the respective data sets. This may be an opportunity for additional study.

Based on the similarity in the percentage of events occurring in the Takeoff and Descent/Landing phases between CAAM 2 and the 2023 data, the change in definition from 3000 feet to 1500 as the transition altitude does not appear to have significantly affected the proportion of events occurring in the different phases of flight.

Comparison to CAAM 3

Figure 5 presents a summary of the data collected in the study in a format similar to what was presented in the CAAM 3 report (see Figure 2 above).

CAAM Level	CAAM 3 Event Count	2023 Event Count	CAAM 3 % (Excl. Unk)	2023 % (Excl. Unk)	Description
0	302	402	91%	93%	Above 1500 feet
1	31	31	9%	7%	Below 1500 feet
2	0	0	0%	0%	
3	0	0	0%	0%	
4	0	0	0%	0%	
5	0	0	0%	0%	
Unknown	1	5			
Total	334	438			

Note the CAAM Level is due to the effects of the IFSD only

Figure 5 – 2023 IFSD data by CAAM Level compared to CAAM 3

As quantified by the percentage of events by CAAM Level, there is consistency between the current data and that report by the CAAM 3 Committee.

Progression to higher Level consequences

In the CAAM 2 report, progression to Level 3 and higher consequences was attributed to Propulsion System Malfunction + Inappropriate Crew Response (PSM+ICR), now called Propulsion System Malfunction Recognition and Response (PSMRR). There were no events identified in the 2023 data that progressed beyond Level consequences due to the IFSD effects. Based on the CAAM 2 estimated Level 4+ Hazard Ratio of 0.0005, the 2023 total of 438 events would only be expected to result in 0.2 Level 4+ events. In other words, the 2023 data is not sufficient to conclude a different Hazard Ratio for PSMRR from the CAAM 2 work based on the relatively small number of IFSD events. In fact, the Committee is aware of at least one Level 4 PSMRR event (2021) and a Level 5 event (2020), validating that these events still occur.

Figure 6 tabulates the 2023 data based on CAAM Level and whether the IFSD was Commanded by the Flight Crew or Uncommanded.

[2] Long haul flights spend a larger percentage of their time during the Cruise phase of flight than do short haul flights. Given this difference in type of operation, general conclusions about breakdown by flight phase may be misleading when combining data from different types of operations.

	0A	1B	Unknown	Total
Commanded	277	16	4	297
Uncomanded	112	13	1	126
Unknown	13	2	0	15
Total	402	31	5	438

Figure 6 – 2023 IFSD breakdown by CAAM Level and Commanded/Uncommanded

It is notable in this data that 16 events (approximately 4%) were Commanded shutdowns below 1500 feet. In other words, crew action was taken to address the situation in a presumed high workload phase of flight.

Analysis/Conclusions

The CAAM Committee has published a comprehensive set of IFSD data covering the year 2023.

The change in definition of the Takeoff/Climb and Descent/Landing transition altitude from 3000 to 1500 feet between the CAAM 2 and CAAM 3 reports did not have a significant impact on the proportion of events occurring during the Takeoff and Descent/Landing phases of flight.

The proportion of events occurring during the Climb and Cruise phases of flight changed between the CAAM 3 report and this study in an apparently significant manner (on the order of 10%). The factors behind this change have not been established.

The number of IFSD events in the 2023 data was insufficient to establish if there have been any changes in the probability of a Level 3+ PSMRR event relative to the assessment in the CAAM 2 report.

While there were no Level 2 or higher events observed in the 2023 data, the Committee is aware of at least two Level 4+ PSMRR events occurring after publication of the CAAM 3 report, supporting the need to have a continued focus on this topic. This conclusion is further supported by the finding that there were 16 commanded IFSD events in the data set recorded during the high workload phases of flight (below 1500 feet).

Recommendations

The newly published data can be used in conjunction with IFSD data published in the CAAM 2 and 3 reports.

Utilization data was not collected as part of this work. Future studies may consider expanding to include this type of information.

Future studies may want to build upon this work with occasional spot check sampling. This may help to provide further insight into the discrepancy between the 2023 data and the CAAM 2 Flight Phase breakdown.

The newly published data is insufficient to provide any further context regarding PSMRR.

The Committee did not review turboprop data as part of this study. Future studies may want to perform a similar spot check on those installations to supplement this work.

References

[1] Technical Report On Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards; A joint effort of The Federal Aviation Administration and The Aerospace Industries Association; October 25, 1999
[2] 2nd Technical Report On Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards; A joint effort of The Federal Aviation Administration and The Aerospace Industries Association; January 31, 2005
[3] 3rd Technical Report On Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards; A joint effort of The Federal Aviation Administration and The Aerospace Industries Association; March 30, 2017