Aerospace Industries Association

Bird Ingestion

Working Group Report

RELEASE/REVISION	RELEASE DATE
Phase III Update 2	**09/04/2025**

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Abstract

The intent of this study was to update the existing AIA bird ingestion database with new data in the period from January 2015 to December 2017. Unlike previous issuances of this report, there is no pending rulemaking driving the update; this work is motivated by a desire to keep the database current. In light of this desire, the plan is to have regular updates to the analyses and this report.

Analysis of the data shows the bird ingestion rates have increased. At least part of this increase is attributed to increased awareness and improved reporting of bird ingestion events. While the ingestion rates have increased since the last review of data, the multiple engine power loss rate has remained roughly constant during the reporting period and continues to meet the safety objective of $1E^{-8}$ per airplane cycle.

Data are also reviewed with respect to engine certification standard to determine any positive impact of newer, stricter bird ingestion regulations. As expected, overall, there is a downward trend in the engine shutdown rates with respect to the certification basis of turbofan engines. This downward trend was shown to be statistically significant. There was an unexpected statistically significant increase seen between Generation 3 and Generation 4. Additional work in the future needs to be done to verify all engine generation levels are properly recorded in the dataset and to see if changes in definition and how the data were analyzed had an effect. If the trend between 3 and 4 continues in further updates, the data will be studied to see if there are reasons for this increase.

At the conclusion of this data analysis, the working group has no recommendations for new or changed regulations.

1 Introduction

1.1 Purpose

The intent of this study was to update the existing AIA bird ingestion database with new data in the period from January 2015 to December 2017. Turbofan and turboprop engines are the focus of this report, as they comprise the bulk of the database. A small fraction of records is from turboshaft and turbojet engines, however there is not enough data to conduct meaningful analysis for these engine types. Unlike previous issuances of this report, there is no pending rulemaking driving the update; this work is motivated by a desire to keep the database current. Trends utilizing the data are observed and monitored for any notable changes.

1.2 Background

FAA, EASA, and AIA have historically studied aircraft engine bird ingestions. Driven by the evolution of engine and airframe designs, changes in bird population, and notable ingestion events, such as the US Airways Hudson River accident in 2009, the intent is to ensure certification requirements meet their intended safety objective. AIA Working Groups have worked to gather, analyze, and report data on ingestions over specific time periods.

Historically, Working Group reports generally correlated to specific rulemaking activities, however with the intent of maintaining the bird ingestion database as current, going forward, the Working Group intends to provide a biennial update to the database. A modified “Phase” designation in report title is reserved for reports correlated to significant rulemaking; revisions for maintaining currency will be designated with the “Update” nomenclature. A summary of each Working Group report update is provided in Appendix A for reference.

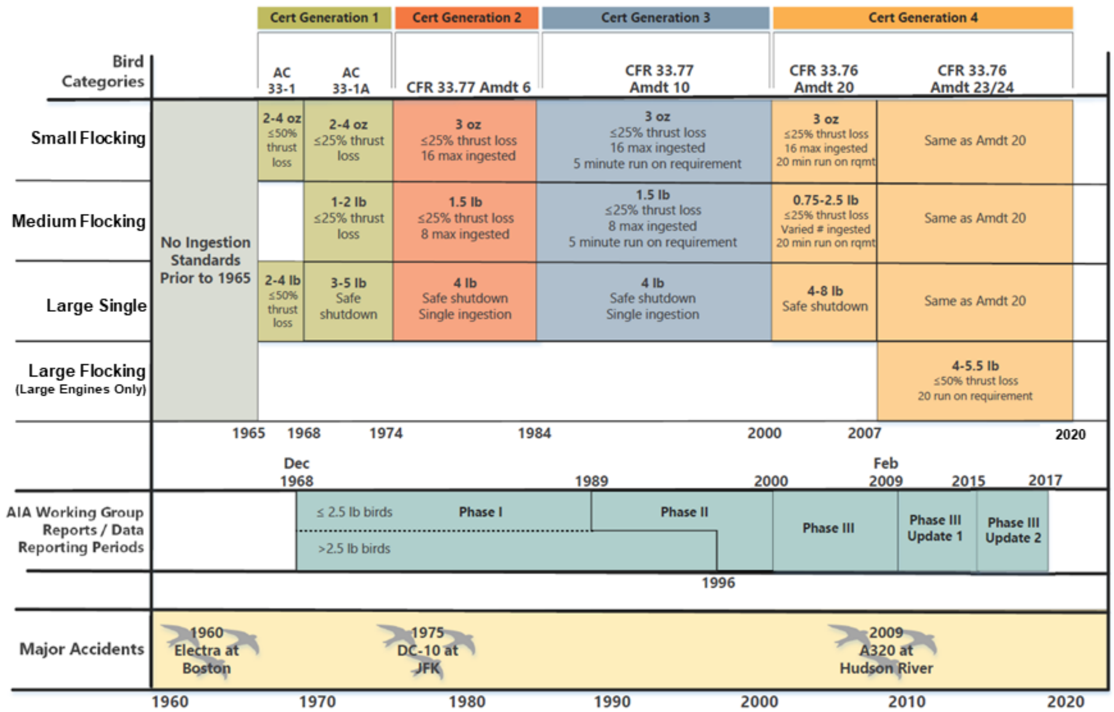


Figure 1-1 Timeline of Rulemaking Activities

Figure 1-1 provides a summary of rulemaking activities, AIA reports/reporting periods, and significant ingestion accidents. The evolution of certification requirements has been categorized by four generations to better allow for trends based on certification standards to be monitored. Certification under AC 33-1 and AC 33-1A have been classified as “Certification Generation 1;” CFR 33.77 Amendment 6 as “Certification Generation 2;” CFR 33.77 Amendment 10 as “Certification Generation 3;” and CFR 33.76 Amendments 20, 23, and 24 as “Certification Generation 4.”

2 Bird Ingestion Database

2.1 Input Data

The data provided by the engine companies included information on each bird ingestion event contained in their own databases. A complete list of data input fields and definitions is in Appendix B and is summarized here. The engine companies provided the following (to the extent known):

- Event Information
  - Event date
  - Aircraft
  - Engine model (Appendix C)
  - Engine position
  - Engine certification basis (Appendix C)
  - Number of engines involved
  - Flight phase
  - Altitude
  - Speed
  - Power level (after the event)
  - Whether there was evidence of core ingestion
  - Recorded damage
  - Number of birds
  - Bird species (typically identified with support from the Smithsonian Institution Feather Identification Lab, Natural History Museum in London and the Natural History Museum in Paris)
  - Bird weight (typically determined from References 1-3)
  - Closest geographic airport to strike location
- Total hours and cycles for each engine model

Many events did not have a bird species identified. This typically happens because remains were not collected (or not available). To enhance the data, the engine manufacturers attempted to identify a bird size based on the damage to the engine (if available). The bird sizes were listed as generic large (72 oz), medium (28 oz) or small

(4 oz) so that this data could be included for purposes of analysis and the weights allocated to classes. These generic classifications were consistent with Phase III. Note that by definition, some indication of bird size is implied in the use of the generic term; that is, if a bird was termed generic, it must also be classified as small, medium, or large.

A standard template was used for each engine company's inputs to promote consistency in reporting and facilitate data compilation and sanitization. Specifically, the flight phases are defined to be:

- Ground operations
- Takeoff roll, ≤ Vr (rotation speed)
- Takeoff / Initial climb, > Vr and ≤ 3,000 ft AGL (above ground level)
- Climb, > 3,000 ft AGL
- Cruise
- Descent, > 3,000 ft AGL
- Approach / landing, ≤ 3,000 ft AGL
- Landing roll
- Reverse thrust

2.2 Sanitization of Data

The data were sanitized to allow analysis of the combined data set by all of the engine companies without sharing proprietary information. The main data that needed to be sanitized were the engine types and airplane models. The engine model was broken down into categories based on inlet area and certification standard. The airplane model was listed by number of engines and their locations (wing- or fuselage-mounted).

The bird classification nomenclature adopted here is as follows: "i-s" designates the small class; "ii-m," "iii-m," and "iv-m" designate the medium class; and "I-L," "II-L," "III-L," and "IV-L" designate the large class.

Because the bird ingestion rules are based on inlet area, no sanitization or analysis was done based on diameter class.

Additional assumptions were made in cross checking and sanitizing the data. A complete description of all data transformations made during the cross check and sanitization process is provided in Appendix B. Notable assumptions were:

- For multi engine ingestions, where birds ingested were classified differently for each engine, the largest weight classification was used for all engines. This was done under the assumption that all birds ingested for a multi engine event were the same species.
- If flight phase was noted only as “climb” and altitude was indicated as “unknown” it was assumed to be “initial climb”
- If flight phase was noted only as “climb” and altitude was greater than 3,000 feet, it was assumed to be “Climb”
- Generic bird weights were used. Specifically, Large = 72 oz; medium = 28 oz; small = 4 oz. This usage matches what was done in the original Phase III report.

2.3 Data Quality

The databases provided by the engine companies contain all of the bird ingestion events known to them. The data were supplemented by some of the engine companies through the review of the FAA/Department of Agriculture National Wildlife Strike Database and an EASA/CAA database. Where there were discrepancies, the data were further reviewed and appropriate modifications or additions were made.

The data collected is considered most complete for events that involved power loss, as these events are typically reported to the engine manufacturer. Similarly, the dataset is considered mostly complete for events that involved damage to the engines, as these are typically reported to the engine companies. Events with no damage are considered under-reported as many of them would either not be reported or may not have been noticed.

The bird weights listed were typically determined by using three sources. Currently, the main source considered is from CRC/Dunning (1). Also used are CRC/Dunning (2) and Brough (3), especially in the legacy data prior to 2009. The bird weights listed mainly use the average adult weight for the species. If a bird event had a species noted but did not list a weight in an engine company's unsanitized data, CRC/Dunning (1) was the source used during the sanitization process for all data starting in 2009.

2.4 Summary of Data

The data comprises 28,784 individual bird ingestion records from 2000 through 2017, of which 28,767 records are for turbofan and turboprop engines, which are the focus of this report. Unless otherwise noted, all plots cover the time period of 2000-2017. Figure 2-1 provides a visual representation of the locations of reported bird ingestion events. Figure 2-2 provides a similar representation of the rates of bird ingestions by geographic area. It is apparent that the majority of reporting occurs in Europe and the United States. It is believed this is due to higher reporting standards and a proportionally higher flight cycle count in these regions.

As shown in Figure 2-3, the majority of ingestion events occur at an altitude of 3,000 ft AGL or below. The small bird category is not shown in this plot given that small bird ingestions are less likely to be reported given their lower propensity to cause damage, or if reported, it may not be discovered until sometime after the actual event. Therefore, the event location and altitude distribution for this population may not accurately reflect the true profile.

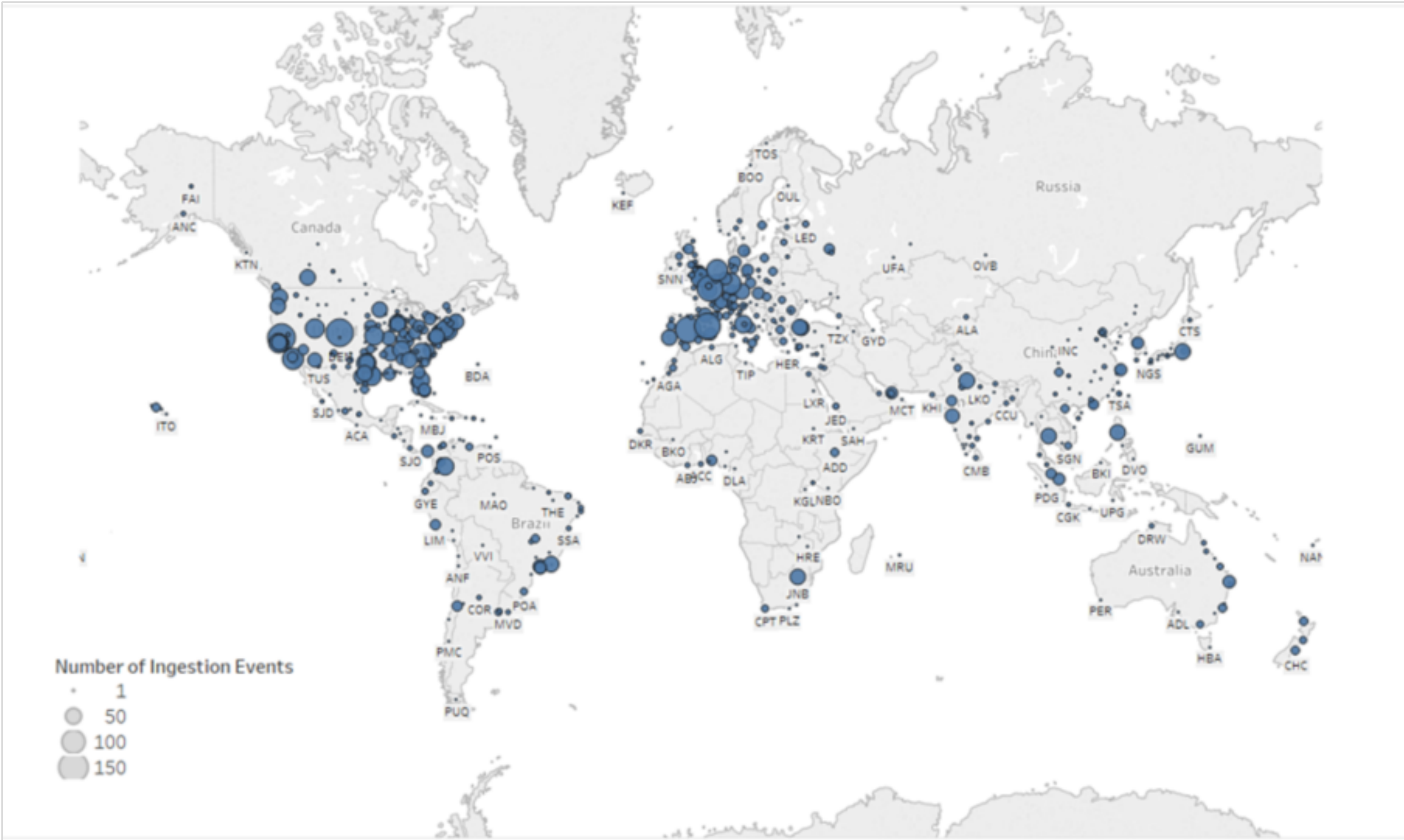


Figure 2-1 Geographic Representation of Number of Bird Ingestion Events

Bird Ingestion Rates (Based on Reported Events, 2000-2017)

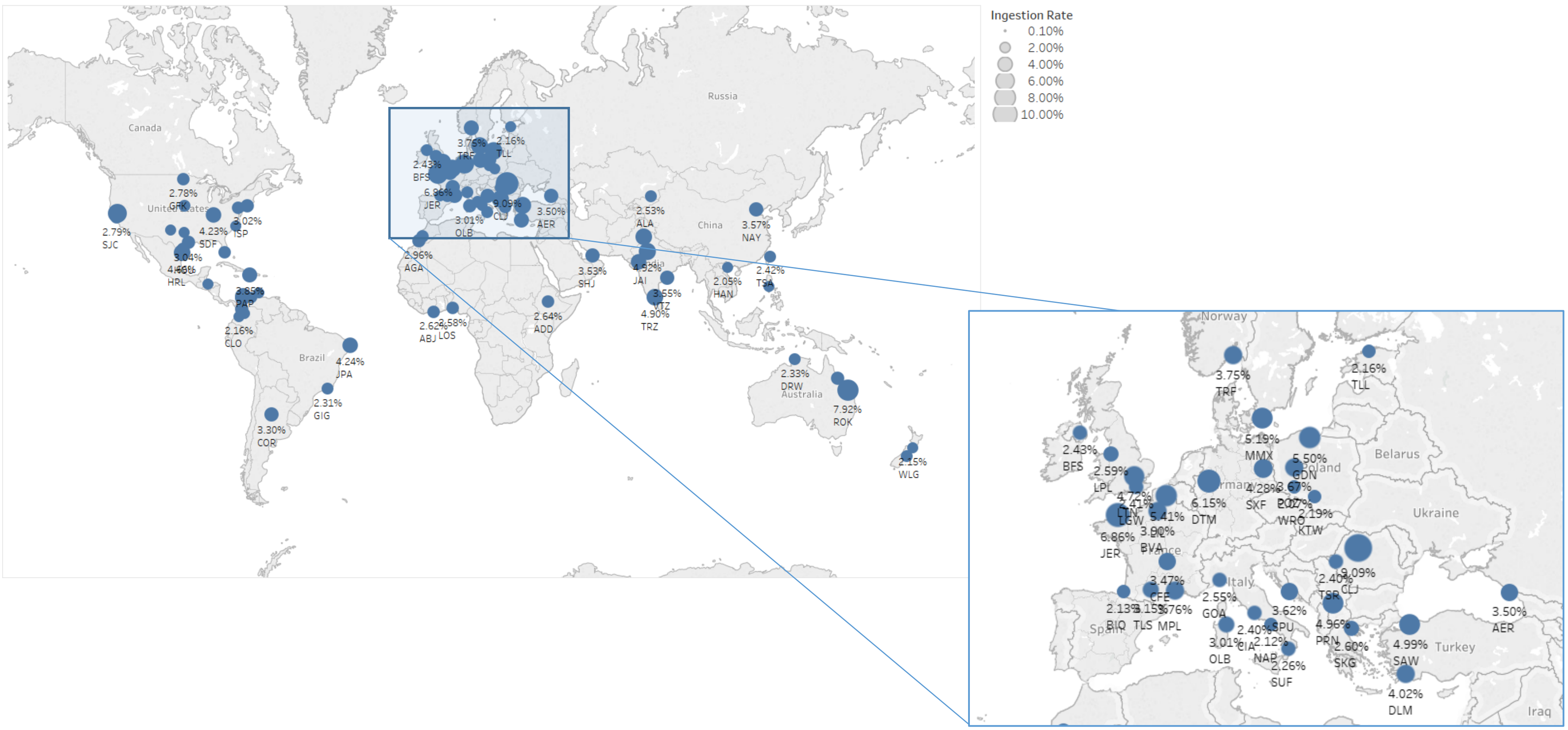


Figure 2-2. Geographic Representation of Number of Bird Ingestion Rates

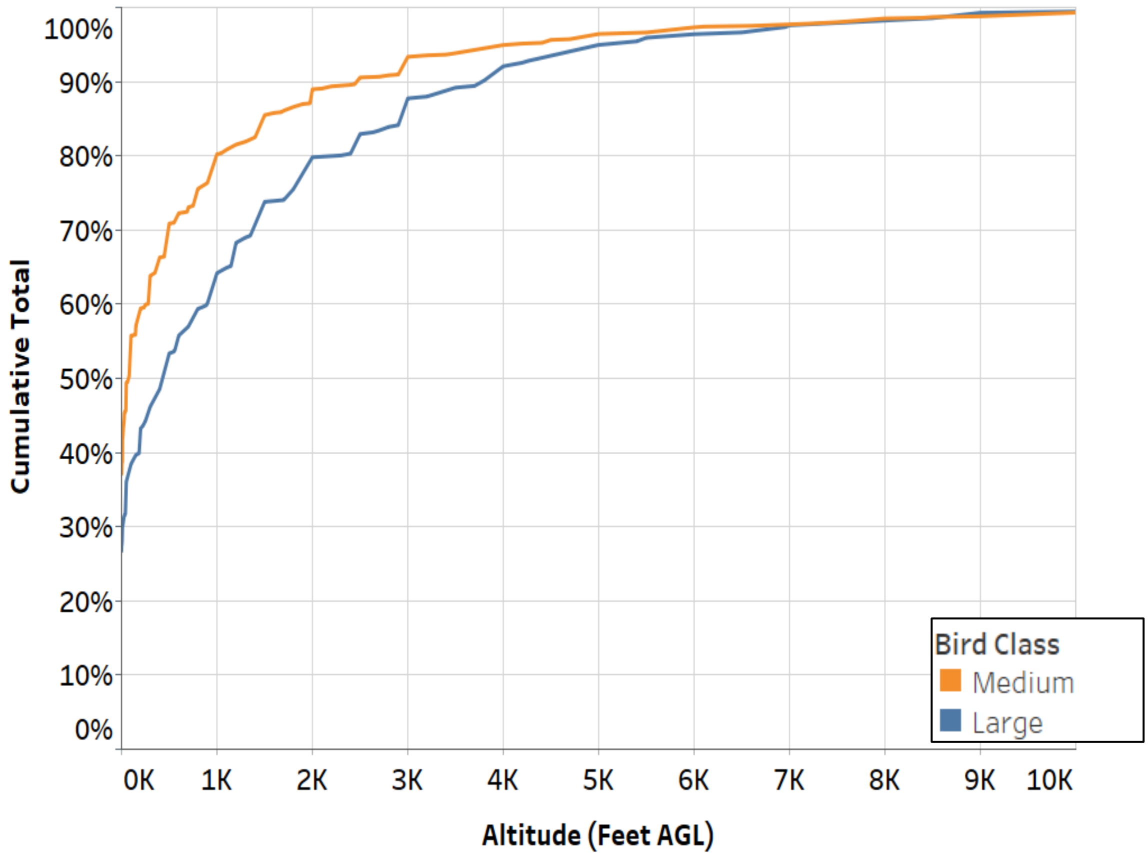


Figure 2-3. Altitude of Medium and Large Bird Ingestion Events

2.4.1 Event Engine and Fleet Data

Table 2-1. Number of Ingestion Engine Events by Engine Inlet Area Class summarizes the number of ingestion events based on the engine inlet area class. The trend of the majority of events occurring with Inlet Area Class D and E engines is maintained from the previous report. This is consistent with the population of engines in service (and the airplane cycle count), as shown in Figure 2-4. Inlet Class D represents the most significant portion of the fleet. For context and reference, a category A Inlet Area is a typical engine for a wide body, long haul airliner, Inlet Area D is typical for a single aisle, medium airliner, and Inlet Area F is typical of a small business jet.

Table 2-1. Number of Ingestion Engine Events by Engine Inlet Area Class

Engine Type	Inlet Area	Inlet Throat Area, A (m^2)	Number of Ingestion Events	% of Total Ingestion Events
turbofan	A	3.90 < A	1,995	6.93%
	B	3.50 < A ≤ 3.90	1,948	6.77%
	C	2.50 < A ≤ 3.50	901	3.13%
	D	1.35 < A ≤ 2.50	19,505	67.76%
	E	0.40 < A ≤ 1.35	3,161	10.98%
	F	A ≤ 0.40	871	3.03%
turboprop	F	A ≤ 0.40	386	1.34%
turbojet	F	A ≤ 0.40	15	0.05%
turboshaft	F	A ≤ 0.40	2	0.01%
Grand Total			*28,784*	*100%*

The total fleet cycles for turbofan engines are shown by inlet area class in Figure 2-4. Figure 2-5 shows the total turbofan fleet cycles by certification generation. Figure 2-6 shows the total turboprop fleet cycles by inlet area class, and Figure 2-7 shows the total turboprop fleet cycles by certification generation. Note that for Figure 2-5, Figure 2-6 and Figure 2-7, data was only available for 2009 and onward. Data for turbofans and inlet areas is the most complete. There has been a decreasing trend in turbofan engine cycles for all inlet area sizes with the exception of inlet sizes A and D. There is some inconsistency with the airplane cycle data that is apparent during the 2009-2010 timeframe. The majority of the issue is with the smaller engine categories which are primarily installed on business jets. Business jet flight activity went down significantly following the economic downturn in 2008; this may explain at least some of the inconsistency. For the 2001-2009 data, the conversion to airplane hours was done after the engine companies had provided the data. After 2009, the engine companies started providing the airplane hours. This may account for some of the discrepancy seen. Additional findings where the conversion from engine hours/cycles to airplane hours/cycles used the incorrect number of engines per airplane were noted. This information is being updated. The inconsistency in the airplane cycle data is still being investigated As part of the investigation, the engine companies have resubmitted all of their engine hours/cycles information from 2000 through 2017 in order to validate any past inconsistencies. Because of this, the rate information could be affected.

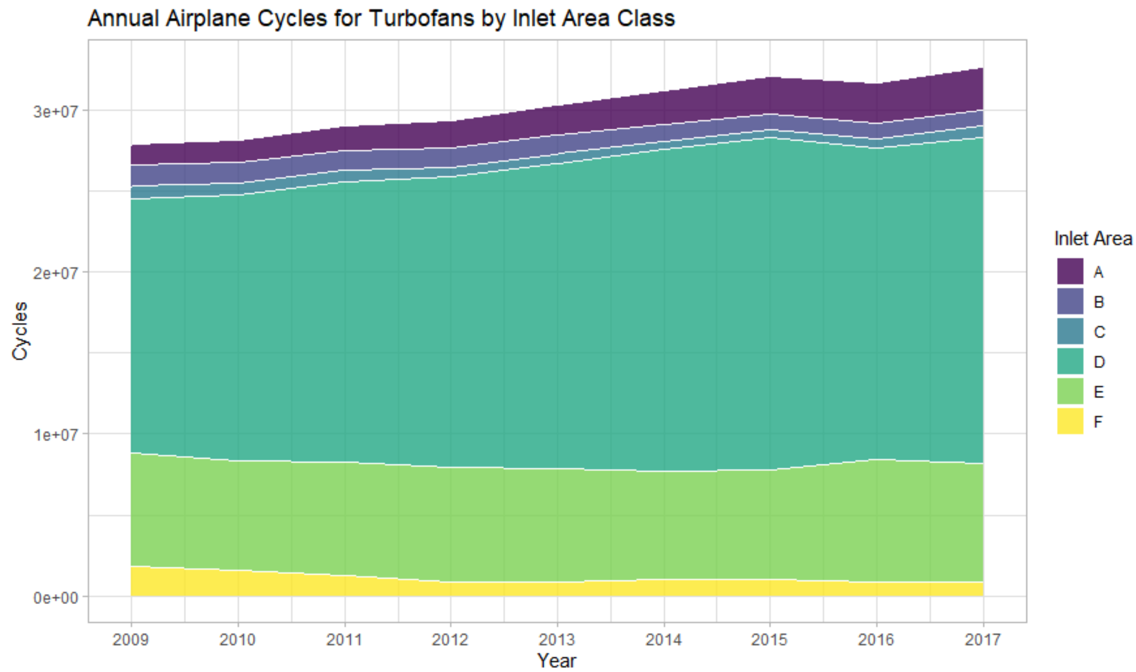


Figure 2-4. Annual Airplane Cycles for Turbofans by Inlet Area Class

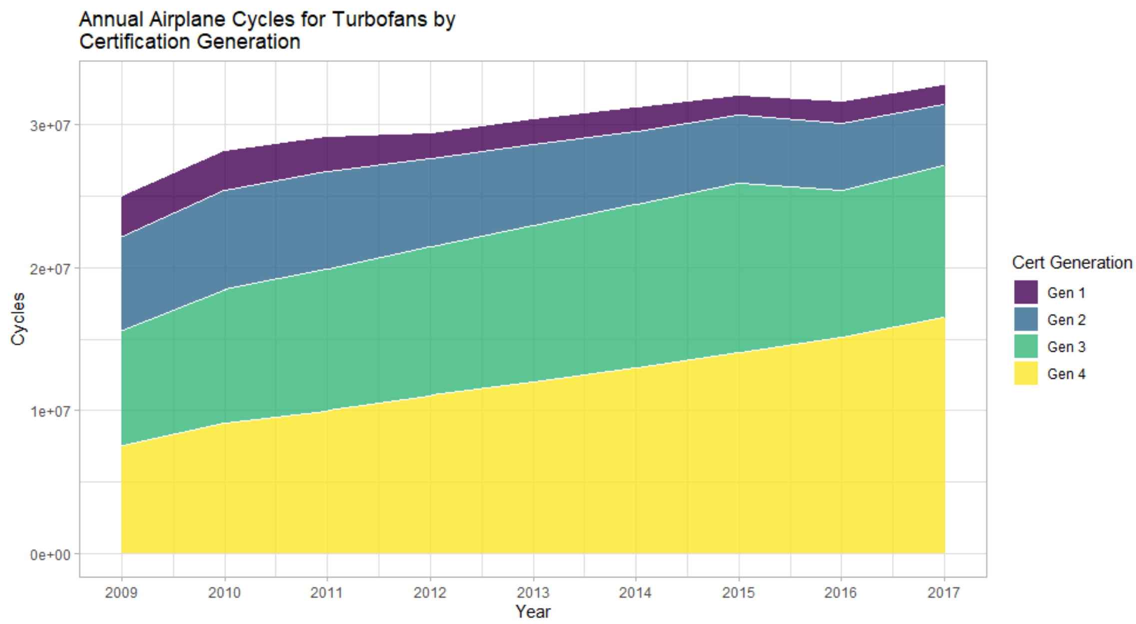


Figure 2-5. Annual Airplane Cycles for Turbofans by Certification Generation

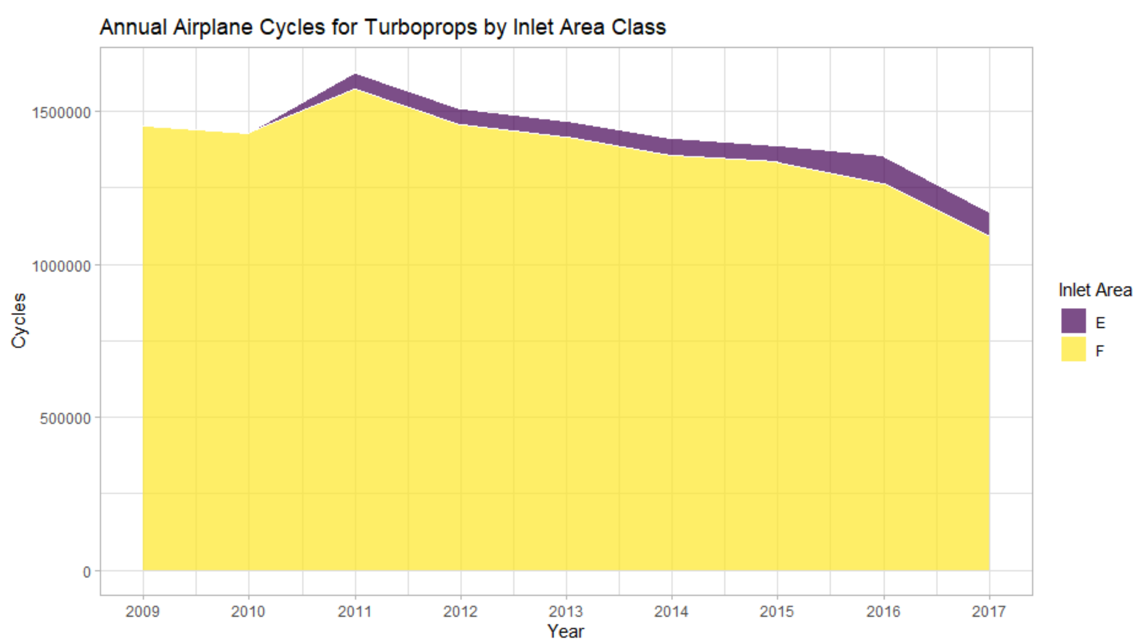


Figure 2-6. Annual Airplane Cycles for Turboprops by Inlet Class

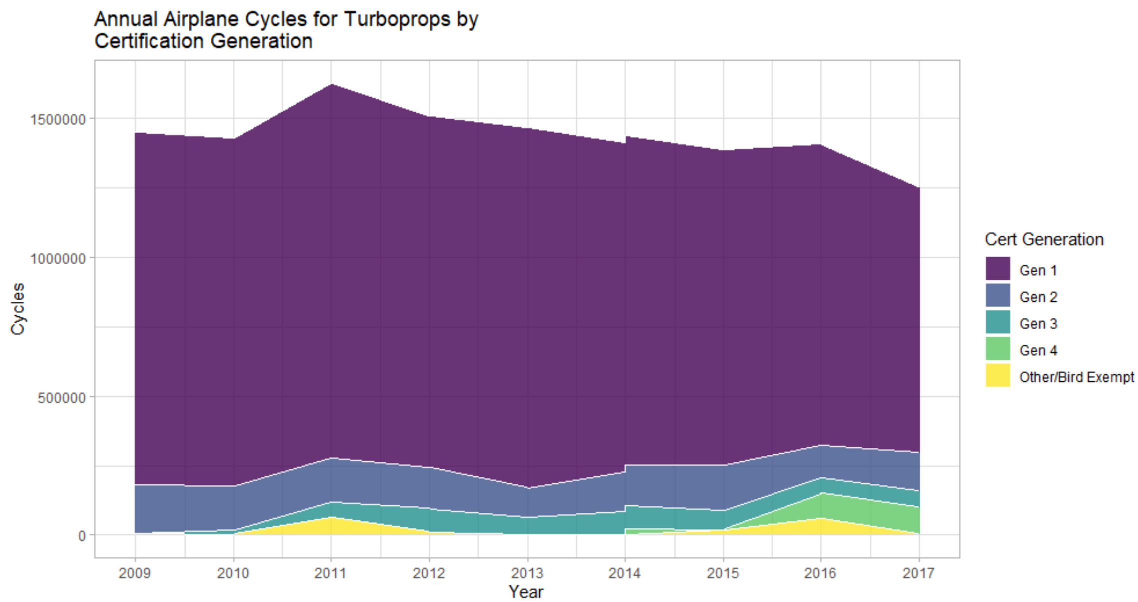


Figure 2-7. Annual Airplane Cycles for Turboprops by Certification Generation

Table 2-2 summarizes the number of turbofan and turboprop ingestion events based on the bird weight class categories, broken down by Core/Bypass Ingestion. For purposes of the analyses done for this report, the definition of core is the primary flow path of the engine leading into the compressor, combustor and turbine section. Any evidence of core ingestion was classified as a core ingestion event. Note, number of airplane events and engine events are different because some events were multi engine events.

Table 2-2. Number of Core or Bypass Ingestion Events by Bird Weight Class

Engine Type	Bird Class	Weight (lb)	Core Ingestion: Unknown	Core Ingestion: No	Core Ingestion: Yes	Total Engine Ingestion Events	Total Airplane Events
turbofan	NA	NA	6,960	3,109	1,973	12,042	11,745
	i-s	0 < w ≤ 0.5	5,253	2,887	1,693	9,833	9,550
	ii-m	0.5 < w ≤ 1.0	316	187	101	604	569
	iii-m	1.0 < w ≤ 1.5	223	198	82	503	483
	iv-m	1.5 < w ≤ 2.5	1,925	1,233	821	3,979	3,873
	I-L	2.5 < w ≤ 4.0	145	67	54	266	260
	II-L	4.0 < w ≤ 6.0	359	312	185	856	828
	III-L	6.0 < w ≤ 8.0	94	59	55	208	189
	IV-L	8.0 < w	44	22	24	90	88
turboprop	NA	NA	51	58	106	215	215
	i-s	0 < w ≤ 0.5	57	35	8	100	96
	ii-m	0.5 < w ≤ 1.0	7	6	2	15	12
	iii-m	1.0 < w ≤ 1.5	4	2	3	9	9
	iv-m	1.5 < w ≤ 2.5	13	8	8	29	28
	I-L	2.5 < w ≤ 4.0	1	1	1	3	3
	II-L	4.0 < w ≤ 6.0	2	2	4	8	7
	III-L	6.0 < w ≤ 8.0	4	1	0	5	5
	IV-L	8.0 < w	1	1	0	2	2
Grand Total			*15,459*	*8,188*	*5,120*	*28,767*	*27,962*

2.4.2 Event Bird Data

Table 2-3 summarizes the number of turbofan and turboprop ingestion events based on the bird weight class categories, broken down by Known Bird, Generic Bird, or Unknown Bird. For clarity, a known bird is one in which bird species has been identified. A generic bird is one in which enough information is available to designate a general size; Small, Medium, or Large, for the specimen. No size or weight information is available for an unknown bird. Note that in Table 2-3 there exists a seeming contradiction – there are unknown bird records with a bird class associated with them. These few records are either previously sanitized data from the Phase III report, which would require additional effort to revisit the raw data and clarify, or records that were categorized as multi engine events where the known bird class on one engine was copied to the other engine per the convention of this analysis.

Figures 2-8 and 2-9 represent cumulative fraction of known birds ingested, from smallest to largest, by engine type and engine inlet area classification respectively. These plots are useful when wanting to cover (for instance) 95% of the bird weight for a particular test.

Table 2-3. Number of Generic Bird and Known Bird Ingestion Events by Bird Weight Class

Engine Type	**Bird Class**	**Weight (lb)**	**Number of Unknown Bird Events**	**Number of Generic Bird Events**	**Number of Known Bird Events**	**Total Engine Events**	**Total Airplane Events**
turbofan	NA	NA	12,037	2	3	12,042	11,745
	i-s	0 < w ≤ 0.5	5	7,641	2,187	9,833	9,550
	ii-m	0.5 < w ≤ 1.0	1	62	541	604	569
	iii-m	1.0 < w ≤ 1.5	1	51	451	503	483
	iv-m	1.5 < w ≤ 2.5	2	3,158	819	3,979	3,873
	I-L	2.5 < w ≤ 4.0	0	4	262	266	260
	II-L	4.0 < w ≤ 6.0	0	657	199	856	828
	III-L	6.0 < w ≤ 8.0	1	11	196	208	189
	IV-L	8.0 < w	0	1	89	90	88
turboprop	NA	NA	215	0	0	215	215
	i-s	0 < w ≤ 0.5	0	55	45	100	96
	ii-m	0.5 < w ≤ 1.0	0	4	11	15	12
	iii-m	1.0 < w ≤ 1.5	0	1	8	9	9
	iv-m	1.5 < w ≤ 2.5	0	23	6	29	28
	I-L	2.5 < w ≤ 4.0	0	0	3	3	3
	II-L	4.0 < w ≤ 6.0	0	4	4	8	7
	III-L	6.0 < w ≤ 8.0	0	2	3	5	5
	IV-L	8.0 < w	0	0	2	2	2
Grand Total			*12,262*	*11,676*	*4,829*	*28,767*	*27,962*

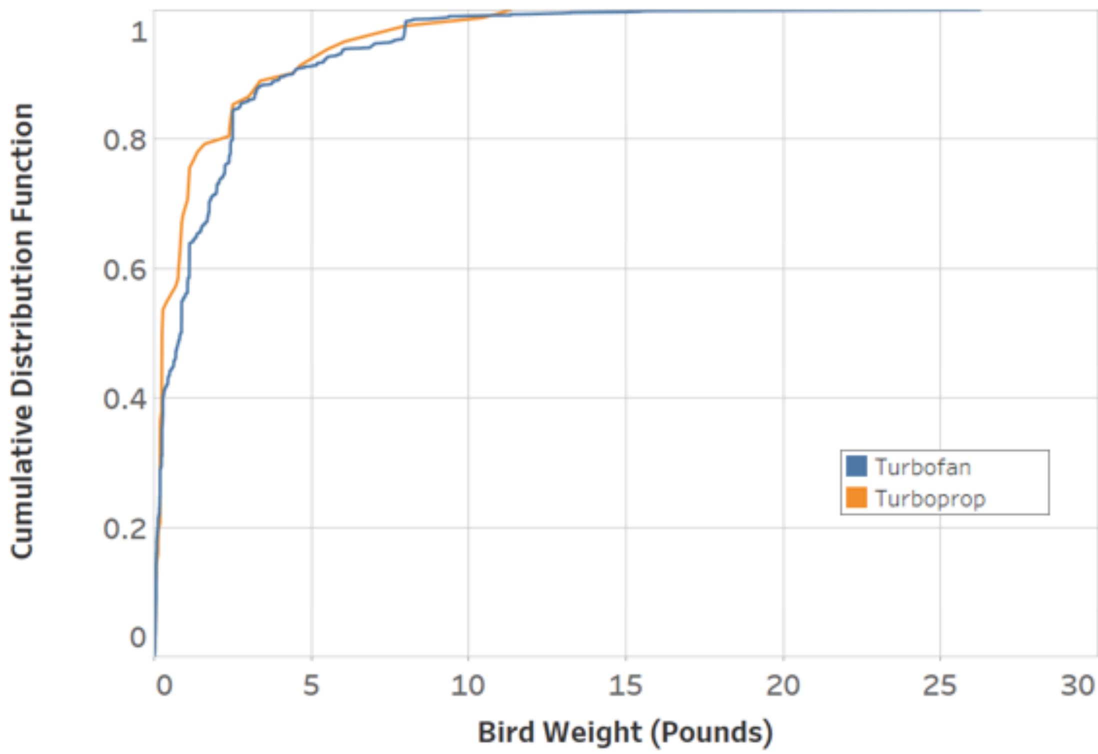


Figure 2-8. Cumulative Distribution of Turbofan and Turboprop Ingested Bird Weights

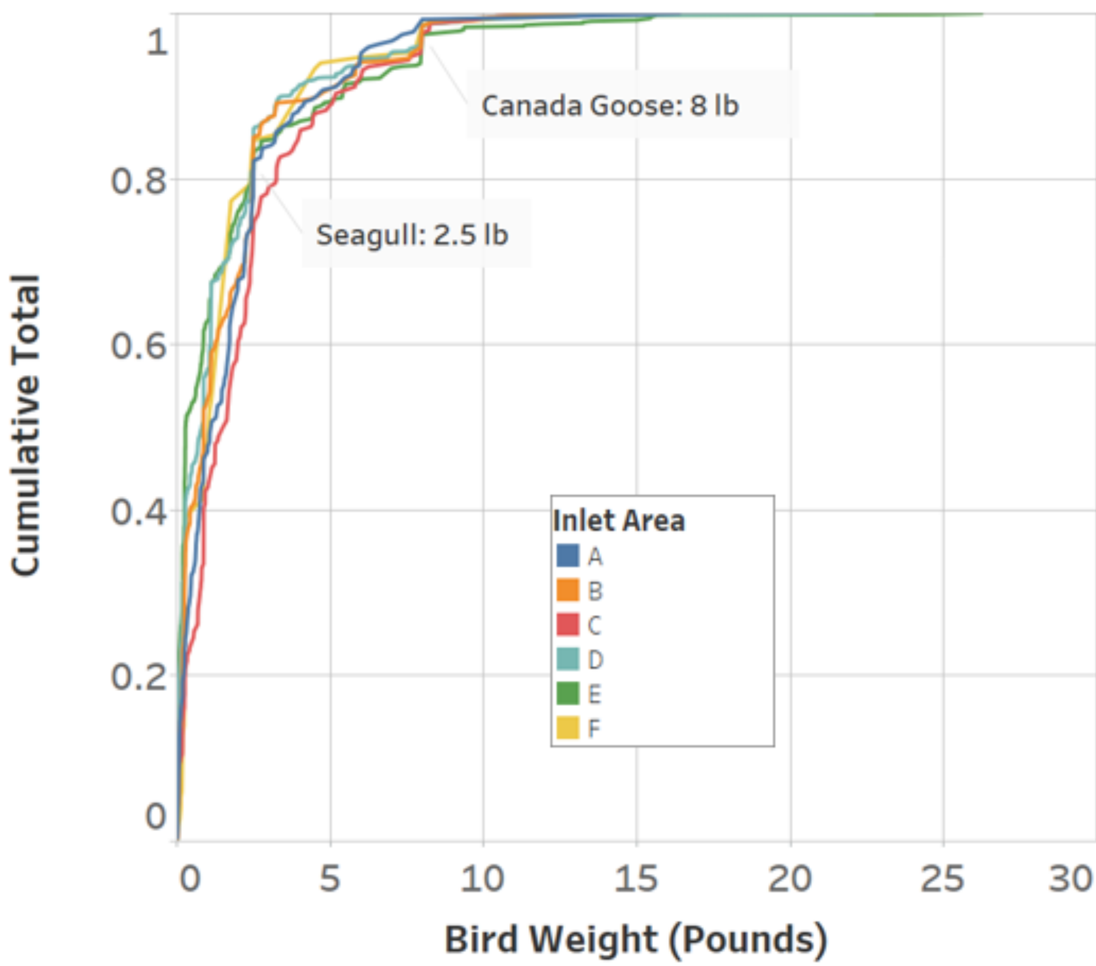


Figure 2-9. Cumulative Distribution of Turbofan Ingested Bird Weights by Inlet Area

Figure 2-10 was generated, categorizing bird species by general bird family. The breakdown by bird size shows the most frequently ingested bird type for each size category. Bird families that comprise less than 0.5% of the total ingestion events were omitted from the plot to aid in clarity.

To understand the most common birds or bird types ingested, Figure 2-11a is a new plot relative to the previous Phase III Update 1 report and shows the ingestions for Turbofan by bird weights and altitude, while Figure 2-11b is for all engines.

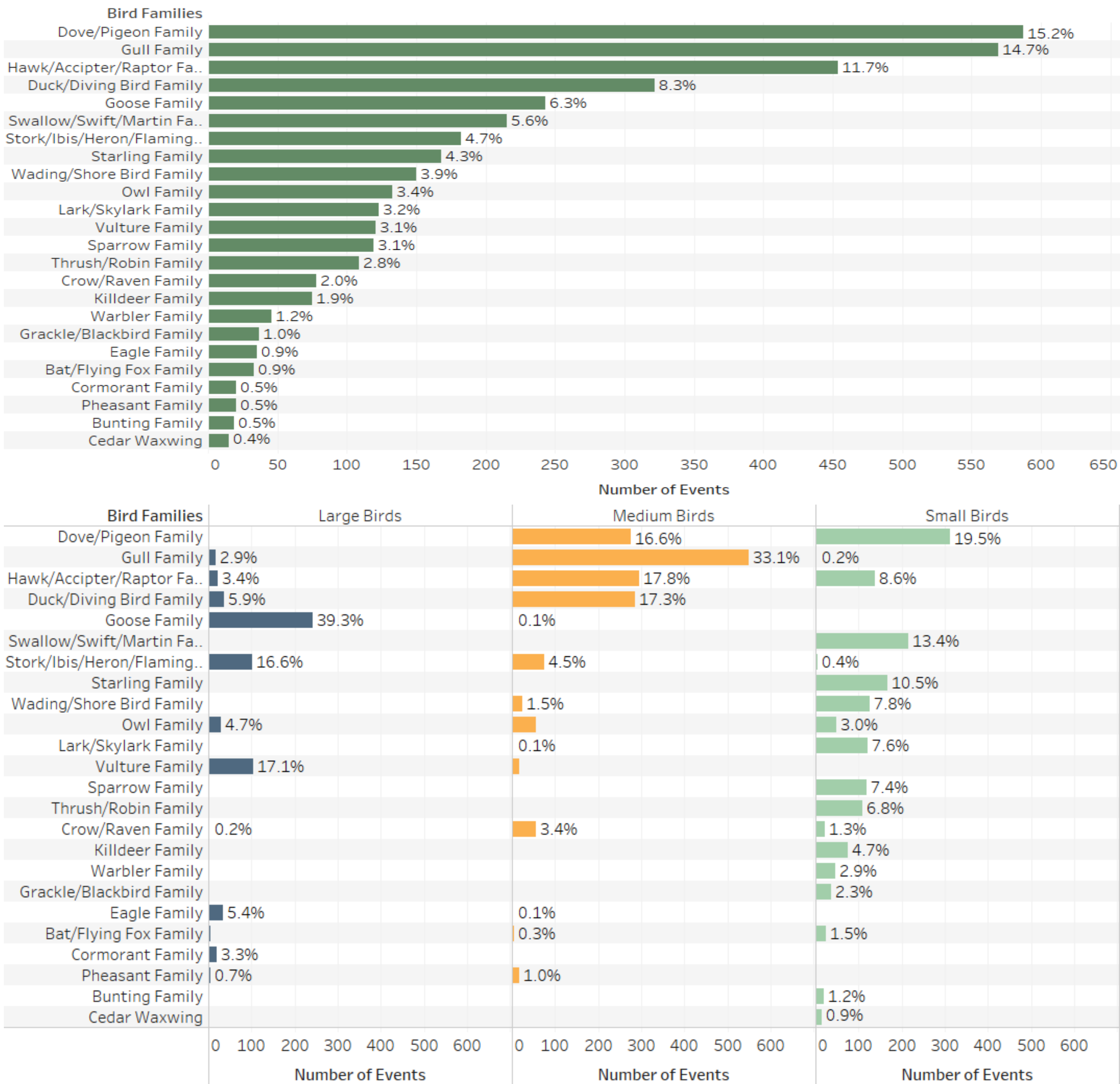


Figure 2-10. Most Common Bird Types Ingested

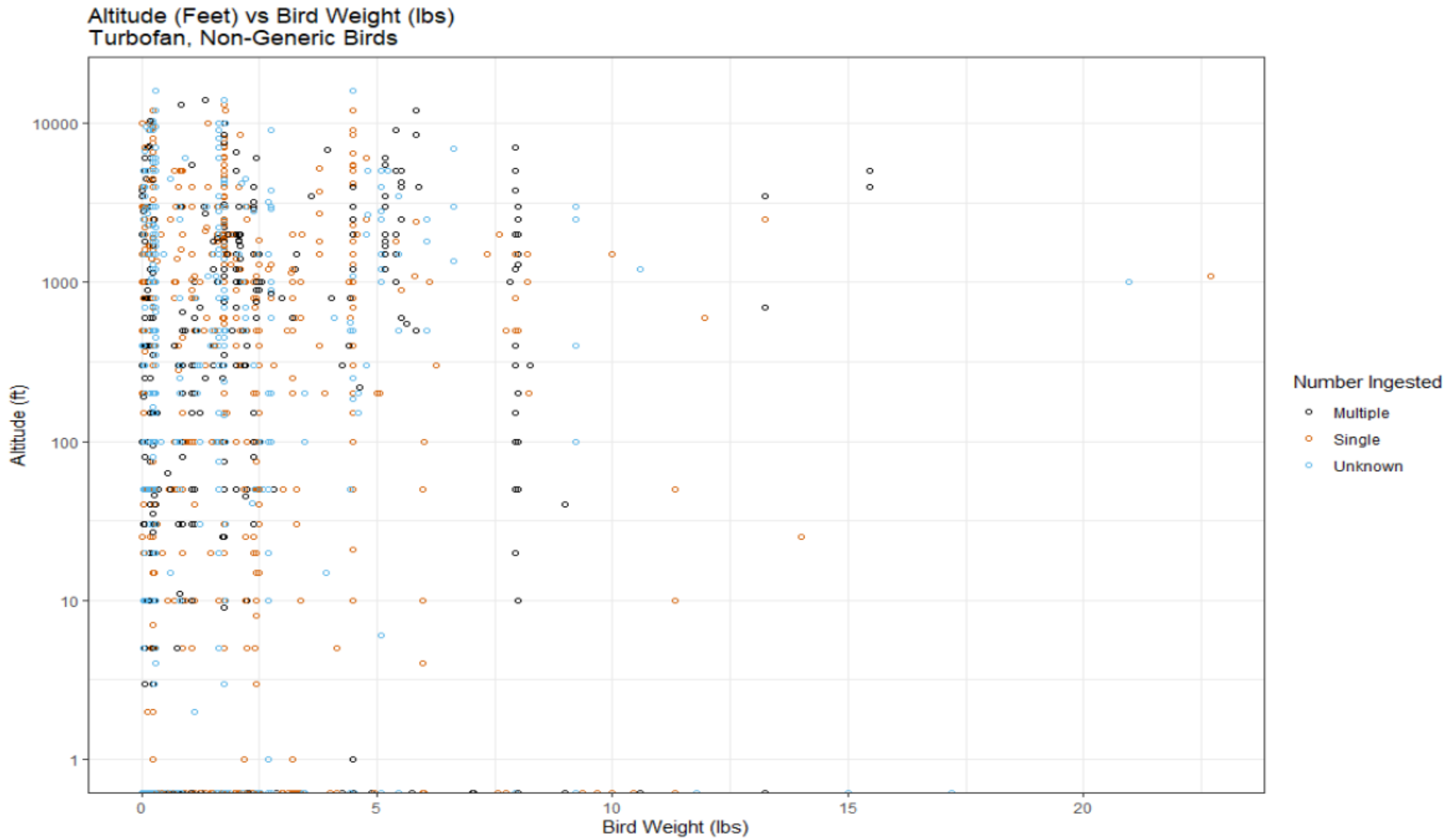


Figure 2-11a. Ingestions for Turbofan by Bird Weights and Altitudes

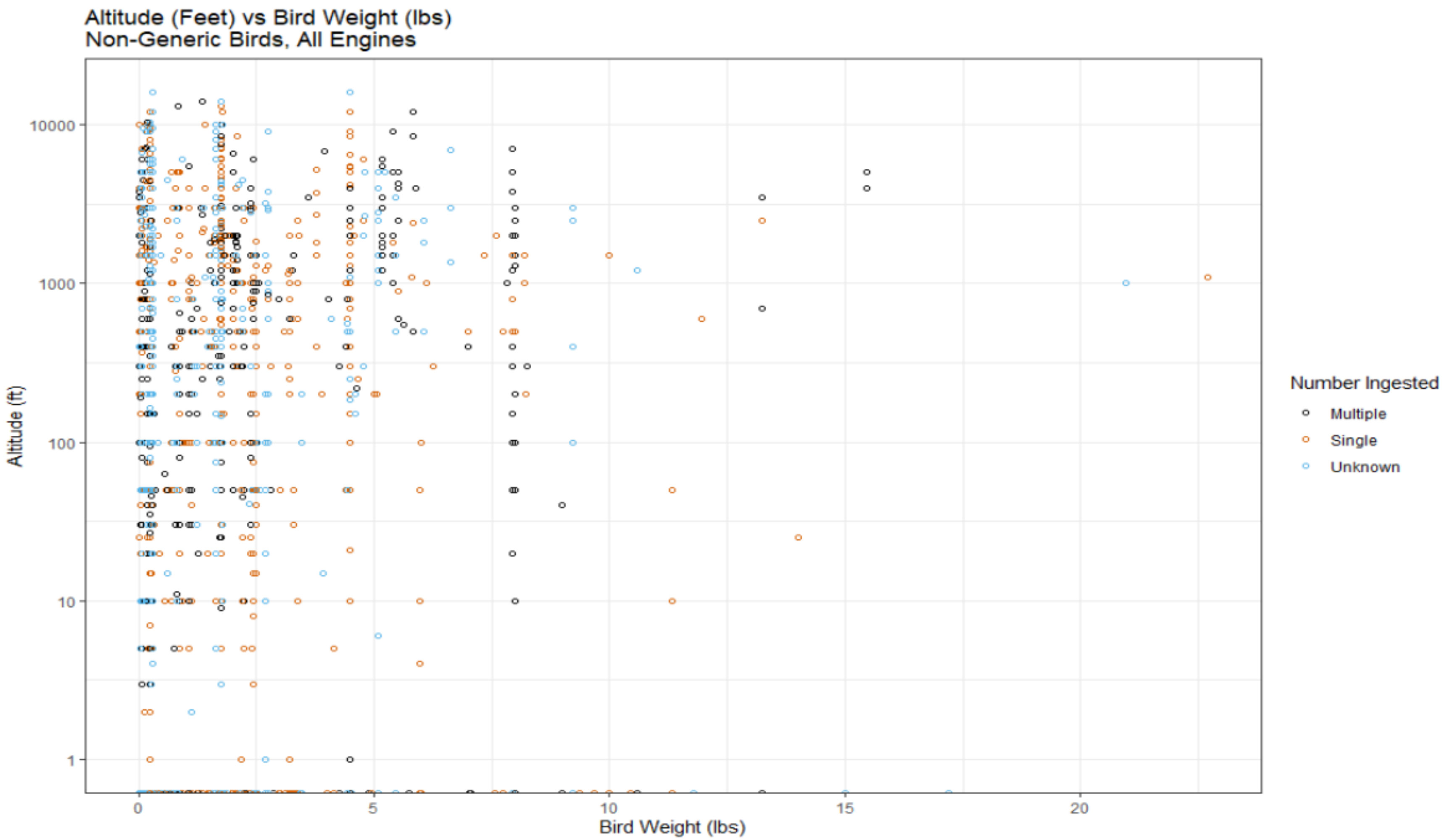


Figure 2-12b. Ingestions for all engines by Bird Weights and Altitudes

3 Analysis

Analysis conducted under this report supersedes analysis covered under prior releases of the AIA bird ingestion report. With the data compilation, cross checking, and sanitization effort conducted here, data previously reported may have been adjusted as a correction, or because of reapplication of a specific assumption in a more consistent manner across all data sets.

3.1 Methodology and Assumptions

Four year rolling averages were used in plotting ingestion rates. Interpretation of the data without using the rolling average was difficult, as the year by year data had significant variation. This was particularly true for inlet areas and bird sizes with few ingestion events. A four-year rolling average provided enough data smoothing for trends to be more evident.

For hours, cycles, and rate analyses, if only engine-level data was provided in the engine company raw data, the airplane hours and cycles were estimated by dividing the engine cycles by the number of engines on that aircraft. This method does not account for the hours and cycles from spare engines, but provided a sufficient estimate for analysis.

3.2 Engine Ingestion Rates

Engine ingestion rates for turbofans and turboprops were calculated for each year and broken out by bird size. The plots shown in Figure 3-1 and Figure 3-2 are the ingestion rates by bird size for turbofans of all inlet areas. Plots for each inlet area classification for turbofans as well as ingestion rates for turboprops are shown in Appendix D.

All ingestion rates are in events per airplane cycle.

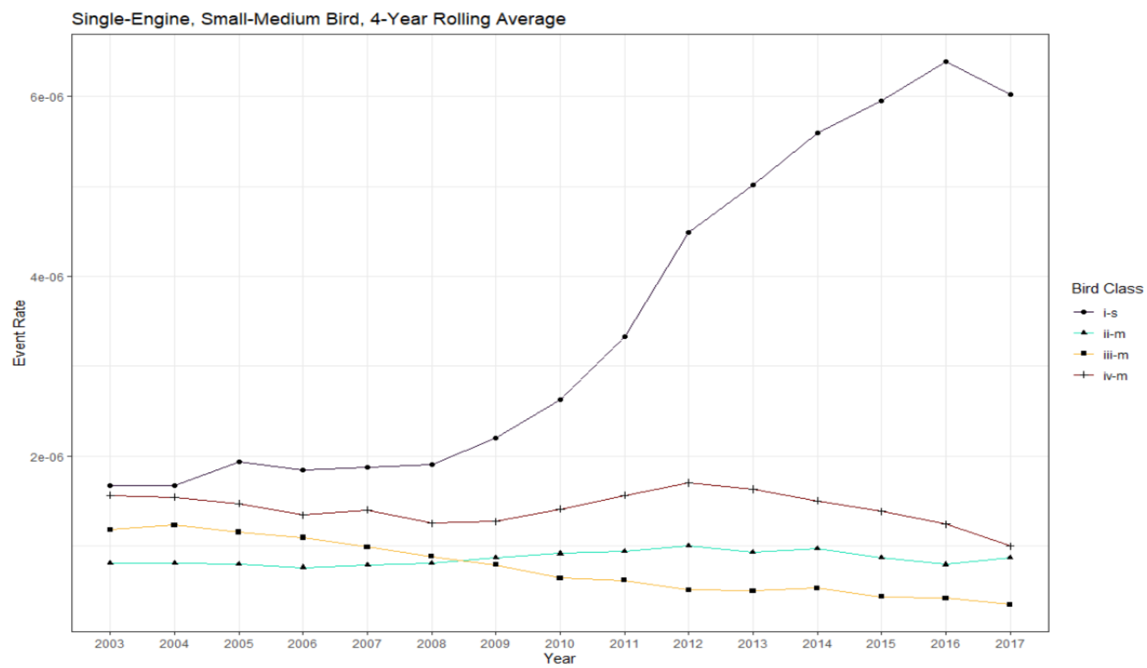


Figure 3-1. Small and Medium Bird Ingestion Rates for All Turbofan Inlet Areas

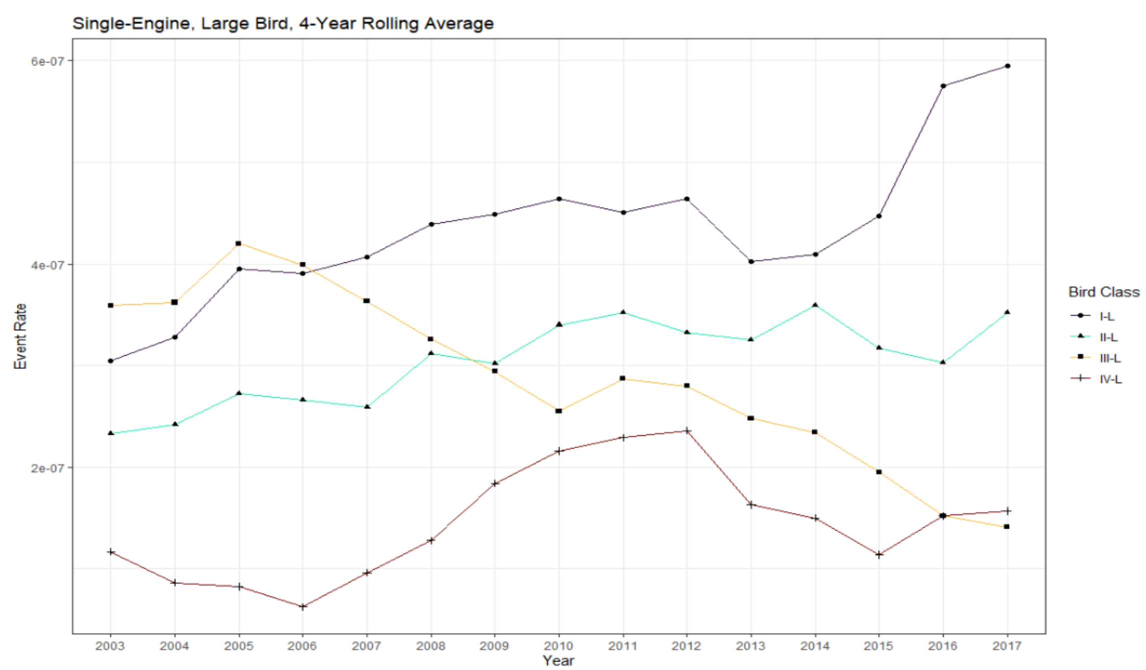


Figure 3-2. Large Bird Ingestion Rates for All Turbofan Inlet Areas

Turbofan Single-Engine Ingestion Events: 4-Year Rolling Average Rate by Bird Weight Class									
Year	**NA**	**i-s**	**ii-m**	**iii-m**	**iv-m**	**I-L**	**II-L**	**III-L**	**IV-L**
2000	NA	NA	NA	NA	NA	NA	NA	NA	NA
2001	NA	NA	NA	NA	NA	NA	NA	NA	NA
2002	NA	NA	NA	NA	NA	NA	NA	NA	NA
2003	1.96e-05	1.67e-06	8.08e-07	1.18e-06	1.56e-06	3.05e-07	2.33e-07	3.59e-07	1.17e-07
2004	2.04e-05	1.67e-06	8.03e-07	1.23e-06	1.54e-06	3.28e-07	2.42e-07	3.62e-07	8.63e-08
2005	1.53e-05	1.93e-06	7.99e-07	1.15e-06	1.47e-06	3.95e-07	2.72e-07	4.20e-07	8.24e-08
2006	1.11e-05	1.84e-06	7.59e-07	1.09e-06	1.34e-06	3.91e-07	2.66e-07	3.99e-07	6.26e-08
2007	7.63e-06	1.87e-06	7.85e-07	9.84e-07	1.40e-06	4.07e-07	2.59e-07	3.63e-07	9.62e-08
2008	3.26e-06	1.90e-06	8.08e-07	8.79e-07	1.25e-06	4.39e-07	3.12e-07	3.26e-07	1.28e-07
2009	3.73e-06	2.20e-06	8.68e-07	7.87e-07	1.27e-06	4.49e-07	3.02e-07	2.94e-07	1.84e-07
2010	4.22e-06	2.63e-06	9.12e-07	6.41e-07	1.41e-06	4.64e-07	3.40e-07	2.55e-07	2.16e-07
2011	1.09e-05	3.33e-06	9.34e-07	6.14e-07	1.56e-06	4.51e-07	3.52e-07	2.87e-07	2.29e-07
2012	2.02e-05	4.49e-06	9.97e-07	5.07e-07	1.70e-06	4.64e-07	3.32e-07	2.80e-07	2.36e-07
2013	2.86e-05	5.02e-06	9.25e-07	4.97e-07	1.63e-06	4.02e-07	3.25e-07	2.48e-07	1.63e-07
2014	3.61e-05	5.59e-06	9.68e-07	5.26e-07	1.50e-06	4.09e-07	3.59e-07	2.34e-07	1.50e-07
2015	3.72e-05	5.95e-06	8.70e-07	4.31e-07	1.38e-06	4.47e-07	3.17e-07	1.95e-07	1.14e-07
2016	3.99e-05	6.39e-06	7.90e-07	4.15e-07	1.24e-06	5.75e-07	3.03e-07	1.52e-07	1.52e-07
2017	3.54e-05	6.02e-06	8.62e-07	3.45e-07	9.95e-07	5.95e-07	3.52e-07	1.41e-07	1.57e-07

3.3 Multi Engine Ingestion Rates

Multi engine ingestion rate for all inlet areas for Turbofans are presented here. A breakdown by Inlet Area classification is in Appendix D.

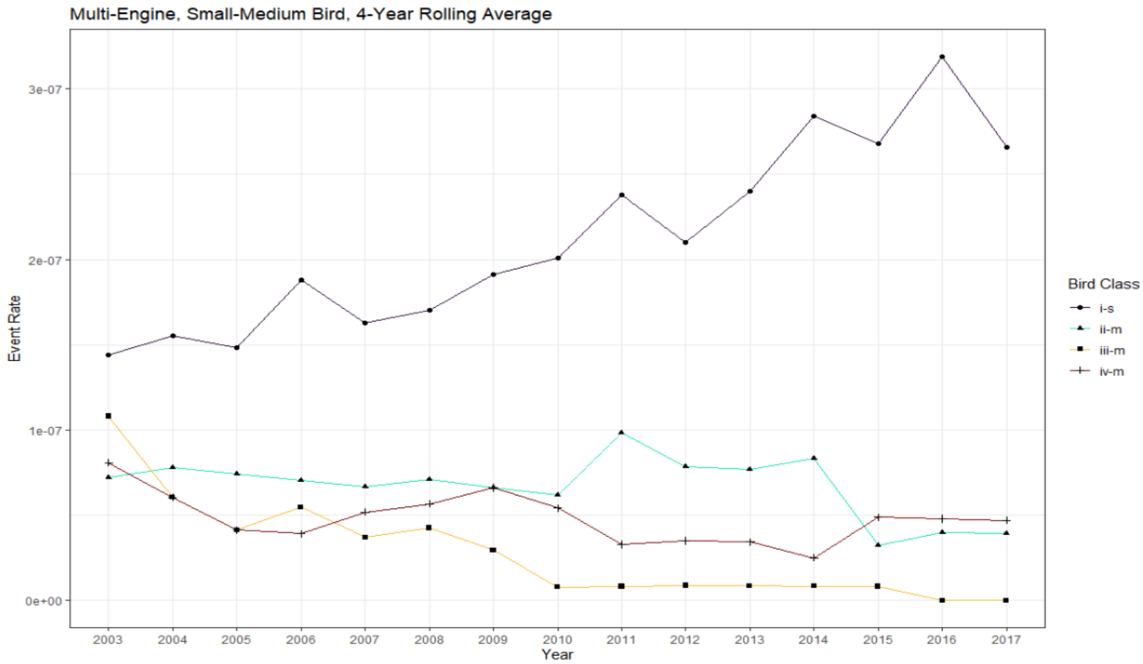


Figure 3-3. Small and Medium Bird Multi Event Ingestion Rates for All Turbofan Inlet Areas

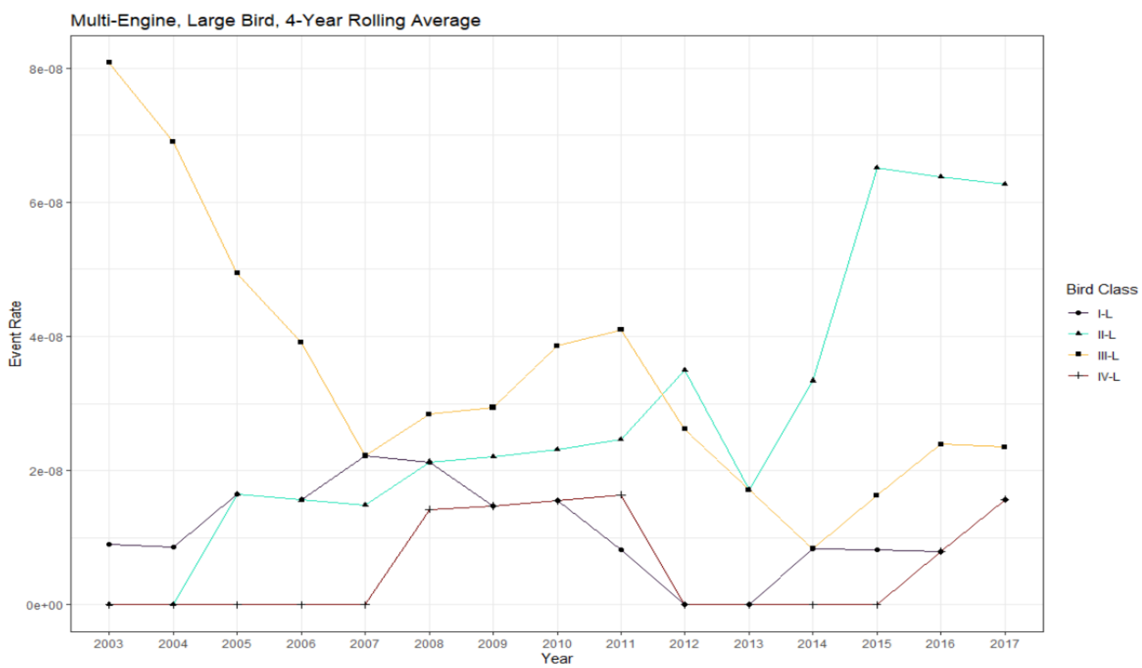


Figure 3-4. Large Bird Multi Event Ingestion Rates for All Turbofan Inlet Areas

Turbofan Multi-Engine Ingestion Events: 4-Year Rolling Average Rate by Bird Weight Class									
Year	**NA**	**i-s**	**ii-m**	**iii-m**	**iv-m**	**I-L**	**II-L**	**III-L**	**IV-L**
2000	NA	NA	NA	NA	NA	NA	NA	NA	NA
2001	NA	NA	NA	NA	NA	NA	NA	NA	NA
2002	NA	NA	NA	NA	NA	NA	NA	NA	NA
2003	4.13e-07	1.44e-07	7.18e-08	1.08e-07	8.08e-08	8.98e-09	0	8.08e-08	0
2004	4.23e-07	1.55e-07	7.77e-08	6.04e-08	6.04e-08	8.63e-09	0	6.90e-08	0
2005	3.21e-07	1.48e-07	7.41e-08	4.12e-08	4.12e-08	1.65e-08	1.65e-08	4.94e-08	0
2006	2.27e-07	1.88e-07	7.04e-08	5.48e-08	3.91e-08	1.56e-08	1.56e-08	3.91e-08	0
2007	1.63e-07	1.63e-07	6.66e-08	3.70e-08	5.18e-08	2.22e-08	1.48e-08	2.22e-08	0
2008	7.80e-08	1.70e-07	7.09e-08	4.25e-08	5.67e-08	2.13e-08	2.13e-08	2.84e-08	1.42e-08
2009	9.56e-08	1.91e-07	6.62e-08	2.94e-08	6.62e-08	1.47e-08	2.21e-08	2.94e-08	1.47e-08
2010	1.24e-07	2.01e-07	6.18e-08	7.73e-09	5.41e-08	1.55e-08	2.32e-08	3.86e-08	1.55e-08
2011	2.38e-07	2.38e-07	9.83e-08	8.19e-09	3.28e-08	8.19e-09	2.46e-08	4.10e-08	1.64e-08
2012	1.01e-06	2.10e-07	7.87e-08	8.75e-09	3.50e-08	0	3.50e-08	2.62e-08	0
2013	1.31e-06	2.40e-07	7.71e-08	8.56e-09	3.43e-08	0	1.71e-08	1.71e-08	0
2014	1.48e-06	2.84e-07	8.34e-08	8.34e-09	2.50e-08	8.34e-09	3.34e-08	8.34e-09	0
2015	1.46e-06	2.68e-07	3.25e-08	8.13e-09	4.88e-08	8.13e-09	6.51e-08	1.63e-08	0
2016	8.62e-07	3.19e-07	3.99e-08	0	4.79e-08	7.98e-09	6.38e-08	2.39e-08	7.98e-09
2017	5.72e-07	2.66e-07	3.92e-08	0	4.70e-08	1.57e-08	6.27e-08	2.35e-08	1.57e-08

3.4 Engine Power Loss Flight Phases and Rates

Flight phases for turbofan power loss events are shown in Figure 3-5. Takeoff/Initial climb as well as Approach/Landing were the most common phases for a power loss event. It is notable that there are a number of unknown flight phases for power loss events. The actual phase information for these events may be available with additional research by individual engine companies, but was not available in the sanitized data at this time. Addressing this unknown flight phase data can be included in the next report update period.

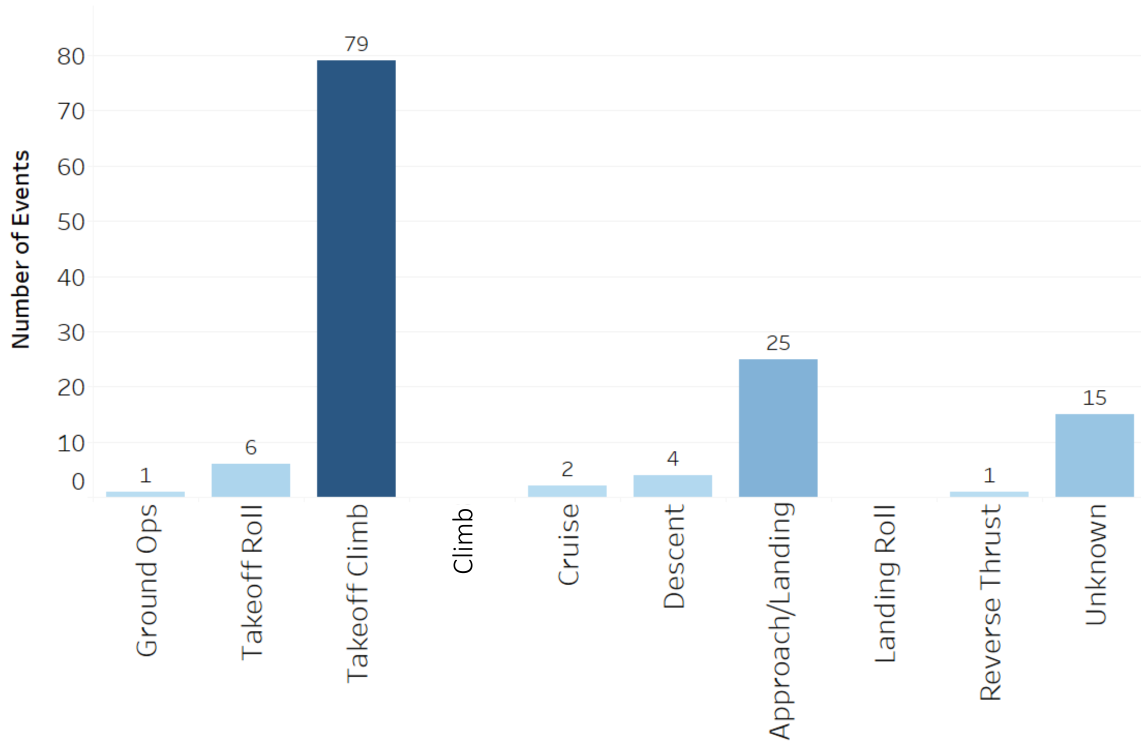


Figure 3-5. Flight Phase of Turbofan Power Loss Events, 2000-2017

The entire fleet power loss rates are shown in Figure 3-6. The power loss rates have been dropping steadily over the entire time period from 1970 with only minor, brief increases. Since power loss events are regularly reported, this downward trend is not considered to be a reporting issue; rather, it is believed that the power loss rate for the fleet has indeed dropped by over an order of magnitude. This downward trend of the power loss rate is an indication that the successive bird ingestion rule amendments are effective.

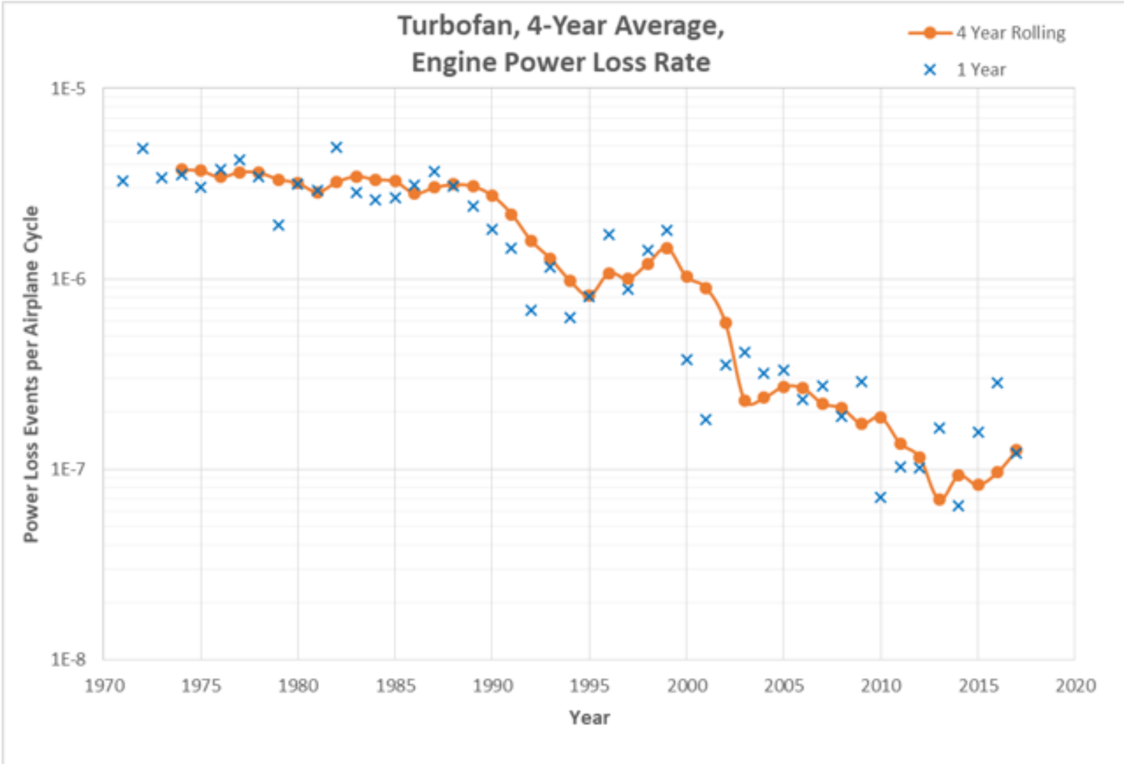


Figure 3-6. Engine Power Loss Rate, Turbofan

Figure 3-7 provides a breakdown of the power loss proportion over the entire reporting period broken down by certification basis. Confidence intervals are plotted with a 95% confidence level. On the whole the trend shows an improvement in power loss rate with the progression of certification generation and the trend was tested statistically. The statistically significant rise seen between Generation 3 and Generation 4 was not expected. Additional work in the future needs to be done to verify all engine generation levels and also to see if changes in definition and how the data were analyzed had an effect. If the trend between 3 and 4 continues in further updates, the data will be studied to see if there are reasons for this difference. Statistical testing was based upon a Chi Squared hypothesis test as presented by Nelson (4).

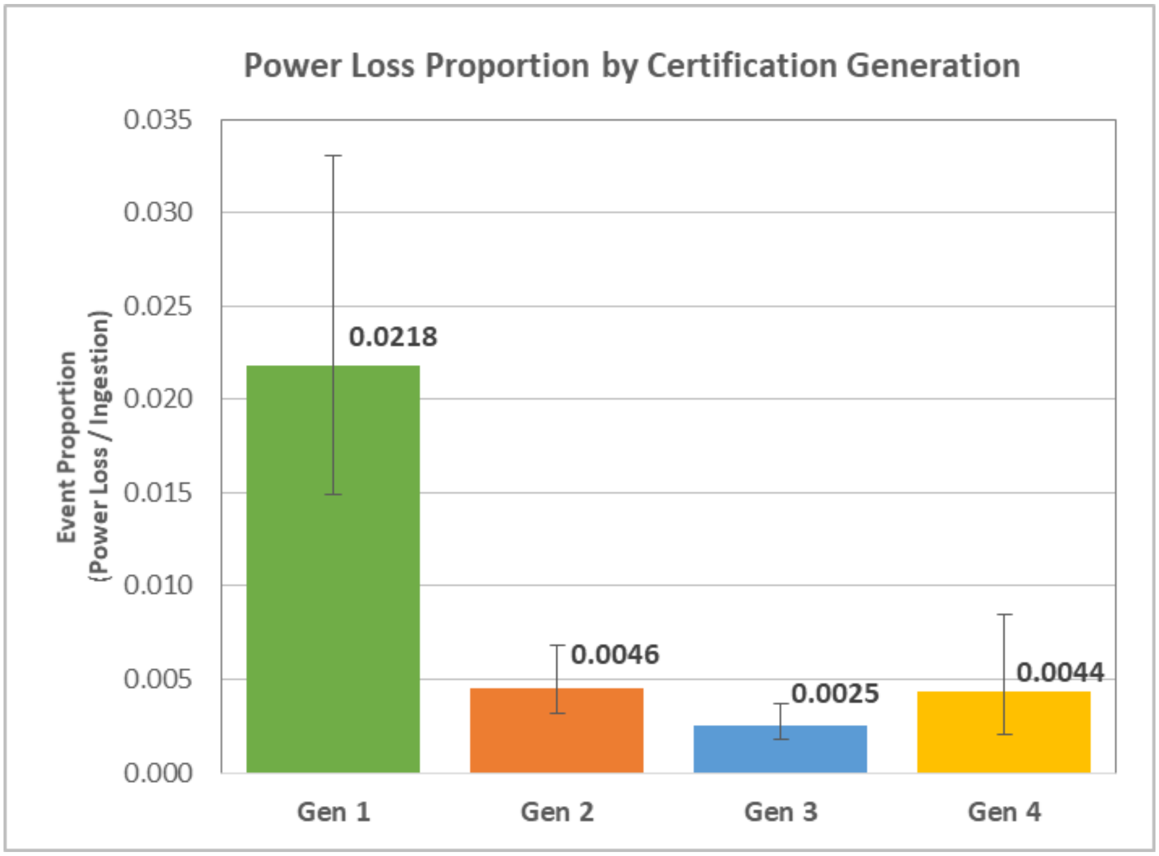


Figure 3-7. Turbofan Power Loss Broken Down by Certification Generation

3.5 Multiple Engine Power Loss Rates

Figure 3-8 shows the multiple engine power loss rate. While the 1-year instantaneous and 4-year rolling average rates appear to be relatively flat, that is somewhat misleading as there are very few multiple power loss events (typically 0 or 1 in any given year). As newer certified engines enter into service, these events should become even more rare. In fact, all of the multiple engine power loss events represented by the chart were with engines certified to amendment 20 or prior. As there have been no multiple engine power loss events past 2009, the 4-year rolling average power loss rate shown in the figure stops at 2012 since the values for 2015 through 2017 are zero and will not plot on a logarithmic scale. Therefore, the cumulative average was tallied, beginning with the 2002 event, and better reflects the 6-year period of no events showing a continuing downward trend in the power loss rate. In the Phase III report the safety goal was transformed to a per cycle multiple engine power loss basis of $1E^{-8}$ per airplane cycle. The data in Figure 3-8 show that from 2003-2011, the goal was met (within the resolution of the data) and since then, as indicated by the cumulative average, the rate is below the goal.

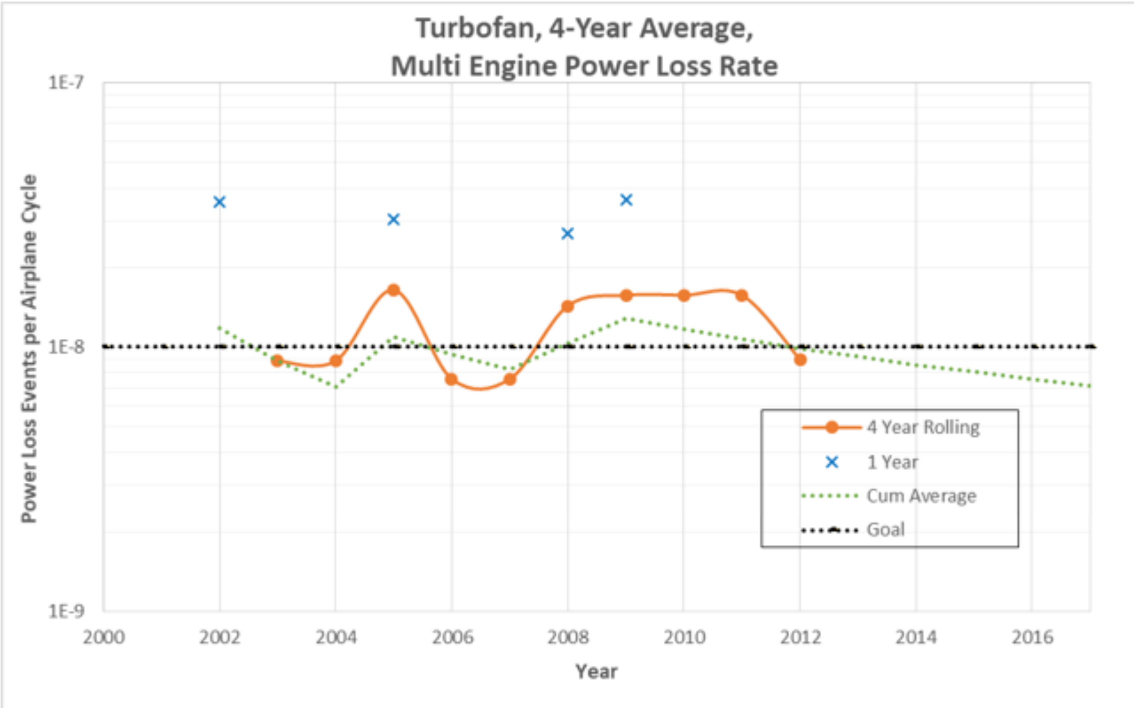


Figure 3-8. Multiple Engine Power Loss Rate, Turbofan

The four events with multiple engine power loss are summarized in Table 3-1. These include the event that caused the re-analysis of the data focusing on core ingestion (the Hudson River event). Two of the events were during climb (Canada geese and mourning doves), one was on approach (starlings) and one is listed as an unknown phase (ring-billed gulls). All except the unknown phase event were identified as core ingestion events.

Table 3-1. Summary of Multiple Engine Power Loss Events

Event Date	Flight Phase	Bird Species	Core Ingestion?
08-May-2002	unknown	Ring-Billed Gull	N
1-Sep-2005	TOCL	Mourning Dove	Y
10-Nov-2008	APPLD	Starling	Y
15-Jan-2009	TOCL	Canada Goose	Y

4 Discussion

4.1 Conclusions

The ingestion rates shown in Figure 3-1 for category i-s birds show an increase by a factor of approximately 3 from 2008 to 2016 with a slight decrease after being relatively constant from 2003 through 2008. It is believed this increase is due largely to increased awareness and reporting of ingestion events and not entirely due to an actual increase in the number of events. Otherwise, one can see a relatively stable ingestion rate for medium and large birds, shown in Figure 3-2.

The multi engine ingestion event rates shown in Figure 3-3 show a similar trend over the same time period of 2008 to 2017, roughly a 50-80% increase. Again, it is believed this increase is due largely to increased awareness and reporting of ingestion events.

The large bird multi engine event rates shown in Figure 3-4 show that ingestion rates for multiple engine events is one to two orders of magnitude smaller than for single engine events. Furthermore, within this category, there is a notable level of variation. This large variation is due to the relatively small number of events each year.

The engine power loss rate in Figure 3-6 shows a decreasing trend over time. Approximately two decades are required for the full influence of a regulation to be felt (5). The current regulations have been in place since 2007 (although issue papers were used prior to this date). Given this, one can surmise that this rate will asymptotically approach a level off point on the order of $1E^{-7}$ events/cycle or lower.

In the Phase III report, the safety goal was transformed to a multiple engine power loss basis of $1E^{-8}$ per airplane cycle. The data in Figure 3-8 show that from 2003-2012, the ingestion rate was on the order of $1E^{-8}$. From 2012 through 2017 the rate is below the $1E^{-8}$ goal.

5 Recommendations

The power loss rate is trending downward but absent a change in airworthiness standard, power loss rates would be expected to level off as older generation engines retire. Regardless of any changes to the Airworthiness Standards, better airport control measures will always be helpful in controlling the ingestion rates and reducing power loss events.

Generation 3 and 4 will be studied further to determine what accounts for the unexpected difference in the shutdown rates.

It is recommended that The Working Group maintain the bird ingestion database as current, providing biennial updates.

No additional recommendations are presented at this time.

6 Future Work

Work is ongoing to include the data prior to 2001. There are several issues that need to be addressed. The earlier data was sanitized but only had the engine sizes listed by engine diameter. The current data has it broken down by inlet area which matches the way the regulations are written. Current work is trying to match up the prior sanitized data with the unsanitized data. Also the prior data did not indicate whether some of the bird was ingested into the core.

Topics for consideration in further work include:

- The engine companies have event location in their data. This data could be used in future analysis, however a challenge with this will be that some locations listed are ambiguous. Also, any event with minor or no damage may just have the location of the finding listed.
- Seasonality of strikes could provide insights to airport control measures.
- Review the breakdown of ingestion rates and power loss events based on engine position (wing vs. fuselage).
- Review the breakdown of ingestion and power loss events based on flight phase.
- Study of core versus bypass ingestion events based on certification generation. As turbofan bypass ratios increase, a review of core versus bypass events would be of interest to look for trends.
- Review engine certification generation assignments. Generation should be assigned based on the original certification basis. In some case, the generation may have been changed depending on testing that the engine manufacturer has done.
- The Phase III report suggested “In future analyses, it is recommended that the ‘generic large’ birds are distributed into the bird classes.” This has not been implemented, and additional discussion would be required in order to establish how the generic data is going to be used.
- Figure 3-5 provided an initial look at the flight phases where power loss events occurred. Additional work could be done to address unknown phases for power

loss events. A comparison to certification generation would be useful for investigating the impact of regulations.

7 References

1. Dunning, John; CRC Handbook of Avian Body Masses, Second Edition; 2007.
2. Dunning, John; CRC Handbook of Avian Body Masses; 1992.
3. Brough, Trevor; *Average Weights of Birds*; Ministry of Agriculture, Fisheries and Food, Aviation Bird Unit, Worplesdon Laboratory, Guildford, Surrey 1983.
4. Nelson, Wayne; Applied Life Data Analysis; 1981, p 532.
5. Reed, Julian; *Statistical Assessment of Changes in Bird Certification Rules for Aero-Engines Through Time*, presented at 2011 Bird Strike North America Conference, September 12-15, 2011, Niagara Falls, Ontario, Canada.

Appendix A Summary of Previous Bird Ingestion Reports

As it is the intention to maintain the AIA bird ingestion database current, Table A-1 is provided as a tool to summarize each update at a very high level for reference.

Table A-1. Summary of AIA Bird Ingestion Reports

Phase	Data Time Period	Motivation	Focus
I	1968-1988 (for birds ≤2.5 lb) 1968-1995 (for birds >2.5 lb)		Harmonization of existing bird rules
II	Previous report up to Dec 1999	Harmonization with DGAC Large Flocking Bird Rule	Flocking bird fan testing
III	Previous report up to Jan 2009	Jan 2009 Hudson River Event	Core ingestion testing
III Update 1	Previous report up to Dec 2015	Periodic update	Shut down rate progression over certification generations
III Update 2 (this report)	Previous report up to Dec 2017	Periodic update	Shut down rate progression over certification generations

Appendix B Data Field Definitions and Sanitization Process

B.1 Data Input Rules

For consistency in inputting and interpreting data, a standard template was developed for bird ingestion data and used by all engine companies. The data fields and definitions are summarized in Table B-1.

Table B-1. Data Template Field Definitions and Rules

Field	Type	Definition	Acceptable Inputs
Internal Event Identification	1	Field used by engine company for internal reference	Any string
Aircraft	1	Event aircraft model	Any string
Engine Family/Engine Model	1	Event engine model	Any string
Operator	2	Event aircraft operator	Any string
Notes / Comments	2	Event description, notes	Any string
Event Date	3	Event date	DD-MMM-YYYY or MM/DD/YYYY format
Engine Position	3	Event engine position	1, 2, 3, 4, or Unknown
Number of Ingesting Engines	3	Quantity of engines ingesting a bird. Note that there should be one record for each engine. The multiple ingestions must occur during the same flight phase in order to be considered a multi engine event. If two (or more) engines ingest a bird on the same flight but the ingestions occur during different flight phases, it is considered two (or more) single engine events.	1, 2, 3, 4, or Unknown

Field	Type	Definition	Acceptable Inputs
Phase Info	3	Flight phase during ingestion event	GOPS (ground operations) TOR (takeoff roll, <=VR) TOCL (Takeoff / Initial climb, >VR and <=3k AGL) CLIMB (climb, >3k AGL) CR (cruise) DES (descent, >3k AGL) APPLD (approach / landing, <=3k AGL) LR (landing roll) LRRT (reverse thrust) Unknown
Altitude (feet AGL)	3	Altitude (Above Ground Level) at time of ingestion event	Numeric (in ft, AGL) or Unknown
Speed (knots)	3	Speed at time of ingestion event	Numeric (in knots) or Unknown
Power < 50%	3	Did the ingestion event cause power to reduce to < 50%?	Y, N, or Unknown
Core Ingestion	3	Were bird remains found in the core?	Y, N, or Unknown
Core Damage	3	Was the core damaged?	Y, N, Unknown, Yes outside of AMM limits, Yes within AMM limits
Fan/Propeller Damage	3	Was the fan/propeller damaged?	Y, N, Unknown, Yes outside of AMM limits, Yes within AMM limits
Operational Consequence	3	What was the operational consequence of the ingestion event? Power loss in the operational consequence field is any power loss that has an operational impact, regardless of amount or duration. So it is possible to have a power loss noted in this field but not a "Power <50% = Yes" in the main Power Loss field	Accident IFSD RTO/Air Turn Back/Diversion Power Loss (any amount) IFSD IFSD – Commanded IFSD – Uncommanded Schedule Interruption/AOG Unknown None
Geographic Closest Airport at Strike	3	What three-letter IATA code airport was nearest at the time of ingestion?	Three-letter IATA code
Number Birds Ingested	3	How many birds were ingested in that particular engine?	"Single", "Multiple", "Unknown"

Field	Type	Definition	Acceptable Inputs
Generic Bird	3	Is bird a known species, unknown, or assumed a generic?	"No", "Yes, small", "Yes, Medium", "Yes, Large", "Unknown"
Flock Observed	3	Did the event report indicate that multiple birds were present?	Y or N
Bird Species	3	Species information of bird	Any string
Bird Weight (ounces)	3	Weight of bird, either known bird weight based on species or using generic bird weights	Numeric (in oz)
Bird Class	4	Bird weight class. Automatically populated based on weight.	auto populated
Airplane Type1	4	Number of engines	auto populated
Airplane Type2	4	Engine mount location	auto populated
Engine Type	4	Engine type	auto populated
Inlet Area	4	Inlet area class as defined by engine model	auto populated
Fan Type	4	Fan type as defined by engine model	auto populated
Cert Info	4	Cert basis as defined by engine model	auto populated from look up table
Event Number	4	Generated by code to track events	auto populated
Flocking Event	4	Leave this blank. Automatically populated field. Assumes the event is a flocking event if a) multiple engines were affected; b) multiple birds were ingested in one engine; or c) the event report described a flock of birds	auto populated
Flocking Species	4	Leave this blank. Code will cross reference bird species against database of flocking species	auto populated

Type of Data

1 – Private engine company data. This data is not shared with the team.

2 – Private engine company data. This data is optional to provide and is not shared with the team.

3 – Sanitized data, shared with the team and utilized in the report.

4 – Sanitized data inferred from look up tables, shared with the team and utilized in the report.

B.2 Cross Checking and Sanitization

Routines in Matlab were created to read the engine company raw data, ensure it conformed to the standard format, cross-check the entries, and finally, compile and sanitize it by removing all private engine company data. This process is summarized in

Figure B-1 and the transformations of the data through each step of the process are described in Table B-2.

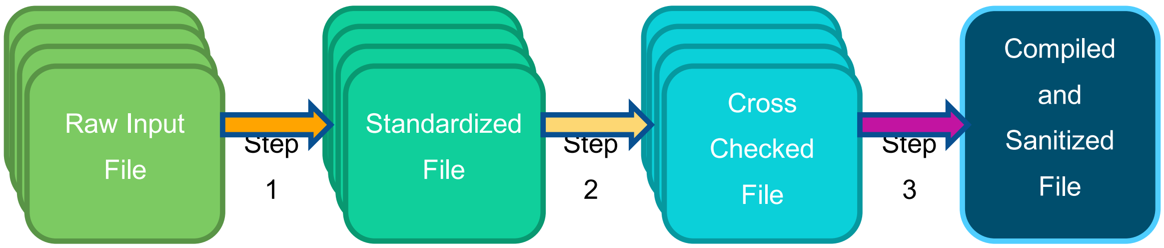


Figure B-1. Data Sanitization Process

Table B-2. Data Transformations Through Sanitization Process

	Step 1 – Raw to Sanitized	Step 2 – Sanitized to Cross Checked	Step 3 – Cross Checked to Compiled and Sanitized
Event Date	Unchanged		
Speed (knots)	Unchanged		
Internal Event ID	Unchanged		
Operator	Unchanged		
Notes/comments	Unchanged		
Bird Species	Unchanged		
Power < 50%	Standardize inputs		
Core Ingestion	Standardize inputs		
Core Damage	Standardize inputs		
Fan/Propeller Damage	Standardize inputs		
Flock Observed	Standardize inputs		
Number Birds Ingested	Standardize inputs		

	Step 1 – Raw to Sanitized	Step 2 – Sanitized to Cross Checked	Step 3 – Cross Checked to Compiled and Sanitized
Operational Consequence	Standardize inputs		
Altitude (feet agl)	non-numerics = NaN		
Engine Position	Standardize inputs		
Number of Ingesting Engines	• Deletes records where Multiple Info = 0	• Identifies discrepancy between number of records and Multiple Info • Looks for possible duplicates by comparing Operator, Aircraft, Engine, Engine Position, and Notes.	
Geographic Closest Airport at Strike	• Turns unknowns into XXX • Compares all three letter entries to IATA database, outputs unknown entries • Compares all four letter entries to ICAO database, overwrites with IATA code • Compares city name to IATA database, writes ICAO code if found	• Notes discrepancies between airports for multi record events. If the discrepant record has XXX airport, then airport is overwritten with the known airport code. No change if the two remain discrepant.	
Phase Info	• Standardize inputs • Climb + >3,000 ft = CLIMB	• Notes discrepancies between phase for multi record events.	
Generic Bird	• Standardize inputs • Pulls generic size information from bird species	• If Bird Species is unknown and Generic is "no", overwrites generic to "unknown"	

	Step 1 – Raw to Sanitized	Step 2 – Sanitized to Cross Checked	Step 3 – Cross Checked to Compiled and Sanitized
	to overwrite Generic column as Yes, <size>	• If Bird Species is unknown and Generic is "Yes" (no size noted), overwrites generic to "unknown" • If Bird Species is provided but is a general descriptor (i.e., duck, goose, dove) and no weight is provided, overwrites generic to "Yes, S/M/L" and assigns generic weight	
Bird Weight (ounces)	• Standardize inputs • Overwrites unknown bird weight for Generic birds with 4, 28, and 72 oz	• For multi events, overwrites the largest weight in all records of the multi set	
Bird Class	• Standardize inputs • If bird info is blank/unknown but Generic size noted, overwrites with correct bird info If bird info is blank/unknown but weight is noted, overwrite with correct bird info		• Identifies discrepancies between bird weight and bird class. Overwrites bird class data with appropriate value. • Identifies discrepancies between bird class/wt and generic category. Overwrites generic category to correct class.
Aircraft			• Checks entry against airplane database. Outputs entries not found.
Engine family/engine model			• checks entry against engine database. Outputs entries not found.

	Step 1 – Raw to Sanitized	Step 2 – Sanitized to Cross Checked	Step 3 – Cross Checked to Compiled and Sanitized
Engine Type			• Data overwritten based on lookup table for engine type
Airplane Type1			• Data overwritten based on lookup table for airplane type
Airplane Type2			• Data overwritten based on lookup table for airplane type
Inlet Area			• Data overwritten based on lookup table for engine type
Fan Type			• Data overwritten based on lookup table for engine type
Cert Info			• Data based on lookup table for engine type
Flocking Event			• Data overwritten based on event data
Flocking Species			• Data overwritten based on lookup table for bird type

Appendix C Engine Models in Data Set and Bird Rule Certification Basis

Engine certification bases associated with the engine types included in the database are noted below. Type Certificate Data Sheets are public data, available within the FAA's Dynamic Regulatory System under "Design and Production Approvals." Dynamic Regulatory System (faa.gov)

Some engines were demonstrated to a higher bird certification level than the type certificate of the engine. In these instances, the demonstrated level is noted in the table and the engine was classified according to this later generation rather than the generation associated with the engine certification basis. A review of the certification generations will be conducted in a follow-on report.

Table C-1. Engine Models and Bird Rule Certification Basis

Engine Model	Bird Rule Certification Basis	Cert Generation	Demonstrated to Higher Level than Certified
AE2100	33-77 A10	Gen 3	
AE3007	33-77 A10	Gen 3	
ALF502	AC33-1	Gen 1	
AS907-1-1A	33-76 A20	Gen 4	
AS907-2-1A	33-76 A24	Gen 4	
AS907-2-1G	33-76 A20	Gen 4	
AS907-3-1E	33-76 A24	Gen 4	
BR710	33-76 A20	Gen 4	
BR715	33-76 A20	Gen 4	
BR725	33-76 A20	Gen 4	
CF34-1	33-77 A6	Gen 2	
CF34-10	33-76 A20	Gen 4	
CF34-3	33-77 A6	Gen 2	
CF34-8	33-76 A20	Gen 4	
CF34-8	33-76 A20	Gen 4	
CF6-50	AC33-1	Gen 1	
CF6-6	AC33-1	Gen 1	
CF6-80A	33-77 A6	Gen 2	

Engine Model	Bird Rule Certification Basis	Cert Generation	Demonstrated to Higher Level than Certified
CF6-80C	33-77 A6	Gen 2	
CF6-80E	33-77 A10	Gen 3	
CF700	AC33-1	Gen 1	
CFE738	33-77 A10	Gen 3	
CFM56-2	33-77 A6	Gen 2	
CFM56-3	33-77 A6	Gen 2	
CFM56-5A	33-77 A10	Gen 3	
CFM56-5B	33-76 A20	Gen 4	
CFM56-5C	33-77 A10	Gen 3	
CFM56-7B	33-76 A20	Gen 4	
CJ610	AC33-1	Gen 1	
CT7	AC33-1	Gen 1	
CT7-9B	33-77 A6	Gen 2	
DART	AC33-1	Gen 1	
GE90-100	33-76 A20	Gen 4	
GE90-115B	33-76 A20	Gen 4	
GE90-90	33-77 A10	Gen 3	
Genx-1B	33-76 A24	Gen 4	
Genx-2B	33-76 A24	Gen 4	
GP7000	33-76 A24	Gen 4	
GP7200	33-76 A24	Gen 4	Y
H80	33-76 A24	Gen 4	
JT15D	AC33-1	Gen 1	
JT3D	AC33-1	Gen 1	
JT8D	AC33-1	Gen 1	
JT9D	AC33-1	Gen 1	
JT9D-7R4	33-77 A6	Gen 2	
LF507	AC33-1	Gen 1	
PT6A	Bird Exempt		
PT6T-3D	AC33-1	Gen 1	
PW1100G-JM	33-76 A24	Gen 4	
PW118A	33-77 A6	Gen 2	
PW119C	33-77 A6	Gen 2	
PW120	33-77 A6	Gen 2	
PW1200G	33-76 A24	Gen 4	
PW121	33-77 A6	Gen 2	

Engine Model	Bird Rule Certification Basis	Cert Generation	Demonstrated to Higher Level than Certified
PW123	33-77 A6	Gen 2	
PW125B	33-77 A6	Gen 2	
PW127	33-77 A6	Gen 2	
PW1400G-JM	33-76 A24	Gen 4	
PW1500G	33-76 A24	Gen 4	
PW150A	33-77 A10	Gen 3	
PW1700G	33-76 A24	Gen 4	
PW1900G	33-76 A24	Gen 4	
PW2000	33-77 A6	Gen 2	
PW207D	Bird Exempt		
PW207E	Bird Exempt		
PW305A	33-77 A10	Gen 3	
PW305B	33-77 A10	Gen 3	
PW306A	33-77 A10	Gen 3	
PW306B	33-77 A10	Gen 3	
PW306C	33-77 A10	Gen 3	
PW307A	33-76 A20	Gen 4	
PW308A	33-76 A20	Gen 4	
PW308C	33-76 A20	Gen 4	
PW4000-100	33-77 A6	Gen 2	
PW4000-112	33-77 A6	Gen 2	
PW4000-94	33-77 A6	Gen 2	
PW530A	33-77 A10	Gen 3	
PW535A	33-77 A10	Gen 3	
PW535B	33-76 A20	Gen 4	
PW535E	33-76 A24	Gen 4	
PW545A	33-77 A10	Gen 3	
PW545B	33-76 A20	Gen 4	
PW545C	33-76 A20	Gen 4	
PW6000	33-76 A24	Gen 4	Y
PW610F-A	33-76 A20	Gen 4	
PW615F-A	33-76 A20	Gen 4	
PW617F-E	33-76 A20	Gen 4	
RB211 524	AC33-1	Gen 1	
RB211 535	AC33-1	Gen 1	
RB211-524	AC33-1	Gen 1	

Engine Model	Bird Rule Certification Basis	Cert Generation	Demonstrated to Higher Level than Certified
RB211-524B	AC33-1	Gen 1	
RB211-524C	AC33-1	Gen 1	
RB211-524G	33-77 A6	Gen 2	
RB211-524H	33-77 A6	Gen 2	
RB211-524H-T	33-77 A6	Gen 2	
RB211-535C	AC33-1	Gen 1	
RB211-535E4	AC33-1	Gen 1	
SPEY	AC33-1	Gen 1	
TAY	33-77 A6	Gen 2	
TFE731-2	AC33-1	Gen 1	
TFE731-20	33-77 A10	Gen 3	
TFE731-3	AC33-1	Gen 1	
TFE731-4	AC33-1	Gen 1	
TFE731-40	33-77 A10	Gen 3	
TFE731-5	33-77 A6	Gen 2	Y
TFE731-50	33-77 A10	Gen 3	
TFE731-60	33-77 A10	Gen 3	
TPE331-10	AC33-1	Gen 1	
TPE331-10GP	AC33-1	Gen 1	
TPE331-10GT	AC33-1	Gen 1	
TPE331-11	AC33-1	Gen 1	
TPE331-11U	AC33-1	Gen 1	
TPE331-12	AC33-1	Gen 1	
TPE331-12JR	AC33-1	Gen 1	
TPE331-12UAR	AC33-1	Gen 1	
TPE331-12UHR	AC33-1	Gen 1	
TPE331-14A	33-77 A6	Gen 2	
TPE331-14GR	33-77 A6	Gen 2	
TPE331-14HR	33-77 A6	Gen 2	
TPE331-15	33-77 A6	Gen 2	
TPE331-8	AC33-1	Gen 1	
TRENT 1000	33-76 A20	Gen 4	
TRENT 500	33-76 A20	Gen 4	
TRENT 700	33-76 A20	Gen 4	
TRENT 800	33-76 A20	Gen 4	
TRENT 900	33-76 A20	Gen 4	

Engine Model	Bird Rule Certification Basis	Cert Generation	Demonstrated to Higher Level than Certified
Trent XWB	33-76 A20	Gen 4	
V2500	33-77 A10	Gen 3	

Appendix D Single and Multi Engine Ingestion Rate Plots for Various Engine Inlet Areas

The following sections summarize single and multi engine bird ingestion rates for Small, Medium, and Large category birds broken down by engine inlet areas for turbofans as well as ingestion rates for Small, Medium, and Large category birds for turboprops.

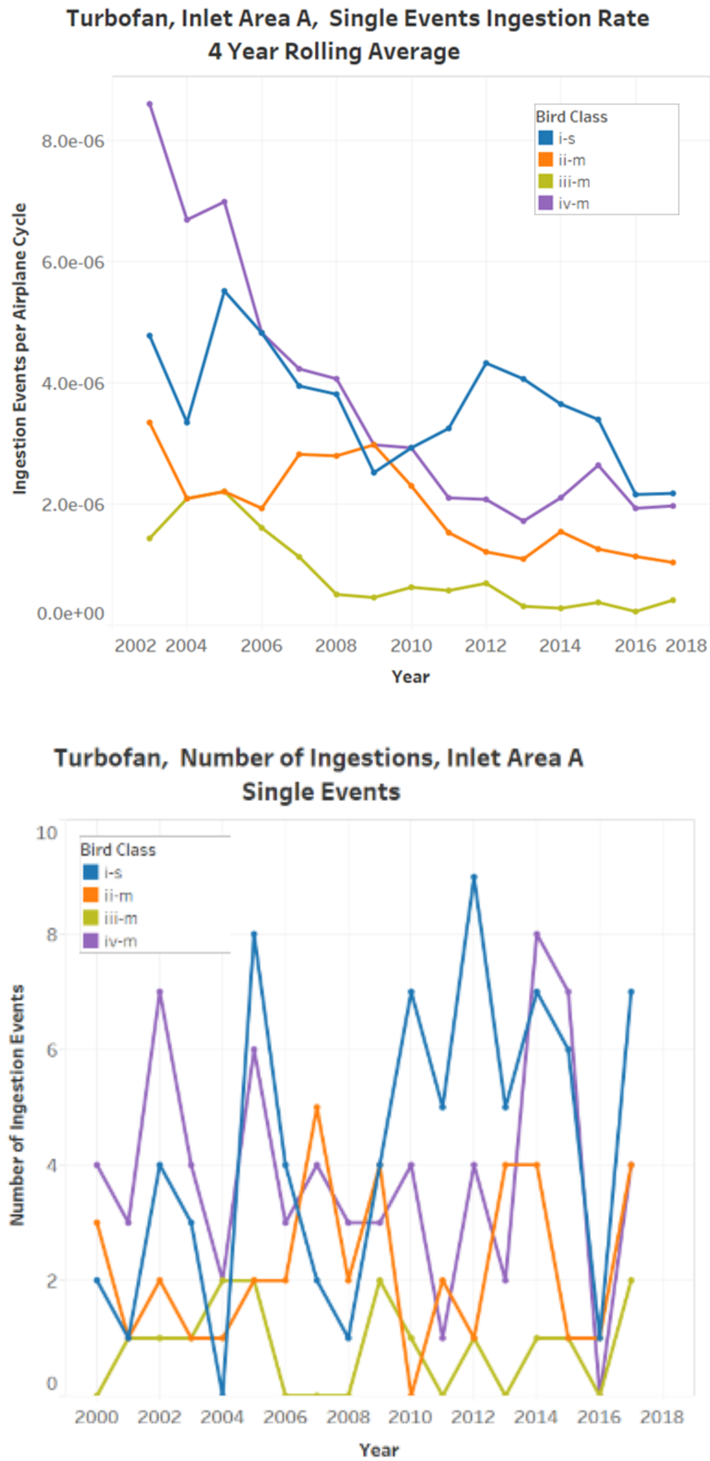
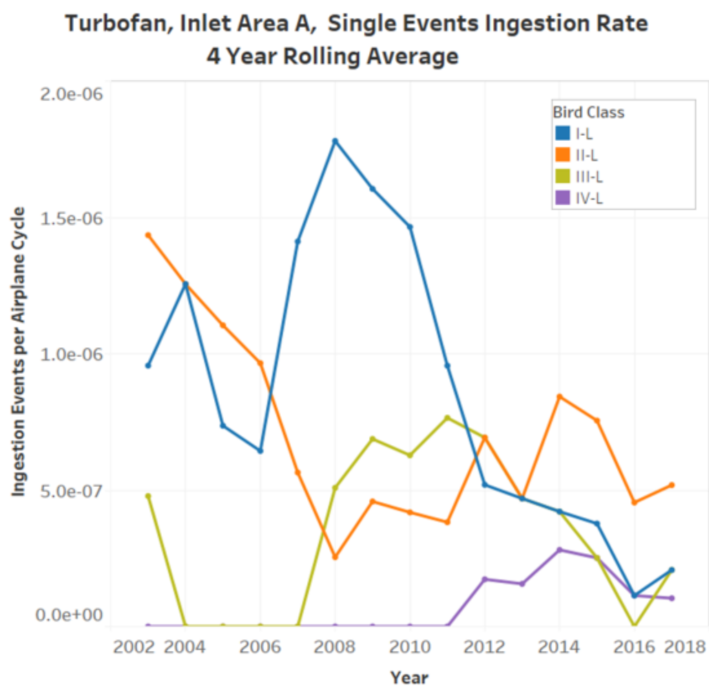


Figure D-1. Inlet Area A Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



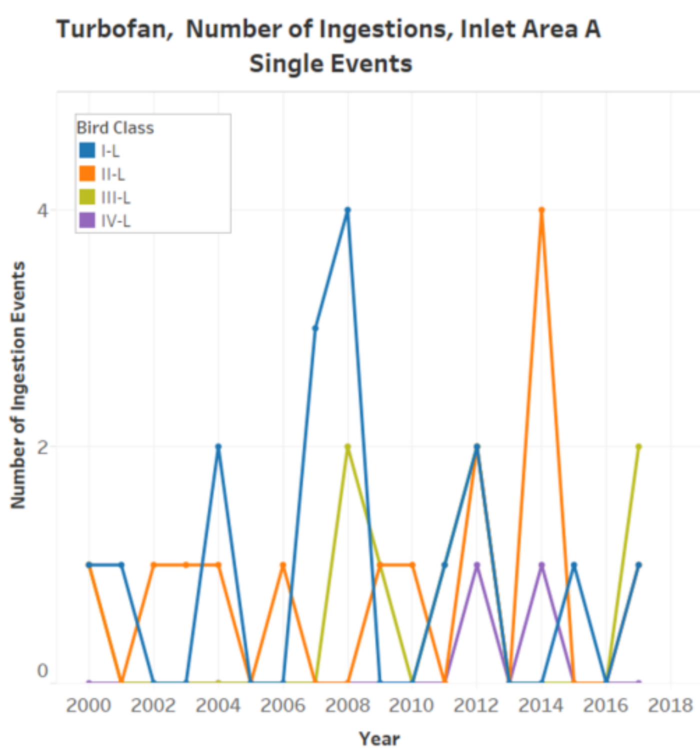
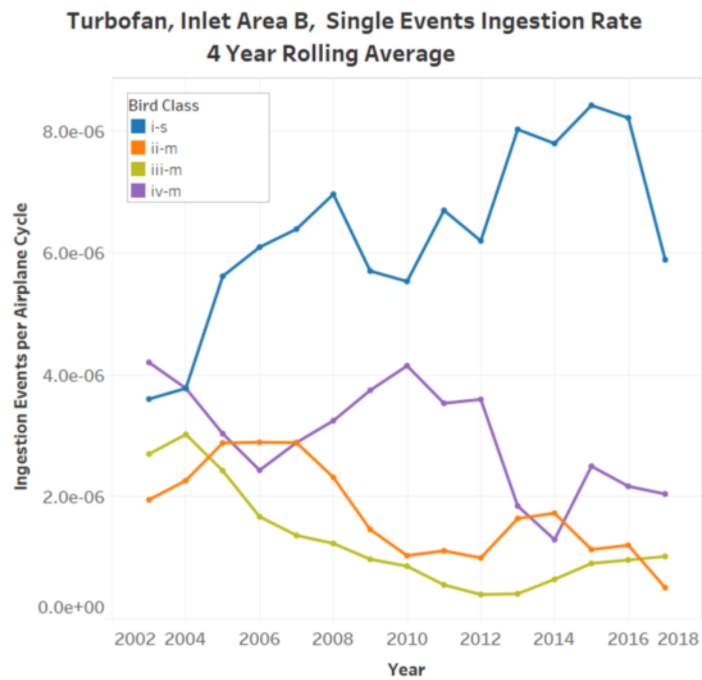


Figure D-2. Inlet Area A Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan



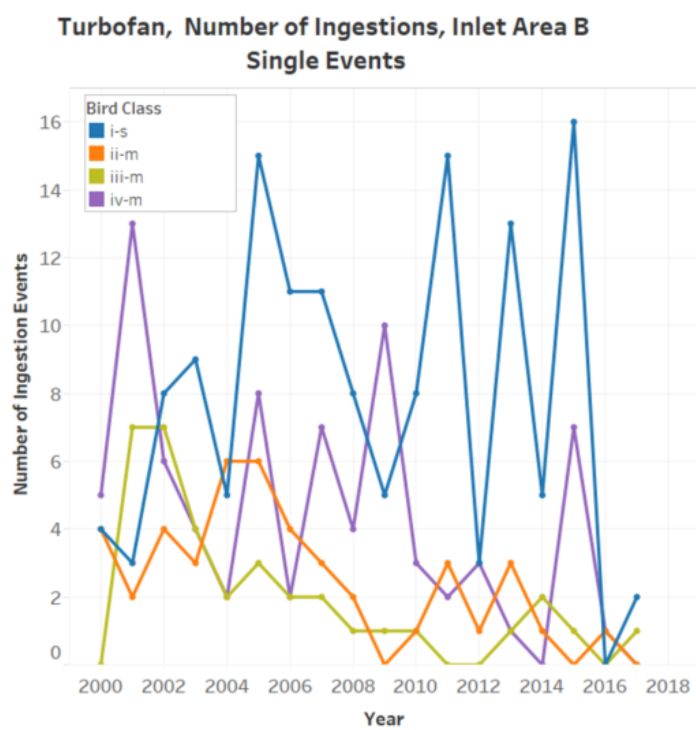
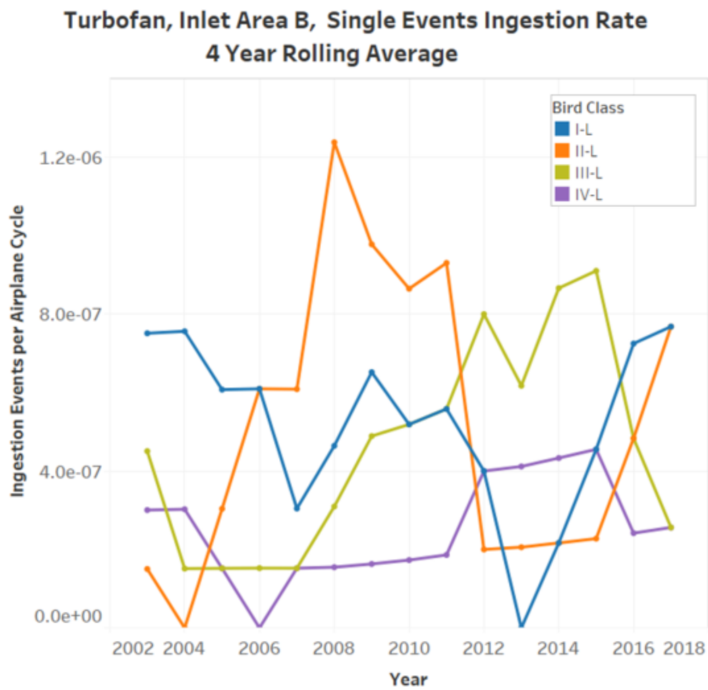


Figure D-3. Inlet Area B Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



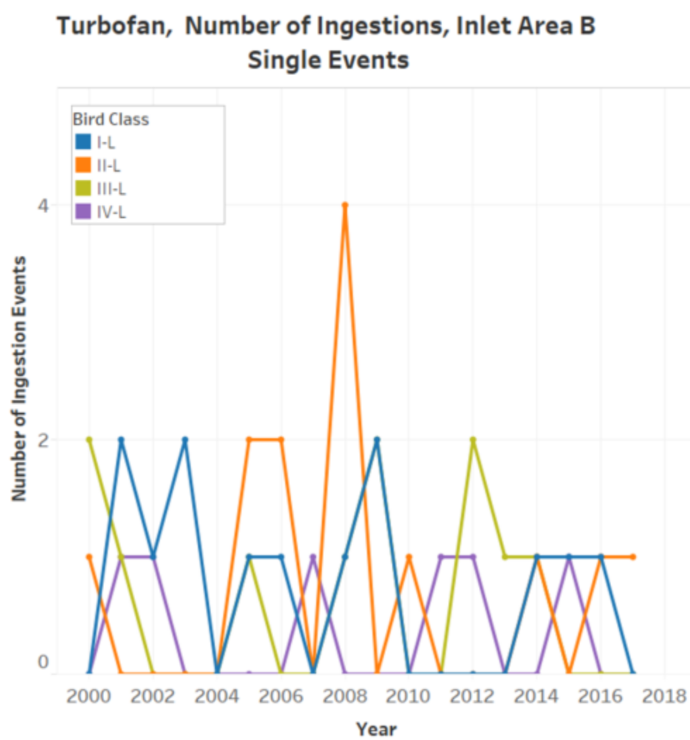
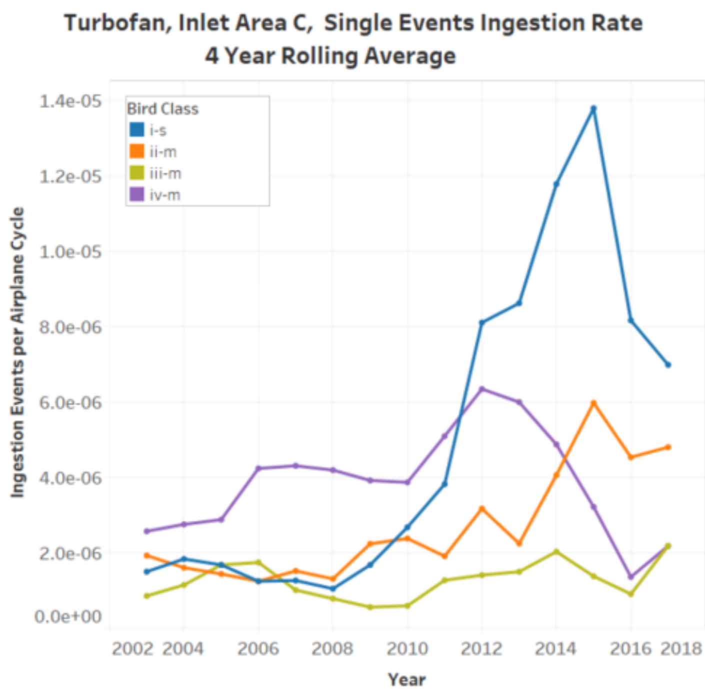


Figure D-4. Inlet Area B Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan



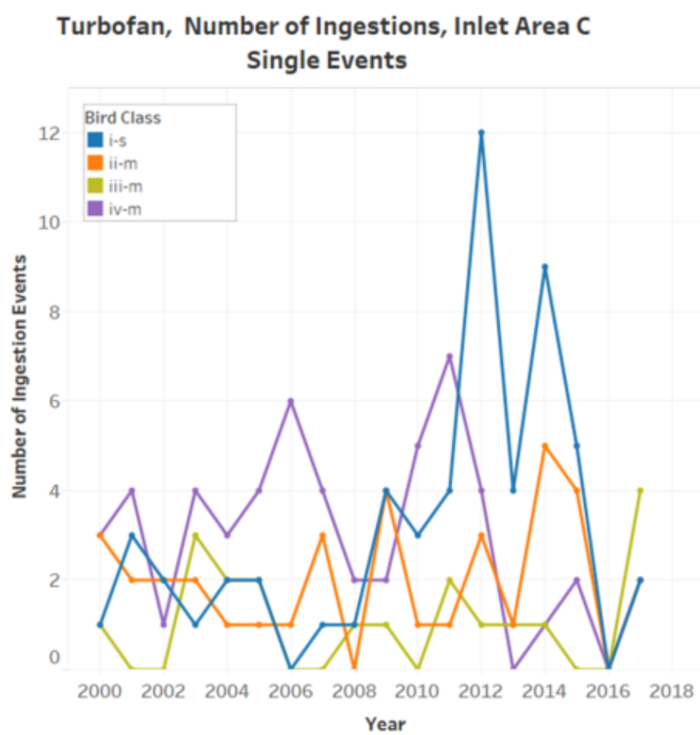
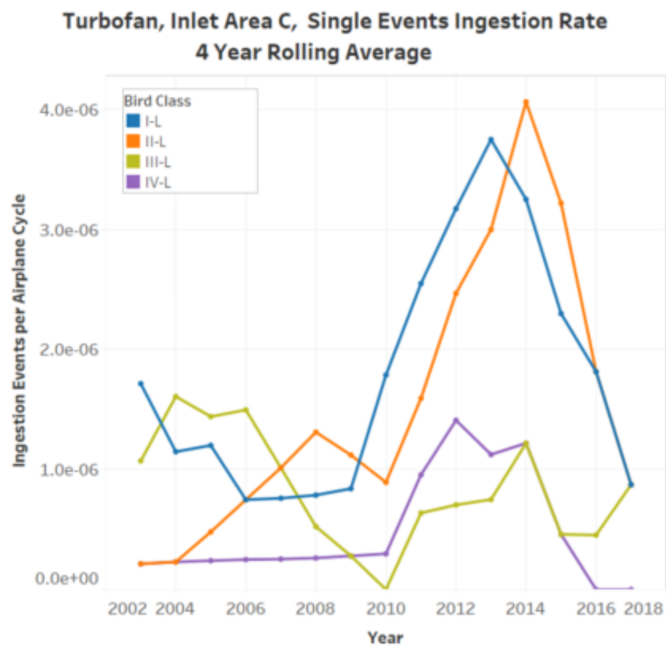


Figure D-5. Inlet Area C Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



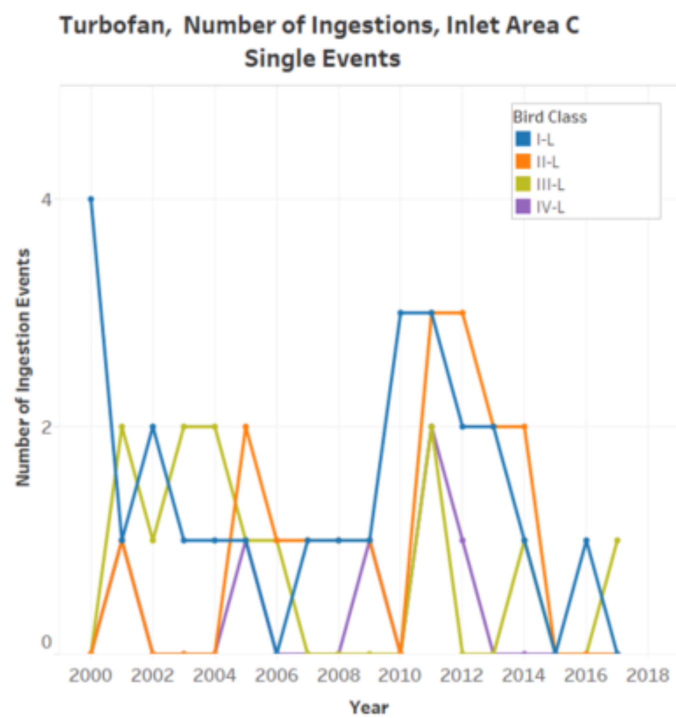
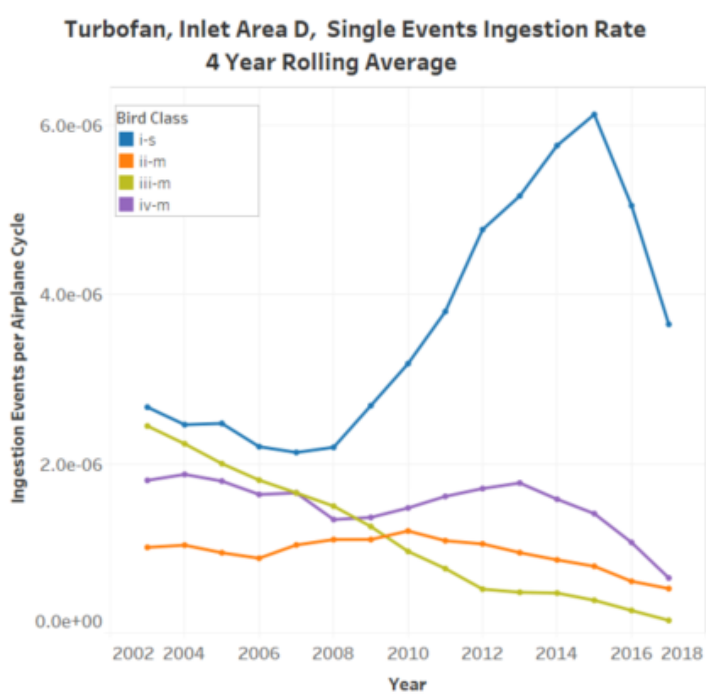


Figure D-6. Inlet Area C Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan



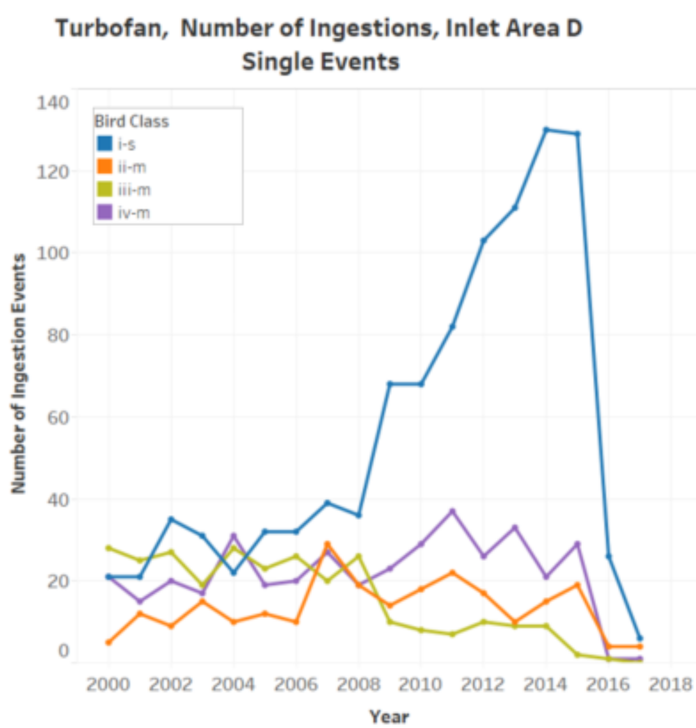
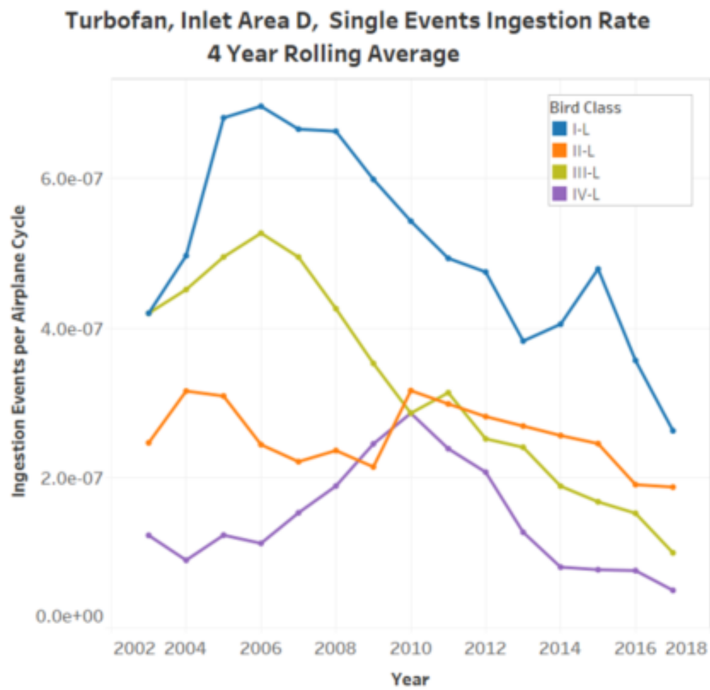


Figure D-7. Inlet Area D Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



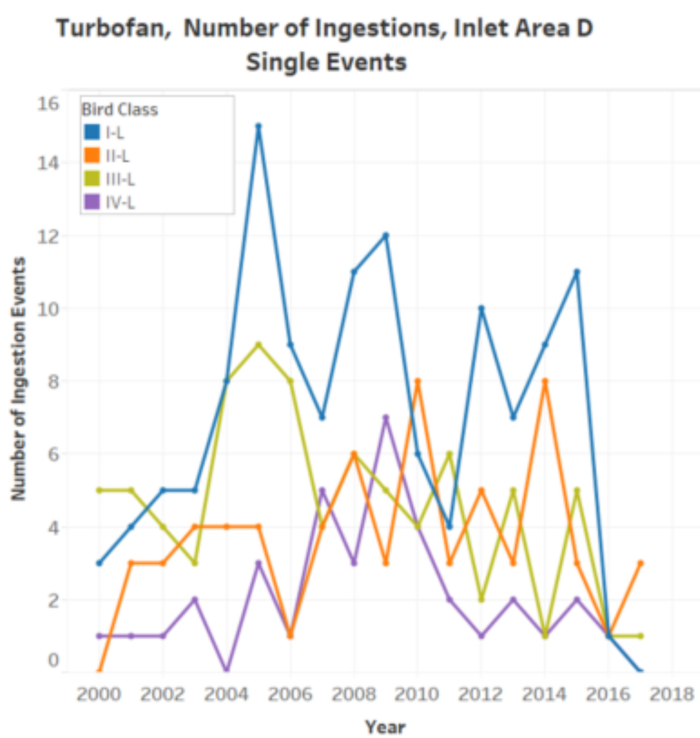
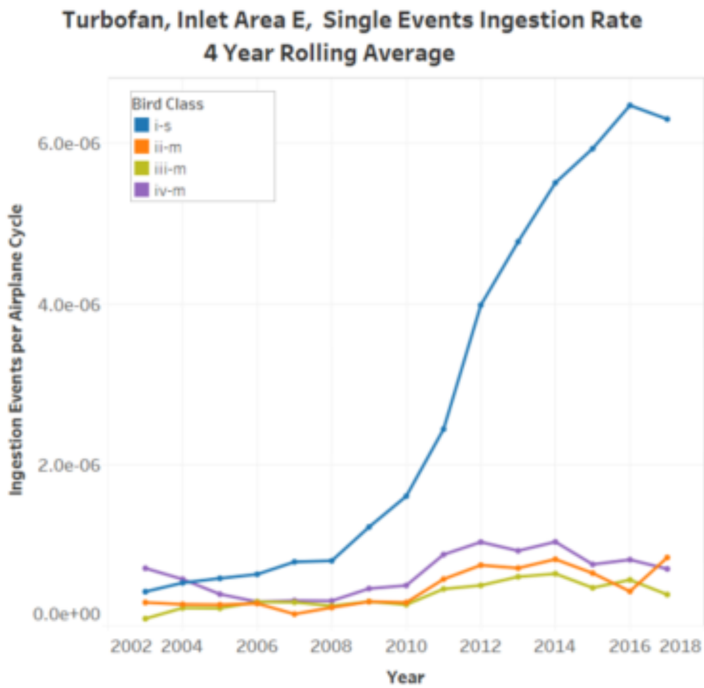


Figure D-8. Inlet Area D Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan



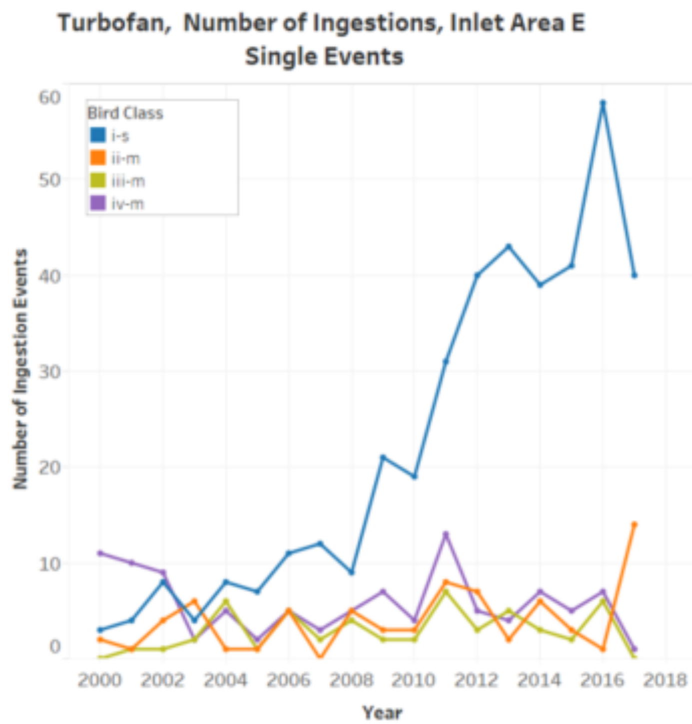
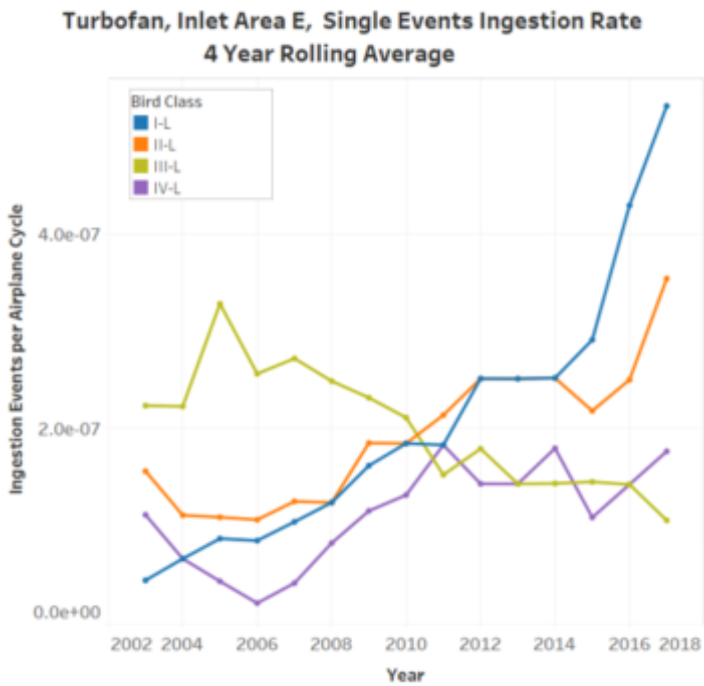


Figure D-9. Inlet Area E Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



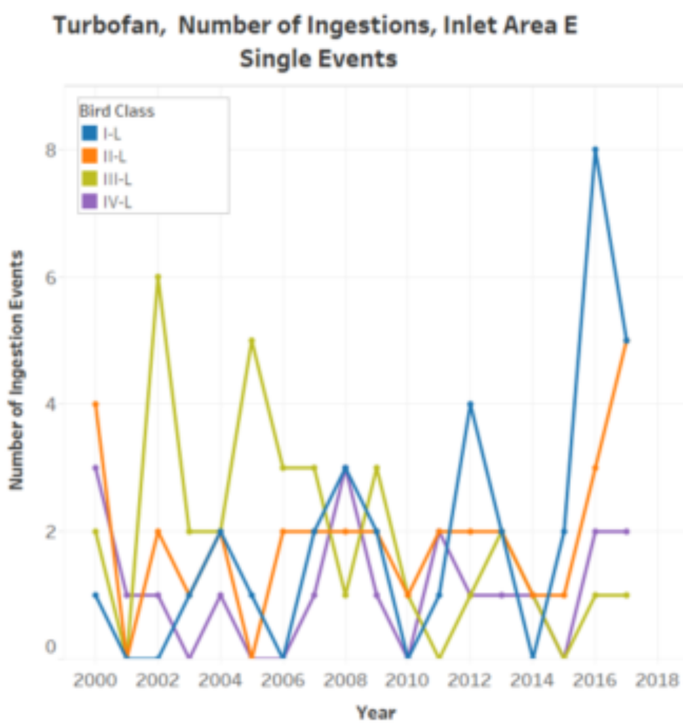
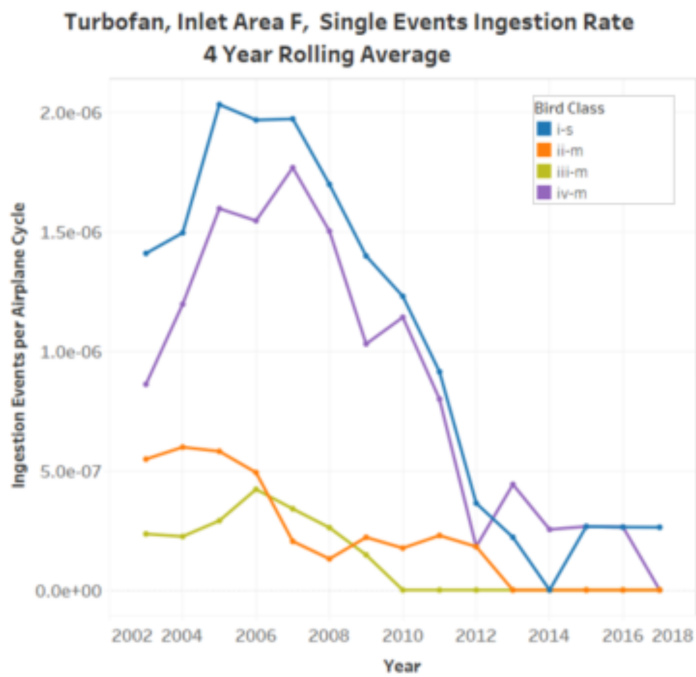


Figure D-10. Inlet Area E Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan



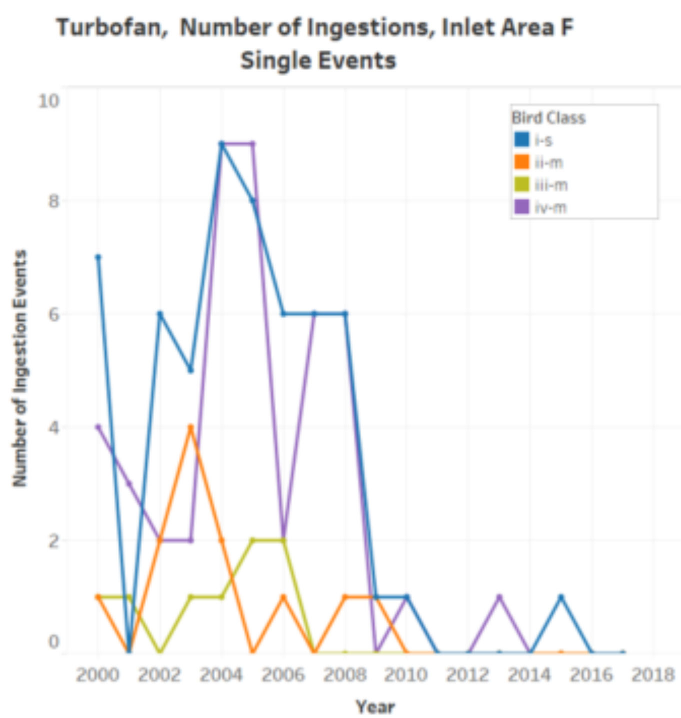
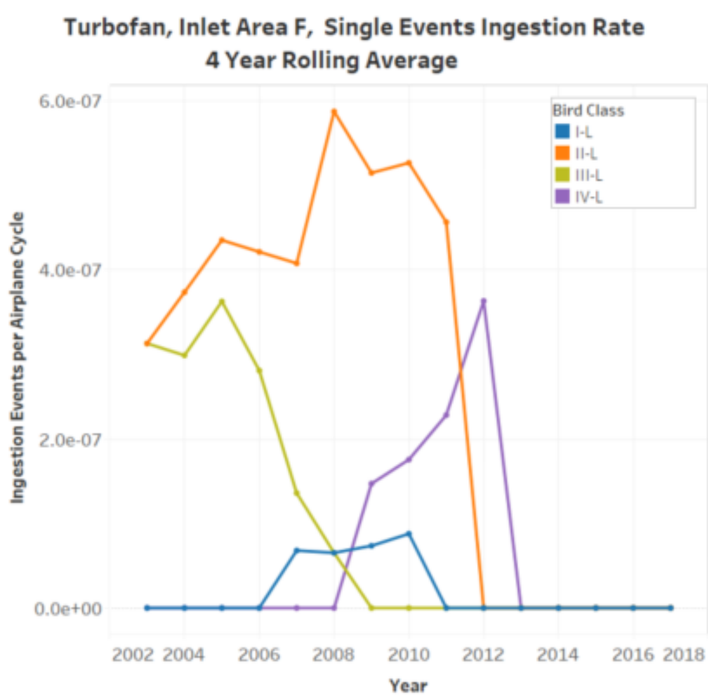


Figure D-11. Inlet Area F Ingestion Rate (top) and Number of Ingestions (bottom) for Small and Medium Birds, Turbofan



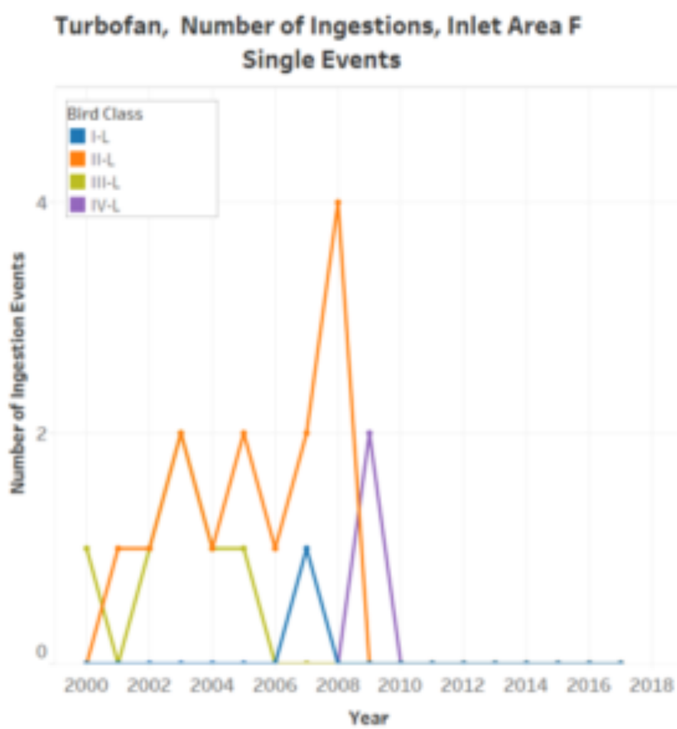
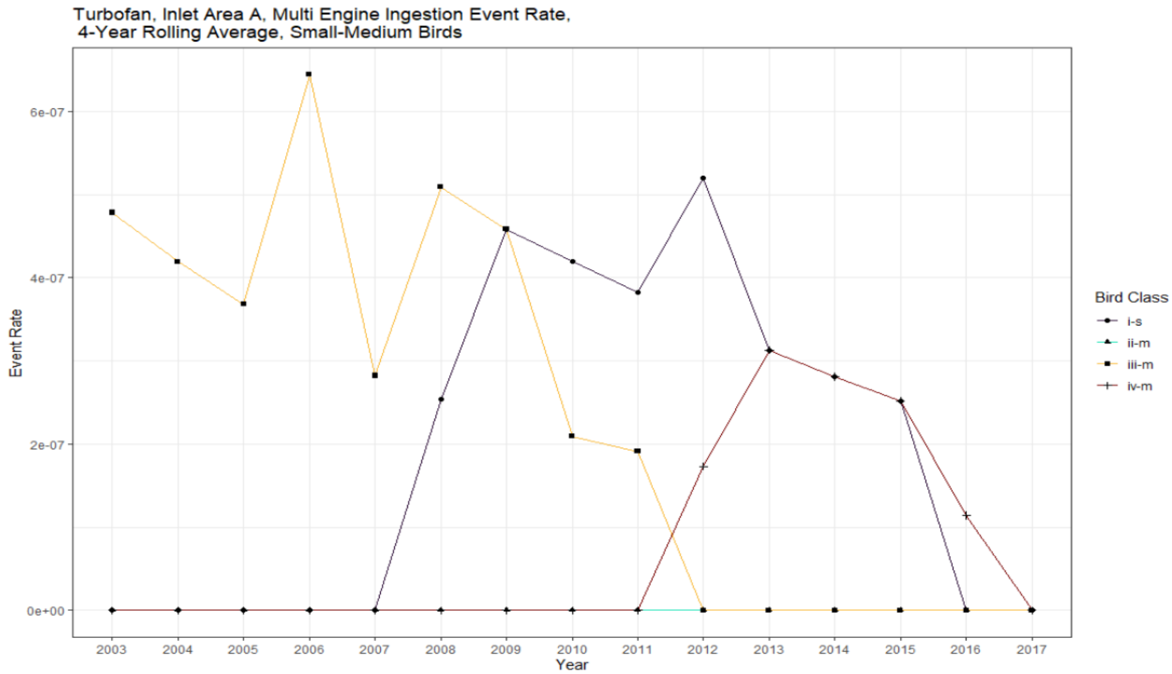


Figure D-12. Inlet Area F Ingestion Rate (top) and Number of Ingestions (bottom) for Large Birds, Turbofan

D.1 Turbofan Multi Engine Event Ingestion Rates



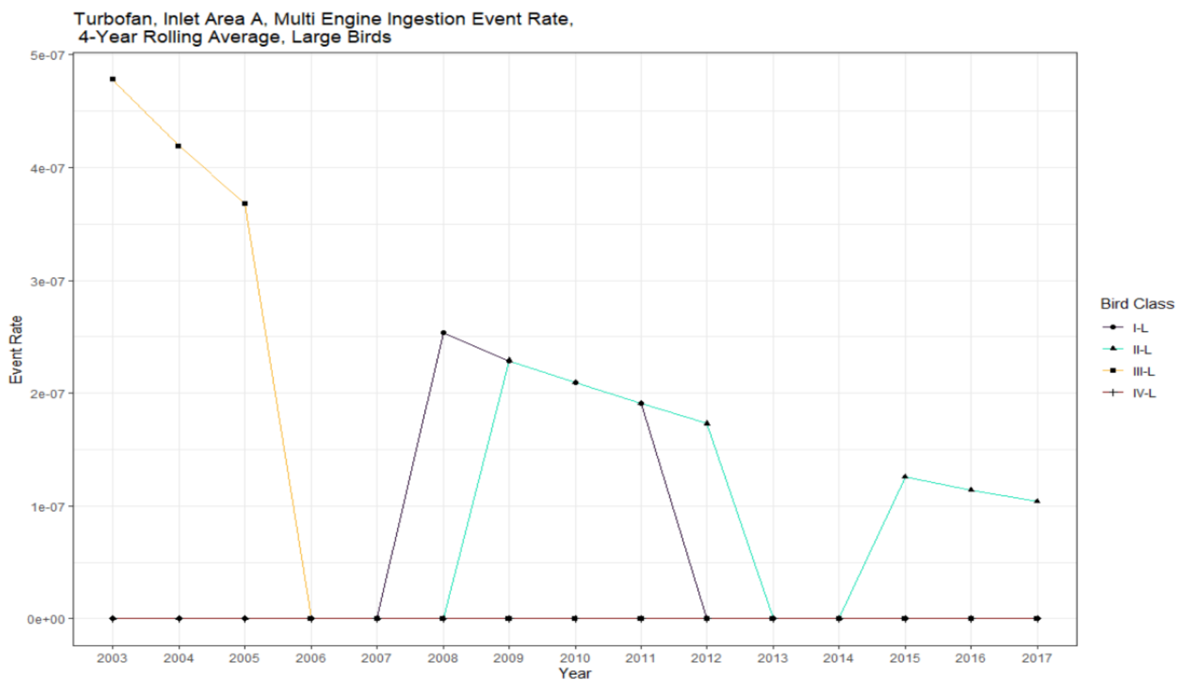
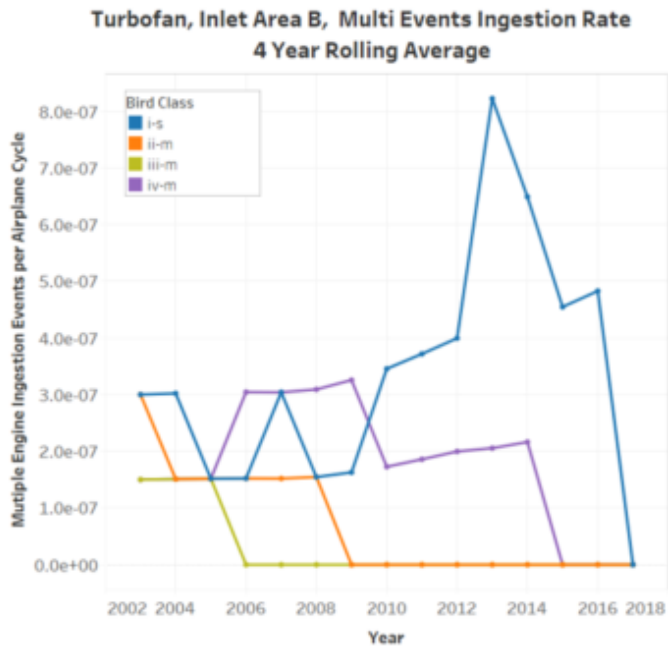


Figure D-13. Inlet Area A Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan



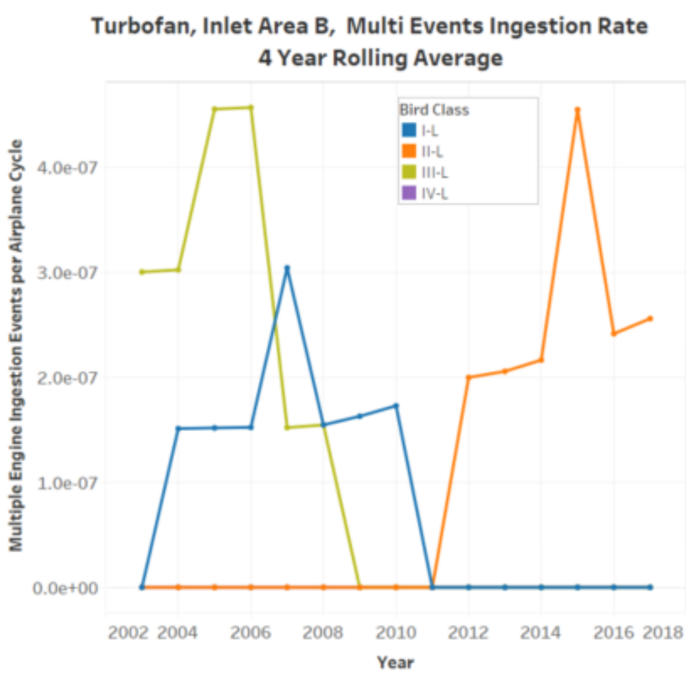
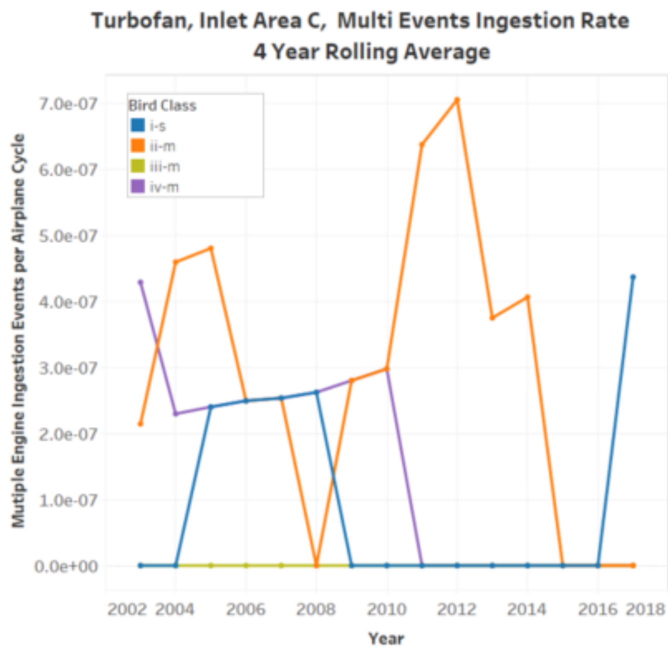


Figure D-14. Inlet Area B Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan



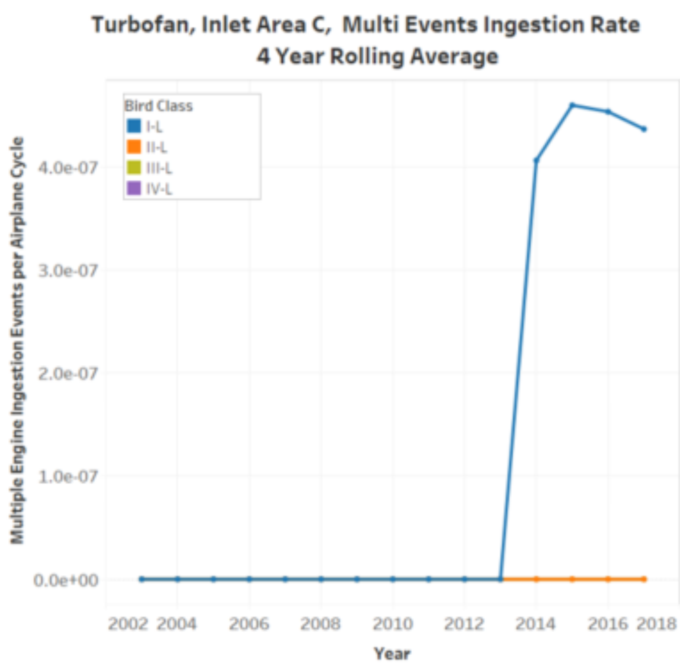
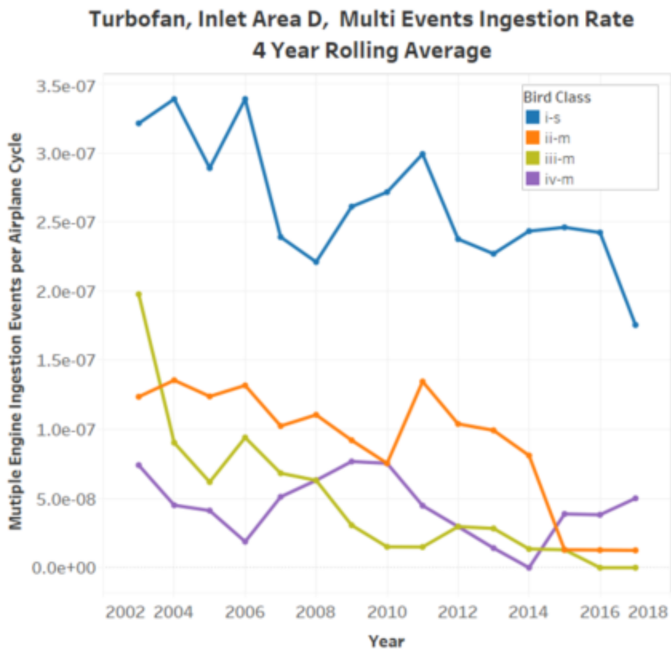


Figure D-15. Inlet Area C Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan



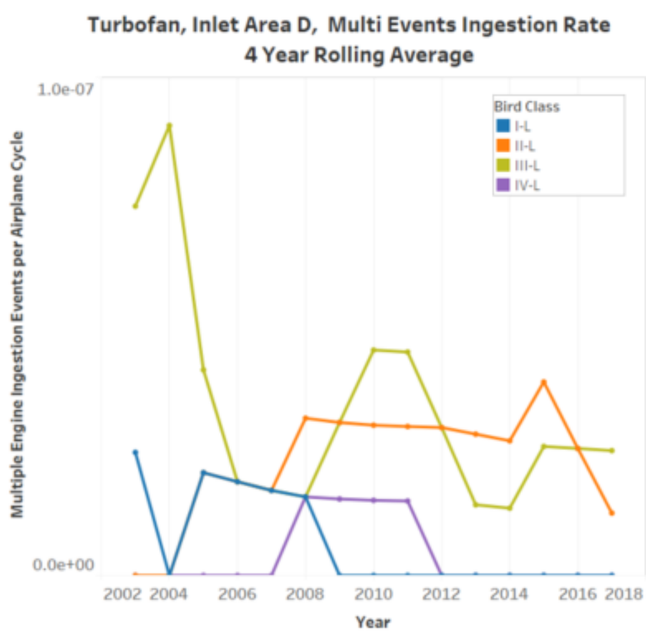
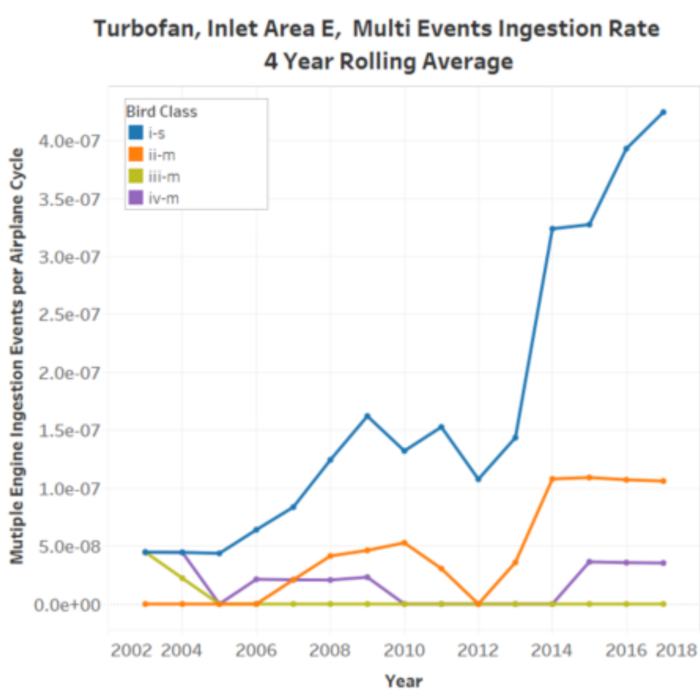


Figure D-16. Inlet Area D Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan



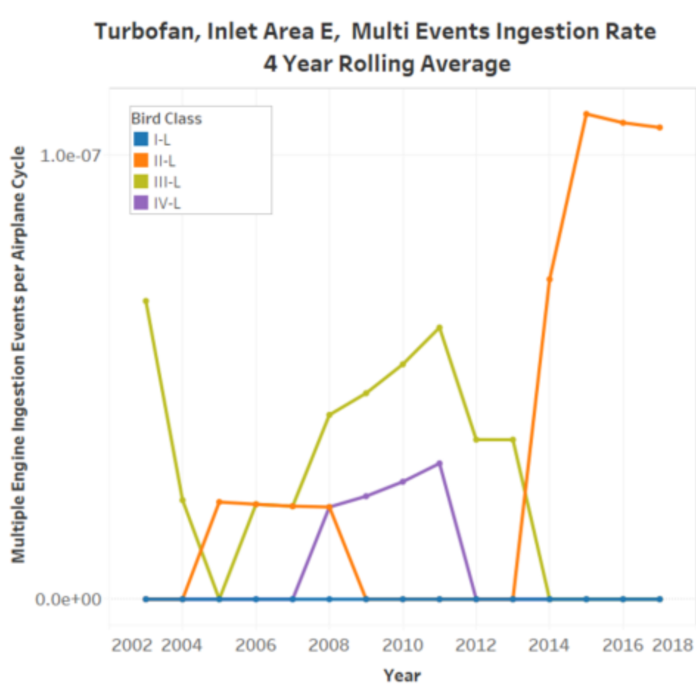
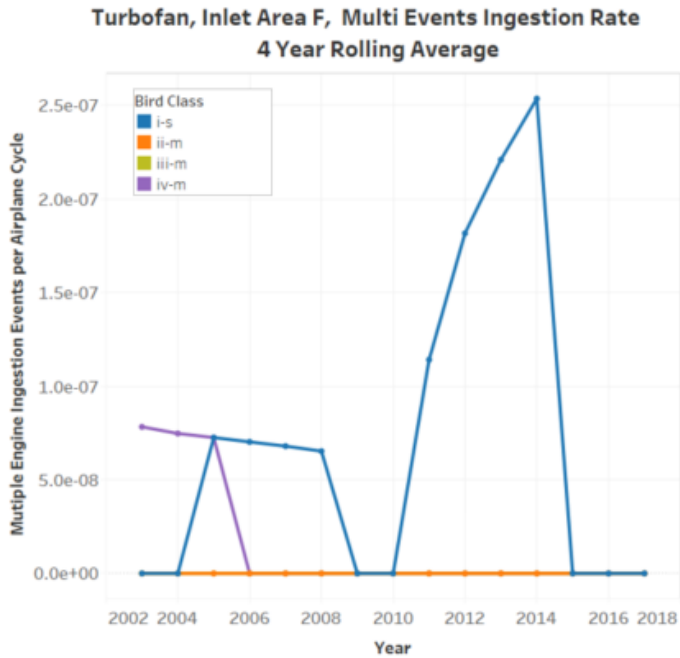


Figure D-17. Inlet Area E Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan



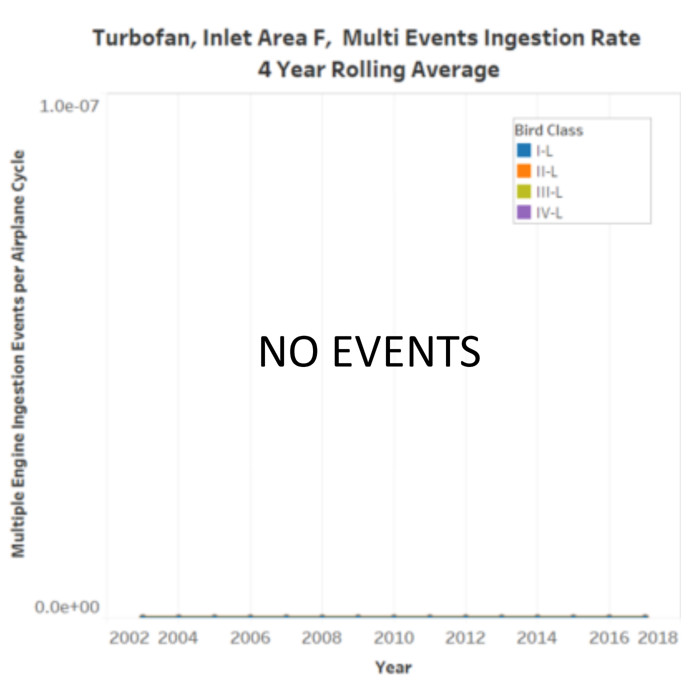


Figure D-18. Inlet Area F Multi Engine Ingestion Rate for Small and Medium Birds (top) and Large Birds (bottom), Turbofan

D.2 Turboprop Single and Multi Event Ingestion Rates

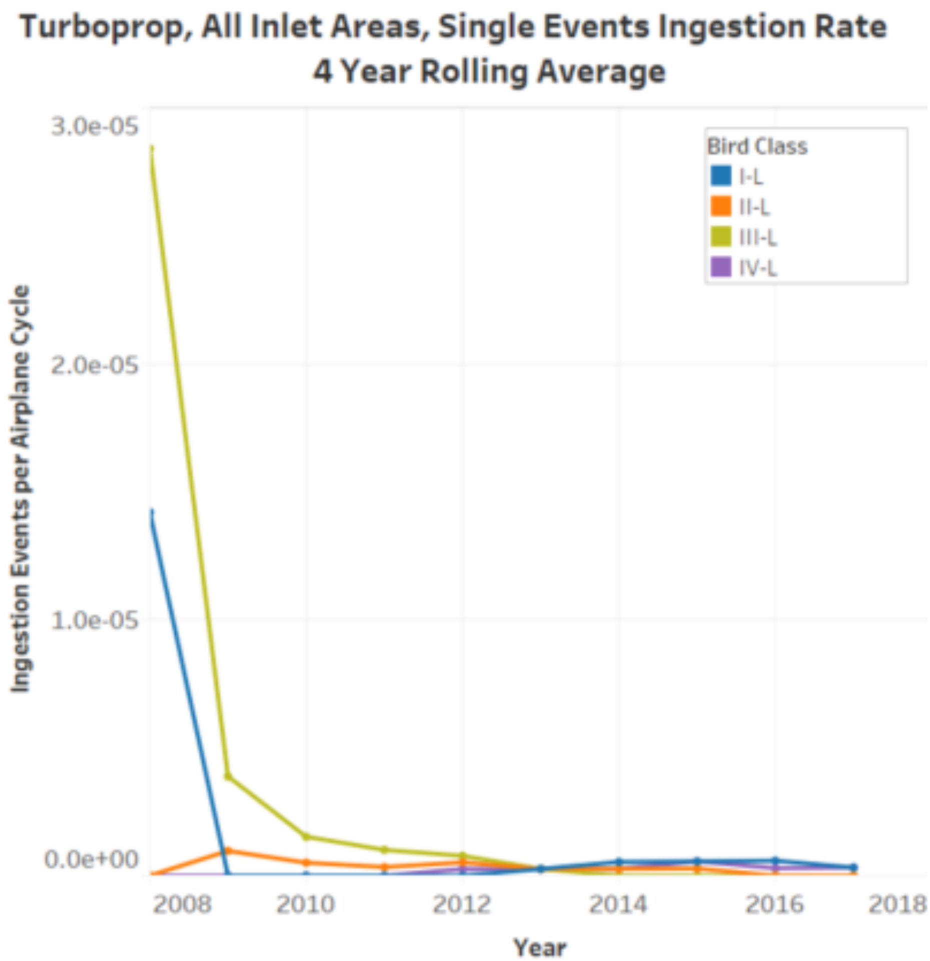


Figure D-19. All Inlet Areas Ingestion Rate for Large Birds, Turboprop

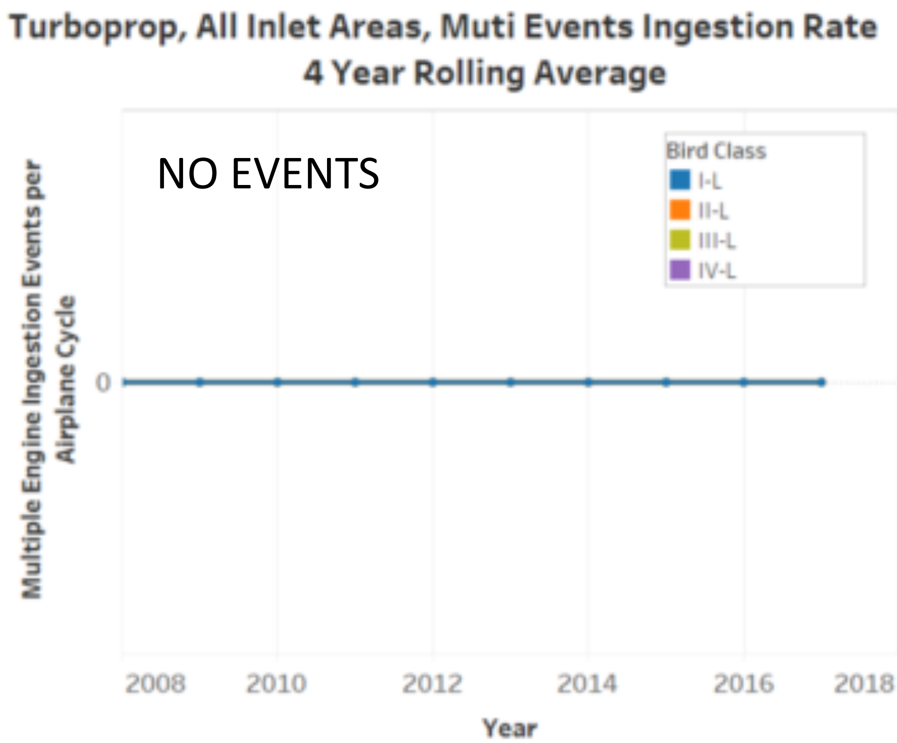


Figure D-20. All Inlet Areas Multi Engine Ingestion Rate for Large Birds, Turboprop

Appendix E List of Working Group Members

The work in this report is the result of collaboration between the following current and previous working group members during this report's update period. **Current members are in bold text**.

Allan Armet	Pratt & Whitney Canada
Alan Castillejo	**Pratt & Whitney**
Daniel Cordasco	**Federal Aviation Administration**
Tom Dwier	**Textron Aviation**
Mary Hussey	**General Electric Aerospace**
Khalid Iqbal	**Transport Canada**
Bryan Lesko	**Air Line Pilots Association**
Florent Loquet	**SAFRAN**
Duncan MacDougall	**Rolls Royce**
Philip Haberlen	**Federal Aviation Administration**
Michael McNamee	**Honeywell**
Michael Millat	**Pratt & Whitney**
Palmer Morehouse	**Boeing**
Antoine Pilon	**Airbus**
Kevin Pittenger	**Boeing**
Craig Quick	General Electric
Russ Repp	**Honeywell**
Charlotte Roiger	**Boeing**
Alan Strom	**Federal Aviation Administration**
Terry Tritz	Boeing
Peter Turyk	**Pratt & Whitney Canada**
Allan van de Wall	**General Electric Aerospace**