Aerospace Industries Association
Bird Ingestion
Working Group Report

November 16, 2012

AIA Bird Ingestion Working Group Report

EXECUTIVE SUMMARY

In January 2009 an Airbus A-320 airplane ingested Canada geese into both engines during initial climb-out from LaGuardia Airport in New York City, USA. Both engines were damaged and lost significant power and the airplane ditched into the Hudson River. There were no fatalities. After this accident a committee was formed under the Aerospace Industries Association (AIA) to review engine bird ingestion experience in commercial aviation [worldwide] from 2000-2009, to re-evaluate the current type certification requirements for bird ingestion and to address NTSB recommendations related to this accident.

The committee included representatives from industry, the FAA and EASA, and provided those agencies with an interim report with recommendations in January 2012 (included here in Section 7.1).

This final report documents the committees overall effort, and the recommendations made to the agencies based on that work. The data shows that the multi-engine ingestion rates of large flocking birds are not significantly greater than those predicted in defining the Large Flocking Bird certification rule, and that the commercial fleet is anticipated to meet the safety objectives as older engines are replaced by engines certified to current standards which are shown to lose power at much lower rates. Recommendations are made for reviewing the core ingestion element of current bird certification requirements, and also for reviewing the requirements for engines in the size range just below that which requires the Large Flocking Bird demonstration.

This report also includes a brief summary of the work of prior bird ingestion committees, and recommendations for data analyses which are intended to provide a useful basis for future committees.

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1. INTRODUCTION

1.1 Purpose

The FAA, EASA and the AIA initiated an engine bird ingestion threat and type certification rule study in 2009. This study was in response to the US Airways Flight 1549 Hudson River accident investigation and related NTSB Recommendations (Appendix B). The intent of the study was to update the existing AIA bird ingestion database with new data through January 2009; to determine any changes to the bird threat observed in service; and to determine whether the existing certification requirements can meet their intended safety objective. The outcome of this work was to determine if any changes are required to the existing bird ingestion engine certification requirements located in 14 CFR Part 33.76.

1.2 Background

In 2007 the FAA revised § 33.76 to include new requirements addressing the large flocking bird threat (bird mass greater than 2.5 lbs.) observed in service. The FAA did this because the large flocking bird population (primarily Canada and Snow geese) had increased significantly in the previous 20 years, increasing the threat to aircraft. Therefore, changes were required to provide an adequate level of safety against this threat. The noted US Airways Hudson River accident ingested Canada geese (species average 8 lbs.) into each engine, which resulted in virtually complete loss of thrust in both engines. The primary intent of this study was to determine whether the existing requirements for large flocking bird ingestion are still adequate to meet the rule's intended fleet wide safety objective. A second intent was to determine whether the existing flocking bird core ingestion tests are conducted in as rigorous a manner as intended. The study used updated bird ingestion data covering the period of 2000-Jan.2009, which includes approximately 11,300 bird ingestion records covering over 250 million flights. Unless otherwise noted, all tables, charts and analyses results are specific to this 2000-2009 data set. The study also provided the FAA with suggested responses to the NTSB Recommendations.

1.3 Code of Federal Regulations: History

The 14 CFR Part 33 regulations have been in place since 1965 to provide engine manufacturers the design and operational requirements to safeguard the public. Through the years, these regulations have become more specific as the increasing quantity of fleet data has pointed to areas of improvement in dealing with such things as bird ingestions. A historical summary of engine bird ingestion requirements is provided in the paragraphs below.

i. Part 33 prior to Amendment 33-6 applied bird ingestion standards via § 33.13 (Design Features) and 33.19 (Durability) with the actual test conditions specified in AC 33-1(1965), 33-1A (1968) and 33-1B (1970). The requirements in AC 33-1B later became the basis for paragraph § 33.77 in Amendment 33-6.

ii. Part 33 Amendment 33-6 (effective date 10/31/1974) introduced new paragraph § 33.77 (Foreign Object Ingestion). Foreign objects were defined as birds, water, hail, rotor blade fragments, sand and gravel, and tire tread.
   a. The bird requirements covered small flocking birds (3 ozs.), medium flocking birds (1.5 lbs.) and large single bird (4 lbs.).

b. The small and medium flocking bird requirements include run-on with no greater than 25% thrust loss.
c. The large single bird requirements are 'safe shutdown' (no run-on required).

iii. Part 33 Amendment 33-10 (effective date 3/26/1984) revised paragraph § 33.77 in a number of areas, two related to bird ingestion, as follows:
a. Added a specific 5-minute run-on period for small and medium flocking birds (no specific run-on time period was included in the original rule).
b. Added a definition for inlet area (previously not defined).

iv. Part 33 Amendment 33-20 (effective date 12/13/2000) deleted the existing bird ingestion requirements from § 33.77, and introduced new paragraph § 33.76 (Bird Ingestion). The new paragraph was a significant expansion of bird requirements over the previous regulation. Significant changes for larger engines included:
a. The medium bird mass changed from 1.5 lbs. for all engines to a combination of 1.5 lb. plus 2.5 lb. birds as a function of engine size.
b. The medium bird run-on time period changed from 5 minutes (no throttle movement) to a 20 minute run-on with throttle movements simulating an air turn-back and landing.
c. The large single bird mass changed from 4 lbs. for all engines to 4 lbs., 6 lbs. or 8 lbs. as a function of engine size.
d. This section was revised (effective date 1/1/2004) to correct typographical errors in the original Amendment 20 (§ 33.76) publication.

Although this amendment became effective in 2000, the anticipated rule changes were being used by manufacturers and agencies from around 1994 in defining approval requirements for new engines.

v. Part 33 Amendment 33-23 (effective date 11/16/2007) revised § 33.76 to add a new class of bird requirement called Large Flocking Birds for larger size engines, as follows:
a. One large flocking bird is ingested with a mass equal to 4.1 lbs.(1.85 kg), 4.6 lbs. (2.1 kg) or 5.5 lbs. (2.5 kg) based on engine size.
b. The run-on requirement is a 20 minute period of operation with throttle movements simulating an air turn-back and landing, and no greater than a 50% rated takeoff thrust loss.
c. Updated the safety analysis reference (§ 33.75 revision) for large single bird.
d. All other requirements from original § 33.76 are unchanged.
e. This section was further revised by Amendment 33-24 (effective date 11/17/2007) to update regulatory references.

Although this amendment became effective in 2007, the anticipated rule changes were being used by manufacturers and agencies from around 2001 in defining approval requirements for new engines.

Table 1.3-1 provides a historical summary of the Code of Federal Regulation's (CFR) sections and amendments dealing specifically with bird ingestion. Also included is the quantity of engines within the data set that were certified under a particular Section or Amendment. As the fleet ages, older engine models are replaced with models approved under the new and more stringent regulations. It is clear from the data that changes in the regulations take a relatively long time to impact a significant part of the fleet.

Table 1.3.1. CFR Bird Sections and Amendments in Data Set

14 CFR Part 33 Sections / Amendments	Year Promulgated	No. of Engine Events in Data Set	Percent of Data Set
§ 33.13 + § 33.19 + AC 33-1, -1A, -1B	1965-70	701	6%
§ 33-77 Amdt. 6	1974	4,044	36%
§ 33-77 Amdt. 10	1984	2,393	21%
§ 33-76 Amdt. 20	2000	2,952	26%
§ 33-76 Amdt. 23, 24	2007	57	1%
Unknown		1,185	10%

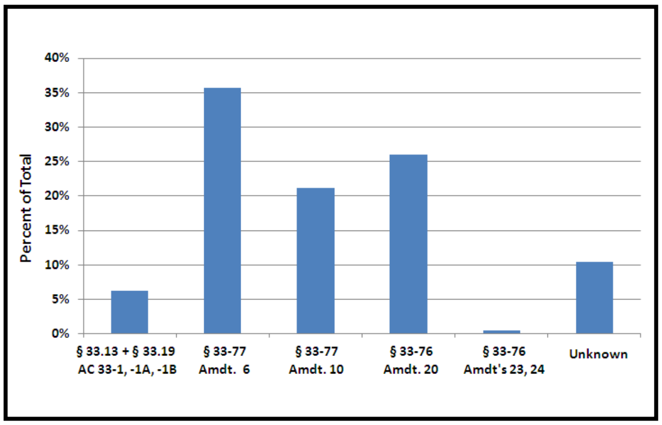


Figure 1.3.1. Distribution of CFR Bird Sections and Amendments in Data Set

2. SAFETY OBJECTIVES

   i. Prior to Amendment 20 there was no numerical safety objective associated with the bird ingestion requirements.

   ii. Amendment 20 (called Phase I rule in this report): The safety objective (small and medium flocking and single large birds) is that hazardous consequences due to these threats will not occur at rate greater than 1E-8 per flight cycle.

   iii. Amendment 23 (called Phase II rule in this report): The safety objective (large flocking birds) is that catastrophic consequences due to this threat will not occur at a rate greater than 1E-9 per airplane operating hour.

   iv. The current large flocking bird rule study activity (called Phase III in this report) is based on the Phase II safety objective.

3. BIRD INGESTION DATABASE

3.1 Input Data

The data provided by the engine companies included information on each bird ingestion event contained in their own databases. The data required for analyses were event date, engine model (Appendix C), airplane model, engine position, number of engines involved, power level (after the event), bird species, and the total hours and cycles for each engine model.

The engine companies included information on whether there was evidence of core ingestion and the certification basis for the particular engine model. Since engines are approved by different authorities and various amendments, the certification bases can differ. Information on certification basis is provided in Appendix C.

3.2 Sanitized 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 size categories (both by fan diameter and inlet area) and certification standard. The airplane model was listed by number of engines and their locations (wing- or fuselage-mounted).

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.

3.3 Data Quality

The databases provided by the engine companies contain all of the bird ingestion events known to them. The data were supplemented by reviewing the FAA/Department of Agriculture National Wildlife Strike Database and an EASA/CAA database and including any events that were previously not included in the manufacturer's data.

The data collected 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 (2007). Also used is Dunning (1992) and Brough (1983). 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, Dunning (2007) was the source used.

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

(>3 lbs.), medium (0.5 – 3 lbs.) or small (<8 ozs.) so that this data could be included for purposes of analysis and the weights allocated to classes. These generic classifications were unique to Phase III. In future analyses, it is recommended that the 'generic large' birds are distributed into the bird classes, see discussion in 3.6.7.

3.4 Phase I (12/1968 to 12/1988 for <2.5 lbs., to 12/1995 for >2.5 lbs.)

A 1975 accident at JFK which, although not bird-caused, was bird related, prompted NTSB Safety Recommendation A-76-64, which stated in part: "Amend 14 CFR 33.77 to increase the maximum number of birds in the various size categories required to be ingested into turbine engines with large inlets. These increased numbers and sizes should be consistent with the birds ingested during service experience of these engines."

Industry at that time was recognizing that the new high bypass ratio turbofans were often ingesting heavier birds in service than was being demonstrated in certification. In 1986, AIA PC Bird Project 331-3A which was created to address ingestion (birds, weather, etc.) made a recommendation to the FAA for new bird regulations; in 1999 FAA issued proposals for new regulations.

At the end of Phase I there was a minority opinion that the gap between 2.5 lbs. medium bird and 8 lbs. large bird was too wide; therefore, the JAA introduced an intermediate rule that required the fan rotor stage to have less than 12% of a single blade imbalance after ingestion of a 1.85 kg (4 lbs.) bird at the Single Large Bird conditions of 200 knots and takeoff engine speed.

3.5 Phase II (Phase I plus all weights to 12/1999) Summary

With the JAA introducing a new intermediate rule and the world goose population on the increase, the regulators and industry felt that an addition to the bird ingestion regulation was needed to address large flocking birds. This new rule would address the JAA's concern about the gap between the medium bird rule and the large single bird rule.

In March 2000, the FAA through the ARAC Engine Harmonization Working Group started an investigation to study the rates and effects of bird ingestion with a focus on dual engine power loss. This study updated the bird database through 1999.

A recommendation was made for a new large flocking bird test based on analyses that extrapolated the ingestion rates along with Monte Carlo analyses that calculated future dual engine power losses based on implementation of this new rule. The analyses were combined to determine whether the catastrophic event safety goal was accomplished for each engine size class. This was then used to set the bird weights needed for the test[5,9].

3.6 Phase III Data (1/2000 – 1/2009)

The engine companies participating on the Working Group Committee provided their bird ingestion information which they had collected for the period of January 1, 2000 through January 31, 2009. The time frame was shorter than the previous Phase durations (30 years total), but the purpose was to expedite the Committee's response regarding bird ingestions after the Hudson River event (January 15, 2009), and to identify any threat changes that may have occurred since the last update in 2000.

To help understand the results of the data that will be discussed below, this section summarizes the data content based on various categories. For each sub-section below, there is a general description of a particular category as well as the quantity of bird ingestions involving that category within the data set. The sub-sections are also arranged in a hierarchy from aircraft classifications to bird type classifications. The purpose is to explain the content of the data in a manner that will help clarify the analyses that were completed by the Working Group and the corresponding conclusions.

3.6.1 Flight Phase Categories

In general, commercial aircraft have similar flight profiles defined by common phases as shown in Figure 3.6.1.1. The ground phase consists of the time between engine start and stop that the aircraft is on the ground. During this phase, engines are set at low power and the activities are mostly characterized by time idling, being pushed by tug, or taxiing to and from the runway. During the takeoff phase the engines are set to takeoff power. This phase will continue until the climb phase begins which can be at an altitude such as 1,500 feet above ground level with an indicated air speed of 175 – 250 knots. Typically the pilot would then reduce engine power to climb rating and accelerate to climb speed. For many aircraft, maximum fan speed will be near the top of climb. At cruise altitude, engine power is set for maximum economy. Engine power is reduced during descent which continues until a certain altitude is reached such as 1,500 feet above ground level. For approach and landing the engine power is increased and even further increased after landing if thrust reversers are deployed. The final phase is again the ground phase where the aircraft will taxi to the terminal.

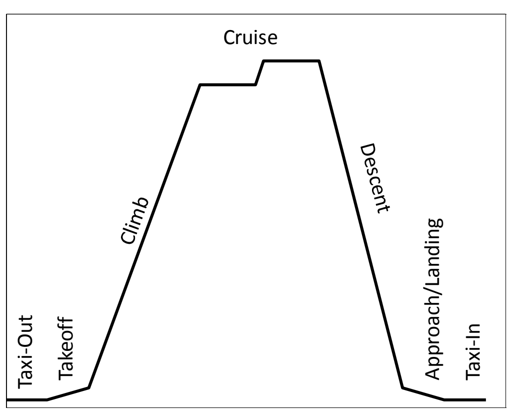


Figure 3.6.1.1 Generic Flight Profile with Common Phases Identified

Table 3.6.1 lists these common aircraft flight phases as recorded within the data set and the corresponding number of bird ingestions within each phase. The data is shown graphically in Figure 3.6.1.2. The combined phases where the most bird ingestions occur are takeoff/climb and approach/landing. The data also shows that there are relatively few bird ingestions at higher altitudes, approximately 0.5% at cruise and 0.6% during descent. This implies that the majority of ingestions during the climb phase occur during the lower altitude region. The largest percentage of the data set falls under the Unknown category. In many cases involving smaller size birds, pilots are unaware of an ingestion event and no record is logged. Evidence of the ingestion event, such as feathers, blood stains, or possibly some minor component damage, is ultimately observed during an engine inspection and the data is then recorded but the aircraft flight phase is unknown.

Table 3.6.1. Quantity of Bird Ingestions by Flight Phase in Data Set

Flight Phase	No. of Aircraft Events in Data Set	Percent of Data Set
Ground	299	3%
Takeoff	1,723	15%
Climb	1,292	11%
Cruise	58	1%
Descent	70	1%
Approach	1,788	16%
Landing	1,012	9%
Unknown	5,090	45%

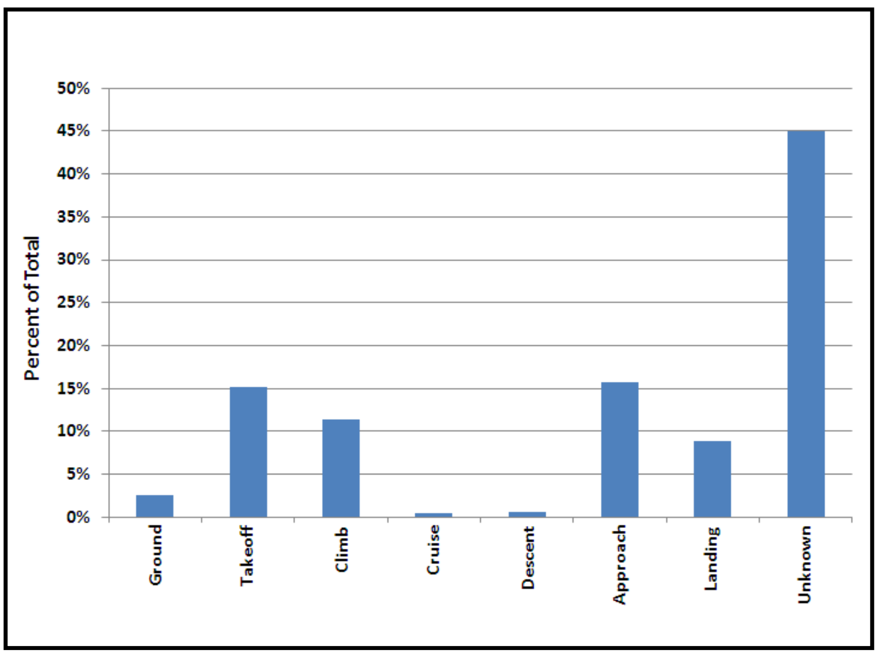


Figure 3.6.1.2. Distribution of Bird Ingestions by Flight Phase in Data Set

3.6.2 Airplane Type Categories

Two categories were used to differentiate the type of airplanes. One was the number of propulsion engines used by the airplane, and the second was the mounting location of the engines. Table 3.6.2 shows the quantity of each category within the data set. The largest population by a significant margin was the twin-engine class, and within this class the largest population of mount location was on the wings, again, by a significant margin. The data is shown graphically in Figure 3.6.2.

Table 3.6.2. Airplane Type Definitions and Quantity in Data Set

Airplane Type (No. Engines)	Airplane Type (Engine Loc.)	No. of Engine Events in Data Set	Percent of Data Set	Percent of Data Set
Twin-Engine	Wing	8,720	77%	87%
	Rear	1,194	11%	
Tri-Engine	Rear	44	0%	2%
	Mix	128	1%	
Quad-Engine	Wing	1,200	11%	11%
	Rear	1	0%	
Unknown	Unknown	45	0%	0%

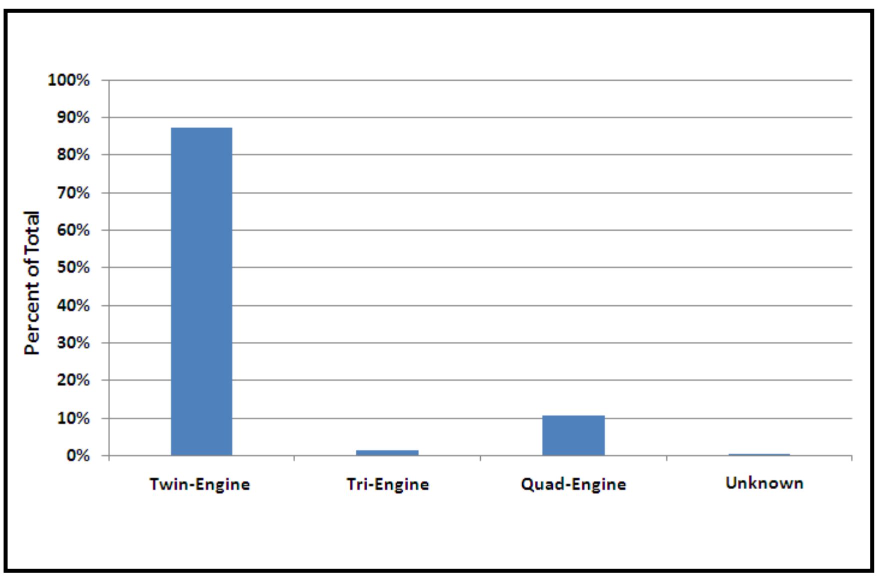


Figure 3.6.2. Distribution of Airplane Types in Data Set

3.6.3 Engine Type Categories

The data set was further categorized into engine types: turbojets, turboprops, and turbofans. The vast majority of the industry data consisted of turbofans as shown in Table 3.6.3. As a subset of the turbofan category, the type of fan blade was also included. This was to distinguish between the higher aspect ratio, narrow chord designs and the more modern, lower aspect ratio, wide chord designs. The purpose for the added classification is that the wide chord fan blades tend to be more resistant to bird impact damage. The modern designs incorporate more stringent FAA regulations and have much better analysis tools and techniques, but there are physical differences as well. Part of the reason is that when chord is increased the thickness is increased as well in order to maintain a similar thickness-to-chord (t/c) airfoil section for good aerodynamics. In addition, thickness is also added to control undesirable frequency crossings of blade fundamental modes and engine excitation orders. The narrow chord fan blade designs, in comparison, typically incorporated a part-span damper (shroud or snubber) to increase the fundamental mode frequency to desired levels when the dampers become engaged at speed. The push for increased fuel economy has essentially removed the part-span damper from modern fan designs. Over time, more and more of the older, narrow chord fan blades will be replaced with the more efficient, more robust, wide chord fan blades.

Since the Phase III effort was the result of a turbofan event the emphasis was on turbofans. Turboprop data was minimal and was specifically not addressed. Very few turbojets are currently in commercial service. Also, bird threats to turboshaft engines were not part of this study.

Table 3.6.3. Engine Type Definitions and Quantity in Data Set

Engine Type	Type of Fan Blade	No. of Engine Events in Data Set	Percent of Data Set	Percent of Data Set
Turbofan	Narrow-Chord	6,651	59%	99%
	Wide-Chord	4,464	39%	
	Unknown	109	1%	
Turboprop		95		1%
Turbojet		13		0%

3.6.4 Engine Size Classes

Several methods have been used to categorize engine size. These include inlet throat area, fan leading edge tip diameter, and inlet capture or face area. Inlet throat area is the minimum open area inside the inlet forward of the fan, the capture/face area typically includes the forward projected area out to the inlet hilite since birds striking at this point or inside it would be at least partially ingested.

The Phase I discussions in 1988-89 selected the "inlet throat area" for the sizing parameter to determine the bird weight requirements for the following reasons:

i. Engine "throat area" is a parameter which directly relates to the bird ingestion threat. It is the forward projected streamtube that 'sweeps' the airspace occupied by the birds.
ii. "Inlet face" geometry was also considered but it was felt that it could vary widely for small engine installations.
iii. Use of "throat" area criteria allows latitude for innovative designs for bird hazard reduction, i.e. a high hub/tip ratio fan engine design would be more resistant but is discouraged by unrealistic "face" area criteria.

This committee recommends the continued use of "inlet throat area" as the defining parameter for engines with nacelles enclosing the fan blades, specifically because of the shielding due to reason iii above. Latest generations of turbofan engines are increasing fan hub/tip which results in greater fan tip shielding and lower probability of tip strikes where blade cross-sections are thinnest and more prone to impact damage. The shielding provides a large degree of protection to this area from direct strikes by whole birds. Future engine designs without nacelles shrouding the fan such as Open Rotor will have to revisit this parameter. However, regardless of how inlet area is defined within the rule, the size and quantity of birds for comparable engines would be the same.

3.6.4.1 Engine Inlet Area Classes

Upper case letters "A" through "F", as shown in Table 3.6.4.1, have been consistently used by the Phase I, II and III Working Groups, although engine class F was not included until Phase III. The largest engine size class, by percentage of data set which reflects the commercial aviation fleet, is Class D with inlet areas between 1.35 m^2 – 2.50 m^2. The CFM56 engine, used on US Airways Flight 1549 (Airbus A320-200) and involved in the Hudson River incident, is in this class.

Table 3.6.4.1. Engine Size Classes Based on Inlet Throat Area and Quantity in Data Set

Engine Class	Inlet Throat Area, A (in^2)	Inlet Throat Area, A (m^2)	No. of Engine Events in Data Set	Percent of Data Set
A	$6045 < A$	$3.90 < A$	724	6%
B	$5425 < A \leq 6045$	$3.50 < A \leq 3.90$	1,172	10%
C	$3875 < A \leq 5425$	$2.50 < A \leq 3.50$	531	5%
D	$2093 < A \leq 3875$	$1.35 < A \leq 2.50$	7,020	62%
E	$620 < A \leq 2093$	$0.40 < A \leq 1.35$	1,245	11%
F	$A \leq 620$	$A \leq 0.40$	544	5%
Unknown			96	1%

3.6.4.2 Engine Fan Diameter Classes

Lower case letters “a” through “f” as shown in Table 3.6.4.2, have been consistently used by the Phase I, II and III Working Groups. The classes were specified in fan diameter increments of 20 ins. (0.51 m). The largest engine size class, by percentage of data set which reflects the commercial aviation fleet, is class c with tip diameters from 60 to 80 ins. The CFM56 engine, used on US Airways Flight 1549 (Airbus A320-200) and involved in the Hudson River incident, is in this class.

Note that the two size methods (area and diameter) do not provide a direct comparison, particularly for the C (c) and D (d) engine size classes. Appendix D proposes a better method for grouping the diameter classes to provide consistency with area classes.

Table 3.6.4.2. Engine Size Classes Based on Fan Diameter and Quantity in Data Set

Engine Class	Fan Inlet Diameter, D (in)	Fan Inlet Diameter, D (m)	No. of Engine Events in Data Set	Percent of Data Set
a	$100 < D$	$2.54 < D$	425	4%
b	$80 < D \leq 100$	$2.03 < D \leq 2.54$	1,941	17%
c	$60 < D \leq 80$	$1.52 < D \leq 2.03$	4,991	44%
d	$40 < D \leq 60$	$1.02 < D \leq 1.52$	2,912	26%
e	$20 < D \leq 40$	$0.51 < D \leq 1.02$	1,047	9%
f	$D \leq 20$	$D \leq 0.51$	16	0%

3.6.5 Bird Weight Classes

Within the input data collected from the engine manufactures, a category for bird type (species) either "known" or "not known" was included. Bird species can be determined by feathers as well as DNA. Unfortunately, not all bird ingestion events have data sent to labs for identification. As a way to try to maximize the data available, the engine companies evaluated the damage to the engine where the bird species was unknown. If they were able to make an estimate of the bird weight from the damage, they included a generic bird weight class and label. If the bird species was identified, then the average species weight was used in the data set.

Field history data of bird ingestions in turbofan engines has shown that the vast majority of ingested bird weights are less than 6 lbs. (2.72 kg). The bird ingestion weights prescribed in the FAA test regulations range from 0 to 8 lbs. (0 – 3.65 kg) depending on the inlet throat area and type of demonstration required (e.g., run-on or safe shutdown). In order to study and compare the field history data, classes were selected which categorized the ingestion events by bird weight up to the maximum weight within the FAA regulations. Roman numerals i, ii, iii, and iv were used to categorize the small and medium bird weights (weights associated with the small and medium flocking bird ingestion tests); whereas I, II, III, and IV were used to categorize the large bird weights (weights associated with the large flocking bird ingestion test and up to, and beyond, the large single bird ingestion test) as shown in Table 3.6.5. Some common examples based on average species weight are provided in this table.

Table 3.6.5. Bird Weight Class Definitions and Quantity in Data Set

Bird Class		Bird Weight, w (lbs)	Bird Weight, w (kg)	No. of Engine Events in Data Set	Number of Real Birds	Percent of Total Real Birds	Number of Generic Birds	Common Examples
Medium/Small	i	0 < w ≤ 0.5	0 < w ≤ 0.23	4,035	634	30%	3,399	Common Lapwing
	ii	0.5 < w ≤ 1.0	0.23 < w ≤ 0.45	319	318	15%	0	Rock Dove
	iii	1.0 < w ≤ 1.5	0.45 < w ≤ 0.68	357	356	17%	0	Ring-Billed Gull
	iv	1.5 < w ≤ 2.5	0.68 < w ≤ 1.13	2,369	456	21%	1,913	Herring Gull
Large	I	2.5 < w ≤ 4.0	1.13 < w ≤ 1.81	122	122	6%	0	Glaucous-Winged Gull
	II	4.0 < w ≤ 6.0	1.81 < w ≤ 2.72	461	89	4%	372	Lesser Snow Goose
	III	6.0 < w ≤ 8.0	2.72 < w ≤ 3.63	134	133	6%	0	Greater Snow Goose
	IV	8.0 < w	3.63 < w	37	36	2%	1	Canada Goose
	Unknown			3,498	0	0%	0	

As noted earlier, the generic bird classes small, medium and large are also used. These classes do not have specific weights assigned by the engine manufacturer, but for the Working Group's analyses a weight was used. In the case of the generic large bird this was 72 ozs, or Class II in the above table, see recommendation in Section 7.4 on how to apportion this data in future work.

3.6.6 Core vs. Bypass Ingestions

The Phase III data included core ingestion information (either "core" or "not core") for 37% of all the reported ingestion events. A core ingestion was noted when any evidence of a bird was found within the core regardless of other locations were bird strike evidence was found. In many of the bird ingestion entries it was difficult to differentiate between data entries in which the core was the primary strike location (a "direct hit"), was an artifact from a strike at another location, or was a core ingestion independent of another bird strike.

Considering only the ingestion events for which core information was provided, 40% indicated the presence of bird material in the core during the post-strike engine inspection. This is a significantly higher percentage than would be expected based on random bird strike locations for a high bypass turbofan engine, which suggests that about 10% of the total engine bird strikes would be directed at the core flow path.

It is believed that the presence of bird remains within the engine core is not a reliable indicator of a core bird strike because bird strikes on aircraft structure other than the core area, such as the inlet lip, spinner cap, and radome, regularly result in some amount of avian material entering the core. One manufacturer's data revealed that of the 706 single, non-flocking bird ingestion reports for the past decade, 8% were inlet strikes (54/706) and 25% of these inlet strike entries (12/54) also reported bird material ingested into the engine core.

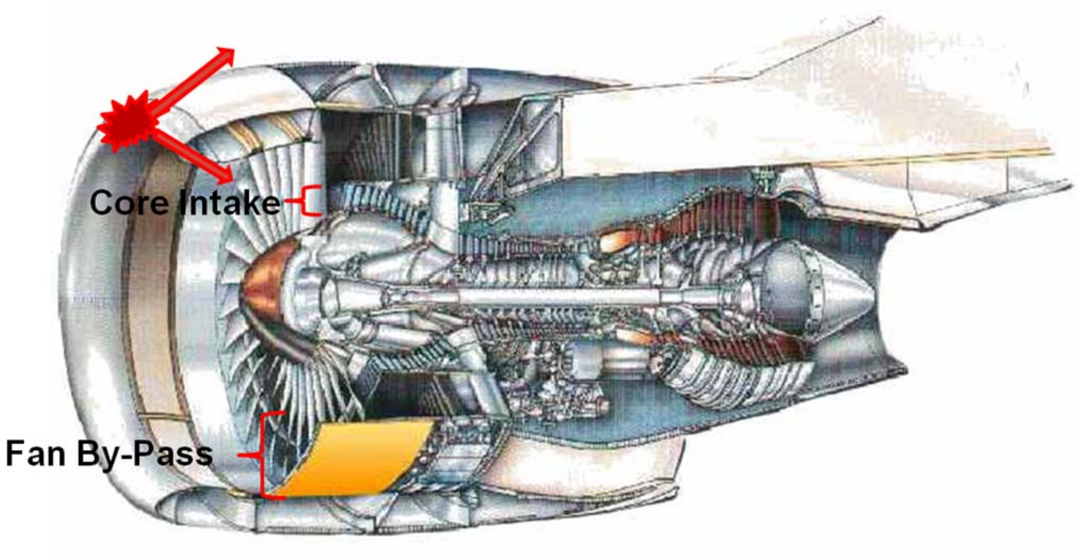


Figure 3.6.6. Inlet Strikes Can Result in Avian Material Core Ingestion

Single bird impacts which have occurred in the outer spans of the fan blades or against the front of the core intake fairing also are known to result in material entering the core. Of the 706 single, non-flocking entries noted above, nearly 27% of the entries (188/706) that indicated strikes in the bypass (outer span) region of the fan blades also reported bird material ingested into the core.

These secondary means of core bird material ingestion imply more direct core ingestion involvement in bird strike related operational discrepancies than has actually occurred. It stands to reason that the larger the bird, the greater the likelihood of at least some material entering the core during an inlet or bypass bird strike. When attempting to assess the proportion of significant bird strike engine effects assigned to core, consideration needs to be given of the concept of bird material ingestion into the core during events in which the core is not the primary strike location. Accurate core ingestion data are of particular concern when attributing an engine power loss event to a strike location on the engine and airframe, with a distinction made between the ingestion of significant amount of bird debris, such as the main body of the bird, directly into the core and ingestions of small amounts of material secondary to a primary strike at another location.

The largest population of entries within the data set was those that did not contain core or bypass information, and were classified as "Unknown". This category included evidence of an ingestion event forward of the bypass and core entry combined with no evidence within the fan duct or core. This would include evidence on the nacelle inlet, spinner, fan rotor, fan casing, and fan stator (if forward of the bypass/core flow splitter). It would be expected that the vast majority of the Unknown category would have gone through the bypass duct based simply on the much larger bypass frontal area relative to the smaller core, but without hard evidence they were classified as unknown. The amount of bird ingestion types within each of the bird weight classes are shown in Table 3.6.6.

Table 3.6.6. Ingestion Type Definitions and Quantity in Data Set

	Bird Class	Bird Weight, w (lbs)	Bird Weight, w (kg)	No. of Engine Events in Data Set	Number of Core Ingestions	Number of Bypass Ingestions	Number of Unknown Ingestions
Medium/Small	i	$0 < w \leq 0.5$	$0 < w \leq 0.23$	4,035	792	1,022	2,221
	ii	$0.5 < w \leq 1.0$	$0.23 < w \leq 0.45$	319	56	111	152
	iii	$1.0 < w \leq 1.5$	$0.45 < w \leq 0.68$	357	65	160	132
	iv	$1.5 < w \leq 2.5$	$0.68 < w \leq 1.13$	2,369	550	476	1,343
Large	I	$2.5 < w \leq 4.0$	$1.13 < w \leq 1.81$	122	31	31	60
	II	$4.0 < w \leq 6.0$	$1.81 < w \leq 2.72$	461	89	125	247
	III	$6.0 < w \leq 8.0$	$2.72 < w \leq 3.63$	134	37	38	59
	IV	$8.0 < w$	$3.63 < w$	37	8	10	19
	Unknown			3,498	56	563	2,879
				11,332	1,684	2,536	7,112

4. ANALYSES

4.1 Phase II

As noted in Section 3.5, the Phase II committee designed a probabilistic LFB rule using Monte Carlo analyses which predicted the dual engine power loss probability given a dual engine ingestion with the new rules in effect (see Section 6 of Reference 5 for details). These analyses utilized the Phase II database with the following assumptions:

1. Bird mass was randomly selected based on relative frequency of encounter in the database; bird mass was the same in both engines. The birds were considered as prolate spheroids (elliptical) with a length to diameter ratio of 1.8, a mass density of 0.035 lbm/in^3 and alignment was such that the bird major axis and direction of travel were parallel to the engine axis.
2. The bird impact location within each engine was random within the nacelle hilite diameter and independently chosen for each engine.
3. The bird/airplane speed was randomized based on a Weibull analysis of reported speeds listed in the database.
4. Engine fan rotational speed was the same for both engines. Half of the events were assumed to be at low power (descent, approach, landing, taxi phases) and half at high power during takeoff/climb. This is considered slightly conservative based on events in the database with flight phase identified, and also the shorter time spent at low altitudes at high power due to vertical speeds in climb being higher than those during approach.
5. Engine size was randomly chosen to be within the particular engine size class being analyzed, with a constant number of fan blades (22), constant fan blade hub-tip ratio (.333) and constant nacelle inlet length to diameter ratio (0.64).
6. Energy of impact calculations into the fan blade used the maximum slice mass which was based on radial location, blade spacing, bird speed and bird dimensions.
7. A power loss would not occur if:
   a. Bird impacted the spinner
   b. More than $^1/_3$ of bird diameter impacted the nacelle inlet lip (it is broken up by the impact)
   c. The engines were at low power.
   d. Bird impact energy into the fan blade would be less than the energy level demonstrated in the Medium and Large Flocking Bird tests (see 8. below)
8. For cases not restricted by other assumptions, then the following were used as limits to determine power loss:
   a. If the bird impact radius was less than the large flocking bird test span location then the energy level from that test (50% span) was used.
   b. If there was no large flocking bird test then the constant mass curve generated by the medium bird test was used above 50%.
   c. If a large flocking bird test was available, a linear interpolation between the medium and large flocking bird test energy levels was used.

If the maximum energy calculated from the bird ingestion is greater than the energy from the appropriate line or curve selected in 8. above from the medium and large flocking bird tests, then for this iteration of the analysis the engine would indicate a power loss. If both engines indicate a power loss, then it was considered a dual engine power loss event.

The rate of multi-engine power losses per event was then combined with multi-engine ingestion rates and hazard ratio (18%) to yield a catastrophic event rate for comparison with safety goals.

4.2 Engine Ingestion Rates

In the previous Phase II report, the data were represented based on engine diameter but the Monte Carlo analysis, and subsequent rule, were based on inlet area. Because of this, engine ingestion calculations were performed for both engine diameter and inlet area. Any ingestion event where the bird weight was noted was included in the Phase III analysis.

Engine ingestion rates were calculated for each year. Since there are more single engine ingestions than multi-engine ingestions, the data are shown on a yearly (or rolling average) basis. Figure 4.2.1 shows the engine ingestion rates (4-year rolling average) for the 80 to 100 inch diameter engine class similar to what was shown in Figure 1 of the 2003 bird report[5]. Additional plots for other engine sizes are shown in Appendix E. These calculations were done using only non-generic birds for comparison with prior reports. All ingestion rates are in events per airplane cycle.

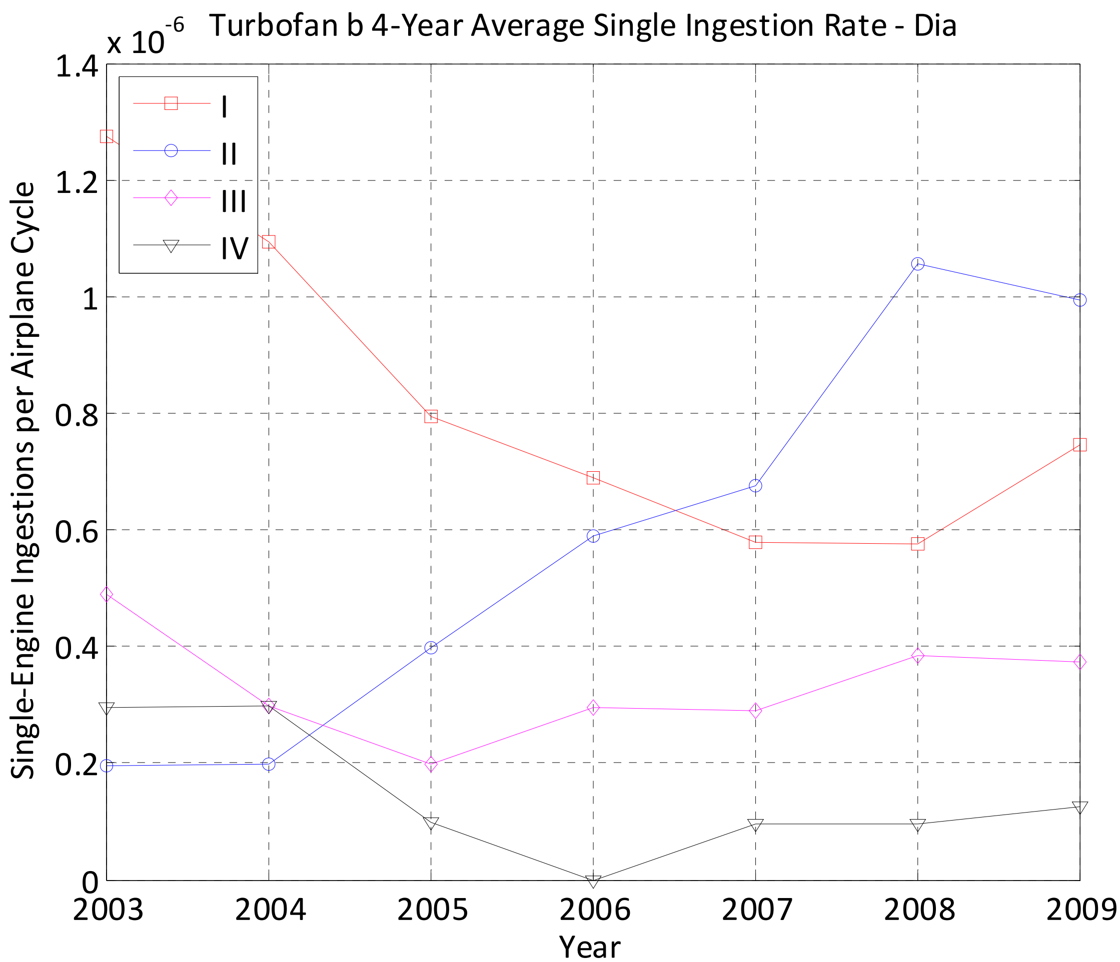


Figure 4.2.1. 80” to 100” Diameter Single Engine Ingestion Rates (4-Year Rolling Average)

Figure 4.2.2 shows the 4-year rolling rate of ingestion events (SEI and MEI) for the whole fleet in the database. After rising through 2005, the latter years appear to be flattening. Thus current ingestion rates can be considered suitable for predicting future fleet performance.

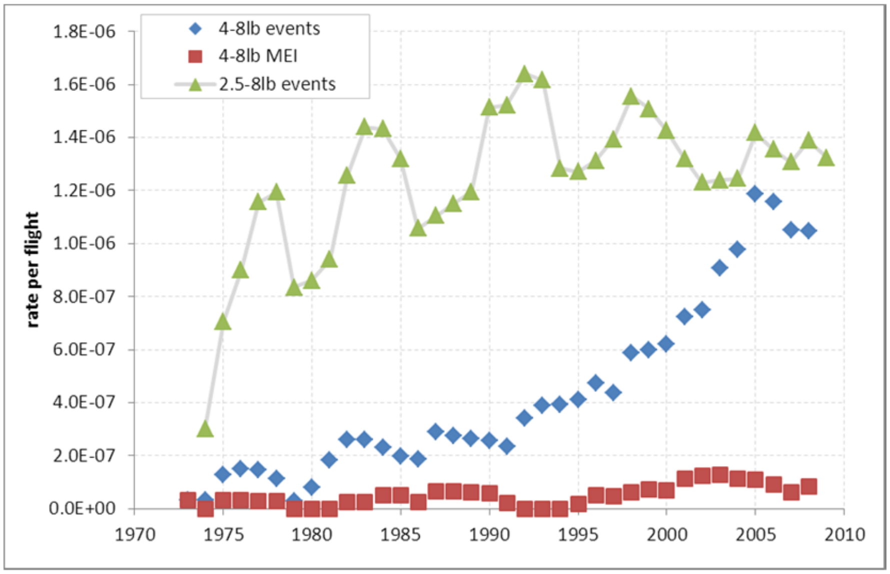


Figure 4.2.2. Whole Fleet 4-Year Rolling Ingestion Rates

4.3 Multi-Engine Ingestion Rates

Multi-engine ingestion rates are calculated based on engine diameter as well as inlet area. Any multi-engine ingestion with known bird weight is included in the calculation. If a multi-engine ingestion event has a known species listed for one engine but not the other engine, it is assumed that the same species is ingested and therefore the same weight is used in the calculation. This ensures that multi-engine ingestions are not counted in two bird weight classes. Tables 4.3.1.1 and 4.3.1.2 shows the multi-engine ingestion rates based on engine diameter and Table 4.3.2 shows the results based on inlet area. These data are calculated from the non-generic bird data.

Table 4.3.1.1. 2000-2009 Multi-Engine Ingestion Rates (Fan Diameter Classes, non-generic)

Bird Class		Bird Weight, w (lbs)	No. of MEI Events in Data Set	Engine Size Class (based on Fan Diameter, inches)					
				a	b	c	d	e	f
				100 < D	80 < D ≤ 100	60 < D ≤ 80	40 < D ≤ 60	20 < D ≤ 40	D ≤ 20
				Total Engine Cycles (1/1/2000 - 1/31/2009)					
				3,768,932	23,377,482	86,040,521	82,995,202	89,313,531	934,993
Medium/Small	i	0 < w ≤ 0.5	49	2.65E-07	1.71E-07	2.67E-07	2.05E-07	4.48E-08	0.00E+00
	ii	0.5 < w ≤ 1.0	21	0.00E+00	2.14E-07	8.14E-08	1.08E-07	0.00E+00	0.00E+00
	iii	1.0 < w ≤ 1.5	18	7.96E-07	4.28E-08	1.05E-07	4.82E-08	1.12E-08	0.00E+00
	iv	1.5 < w ≤ 2.5	17	0.00E+00	2.57E-07	4.65E-08	4.82E-08	3.36E-08	0.00E+00
Large	I	2.5 < w ≤ 4.0	5	0.00E+00	1.28E-07	1.16E-08	1.20E-08	0.00E+00	0.00E+00
	II	4.0 < w ≤ 6.0	3	0.00E+00	0.00E+00	2.32E-08	0.00E+00	1.12E-08	0.00E+00
	III	6.0 < w ≤ 8.0	15	2.65E-07	1.28E-07	3.49E-08	9.64E-08	0.00E+00	0.00E+00
	IV	8.0 < w	2	0.00E+00	0.00E+00	1.16E-08	1.20E-08	0.00E+00	0.00E+00

Table 4.3.1.2. 2000-2009 Multi-Engine Ingestion Rates (Grouped Fan Diameter Classes)

Bird Class		Bird Weight, w (lbs)	Engine Size Class (based on Fan Diameter, inches)					
							d (Rear)	d (Wing)
			60 < D ≤ 100	70 < D ≤ 100	70 < D ≤ 80	60 < D ≤ 70	40 < D ≤ 60	40 < D ≤ 60
			Total Engine Cycles (1/1/2000 - 1/31/2009)					
			109,418,003	34,488,311	11,110,829	74,929,692	49,677,779	33,317,423
Medium/Small	i	0 < w ≤ 0.5	2.47E-07	2.32E-07	3.60E-07	2.54E-07	8.05E-08	3.90E-07
	ii	0.5 < w ≤ 1.0	1.10E-07	2.03E-07	1.80E-07	6.67E-08	4.03E-08	2.10E-07
	iii	1.0 < w ≤ 1.5	9.14E-08	8.70E-08	1.80E-07	9.34E-08	2.01E-08	9.00E-08
	iv	1.5 < w ≤ 2.5	9.14E-08	1.74E-07	0.00E+00	5.34E-08	2.01E-08	9.00E-08
Large	I	2.5 < w ≤ 4.0	3.66E-08	8.70E-08	0.00E+00	1.33E-08	0.00E+00	3.00E-08
	II	4.0 < w ≤ 6.0	1.83E-08	2.90E-08	9.00E-08	1.33E-08	0.00E+00	0.00E+00
	III	6.0 < w ≤ 8.0	5.48E-08	1.45E-07	1.80E-07	1.33E-08	8.05E-08	1.20E-07
	IV	8.0 < w	9.14E-09	0.00E+00	0.00E+00	1.33E-08	2.01E-08	0.00E+00

Table 4.3.2. 2000-2009 Multi-Engine Ingestion Rates (Inlet Area Classes, non-generic)

Bird Class		Bird Weight, w (lbs)	No. of MEI Non-Generic Bird Events in Data Set	Engine Size Class (based on Inlet Throat Area, m^2)					
				A	B	C	D	E	F
				3.90 < A	3.50 < A < 3.90	2.50 < A < 3.50	1.35 < A < 2.50	0.40 < A < 1.35	A < 0.40
				Total Engine Cycles (1/1/2000 - 1/31/2009)					
				6,854,734	14,914,746	9,573,065	117,874,234	105,322,113	31,891,769
Medium/Small	i	0 < w ≤ 0.5	49	1.46E-07	2.68E-07	1.04E-07	2.88E-07	7.60E-08	3.14E-08
	ii	0.5 < w ≤ 1.0	21	0.00E+00	2.01E-07	2.09E-07	1.19E-07	1.90E-08	0.00E+00
	iii	1.0 < w ≤ 1.5	18	4.38E-07	6.70E-08	0.00E+00	1.02E-07	1.90E-08	0.00E+00
	iv	1.5 < w ≤ 2.5	17	0.00E+00	2.01E-07	3.13E-07	5.94E-08	2.85E-08	3.14E-08
Large	I	2.5 < w ≤ 4.0	5	1.46E-07	1.34E-07	0.00E+00	1.70E-08	0.00E+00	0.00E+00
	II	4.0 < w ≤ 6.0	3	0.00E+00	0.00E+00	0.00E+00	1.70E-08	9.49E-09	0.00E+00
	III	6.0 < w ≤ 8.0	15	1.46E-07	2.01E-07	0.00E+00	5.09E-08	4.75E-08	0.00E+00
	IV	8.0 < w	2	0.00E+00	0.00E+00	0.00E+00	8.48E-09	9.49E-09	0.00E+00

4.4 Engine Power Loss Probability

Engine power loss probability (EPL%) was calculated for any given engine size/bird size combination by calculating the number of power loss events divided by the total number of events for the particular combination. For the purposes of this bird ingestion study, if the thrust generated was less than 50%, the ingestion was considered to have had a power loss. This definition was used in the Phase II report as well.

The engine power loss probability included all events where a bird weight was identified and power loss indicated. When a power loss was not indicated, it was believed that the engine probably did not experience a power loss, however, these events were not included in the calculations and therefore the power loss probability is believed to be conservative.

4.5 Dual Engine Power Loss Probability

In prior reports, dual power loss probability was taken as the square of the engine power loss probability, i.e. $EPL\%^2$. However, this is not an appropriate method to calculate this probability in bird ingestion events since the engines are typically at the same power setting and the bird weight would probably be similar. Using the square method underestimates the risk.

The dual engine power loss probability can be calculated for any given engine size/bird size combination by dividing the number of dual power loss events by the total number of dual ingestion events for the particular combination. (Note that this is different than a multi-engine power loss probability calculation where, say, three engines with power loss on a four engine airplane would be included in the calculation, it has been determined that this type of event is extremely remote and need not be considered.)

Since actual dual engine power losses are extremely rare, it is not possible to do meaningful statistical analyses on subsets of the data (by engine class, bird class, etc.) to assess how each group is performing versus desired safety goals.

In the Phase II committee work, Monte Carlo analyses were used to define LFB tests which should yield minimum engine capability (in terms of EPL%) to achieve the safety goal. However, it is possible to compare each engine class in the database to the predictions of the Phase II Monte Carlo by using the ratios of current to predicted EPL% and current to prior MEI rates.

Note that this will give a rough comparison between how the fleet is performing compared to predictions and safety goals, but it cannot be considered a statistically meaningful assessment.

Results are shown in Table 4.5. It can be seen that all fleets are operating close to the 1E-9 goal, and the class D and E engines which are marginally above the goal are expected to meet the goal in future as older engines are retired and new, more robust engines certified to later standards become the majority of those fleets.

Table 4.5. Current Performance of each Engine Size Class against Phase II Predictions.

Engine		Phase II			Phase III		
Class	Size	MEI rate (2.5-8lbs)	Pred. EPL%	Predicted CE Rate	MEI rate (2.5-8lbs)	Demo. EPL%	Predicted CE Rate
A	> 3.9 m^2 (6045 in^2)	1.75E-07	7.9	8.7E-10	2.92E-07	5.3	9.7E-10
B	>3.5 - 3.9 m^2 (5425-6045 in^2)	1.78E-07	10.8	8.9E-10	3.35E-07	0	0.0E+00
C	>2.5 - 3.5 m^2 (3875-5425 in^2)	1.24E-07	11.3	9.0E-10	0	17.6	0.0E+00
D	>1.35 - 2.5 m^2 (2093-3875 in^2)	6.19E-08	10.9	9.4E-10	8.48E-08	8.6	1.02E-09
E	>0.4 - 1.35 m^2 (620-2093 in^2)	5.37E-08	14.6	8.6E-10	5.70E-08	16.4	1.03E-09

Class F engines were not analyzed in Phase II, thus cannot be incorporated in Table 4.5. Data is available for this class and future assessment is recommended.

5. COMPARISONS WITH GOALS

5.1 Engine Ingestion Rates

In the Phase II analyses, multi-engine ingestion rates were extrapolated out 10 years. These rates were compared against what was seen during the 9 years of the current study. This is a test of a specific rate against an estimated rate and is described in Appendix F (test 4). These comparisons were done both with and without the generic data (Table 5.1.1 is non-generic and Table 5.1.2 is generic). Where there is data (no comparisons can be made when there are no ingestions), the test results are not shown to be statistically different from previous data. This applies to both the generic and non-generic data. Note that while some values do appear to be larger, the statistical test cannot show a difference with the current amount of data.

Table 5.1.1. Comparison of Current Non-Generic MEI Rates with Extrapolation from Phase II

Bird Class		Bird Weight, w (lbs)	MEI Rate Description	Engine Size Class (based on Inlet Throat Area, m^2)				
				A	B	C	D	E
				3.90 < A	3.50 < A < 3.90	2.50 < A < 3.50	1.35 < A < 2.50	0.40 < A < 1.35
Large	I	2.5 < w ≤ 4.0	Extrapolated	4.97E-08	5.06E-08	3.53E-08	2.01E-08	1.75E-08
			Current	1.46E-07	1.34E-07	0.00E+00	1.70E-08	0.00E+00
			Comparison Test 4	Not shown different	Not shown different	(No data)	Not shown different	(No data)
	II	4.0 < w ≤ 6.0	Extrapolated	2.49E-08	2.53E-08	1.76E-08	1.01E-08	8.74E-09
			Current	0.00E+00	0.00E+00	0.00E+00	1.70E-08	9.49E-09
			Comparison Test 4	(No data)	(No data)	(No data)	Not shown different	Not shown different
	III	6.0 < w ≤ 8.0	Extrapolated	1.00E-07	1.02E-07	7.09E-08	3.17E-08	2.75E-08
			Current	1.46E-07	2.01E-07	0.00E+00	5.09E-08	4.75E-08
			Comparison Test 4	Not shown different	Not shown different	(No data)	Not shown different	Not shown different

Table 5.1.2. Comparison of Current Generic MEI Rates with Extrapolation from LFB Committee

Bird Class		Bird Weight, w (lbs)	MEI Rate Description	Engine Size Class (based on Inlet Throat Area, m^2)				
				A	B	C	D	E
				3.90 < A	3.50 < A < 3.90	2.50 < A < 3.50	1.35 < A < 2.50	0.40 < A < 1.35
Large	I	2.5 < w ≤ 4.0	Extrapolated	4.97E-08	5.06E-08	3.53E-08	2.01E-08	1.75E-08
			Current	1.79E-07	1.34E-07	0.00E+00	2.08E-08	6.38E-09
			Comparison Test 4	Not Shown Different	Not Shown Different	No Data	Not Shown Different	Not Shown Different
	II	4.0 < w ≤ 6.0	Extrapolated	2.49E-08	2.53E-08	1.76E-08	1.01E-08	8.74E-09
			Current	3.73E-08	0.00E+00	0.00E+00	2.13E-08	1.68E-08
			Comparison Test 4	Not Shown Different	No Data	No Data	Not Shown Different	Not Shown Different
	III	6.0 < w ≤ 8.0	Extrapolated	1.00E-07	1.02E-07	7.09E-08	3.17E-08	2.75E-08
			Current	2.22E-07	2.01E-07	0.00E+00	5.97E-08	6.23E-08
			Comparison Test 4	Not Shown Different	Not Shown Different	No Data	Not Shown Different	Not Shown Different

5.2 Engine Power Loss Rates

The second part of the Phase II work was a Monte Carlo analysis to determine what the effect of the new LFB rule would be on the power loss probability. These values were calculated for both single engine power loss and dual engine power loss. Since there would be fewer data points for the dual engine events, a comparison was made of the single engine prediction against the current single engine power loss probability (using test 2 from Appendix F). The dual engine power loss probability should follow the single engine power loss probability.

The results are shown in Table 5.2. The predicted power loss probabilities were approximated from the prior report. The results show that the current single engine power loss probabilities are not shown to be statistically different from the predicted power loss probabilities. In the case of inlet size C, it should be noted while the current value is higher than the predicted value, there were only three power losses. Even with this the test could not show a difference.

Also, the Monte Carlo predictions were based on the entire fleet being certified to 14CFR33.76 with the LFB rule (inlet areas A, B and C) whereas the current fleet is still a mixture with pre-33.76 and pre-LFB engines. Had the entire current fleet been certified to the current rules, it is expected that the actual power loss rates would have been lower.

Table 5.2. Power Loss Probability Comparison

Single Engine Shutdown Probabilities (2.5 < w ≤ 8 lbs)	Engine Size Class (based on Inlet Throat Area, m^2)				
	A	B	C	D	E
	3.90 < A	3.50 < A < 3.90	2.50 < A < 3.50	1.35 < A < 2.50	0.40 < A < 1.35
Monte Carlo Average	0.09	0.09	0.09	0.08	0.12
2000 - 2009 Data Set	0.05	0.00	0.18	0.09	0.16
Comparison Test 2	Not shown different	Not shown different	Not shown different	Not shown different	Not shown different

5.3 Safety Goals

In assessing current fleet performance against the desired goal of 1E-9 per hour freedom from catastrophic consequence, the ingestion rates and power loss rates are compared with those used in the Phase II final report for designing the LFB regulation. Although, as noted in Section 2.4, the current rates are not shown to be statistically different, it is believed that using the current data is a conservative approach for several reasons:

1. The Monte Carlo analysis assumes all engines are certified to the current rules, which is not the case. As older engines are removed from fleet, EPL rates should improve.
2. This analysis uses only data with 'real' bird identifications. Had 'generics' been used EPL rates would be significantly lower.
3. This analysis does not use the ~13% of events which had no information regarding EPL. Since events which have significant damage and power loss are typically well documented, it is believed there will be very few EPL events in this group and thus EPL rates used will be higher than actual.

Specifically for Category D engines, which is the inlet size focus of the NTSB recommendations, the total MEI rate for 2.5-8 lb. birds is now 8.5E-8 compared to 6.2E-8 predicted, a 37% increase. However, the Category D engine power loss rates for 2.5-8 lb. ingestions are lower than those that resulted from the Monte Carlo analyses by ~21% (0.086 vs 0.109). Thus overall, the calculated rate of catastrophic consequence is now 1.02E-9, which is ~8% higher than the 0.94E-9 quoted in the Phase II final report. This is slightly higher than the safety goal, but as noted this method is conservative and the fleet is expected to meet the safety goal in practice.

6. DISCUSSION

6.1. Bird Population Trends

The Phase II Bird Committee made note of an increase in bird populations, particularly the large flocking waterfowl species, after reviewing the population trend data from 1970 to 1990. To ensure that the new rules would meet the safety objective in the future, the analysis included assumptions of bird population growth for the decade following the rule recommendation[5]. These assumptions led to a 35% predicted increase in bird size class III (2.5 – 4 lbs.) ingestion rate for fan size class B engines from the 1999 level of 8.79E-7 to 1.17E-6 per flight by the year 2010. The most recent data up to 2009 indicates an ingestion rate for this category of 4.28E-7 per flight, which is a statistically significant reduction in large flocking bird ingestions relative to the predictions used to develop the LFB rule.

The Phase II Bird Committee also predicted a small (5%) increase in the Class III bird ingestion rate for fan size class C engines from an Entry into Service (EIS)-1999 rate of 3.83E-7 to 4.02E-7 per flight by 2010. The demonstrated ingestion rate for this category as of January 2009 is 5.5E-7 per flight, which is not statistically different than the Phase II prediction. These demonstrated rates indicate that either the bird population trend for the past decade for the size class III birds (Mallards, Buteos, the larger gulls, etc.) was lower than anticipated, recent airport mitigation efforts have been effective, or both.

The most frequent ingestion involving the larger birds (greater than 4 lbs.) were Canada geese at 35% of the reported species, followed by Turkey and Black vultures at 20% and Snow geese at 9% respectively. According to the recent FAA report "Wildlife Strikes to Civil Aircraft in the United States 1990-2009" issued May 2011, the population of Canada geese in North America has steadily increased since 1970. The data from the past decade in Figure 6.1.1 shows the migrant Canada goose population has remained steady at about 1.6 million birds since 1990, and the resident Canada goose population trend begins to level off in 1999.

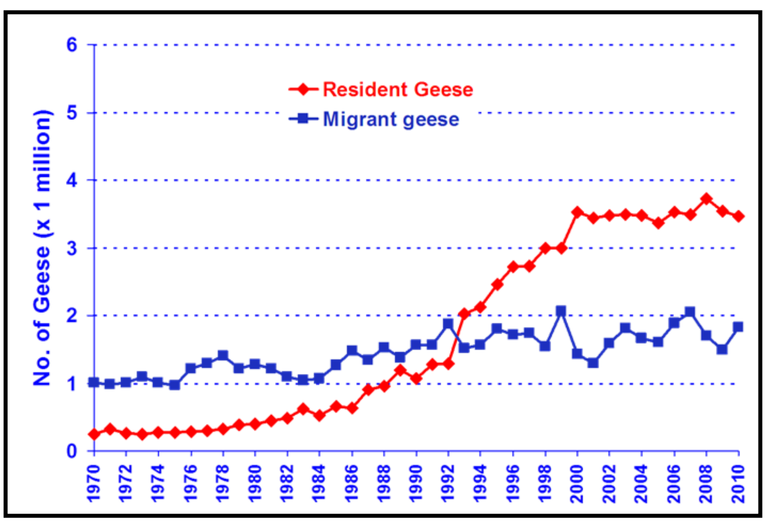


Figure 6.1.1. Canada Goose Population Trends[8]

Although overall Snow goose populations continue to rise, a similar trend is noted in the population estimates which show stagnation in population growth from 2000 to 2006 at 4 million birds before resuming a positive growth trend, see Figure 6.1.2.

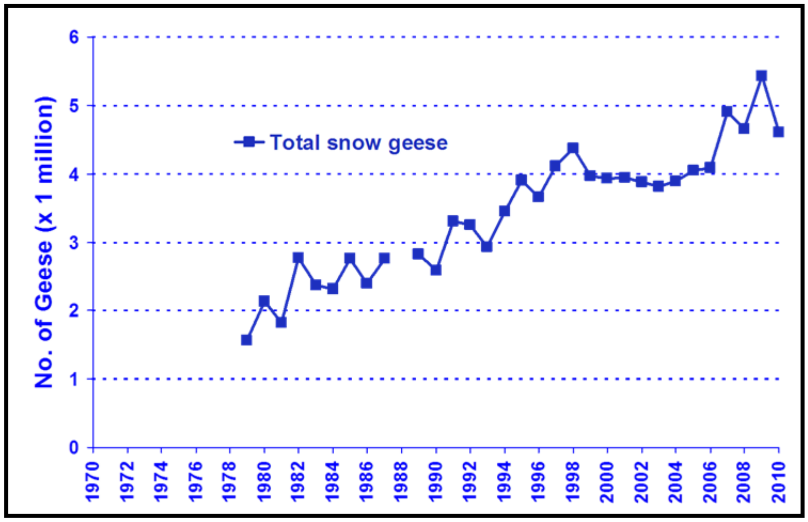


Figure 6.1.2. Snow Goose Population Trends[8]

Although the biological carrying capacity of these large waterfowl is not known nor readily established, these data suggest that after rapid population growth through the 1990's the populations appear to be approaching the biological capacity of the existing habitat to support these waterfowl.

Contrary to the Canada and Snow goose trends, the population of vultures in North America is continuing a steady climb at an average rate of +2.4% per year for Turkey vulture and 4.6% per year for Black vulture through 2010 with no indications of leveling off[8]. The reported ingestion of vultures was nearly equally split between Black (25 each) and Turkey (24 each) vultures. Although the vulture populations are increasing, this species is not considered a flocking bird and therefore the risk of a MEI occurrence is considered low.

This information suggests that adjustments made during the probabilistic method of meeting the predicted bird threat during Phase II rulemaking to accommodate an anticipated increase in bird populations have resulted in a LFB rule which conservatively addresses the present and immediate future threat based on strike probability. The population trends of large flocking bird species such as Canada and Snow goose should continue to be monitored for significant increases which might occur in the future. The distribution of bird species ingested by the engines should also continue to be monitored to identify any new trends relative to species struck.

6.2. Engine Power Loss Rates vs. Rule Changes

The current data set shows that the probability of an engine power loss (EPL) after bird ingestion has steadily decreased since 1970, with clear improvement over the past 20 years (Figure 6.2). This reduction in EPL rates is particularly notable in light of the significantly increased overall ingestion rates which occurred from 1990 through 2005 (Figure 4.2.2). This effect is attributed to improved engine bird strike damage tolerance that has occurred as new technology engines acquire service experience.

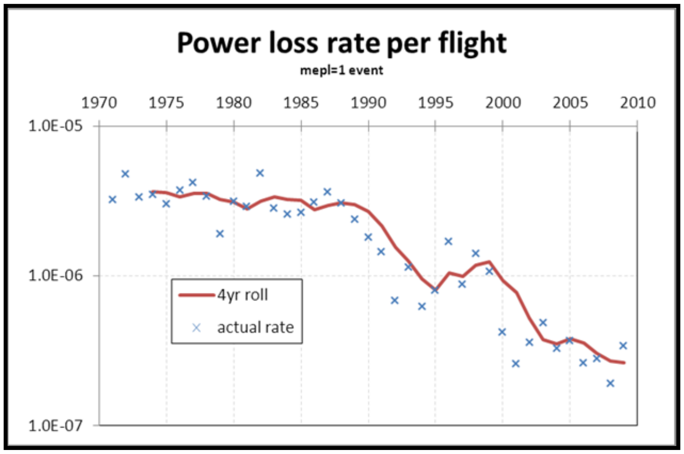


Figure 6.2. Engine Power Loss Rate Trend

Over the years, the engine capability has evolved in response to more rigorous bird ingestion regulations which were developed in response to improved understanding of the bird threat in service. Whereas the fleet in 1970 was populated by first generation turbofans which were certified to generalized foreign object ingestion requirements defined by FAA Advisory Circular 33-1, the current fleet is now comprised of a mixture of first, second and third generation turbofan engines.

The fleets are changing with technology, typically moving to higher bypass ratios and larger fans. In the future, larger portions of the fleet will be covered by the updated regulations, including the large flocking bird. This trend can be seen in the data shown in Table 6.2. For the period covering 1969 to late 1995, engines which were certified to the foreign object ingestion requirements of AC33-1 accounted for 83% of the flight cycles. For the most recent decade, this number decreased to only 14% of the flights, with the remaining 86% of flights occurring with engines certified to the more recent standards codified in FAR 33.77 and 33.76. The large flocking bird (LFB) requirement was promulgated in 2007, and engines certified to this standard have only recently entered into service.

Table 6.2 Proportional Flight Cycle Split of Certification Standards in Databases

Data Set	AC33-1	33.77	33.76	LFB
1969 to Oct 1995	83%	16%	1%*	0
1995 – 2000	47%	47%	7%	0
2000 – 2009	14%	64%	22%	0

As more of the newer technology engines enter service and displace the older engines, the improved capability of these engines is expected to result in further improvements to EPL rates in the future.

6.3. Bird Weight Ranges vs. Average Weight for Species

The bird weight classifications used for both rulemaking and engine test are based on statistical averages of samples acquired by various wildlife agencies. Although it is accepted that each species has weight variations between individual birds, it is generally not possible to obtain the specific weight of the bird ingested due to the damage caused to the bird. Therefore the probable size of an identified bird is based on an average for that species.

Although the engine damage level in service is often associated with a particular bird and its associated average weight, this can be misleading. Individual weight variations within a species can vary a great deal depending on geographic location, gender, time of year (especially for migratory birds), age, etc. For example, the familiar species Branta canadensis (Canada goose) has several sub-species and the weight variation within this group can be more than 2.5X, with a male B.c. canadensis weighing in at 13.8 lbs. and a very similar looking female B.c. occidentalis at 5.4 lbs. Likewise, the mass of a given bird can vary significantly based upon recent food intake history, with migratory birds weighing significantly more at the start of their migration, and vultures increasing weight after feeding during the day.

Past determinations of bird weights relied upon the paper "Average Weights of Birds"[1] by T. Brough. Today, the most current comprehensive source of bird weights employed by the engine manufacturers is the CRC Handbook of Avian Body Masses[2], 2nd Edition by John B. Dunning, Jr.

In instances where the ingested bird ID is provided in generic terms, such as goose or gull, providing a weight classification can be problematic. The previously mentioned weight variation with Canada geese is amplified when accounting for other goose species which might be the bird of interest. Similarly, there is a large number of gull species with an equally significant variation in body mass which confounds weight class assignments. However, by using the available strike data in which species data are known, a generic avian mass can be attributed by weighting the generic bird average body mass by the frequency of reported ingestion. For generic goose reports, the vast majority of strikes are due to Canada goose (8 lbs. typical for Branta canadensis) and therefore the weighted generic goose weight would be quite close to the average weight of B. canadensis at 7.6 lbs. Vultures are evenly split between Black and Turkey vultures, so a generic vulture weight would be about the average (e.g. 4.6 lbs.) of these two species.

6.4. Core Power Loss

The Phase II committee did not include power loss due to core ingestion in the Monte Carlo analyses. At that time, the main focus of the LFB rule was as a fan blade capability test. This approach was driven by the agencies' desire to ensure new-technology turbofans could achieve an adequate level of safety, where the primary risk was assumed to be associated with fan rotor capability during high power operation. The Working Group has reconsidered this original assumption and has the following comments:

a) Introducing a core power loss element to the Monte Carlo analyses is not considered practical for several reasons. First, defining the critical component in the core flow path which instigates the power loss is not possible for a generic model, as engine designs vary considerably in this regard. Also, the effects of the fan centrifuging cannot be readily predicted, as engine designs also vary considerably in this regard. Rates of power loss due to core as opposed to fan contributions are often not known, thus a generic model could not be calibrated to field data.

b) The predicted rates for catastrophic consequence in the Phase II final report are some 10% below the goal on average, and the data showed power losses occurred approximately 15% of the time after ingesting birds in the 2.5-8 lbs. range. Since the core inlet is only ~10% of the engine inlet throat area and ingestions occur randomly across the fan face, the predicted increase in power loss rate when including core ingestion may have been small resulting in only a minor effect on the LFB rule design. So even though a core ingestion power loss contribution might possibly have resulted in calculated exceedence of the safety goal, a core ingestion element to the LFB test would not likely have been recommended since this would not have been the dominant contributor. Instead the test criteria for the fan blade may have been changed to bring the combined predictions back within the safety goal.

6.5. Weights of Birds Required for Certification as Engine Size Changes

All bird Working Groups have noted that ingestion rates of large birds increase with engine size, see Figure 6.5.1. For this reason, the weight of the bird required for certification also increases for larger engines to ensure each engine class meets the safety goal.

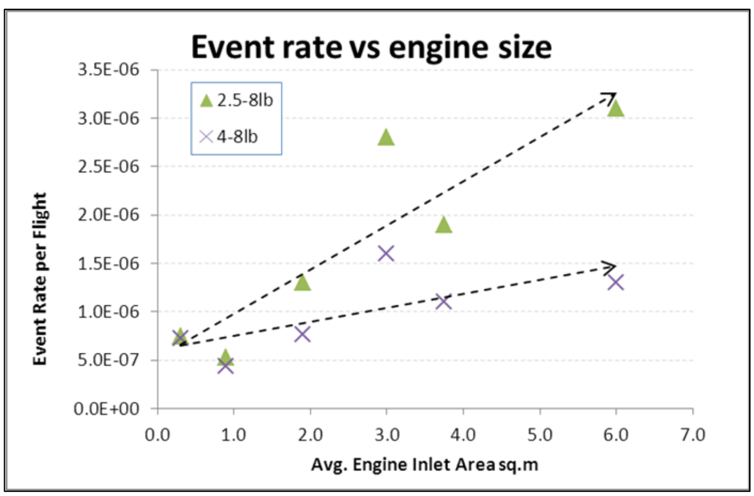


Figure 6.5.1. Ingestion Rates vs. Engine Size Class

Figure 6.5.2 shows that there is a gradual progression in weight requirements for run-on which is designed to ensure each engine size class can meet the safety objective. However, it is observed that the removal of the JAA 1.85 kg / 12% imbalance rule (JAR-E change 11, JAR-E 800 (b)(3)) took away a test demonstration of capability in the 1.35-2.5 m^2 size range (size Class D) that was not brought forward and covered by the LFB rule. Although introducing an additional requirement in this engine class does not appear to be statistically necessary to achieve the safety goal, and could effectively mean that this specific size category is meeting a safety standard beyond the other categories, the Working Group recommends that any future rulemaking activity continues to investigate potential means of assuring capability of future turbofan designs to safeguard the future fleet in this important size category.

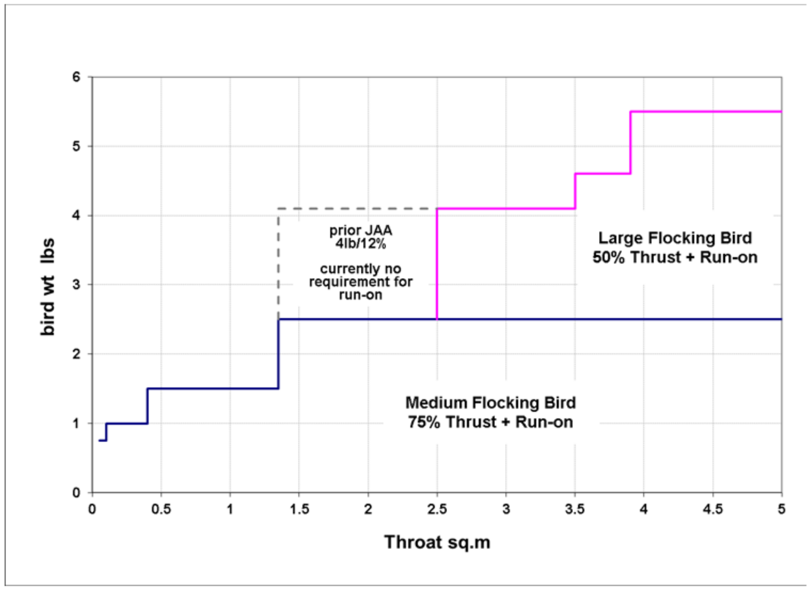


Figure 6.5.2. Current Flocking Bird Demonstration Requirements

6.6. Ingestion of Partial Bird vs. Full Bird

The method by which engine ingestion data is collected cannot make a clear distinction between a whole bird ingestion or a partial bird because the post-ingestion inspection is looking simply for evidence of bird remains in the engine. Large birds which impact the aircraft nose section, engine inlet or engine spinner will break apart, with fragments of the bird likely to be ingested into the engine. This leads to findings of feathers or snarge (bird matter) in the engine with subsequent reporting of a bird ingestion event, and gives the perception of a higher rate of large bird engine strikes than has actually occurred.

The expected result of a higher rate of whole birds striking the engine than actual in service is that the likelihood of a large bird strike to an engine is conservative, but the probability of engine damage given the ingestion of a large bird is understated. The low overall risk of engine damage on a per flight basis, however, remains unchanged.

6.7. Large Single Bird Test

Current ingestion regulations specify a large single bird be ingested by the fan at the critical location (historically no less than 50% span) at climb conditions with a required satisfactory outcome. This test should not result in uncontained high-energy debris, an uncontrolled fire, failure of the engine mount system leading to inadvertent engine separation, or loss of capability to shut the engine down.

These requirements are defined in FAR 33-75 paragraph (g)(2) and apply to other engine certification tests such as a full fan blade loss containment demonstration. The large single bird ingestion test then becomes a demonstration that ingestion of a large (up to 8 lbs. depending on engine size) single bird will not result in more than a full blade release. As such, this test does not necessarily drive improved bird strike tolerant designs because the loss of a full blade would be expected to liberate significantly more blade material and higher engine loads and engine containment challenges than a large bird impact at the critical span in which a fan part-span transverse fracture would be the worst case outcome.

The requirement to demonstrate continued run-on for the medium and large flocking bird ingestion tests (up to 5.5 lbs., depending on engine size) effectively drives blade structural capability to ensure that thrust requirements can be maintained and the engine can handle any resulting aerodynamic or mechanical imbalances. To achieve these desired states, fan blades typically need to resist fracture after a large flocking bird impact and have, as a result of the large flocking run-on requirement, more than sufficient integrity to meet the requirements defined for the fan blade loss demonstration. The successful demonstration of a large single bird ingestion, therefore, represents more of a demonstration of fan partial-blade loss engine capability and less relevance to improved bird strike capability.

6.8. Diminishing Returns and Payback Periods of New Regulations[6]

The typical bird strike event is best understood by using statistics and best characterized by the use of statistical modeling. This is because, for any given bird strike event, the variation of key parameters such as bird weight, engine strike location, operating speeds, etc. is essentially random and most easily described in the form of a statistical distribution. The most obvious example of this is the bird weight distribution shown in Figure 6.8.1.

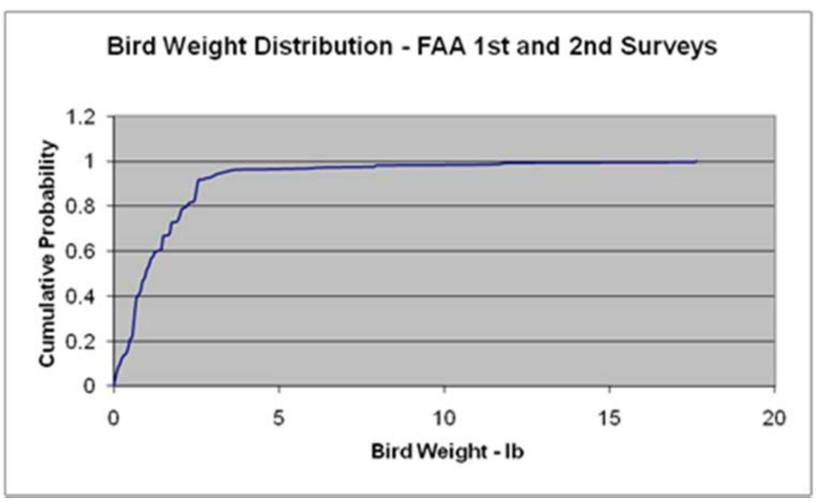


Figure 6.8.1. Bird Weight Cumulative Probability in Ingestion Events

Here the probability of ingesting a bird of a given size, and hence the population distribution, is described using historical data. Two conclusions about the bird population may be immediately drawn from the shape of this curve. The first is that the bird population distribution is very non-linear and the second is that the bulk of the population is biased toward the lighter end; i.e. ingestions with heavier birds are relatively unlikely.

The current medium bird weight for certification testing for large engines is 2.5 lbs. From Figure 6.8.1 it is clear that approximately 90% of all ingested birds weigh 2.5 lbs. or less. The conditions that the medium bird certification test is performed at are very much the worst of all possible such that the capability demonstrated by a 2.5 lbs. bird test is the minimum level of capability of the engine in service to continue to produce thrust; i.e. for any bird strike, the probability with the current certification rules of an engine continuing to operate should be at least 90%.

The shape of the curve, with a distinct change in gradient around the 2.5 lbs. point means that the law of diminishing returns applies to this distribution; i.e. below this weight, a small change in test bird weight accounts for a significant part of the bird population. However, above this weight, a much bigger change in test bird weight would only account for a very modest part of the bird population. Thus, in order to make a significant improvement to the capability of engines to withstand bird strike from today's standard, engines need to be designed to withstand proportionally much larger birds than with previous rule changes.

For example, to increase the engine bird strike capability from 90% to 91% of the bird population the size of bird tested would have to increase by 16% to 2.9 lbs. – clearly a very disproportionate exchange rate. This disproportionate exchange rate becomes worse as effects such as the probability of impact location on the engine and ingestion conditions, etc. are considered because the comparison of the before and after condition becomes much more difficult to measure owing to the small number of events. Second order effects such as local bird population changes become significant when trying to determine a trend in an event where there will only ever be a low rate of occurrence.

A further consideration is the subject of fleet mix. The current level of safety experienced by the fleet is a function of the mix of engine certification standards and aircraft types. The number of cycles flown each year is on a steady upward trend which implies that older aircraft are not being retired at a higher rate than new aircraft are introduced, i.e. older aircraft tend to survive in service beyond their operations with major carriers. In addition, there is no requirement for a prospective carrier to buy a product certificated to the latest rules and new rules are known from experience to take on the order of a decade to become codified. All this means that there is naturally a significant lag between introduction of a new certification rule and being able to see the effect in terms of fleet statistics. This effect was discussed at the 2011 Bird Strike North America[6] conference and data presented based on Monte Carlo simulation showed no sudden changes after major rule revisions but rather a smooth downward trend in risk to date.

Data was also presented looking forward over the next 20 years and considering three scenarios:

1. The fleet continued to expand at its current rate and the fleet mix of engine certification standards and aircraft types was maintained (OFOR).

2. The fleet continued to expand at the current rate but carriers were constrained only to expand by acquiring aircraft with engines certificated to the latest rules (NFOR).
3. The fleet continued to expand with carriers constrained only to expand by acquiring aircraft certificated to the latest rules but incorporating a rule change for one of the classes of engine in 2012 (NFNR).

The results shown in Figure 6.8.2 indicate curve NFNR is not significantly different from curve NFOR. What this study clearly shows is that future risk to the fleet is very much dependant on the current fleet mix and that incorporation of a new rule takes significant time (>20 years) to become effective. What the graph also shows is that the trend is still downward but is beginning to asymptote. This is essentially a reflection of the bird population distribution and indicates that as the fleet becomes safer, gross change becomes more difficult to do through rulemaking alone.

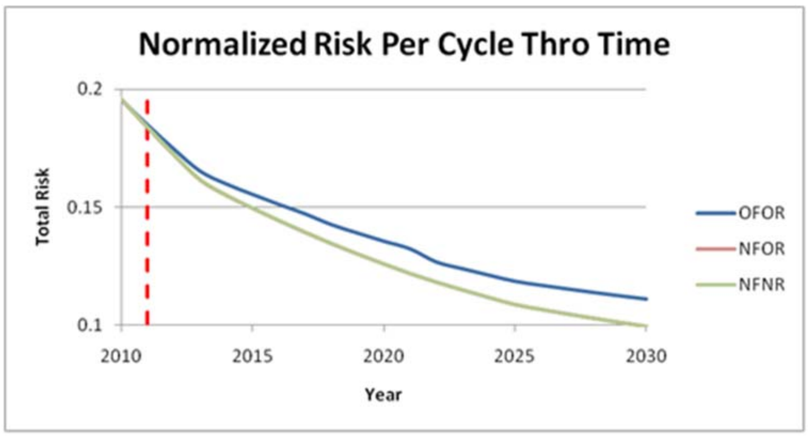


Figure 6.8.2. Predicted Reduction of Risk with Time

6.9. Increase Emphasis on Bird Detection/Avoidance Technology

In service, the level of risk experienced at the airframe level from engine bird strikes is simply a function of the capability of the engine and the rate of occurrence. As discussed in Section 6.8, improving the capability of the engine is relatively difficult to do and inevitably takes a long time due to the established size of the fleet. Any reduction in the rate of occurrence, however, has a direct linear effect on the ultimate level of risk experienced by the airframe and is a much more effective way of improving the level of safety particularly as any installed system is likely to have immediate effect rather than a response time measured in years.

Systems using detection methods such as radar and infra-red are currently being trialed at major airports worldwide and offer real time detection of bird threats. There are some issues with this approach in that once a bird and an aircraft have been established as being on a potential collision course, what should be done with the information and what avoiding or mitigating action, if any, may be taken. This can only be the subject of further discussion by all interested parties but it remains the case that real time detection of the bird threat is the most direct means of making a step change in fleet risk levels.

7. RECOMMENDATIONS

7.1. Rulemaking

The NTSB issued three safety recommendations addressing the current turbofan bird ingestion regulatory requirements. The NTSB recommendations are presented below with the Phase III bird Working Group recommendations and comments provided based on the recent analysis of the bird strike data through January of 2009.

7.1.1. NTSB Recommendation A-10-65 (Part 1)

During the bird-ingestion rulemaking database (BRDB) working group's reevaluation of the current engine bird-ingestion certification regulations, specifically reevaluate the 14 Code of Federal Regulations (CFR)33.76(d) large flocking bird certification test standards to determine whether they should apply to engines with an inlet area of less than 3,875 sq. inches (2.5m^2).

The A320 aircraft involved in the "Hudson event" used engines in the 1.35-2.5 m^2 (2092-3875 sq.ins) category (size Class D). These engines were designed prior to the LFB rule which is intended to demonstrate fan blade capability in terms of thrust loss and engine operability. The fan blades of the engines involved in the "Hudson event" were not severely damaged, and are believed to have been capable of producing substantial continued thrust. Thus the event did not indicate a deficiency in current bird ingestion requirements on the fan blades at this engine size.

The LFB rule was carefully designed taking into consideration field service data from over two decades to meet the required safety goals in each of the engine size classes (>0.4m^2) defined in the bird ingestion regulations. Appropriate flocking bird weights were assigned to each engine class based on probabilistic methods which then used projected ingestion experience in terms of weights and rates for that category. Since the 1.35-2.5 m^2 category was predicted to meet the 1E-9 safety objectives with the 2.5 lbs. MFB demonstration as is presently performed, it has been concluded that there was no need to introduce a heavier flocking bird test at the LFB derated conditions as was done for larger engines (>2.5 m^2). The field service data supported this conclusion. This is believed to be due to a couple of factors:

- Smaller engines ingest heavier birds at lower rates – see Fig. 6.5.1.
- The critical span impact height for the MFB is outboard of the 50% span height required by the LFB test, and since these impact locations would be within just a few inches on such relatively short (<25") fan blades, the natural increase in blade thickness, and thus capability, at lower spans to meet physical retention requirements will result in a sufficiently heavier LFB capability at lower spans.

Improvements in bird strike capability due to earlier rule changes are being reflected in the fleet experience, and it will continue to improve as discussed in Section 5.3. The effects of the LFB rule will not be seen for many years, but this rule will apply to many of the engines which will power the next versions of the mid-sized aircraft class which is currently powered by 1.35-2.5 m^2 engines, thus future fleets should show further safety gains.

In the current field service data period (2000-2008) the 1.35-2.5 m^2 (Class D) engines are the most statistically significant category with over 117 million flights. There were 159 engine ingestions of bird species identified with average weights over 2.5 lbs. and up to 8 lbs., and an additional 207 events where, based on damage levels, a bird of 2.5-8 lbs. was suspected to have been ingested. Although multi-engine ingestion rates of 2.5-8 lb. birds are ~37% higher than originally predicted by the LFB committee (8.5E-8 compared to 6.2E-8), there is an improvement in power loss rates compared to the Phase II Monte Carlo analyses of 21% (0.086 vs 0.109 per event), which offsets the increase in ingestion rates resulting in a calculated rate of catastrophic consequence of 1.02E-9, which is ~8% higher than the 0.94E-9 quoted in the Phase II final report. Although this is slightly higher than the safety goal, but as noted this method is conservative and the fleet is expected to meet the safety goal in practice because of the introduction of new engines to the fleet which are certified to later, more stringent, certification standards. Thus, over the years, it is anticipated that newer engines will meet the safety goal without an additional LFB test demonstration requirement.

The introduction of § 14CFR33.76 increased the MFB requirement from 1.5 lbs. to 2.5 lbs. at critical conditions with a 20 minute run-on instead of 5 minutes for this engine class. Engines designed to this new regulation comprise 22% (Table 6.2) of the current fleet data, and are showing improved power loss rates (see Section 6.2), although this data cannot be shown to be statistically different yet. However, it is expected that as engines designed to this new regulation become predominant in the fleet, overall power loss rates will continue to improve and further increase the safety margin to requirements.

The LFB test is at a derated condition, and requires only 50% thrust capability instead of 75% for the MFB. As shown in Fig. 6.5.2, the steady ramping up of requirements with engine size to meet the threat does not reveal a "gap" in the requirements in the 1.35-2.5 m^2 class. It is understood that birds >2.5 lbs. will be ingested, but adding an LFB test between 2.5 lbs. and 4.1 lbs. with the LFB test conditions would not significantly affect the blade design requirements.

The ingestion rate of 2.5-8 lb. birds has been relatively constant (see Fig. 4.2.2) for almost three decades. The major goose populations (Canada and Snow) appear to have flattened after growing rapidly through the 90's, this is reflected in the flattening of 4-8 lb. single engine ingestions (Fig. 4.2.2). The annual number of 4-8 lb. MEIs is not showing an increasing trend. Thus the threat is not significantly increasing as it did through the 1990's.
The prior LFB committee concluded that the current MFB critical test conditions effectively drive capability for larger birds in this size class; based on the latest data and engineering judgment, this Working Group has drawn the same conclusion.

Based on these observations, a Large Flocking Bird test requirement for engines less than 2.5 m^2 is not recommended since the current 2.5 lbs. Medium Flocking Bird test is providing sufficient margin for larger birds. However, it is observed that the removal of the JAR-E 12% imbalance rule removed a test demonstration of capability in this size range that was not brought forward and covered by the LFB rule. The Working Group recommends that any future rulemaking activity identify means to introduce a requirement which assures capability of future fan designs in this engine size class against an LFB threat.

7.1.2 Recommendation A-10-65 (Part 2) and A-10-64:

During the bird-ingestion rulemaking database (BRDB) working group's reevaluation of the current engine bird-ingestion certification regulations, specifically reevaluate the 14 Code of Federal Regulations (CFR) 33.76(d) large flocking bird certification test standards to determine whether they should ……include a requirement for engine core ingestion. Modify the 14 Code of Federal Regulations 33.76(c) small and medium flocking bird certification test standard to require that the test be conducted using the lowest expected fan speed, instead of 100-percent fan speed, for the minimum climb rate.

Although these are two separate recommendations, they will be treated together since both recommendations are requesting a reassessment of the current core ingestion certification criteria.

The Hudson event was caused by power loss on both engines due to ingesting large amounts of material into the cores of both engines. As noted above, the Large Flocking Bird (LFB) rule was developed to ensure that there was sufficient capability demonstrated in the large-engine fan blade designs against birds >2.5 lbs., power loss due to core ingestion was not perceived to be a significant risk at that time and was not specifically addressed. The rationale for this was that power loss would be predominantly driven by fan blade transverse fractures, material loss or significant leading edge foldover, which are more likely to occur (based on experience and engineering judgment) due to impacts at or above 50% span where fan blade cross-sections are relatively thin to address the higher relative Mach numbers. Lower sections of the fan blades are significantly more robust to meet the strength requirements for restraining the outer span blade sections. Thus the only requirement specific to the core is in the medium bird (MFB) test.

The MFB rule was designed to test the critical takeoff conditions (i.e. performed at conditions which would be critical for safety of flight). Typically, this would be a multi-engine flock ingestion after the aircraft has reached V1 during takeoff. At this phase of flight, if power were lost on multiple engines there would be insufficient runway available to perform a safe rejected takeoff, and the thrust available may be insufficient to perform an air turnback, thus an accident would be more likely. For this reason, the test is performed with the engine at maximum takeoff thrust, and the birds at a speed which is calculated to produce maximum stress in the fan blades in the aircraft takeoff speed range above V1. Since the requirement is for multiple birds to be ingested within one second, the test is performed at fan blade critical conditions in terms of fan rpm and bird speed. This is a good requirement since birds will always strike the fan blades first, and in modern high bypass ratio engines only ~10% will pass through the fan into the core, the remainder passing into the bypass duct. Performing the test at fan-critical parameters for birds which strike outside the core region should not be changed as this is a severe test for the fan.

The "Hudson event" occurred during climb, five miles from the airport and ~2,800ft altitude. At this phase of flight it is normal for engine power and fan rpm to be reduced, and the aircraft to be flying much faster than V1. This means that a bird ingestion at the root of the fan blade will result in a higher mass of bird remains ingested into the core than at the tested fan-critical condition.

A core test with the currently defined LFB's, which weigh from 4.1 to 5.5 lbs. would mean increasing the weight of bird aimed at the core by +60% to 120% above the current 2.5 lbs. requirement, and the conditions of higher bird speed and lower fan rpm would also be more severe. This would require a significant step change in engine design and technology, and based on the service experience data it is not believed that such a change is necessary to achieve the required safety goals.

The Working Group believes that the current core ingestion certification requirements may not be as rigorous as intended when the Phase I rule was designed. The Working Group recommends a rulemaking activity with the goal to define changes to the core ingestion requirements and render future engines more tolerant to this threat (e.g. define a condition which is more critical for core ingestion in terms of ingested bird mass and/or rotor speeds and bird speed).

Although the LFB test was designed using probabilistic methods utilizing the gathered field data, similar probabilistic methods may not be readily applicable to core ingestion capability, and a combination of probabilistic analysis and engineering judgment will be necessary in this process.

7.2. Field Management Recommendations

Avian threats to aircraft and engines have been shown to evolve as the environment, habitat, and food availability change over time. It is important too that bird populations and migration patterns be continuously monitored and evaluated going forward for changes which might adversely affect the established rate of single and multi-engine ingestion events and result in new challenges to meeting the current safety objective.

Based on current records of the larger bird species ingested as a percent of the total ingestion counts, the populations of Canada goose, Snow goose and Black and Turkey vultures should continue to be monitored for increasing population trends.

The population trend data for large flocking birds provided to the Phase II committee drove changes to the regulations in anticipation of a predicted increased strike rate over the following decade. Although the population trends for these large flocking birds finally appears to be leveling over the past decade, the rulemaking response was appropriate for the predicted threat; the recent data, while not yet statistically conclusive, suggests improvements in overall power loss rates driven by more recent engine designs.

7.3. Recommendations for Bird Strike Data Collection

The analysis of bird ingestion rates and engine outcomes is completely dependent on quality information being provided from the field. The most critical data needed includes aircraft flight phase (for bird to blade relative velocity estimates), fan/core strike location, bird species (avian mass), and outcome (engine thrust capability). Of these critical items, obtaining credible bird identifications proved the most elusive. Of the 11300+ entries in the database only about 18% contained bird identifications sufficiently definitive to establish a bird weight at a credible level. An aircraft flight phase was provided 55% of the time, and a strike location was specified on 37% of the reports. The ability to determine continued thrust capability after a bird strike is either self-evident (uncommanded IFSD) or required some level of analysis based on documented engine damage and experience. It is believed that damage assessments were provided in most cases where a question of thrust capability was raised because there was an impact on aircraft operations.

Large birds are reported on a more consistent basis than the small birds. This was noted in the Phase II Bird Working Group final report[5] where it is observed that large flocking bird strike reports are less variable during contract years relative to the small bird ingestion reports. This suggests that birds most likely to result in some level of engine damage (e.g. bird size class I – IV) are generally being reported, and that the best use of efforts to improve reporting would be to improve on bird feather/remains collection and species identification, which would result in a significant improvement in quality of the reported data in the future.

The consistent collection of bird feathers/remains can be difficult due to the schedule demands of the aircraft and workload of the ground crew, and any non-safety interruptions or delays in returning a revenue producing aircraft back to service are economically painful to implement. Although the actual collection of feathers or remains (snarge) is a very simple and quick process, the process may not be very familiar to the ground crew performing the post-strike engine inspection. Improvements in feather/snarge collection could be achieved by modification of the Aircraft Maintenance Manuals (AMM) to include collection instructions for avian materials and also instructions on contacts (i.e. the airport wildlife manager, airside operations manager or local engine manufacturing representative) to collect and forward the samples for analysis. An improvement of the AMM's in this manner makes the collection of avian material an integral part of the post-strike inspection activities, and is strongly recommended.

7.4. Recommendations for Future Database Entries

The Phase III analysis efforts identified shortcomings in the data with regard to identifying power loss events that were specifically caused by core ingestion, and an inability to resolve the difference between above ground level (AGL) and pressure altitude for in-flight strikes during approach and initial climb.

The current database is only able to differentiate between strikes in which avian material was reported as found in the core gaspath and those in which there was no report of core material. As discussed in Section 3.6.8, this does not provide an accurate depiction of the rate or consequence of core ingestions in which the core is the primary strike location. Information on primary core strike events is expected to be very useful going forward in validating the assumptions about core ingestion outcomes, therefore future database entries should include a notation to identify primary strike locations and secondary finds (i.e. inlet primary, core and bypass secondary).

Ingestion reports that indicate an altitude in which the strike occurred can be confusing for strike reports during approach and initial climb because the reported altitude is not always specified as AGL or Pressure Altitude. Strikes on the ground are usually listed as 0 ft. altitude, strikes during initial climb or final approach are often expressed in AGL (Radio Altitude) while step climb, cruise, or initial approach are generally assumed to be Pressure Altitude. In the interest of clarity and simplicity, future altitude reports should all be expressed as AGL. The effect of AGL PA becomes less significant as the altitude increases given the prevalence of strikes that occur under 5000 ft., so this change would be expected to result in simpler and cleaner reporting.

To better represent the large bird ingestion data, it is recommended that the generic large be split between Classes I, II, III and IV in the same proportions as the 'real' bird identifications. Similarly, apportioning Medium and Small generic classes may also be considered.

8. FUTURE ENGINE PRODUCTS AND BIRD INGESTION CERTIFICATION REQUIREMENTS

At the current time the "Open Rotor" engine is again being considered as a potential candidate for commercial aircraft propulsion since it offers significant fuel savings over conventional turbofans. Since this type of engine is essentially a cross between a turbofan and a turboprop, i.e. an unducted multi-bladed fan propulsor driven by a turbine, it is not covered by current FAA or EASA regulations. EASA is in the process of creating rules to cover this type of engine. This committee recommends that any bird rule proposals be considered by the upcoming ARAC committee in light of the data contained herein. The collected experience of the industry and agency personnel who have been close to this issue for an extensive period of time should be utilized to develop a fully harmonized rule that is consistent with the safety goals used in developing the current bird ingestion regulations.

9. SUMMARY

i. The dedicated AIA (Aerospace Industry Association), FAA and EASA engine bird ingestion Working Group has completed its assigned task to:

   a. Evaluate the safety objective and test methods for the core ingestion element of § 33.76(c) [medium flocking bird]. The specific task was to determine whether the rule should include more critical test conditions for the core element of the current requirements.

   b. Update the Bird Rulemaking Database and to re-evaluate the large flocking bird certification requirements of § 33.76(d). The specific task was to determine whether the existing requirements can be relied upon to provide the intended level of safety over time with respect to the large flocking bird threat observed in recent service.

   c. Provide the FAA with recommended responses to related NTSB Safety Recommendations.

ii. The Working Group has reached the following conclusions that are related to these tasks:

a. Medium Bird Core Ingestion (§ 33.76(c)): The Working Group has concluded that the existing medium bird ingestion requirements are not as rigorous as originally intended by the Phase I rulemaking safety objective. The Phase I rulemaking effort was primarily focused on fan damage, as damage to fan rotating stages is considered the most likely cause of multi-engine power loss, especially during takeoff at high power and fan speed. A multi-engine power loss during this phase, would allow little time for the crew to respond, and is considered the critical scenario. The engine operating conditions (fan speed and airplane airspeed) that are critical for fan rotating stages and core ingestion are not common, and to an extent are in opposition to each other. Therefore the existing rule was primarily designed to protect against fan rotating stage damage and related power loss.

b. Large Flocking Bird Core ingestion (§ 33.76(d)): The Working Group has concluded that a large flocking bird core ingestion test is not required because this threat is a relatively small percentage of the overall risk of multi-engine power loss. Since power losses are predominately driven by fan blade damage and fracture, the current engine certification test is considered the best demonstration of overall engine capability against this threat. The previous rulemaking effort also determined that fan ingestions make up the majority of related risk, and that the safety objective of the rule is met without an additional core ingestion element to the test.

c. Overall Large Flocking Bird Safety Objective: The Working Group has concluded that the overall risk of multi-engine power loss due to large flocking bird ingestion is generally consistent with the Phase II rule safety objective. The study also shows that the multi-engine ingestion rates for the current study period are not significantly greater than the actual rates from the 2000 data and are close (statistically not different) to the predicted rates for 2010. The current rule is based on the predicted rates for 2010. Also, the new data shows that engine power loss rates for a given ingestion have generally improved over this time period. This is likely a result of the world-wide fleet now including a greater number of newer, more capable engine models. It is expected this trend will continue into the future and improve fleet safety.

d. Class D Engines: This class of engine accrues the highest number of total flights within the transport category world fleet, and thus is the most statistically significant category.
The Working Group has concluded that Class D size engines are currently operating close to the safety objective of the current rule; therefore, there is no need to include this class engine in the current large flocking bird engine test requirement at this time. Also, the Working Group expects that overall Class D fleet capability and safety margin will increase markedly in the future as engines designed to the current rule become more prominent in the world fleet. However, the anticipated improvements in safety margin rely on the capability of new technology engines to match, or exceed that demonstrated by the latest engines today.
Based on this observation, the Working Group recommends that any future rulemaking activity identify means to introduce a requirement which assures capability of future engine designs in this size class against a LFB threat.

iii. The Working Group makes the following recommendations for further rulemaking, policy and/or guidance development relative to the above tasks and conclusions:
   a. Establish an ARAC project to revise and strengthen the core ingestion element of current § 33.76 such that the original intent of the rule is achieved. This action will make future engine models more tolerant of the core threat (e.g., define a condition that is more critical for core ingestion in terms of ingested bird mass and/or rotor speeds and bird speed).
   b. Establish an ARAC project to identify a means to assure that future designs within the world fleet of Class D engines meet the intended safety objective of the current rule. Alternatives to the standard test demonstration requirements such as a basic design requirement validated by analysis should be considered.

iv. The Working Group recommends that the Bird Rulemaking Database be updated periodically (no longer than 10 yrs.) so that industry and the authorities can maintain an awareness of any changes to the bird ingestion threat observed in service.

v. The Working Group recommends that any future bird ingestion rulemaking activity for Open Rotor engines be conducted under an ARAC tasking (see Section 8 discussion).

10. REFERENCES

1. Brough, Trevor; *Average Weights of Birds*; Ministry of Agriculture, Fisheries and Food, Aviation Bird Unit, Worplesdon Laboratory, Guildford, Surrey 1983.
2. Dunning, John; CRC Handbook of Avian Body Masses, Second Edition; 2007.
3. Dunning, John; CRC Handbook of Avian Body Masses; 1992.
4. Nelson, Wayne; Applied Life Data Analysis; 1981.
5. U.S. Department of Transportation Report No. DOT/FAA/AR-TN03/60,"Study of Bird Ingestions Into Aircraft Turbine Engines (December 1968 – December 1999)", September 2003. An amendment correcting two figures is included in Appendix G.
6. Statistical Assessment of Changes in Bird Certification Rules for Aero-Engines Through Time Dr Julian Reed, paper presented at 2011 BSC-NA conference.
7. NTSB/AAR-10/03PB2010-910403; NTSB Accident Report - Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River
8. Graph courtesy of Dr. Richard Dolbeer using data from U.S. Fish and Wildlife Service Breeding Bird Survey
9. NPRM Docket No. FAA–2006–25375; Notice No.06–09 RIN 2120–AI73

11. NOMENCLATURE

AIA	Aerospace Industries Association – Association representing the United States' major aerospace and defense manufacturers and provides a forum for government and industry representatives to exchange views and resolve problems on non-competitive matters related to the aerospace industry.
Airplane Event	A bird event which has one or more engine ingestions, a bird strike to the airplane without an engine ingestion is not included
ARAC	Aviation Regulatory Advisory Committee

Bird weight classes (based on species average weights) – see Section 3.6.7

CARS	Civil Aviation Regulatory and Safety Committee under AIA
EHWG	Engine Harmonization Working Group

Engine size class – see Sections 3.6.5 and 3.6.6

EPL	Engine Power Loss (engine considered incapable of continued operation at ≥50% rated take-off thrust)
Ingestion Rate	Airplane events per cycle
Inlet hilite	The ring formed by the forward-most points on the inlet lip.
LFB	Large Flocking Bird - Birds which weigh over 2.5 lbs. which tend to travel in large organized flocks and are generally represented by waterfowl such as Snow and Canada Geese, and Double-crested Cormorants.
MEI	Multi-Engine Ingestion
MFB	Medium Flocking Bird - Birds which weigh over 1 lb. up to 2.5 lbs. that tend to travel in large organized flocks typically represented by various gull species, and smaller waterfowl such as ducks.
Phase I	The initial ARAC rulemaking committee which developed the § 14CFR33.76 Amendment 20 requirements using data gathered through 1995.
Phase II	The ARAC rulemaking committee which developed the § 14CFR33.76 Amendment 23/24 (LFB) requirements using data gathered through 1999.
Phase III	The current CARS committee which reviewed the turbofan engine fleet experience with respect to § 14CFR33.76 Amendment 23/24 LFB requirements and NTSB recommendations A-10-64 and A-10-65 using data gathered through January 2009.
SEI	Single Engine Ingestion
Snarge	Bird matter – remains of birds, often only stains, which are found after bird strikes. This can be used to obtain species identification either through DNA analysis, or from embedded microscopic feather material.
Span Height	The distance from the base of the fan blade leading edge above the flowpath surface where it is exposed to the airstream to the tip.

Appendix A. List of Working Group Members

Les McVey	GE Aviation	Co-Chairman
Chris Demers	P&W	Co-Chairman
Angus Abrams	EASA	
Mark Beauregard	P&W Canada	
Marc Bouthillier	FAA	
Philippe Feuillard / Marc Rieugnie	Airbus	
Chip Queitzsch	FAA	
Herve Quineou	Snecma	
Julian Reed	Rolls-Royce	
Russ Repp	Honeywell	
Todd Sigler	AIA	
Terry Tritz	Boeing	

Appendix B. National Transportation Safety Board Investigation

The NTSB investigation into the US Airways 'Hudson' event included a public hearing. All of the presentations are available in the docket at this site:
http://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=47230andCFID=66829andCFTOKEN=93514487

NTSB recommendations are included in the Final Report[7], those relevant to the engines (A-10-64 and A-10-65) are contained in Section 7.1.

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

Table C.1. Engine Models and Bird Rule Certification Basis (see Section 1.3)

Engine Model	Bird Rule Certification Basis	FAA Equivalent
AE2100	FAR 33-77 A10	
AE3007	FAR 33-77 A10	
ALF502	AC 33-1	
AS907-1	FAR 33-76 A20	
BR710	JAR-E Change 8	FAR 33.76 A20
BR715	JAR-E NPAE-20	FAR 33.76 (Draft)
CF6-6	AC 33-1	
CF6-50	AC 33-1	
CF6-80A	FAR 33-77 A6	
CF6-80C2	FAR 33-77 A6	
CF6-80E	FAR 33-77 A10	
CF34-3	FAR 33-77 A6	
CF34-8C	FAR 33-76 A20	
CF34-8E	FAR 33-76 A20	
CF34-10E	FAR 33-76 A20	
CF700	AC 33-1	
CFE738	FAR 33-77 A10	
CFM56-2C	FAR 33-77 A6	
CFM56-3	FAR 33-77 A6	
CFM56-5A	FAR 33-77 A10	
CFM56-5B	Far 33-76 A20	
CFM56-5C	Far 33-77 A10	
CFM56-7B	Far 33-76 A20	
CJ610	AC 33-1	
CT-7	AC 33-1	
DART	CAR 10	AC 33-1
GE90-90	FAR 33-76 A20	
GE90-100	FAR 33-76 A24	
GP7200	FAR 33-76 A24	
JT3D	AC 33-1	
JT8D-Std	AC 33-1	
JT8D-200	AC 33-1	
JT9D-3	AC 33-1	
JT9D-7R4	FAR 33-77 A6	
JT9D-70	FAR 33-77 A6	
JT15D	AC 33-1	
LF507	AC 33-1	
OLYMPUS	AC 33-1	

Table C.1. Engine Models and Bird Rule Certification Basis (Cont)

Engine Model	Bird Certification Basis	FAA Equivalent
PW305	FAR 33-77 A10	
PW306	FAR 33-77 A10	
PW307	FAR 33-76 A20	
PW308	FAR 33-76 A20	
PW530	FAR 33-77 A10	
PW535A	FAR 33-77 A10	
PW535B	FAR 33-76 A20	
PW535E	FAR 33-76 A24	
PW545A	FAR 33-77 A10	
PW545B	FAR 33-76 A20	
PW545C	FAR 33-76 A20	
PW610	FAR 33-76 A20	
PW615	FAR 33-76 A20	
PW617	FAR 33-76 A20	
PW2000	FAR 33-77 A6	
PW4000	FAR 33-77 A6	
PW4084	FAR 33-76 A20	
PW4098	FAR 33-76 A20	
PW4168	FAR 33-77 A6	
PW6000	FAR 33-76 A20	
RB211-22	BCAR Section C, issue 6	AC 33-1
RB211 524-D	BCAR Section C, issue 6	AC 33-1
RB211 524-G	JAR-E Change 6	FAR 33-77 A6
RB211 535-C	BCAR Section C, issue 6	AC 33-1
RB211 535-E4	BCAR Section C, issue 6	AC 33-1
Spey	BCAR Section C, issue 6	AC 33-1
Tay	JAR-E Change 6	FAR 33-77 A6
TFE731-2/-3/-4	AC 33-1	
TFE731-5	FAR 33-77 A6	
TFE731-20/-40	FAR 33-77 A10	
TFE731-50	FAR 33-76 A20	
TFE731-60	FAR 33-77 A10	
Trent 500	JAR-E NPAE-20	FAR 33.76 (Draft)
Trent 700	JAR-E Change 8	FAR 33.76 A20
Trent 800	JAR-E Change 8	FAR 33.76 A20
Trent 900	JAR-E Amendment 11	FAR 33.76 (Draft)
Trent 1000	FAR 33-76 A21	
V2500	FAR 33-77 A10	

Appendix D. Comparison of Inlet Throat Area and Fan Diameter Classes

Currently, the fan diameter and throat area classes are not well aligned as shown in Figure D.1.

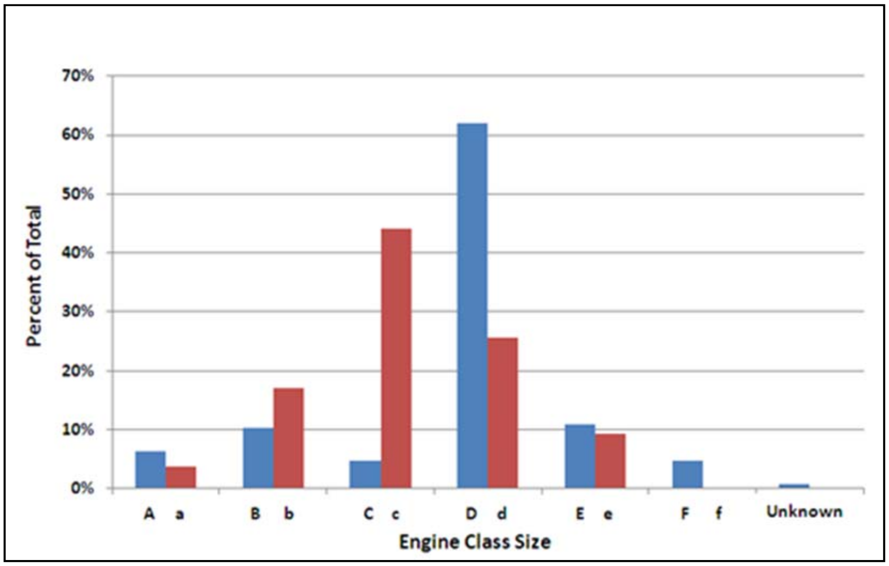


Figure D.1 Comparison of Engine Size Based on Area and Fan Diameter Within the Data Set

If comparisons are required in future work, it is recommended to adjust the fan diameter classes as shown in Figure D.2. Instead of using 20-inch steps for each class, the ranges shown (10-30, 30-55, 55-75, 75-89, 89-94, >94 ins.) will better align the throat area and fan diameter classes. This will allow consistent comparisons, and may also be useful for future technology engines with unducted fan blades where no throat area can be defined.

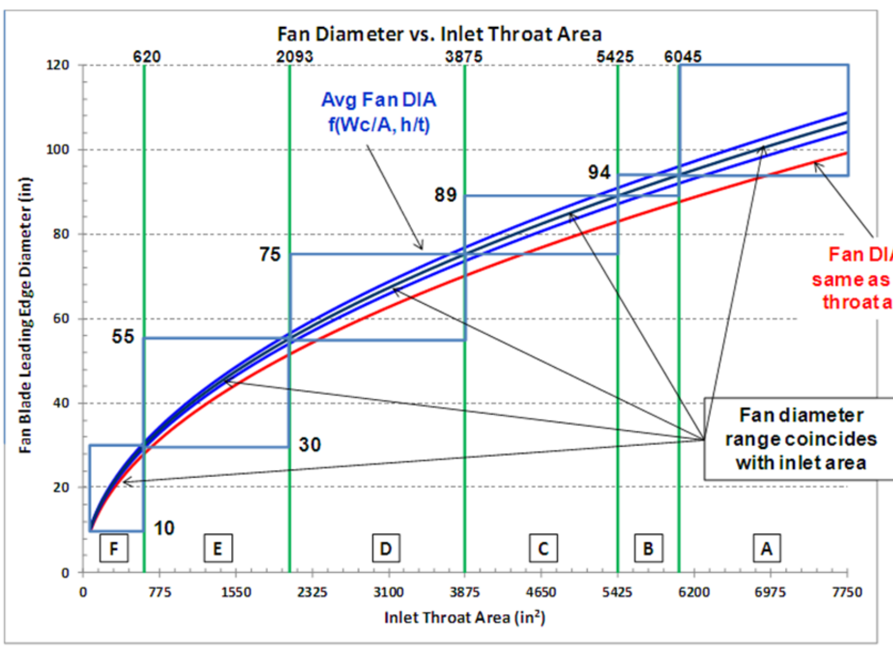
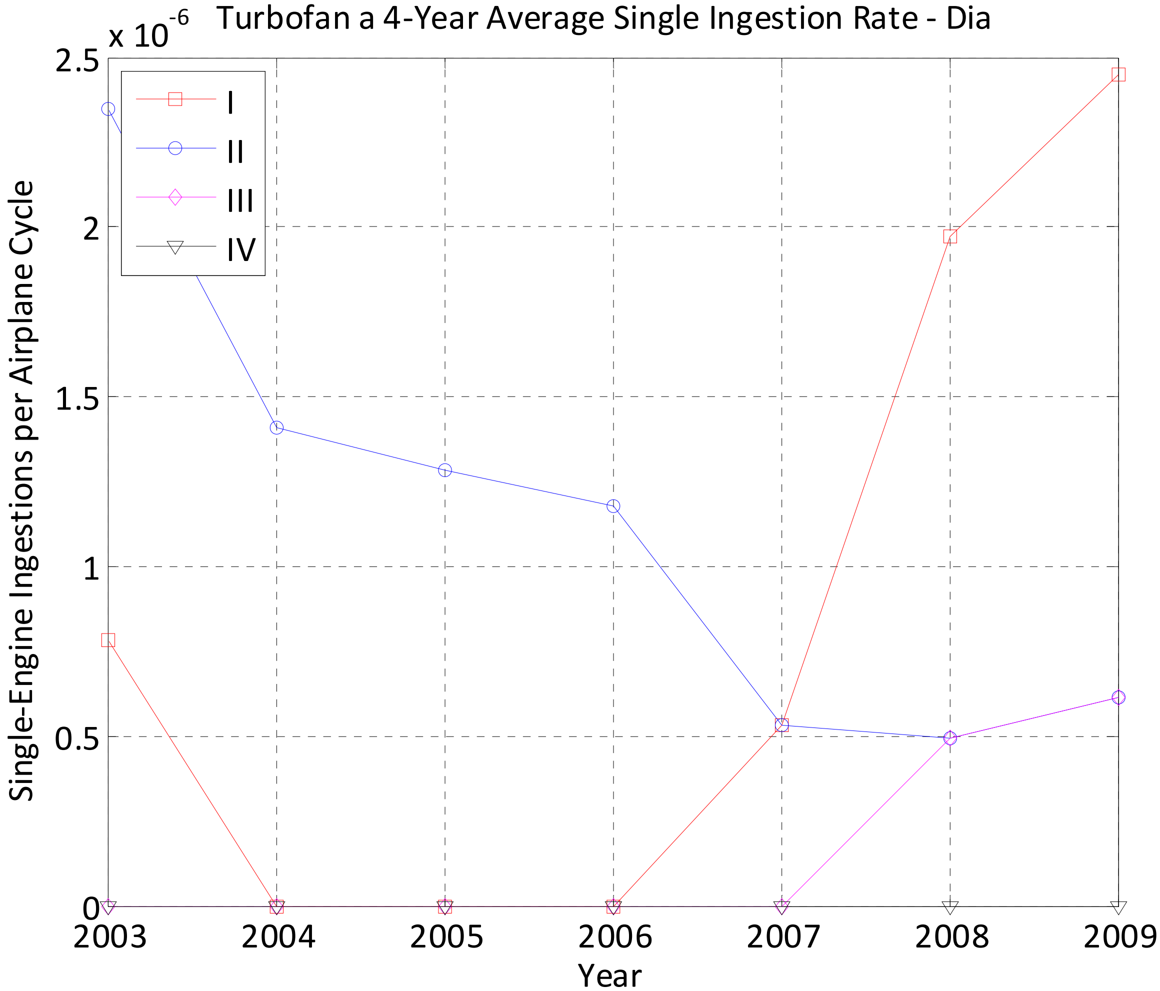
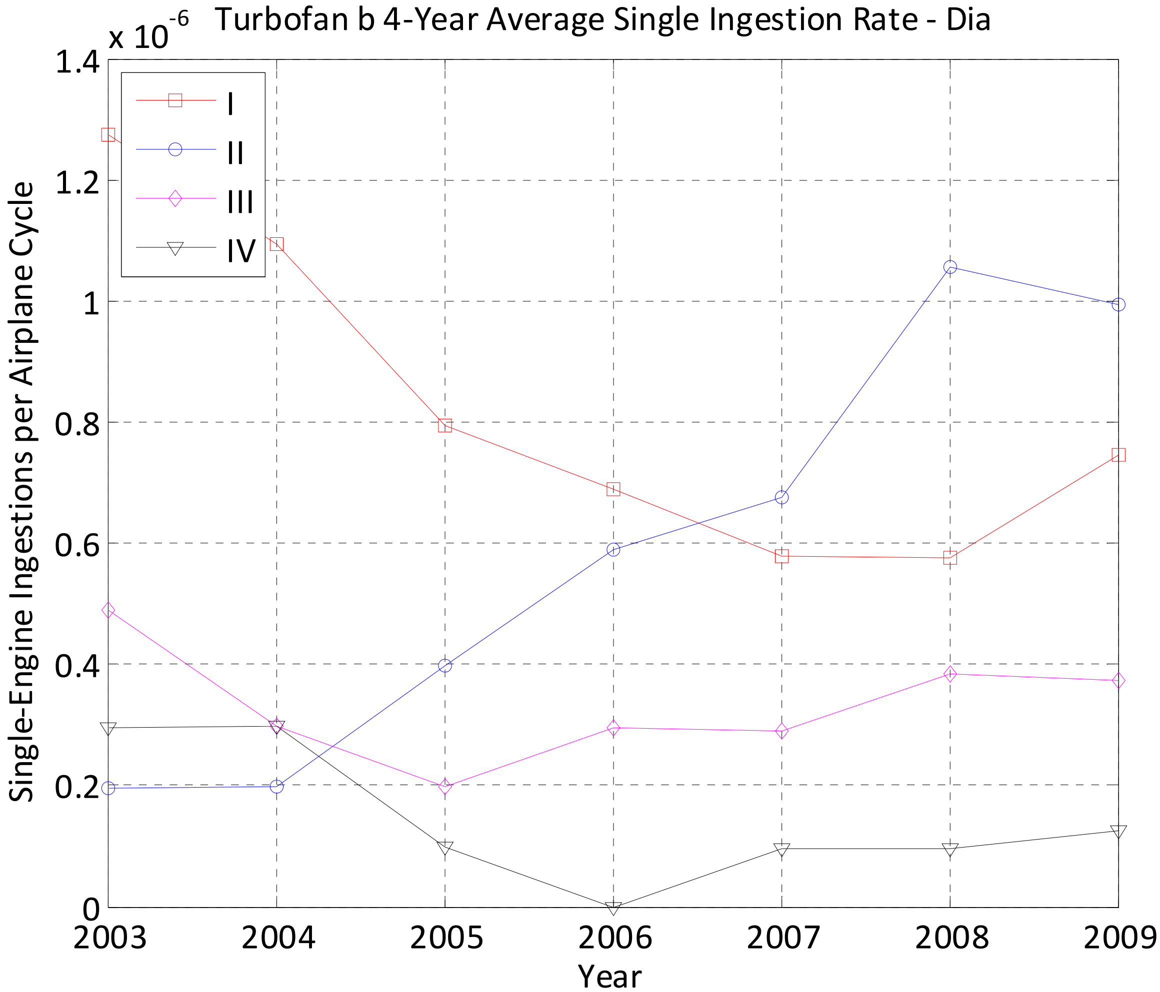
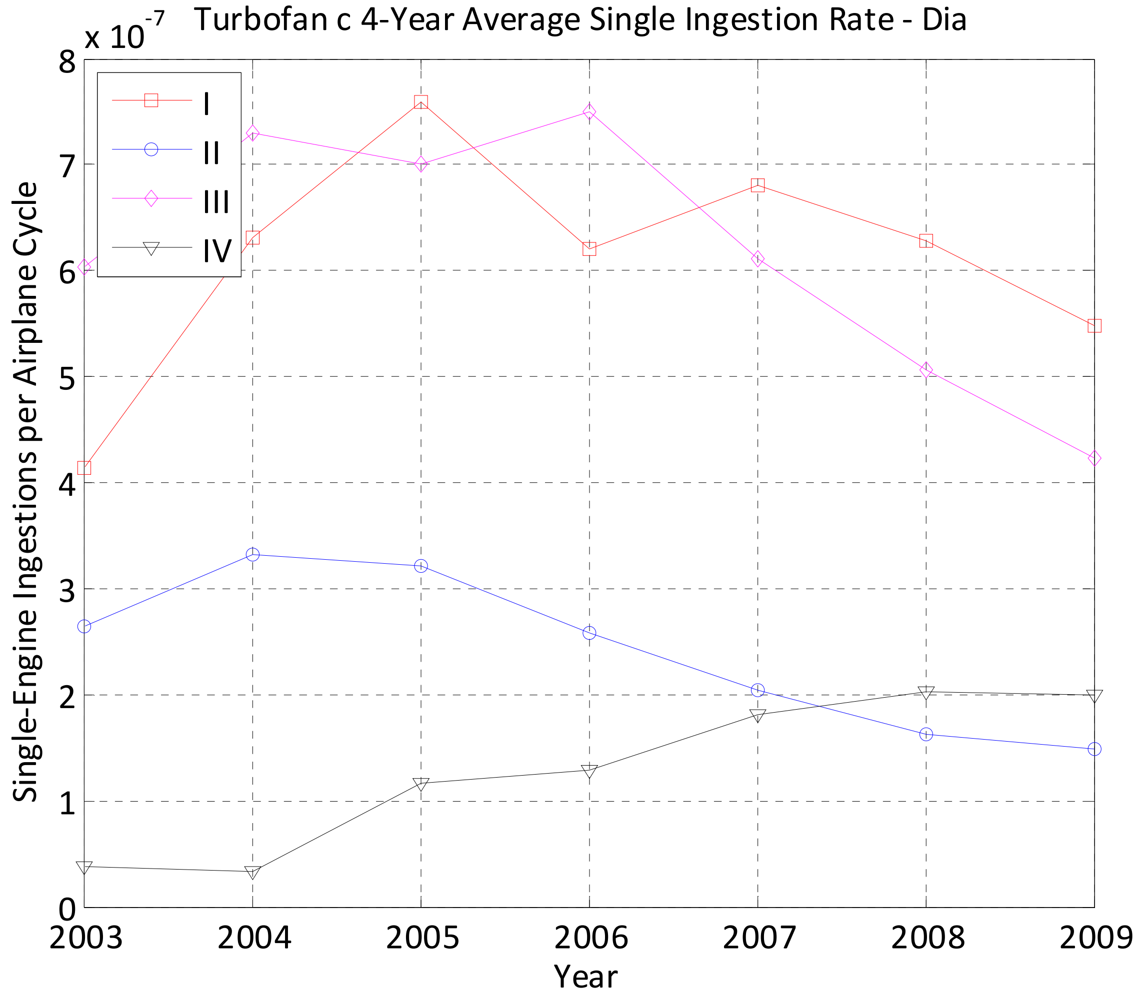


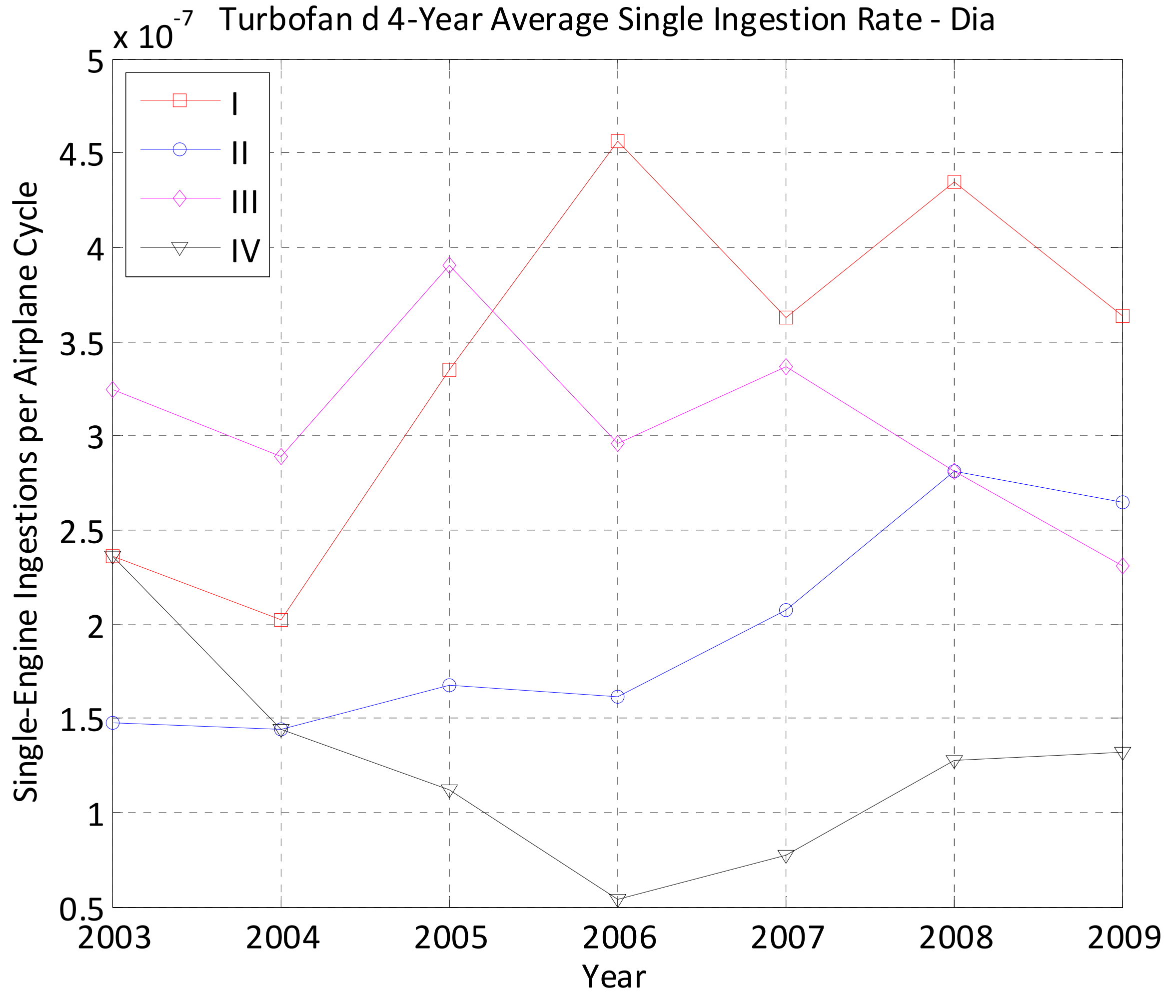
Figure D.2 Reclassification of Fan Diameter Ranges to Better Align with Engine Areas


Turbofan a 4-Year Average Single Ingestion Rate - Dia
x 10^-6
2.5
2
1.5
1
0.5
0
I
II
III
IV
Single-Engine Ingestions per Airplane Cycle
2003
2004
2005
2006
2007
2008
2009
Year

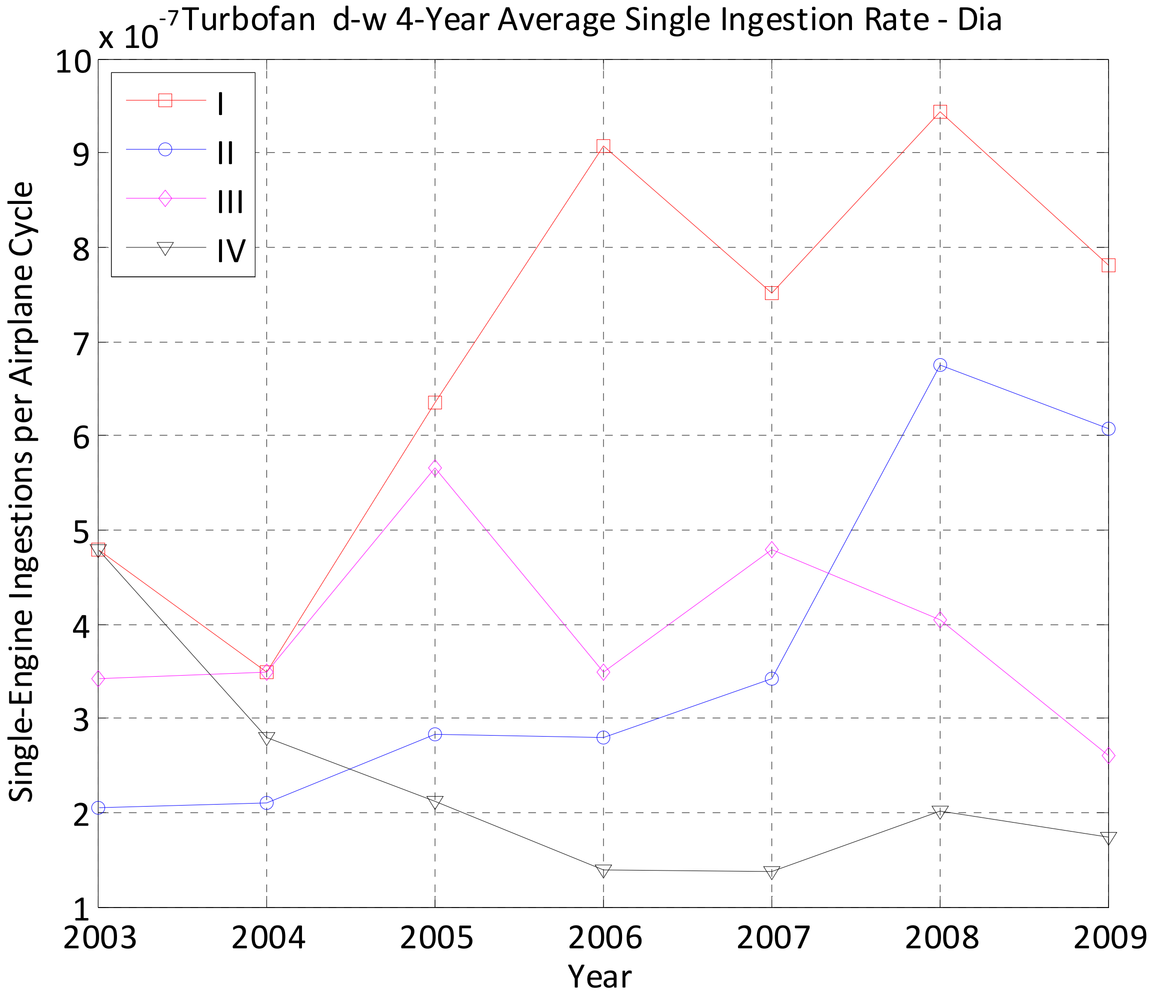


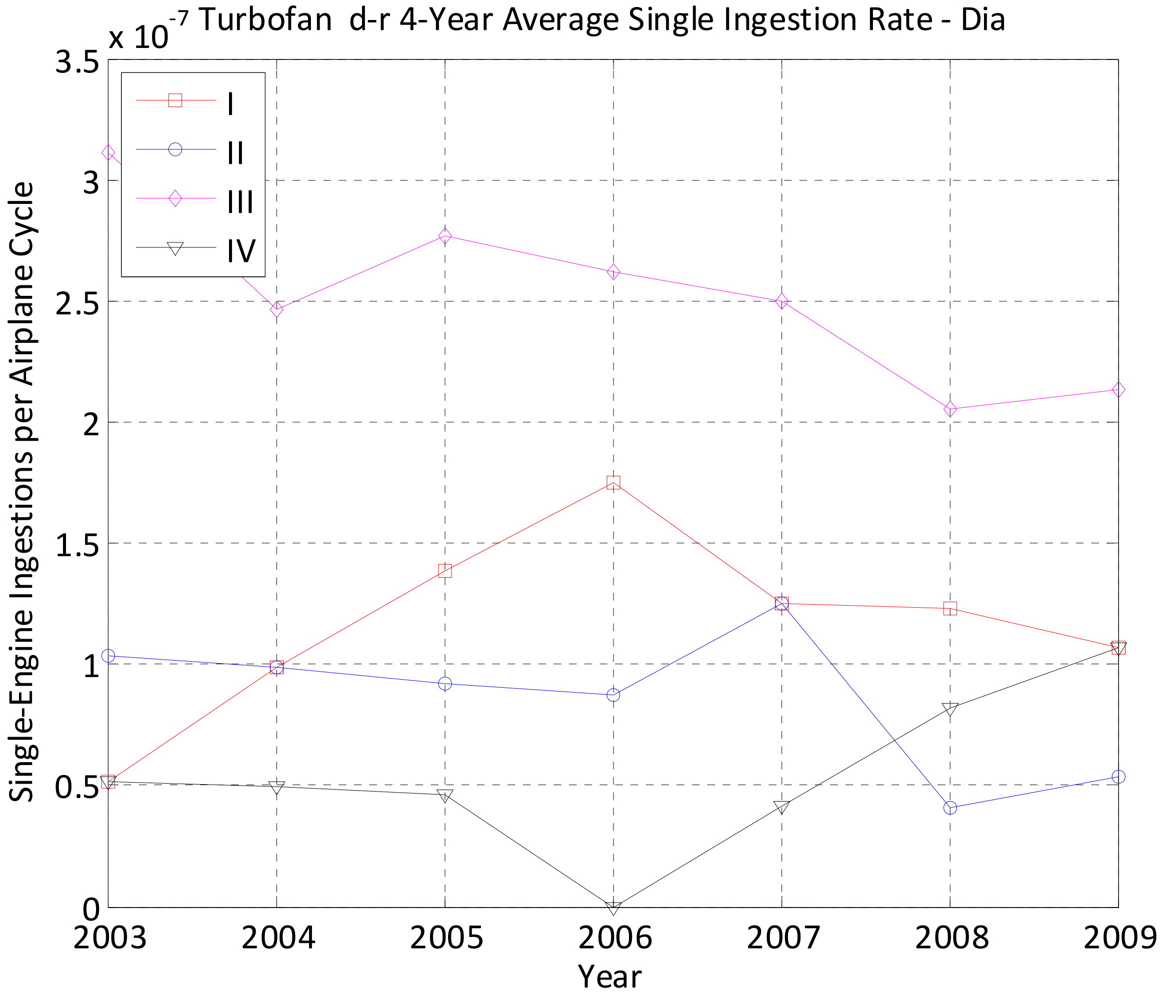
Turbofan b 4-Year Average Single Ingestion Rate - Dia
x 10^-6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Single-Engine Ingestions per Airplane Cycle
I
II
III
IV
2003
2004
2005
2006
2007
2008
2009
Year

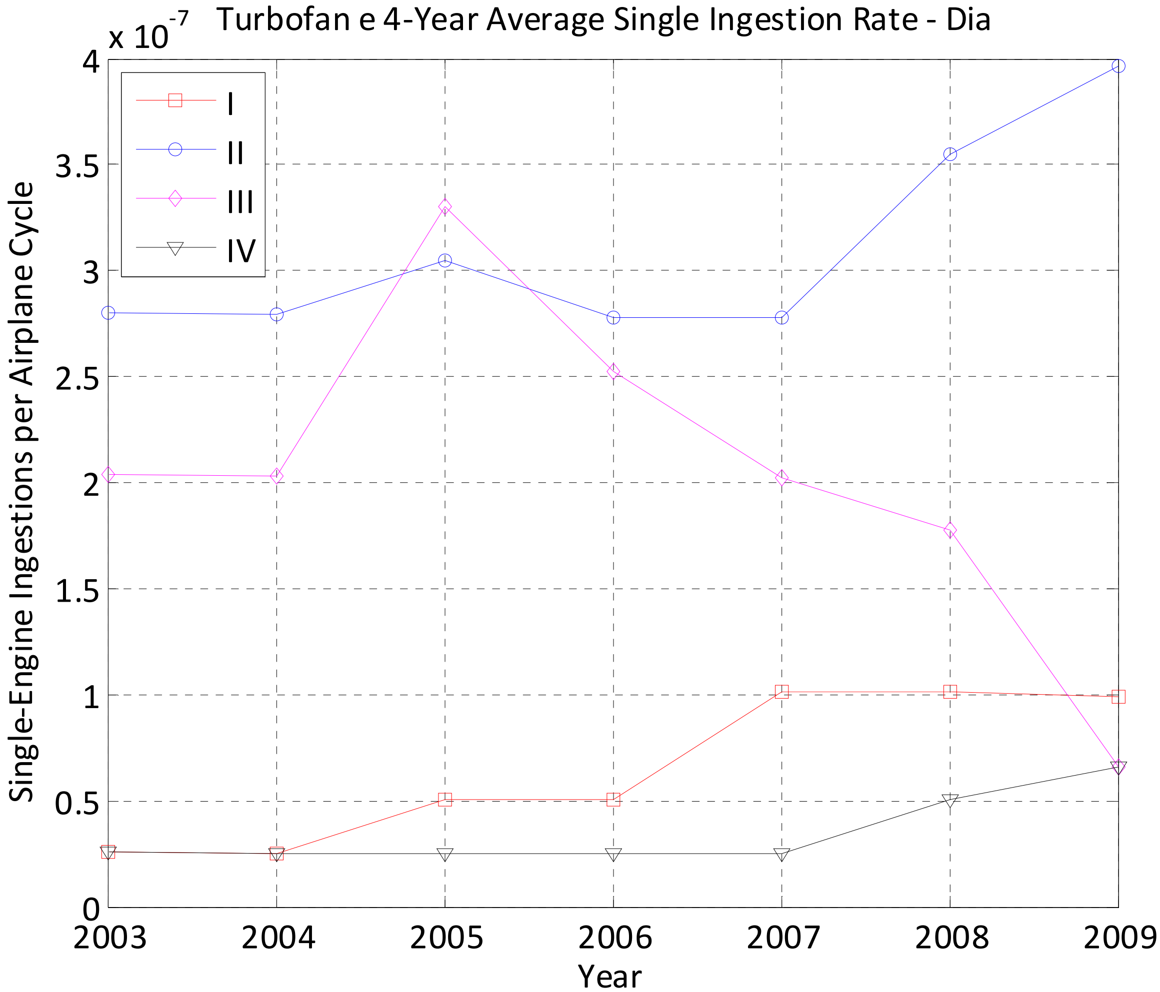

Turbofan c 4-Year Average Single Ingestion Rate - Dia
x 10^-7
Single-Engine Ingestions per Airplane Cycle
Year
0
1
2
3
4
5
6
7
8
2003
2004
2005
2006
2007
2008
2009
I
II
III
IV



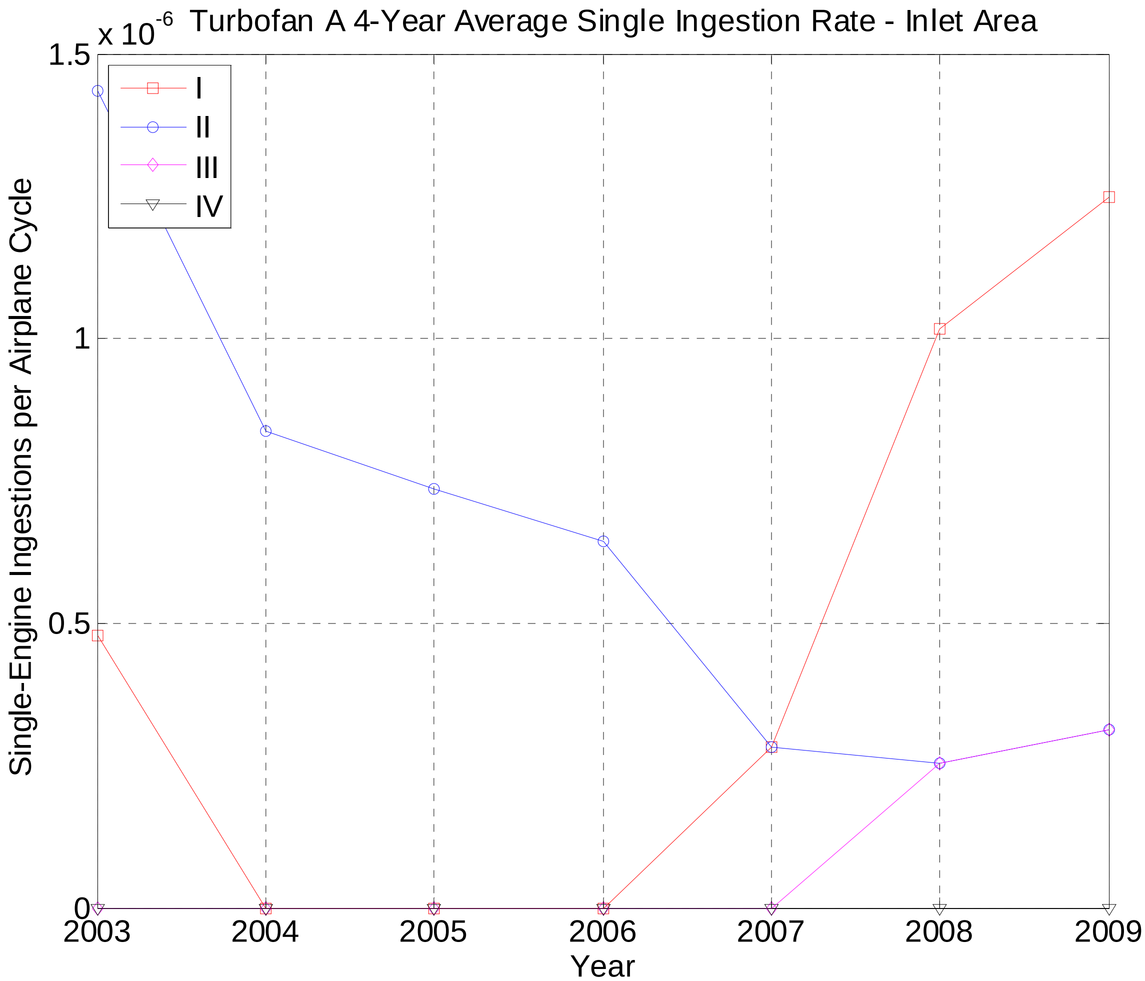
Turbofan d 4-Year Average Single Ingestion Rate - Dia
x 10^-7
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
Single-Engine Ingestions per Airplane Cycle
I
II
III
IV
2003
2004
2005
2006
2007
2008
2009
Year


x 10^-7 Turbofan d-w 4-Year Average Single Ingestion Rate - Dia
Single-Engine Ingestions per Airplane Cycle
Year
I
II
III
IV
10
9
8
7
6
5
4
3
2
1
2003
2004
2005
2006
2007
2008
2009

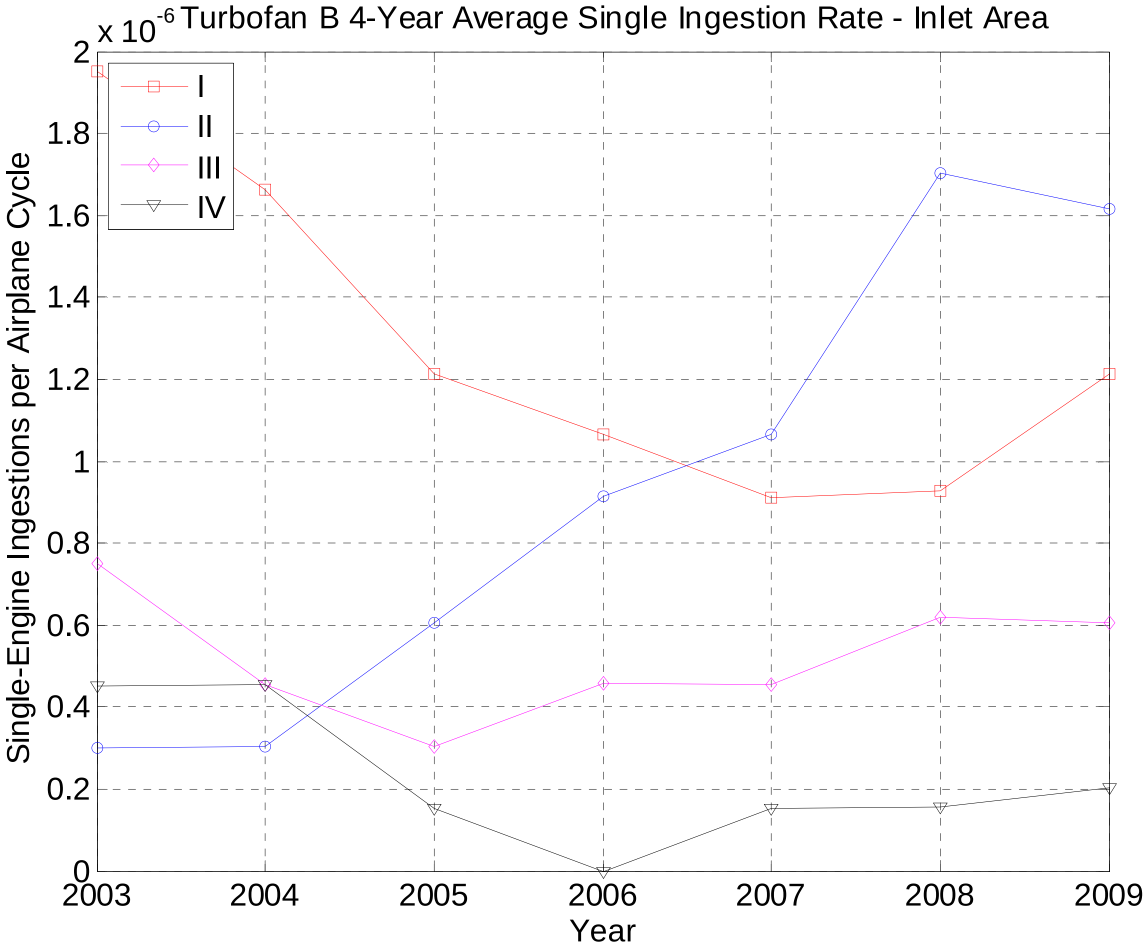

x 10^-7 Turbofan d-r 4-Year Average Single Ingestion Rate - Dia
Single-Engine Ingestions per Airplane Cycle
Year
I
II
III
IV
0
0.5
1
1.5
2
2.5
3
3.5
2003
2004
2005
2006
2007
2008
2009

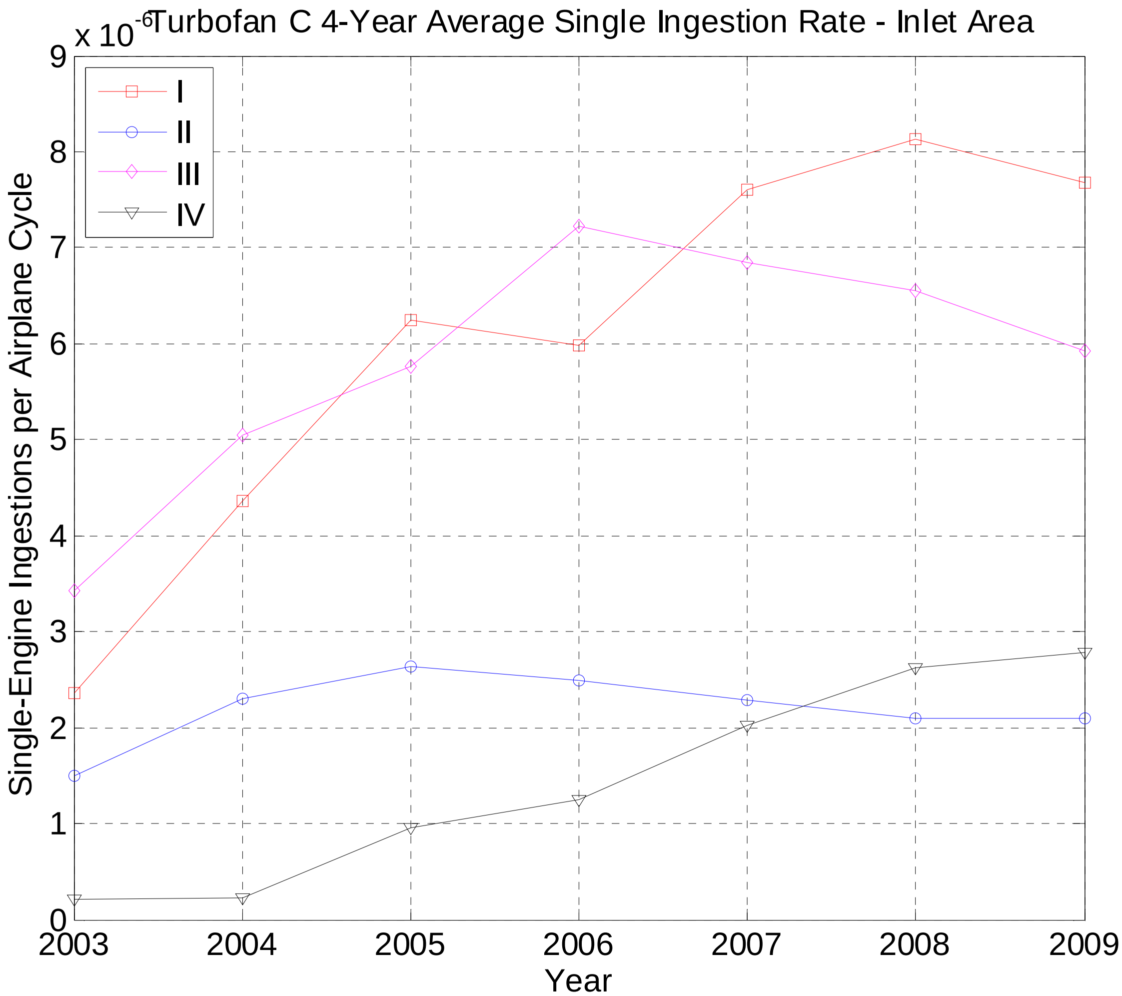


Turbofan e 4-Year Average Single Ingestion Rate - Dia
x 10^-7
4
3.5
3
2.5
2
1.5
1
0.5
0
Single-Engine Ingestions per Airplane Cycle
I
II
III
IV
2003
2004
2005
2006
2007
2008
2009
Year

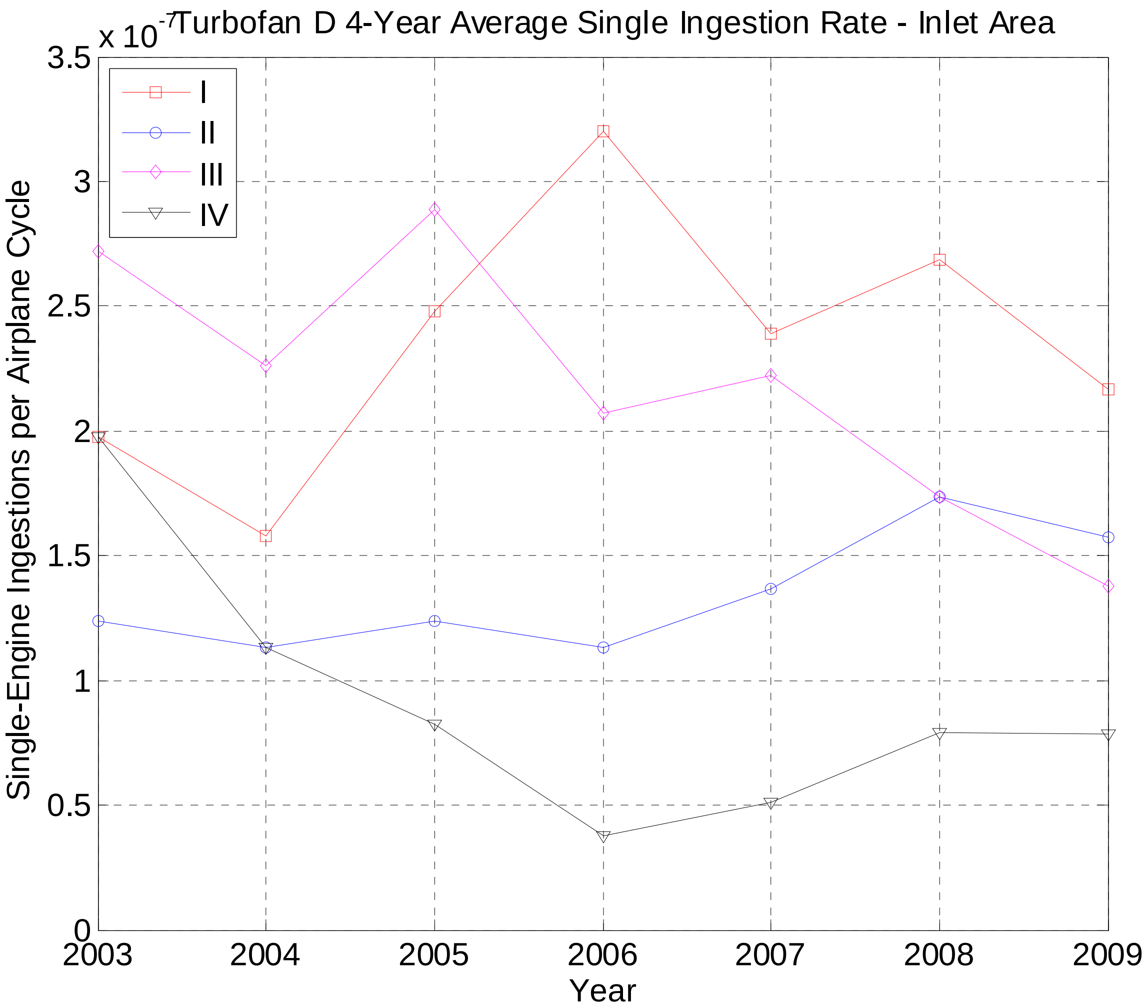


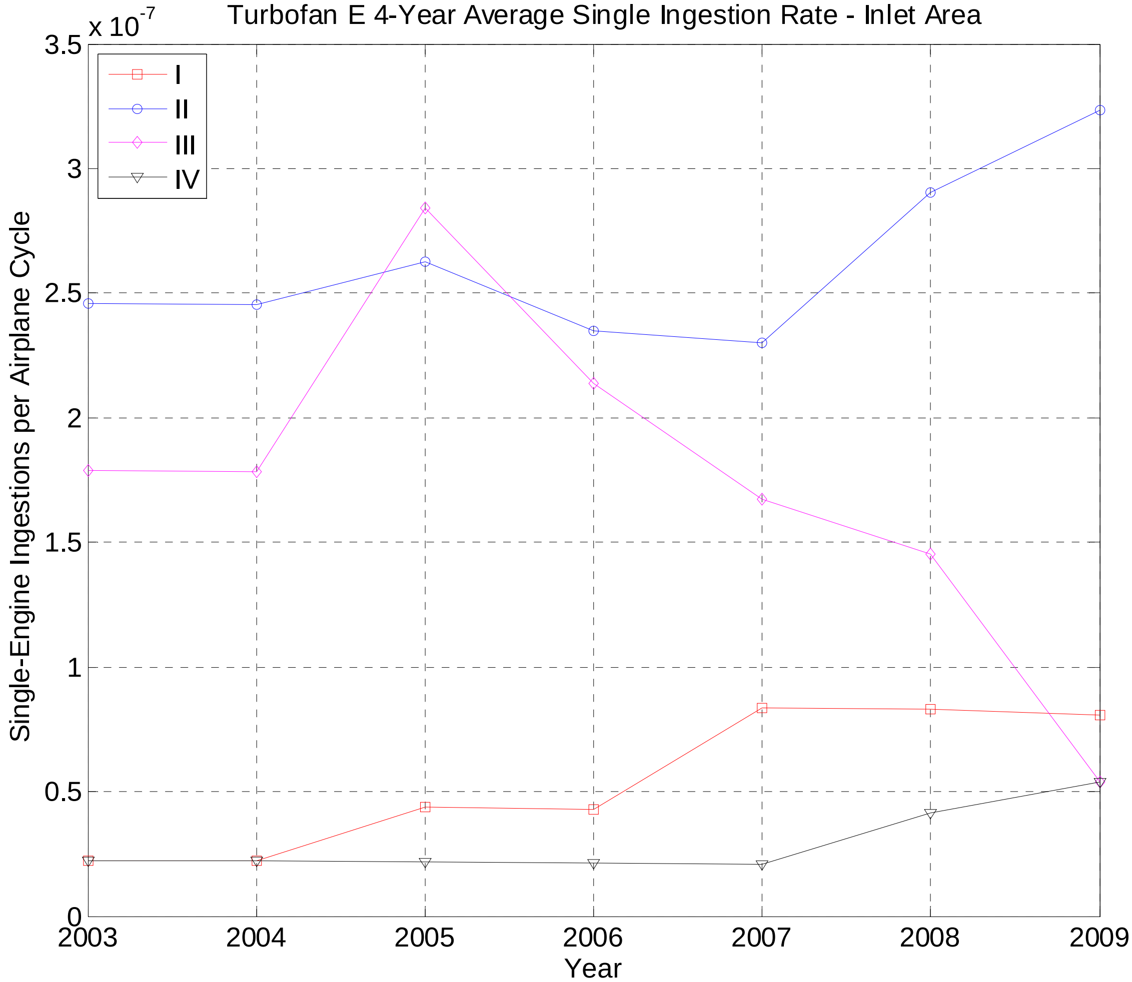
x 10^-6 Turbofan A 4-Year Average Single Ingestion Rate - Inlet Area
1.5
1
0.5
0
2003
2004
2005
2006
2007
2008
2009
Year
Single-Engine Ingestions per Airplane Cycle
I
II
III
IV


Turbofan B 4-Year Average Single Ingestion Rate - Inlet Area
x 10^-6
Single-Engine Ingestions per Airplane Cycle
Year
I
II
III
IV
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2003
2004
2005
2006
2007
2008
2009



Turbofan C 4-Year Average Single Ingestion Rate - Inlet Area
x 10^-6
Single-Engine Ingestions per Airplane Cycle
Year
I
II
III
IV
0
1
2
3
4
5
6
7
8
9
2003
2004
2005
2006
2007
2008
2009


x 10^-7 Turbofan D 4-Year Average Single Ingestion Rate - Inlet Area
Single-Engine Ingestions per Airplane Cycle
Year
I
II
III
IV
3.5
3
2.5
2
1.5
1
0.5
0
2003
2004
2005
2006
2007
2008
2009



Turbofan E 4-Year Average Single Ingestion Rate - Inlet Area
x 10^-7
3.5
3
2.5
2
1.5
1
0.5
0
Single-Engine Ingestions per Airplane Cycle
I
II
III
IV
2003
2004
2005
2006
2007
2008
2009
Year

Appendix F. Statistical Tests

Comparisons between two values are also called hypothesis tests. The tests are either between two values calculated from samples or a value from a sample compared against a specified value. There are tests that can be used between multiple values calculated from samples but these were not needed here.

The tests described below are tests to show whether a difference is statistically significant. It is necessary to understand the difference between being statistically significant and practically significant. Differences in data are assumed to be statistically significant if they are larger than would happen by chance. Differences in data are assumed to be practically significant if they would be large enough to be of practical use.

A practically significant difference is defined by whoever is involved in an experiment or analysis. In an experiment, the number of iterations or trials can be defined to ensure that this practically significant difference, if present, can be shown to be statistically significant. In an analysis of observational data, the amount of data is pre-determined. This amount of data may mean, given the uncertainty of the data, the statistical significance of the difference cannot be shown.

The three statistical tests used and described below are all detailed in 'Applied Life Data Analysis' by Wayne Nelson, 1982:

Test 1
Any comparison of two sample probabilities (such as power loss probabilities) is a comparison of binomial probabilities. The comparison methodology uses the Fisher exact test for equality of the two probabilities. The test calculates the hypergeometric tail probability and compares it against the significance level desired. This test is useful for this situation because it can be used when the number of values involved is small. This test is described in detail on pp. 449-450 (Nelson).

Test 2
A comparison of a sample probability against a specified value can be done using the binomial distribution. Essentially the test will determine if the sample is consistent with the specified value. If it is, the test will have a large probability otherwise the value will be small and the values can be called different. This test is described on pp. 447-448 (Nelson).

Test 3
The SEI rates are a comparison of two estimated rates. The test uses the ratio of the two rates and calculates a confidence interval for this ratio. The ratio confidence interval uses the F distribution. If the confidence interval (at the prescribed significance level) does not enclose 1, then the two rates are considered statistically different. Details are described on pp. 462-463 (Nelson).

Test 4
The MEI rates are compared against a specified value. The specified value is either a rate which is derived from an analysis (and therefore is considered known) or is a value that the sampled rate is to be shown better (or worse) than.
The test calculates the confidence interval for the particular MEI rate. This confidence interval is calculated using the chi-square distribution. If the confidence interval does not enclose the specified value then the rate is considered statistically different from the specified value. This test is described on p. 460 with the confidence interval described on p. 320 (eq. 1.8) (Nelson).

Appendix G. Amendment to Phase II Final Report

The final report from Phase II (DOT/FAA/AR-TN03/60) contained an error on page 10, the two charts were switched and should have been shown like this:

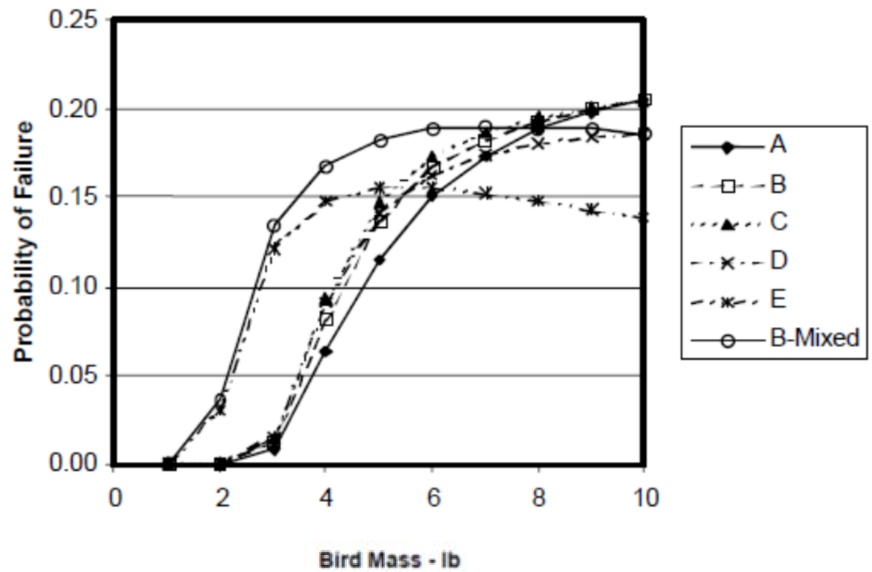


FIGURE 4. SINGLE ENGINE POWER LOSS PROBABILITY, GIVEN AN INGESTION

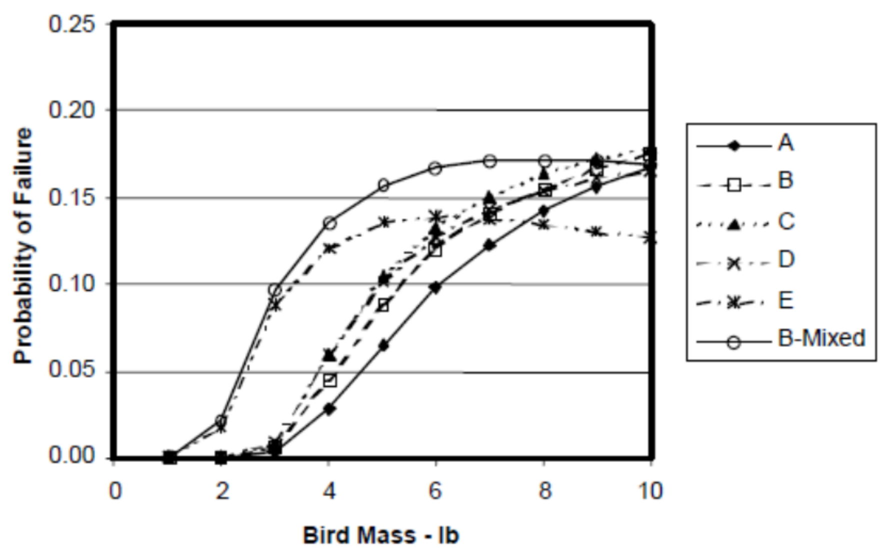


FIGURE 5. DUAL ENGINE POWER LOSS PROBABILITY, GIVEN A DUAL INGESTION

As they were shown originally, it appeared that a dual engine power loss was more probable than a single engine power loss. A power loss is dependent on four primary conditions, aircraft speed, engine rotational speed, bird mass and impact location on the engine face. For a dual engine ingestion event, only the impact location will vary between the two engines, the other parameters will be the same or similar, so the probability of dual power loss given a dual ingestion is less than the probability of single engine power loss, but is more than the single engine power loss probability squared which has been suggested. For this reason, a Monte Carlo method was used to derive the figures above, and as shown here they are correct.