# (20) An Inside Look at Bird Ingestion Engine Certification Standards for Commercial and Business Jet Engines

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Large commercial and business jet engine bird ingestion certification standards have evolved with advances in technical knowledge gained through empirical and analytical processes. Often, this evolution is perceived by the public as taking an unjustifiably long time, particularly after a high profile event occurs, such as the USAir ditching in the Hudson River in 2009. A brief historical review of bird ingestion regulations is presented to document the evolution of the certification standards. The process by which the more recent improvements were established is presented to highlight the global inter-agency and collaborative industry effort that is expended to assist the regulators in addressing known and emerging threats to aviation safety due to bird strikes.

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# An Inside Look at Revising Bird Ingestion Certification Standards for Commercial and Business Jet Engines

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## Introduction

More than six years have passed since US Airways Flight 1549 ditched in the Hudson River on January 15, 2009. In its final investigation report on the accident, released on May 1, 2010, the NTSB issued a multitude of safety recommendations. The aircraft powerplant specific recommendations were to 1) modify the Code of Federal Regulations to prescribe testing at the lowest expected climb fan speed for the medium flocking bird ("MFB") and large flocking bird ("LFB") certification tests, 2) require a large flocking bird demonstration for smaller engines, and 3) include a requirement for LFB core ingestion.

In the six years between the Hudson River event and the FAA Aviation Rulemaking Advisory Committee (ARAC) bird ingestion rule recommendations that were issued in February 2015 it might appear, to the layman, that there was little response regarding regulatory changes in reaction to the accident. However, from an industry and regulatory perspective, there was a high level of ongoing activity out of the public spotlight to make meaningful, long term improvements to flight safety.

On March 16, 2010, in advance of the NTSB recommendations and anticipated rule making activity, the FAA requested that the aerospace industry update the industry bird ingestion database and the detailed statistical analyses that were utilized to recommend the previous bird ingestion regulation update in 2000. This earlier database effort did include a recommendation for a database update which would have occurred in 2010. In response to the FAA request, the aircraft industry formed a committee under the auspices of the Aerospace Industries Association. The database update, analysis and recommendations were completed on November 16, 2012 and provided to the FAA.

On March 8, 2013 the FAA issued notice of a new task assignment for the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the current bird ingestion requirements in the Code of Federal Regulations (CFR), and provide recommendations as appropriate. The ARAC Bird Ingestion Engine Harmonization Working Group convened on May 21, 2013, and completed its final report to the FAA ARAC on February 19, 2015.

## Aircraft Engine Regulatory History

Engines are currently certified to §33.76, but this was not always the case.

In the 1960s and '70s, there were no specific ingestion rules, just Advisory Circular (AC) material (AC33-1 and updates) which may have been based on earlier experience with propeller driven aircraft. At that time, there had been a few accidents with prop-powered commercial transports – the most significant in 1960, when a Lockheed Electra taking off from Boston ingested starlings into 3 of 4 engines, resulting in a crash with 62 fatalities.

AC33-1B recommended ingesting several medium (1 to 2 lb.) birds at takeoff power and climb speed with a "desired" 5 minute run-on at 75% thrust or more, and also a large single bird of 4 lbs. with "safe shutdown" – i.e. lose all power/thrust but do not hazard the aircraft.

In 1974, the general FOD rule §33.77, which included tires, ice, gravel, etc., was established. Bird requirements were similar to AC33-1B: medium birds were 1.5 lbs. A subsequent study by the FAA showed a significant improvement in engine capabilities against birds with introduction of this rule.

In 1975, an ONA DC-10 ingested a mix of medium (2.5 lb. herring) and large (4 lb. greater black backed) seagulls while taking off at JFK, causing high fan imbalance, and heavy tip rubs. The crew aborted the takeoff, but during braking, several tires and a wheel disintegrated, and more debris was also ingested into the engine. A fire ensued, and the aircraft was destroyed. This and other ingestion events during that timeframe resulted in some changes to the bird requirements in 1984, including aiming birds at critical areas on the fan blades instead of random locations.

Through the 1980s, high bypass turbofans came into use more and more. Because of their larger diameter, they ingested birds at higher rates than earlier engine types. Also, the fan blades on these new engines, lacking engine inlet vanes, were exposed to direct impacts from birds; if those blades fractured, most of the engine's thrust would be lost. Industry realized that birds larger than the 1.5 lb. medium bird were regularly being ingested, so an industry/agency committee was formed to collect ingestion data, and assess the adequacy of the §33.77 rule.

The result of this committee, now referred to as "Phase I" was a totally separate bird ingestion regulation, §33.76. This was promulgated in 2000, but engines were being certified to the proposed requirements in the mid-'90s. The size of medium birds was increased to 2.5 lbs. (dependent on engine inlet area), at more stringent critical ingestion conditions. A run-on for 20 minutes demonstrating no less than 75% takeoff thrust to simulate ingestion at rotation followed by a "go-around" and then a "baulked landing" was required to ensure that a multi-engine ingestion of a flock of medium birds (MFB) during takeoff would allow the aircraft to continue flight to a safe landing. This rule also increased the large single bird (LSB) weight from 4 lbs. for all engines to 4, 6 or 8 lbs., dependent on engine inlet area.

During the late '90s, goose populations began to increase, and aircraft encounters with flocks of geese rose. Up until then, the LSB rule had always been considered adequate to protect against large flocking birds (LFB). Its main requirement was "safe shutdown," and since the majority of large bird ingestions were species such as vultures, which do not travel in tight, organized flocks, the risk of multi-engine ingestion was remote. However, it became clear that if an aircraft were to encounter a flock of geese or similar large flocking birds, then a multi-engine ingestion was more likely, and allowing two engines to lose all thrust could make continued safe flight impossible. Another committee, dubbed LFB (or "Phase II") was formed in 2000. It added to the earlier ingestion database, and produced a probabilistic rule which could ensure that the commercial fleet was capable of meeting safety goals against the LFB threat. Each engine size class was assessed based on the probability of ingesting an LFB into two engines at random locations on the fan blades, and at typical takeoff thrust settings (including derates). The resulting rule (promulgated in 2007) was applied to engines with inlets greater than $2.5m^2$, and required ingestion of a 4.1 to 5.5 lb. bird (depending on engine inlet area) on the outer 50% span of the fan blade at 200kts and 10% takeoff thrust derate (the "average" takeoff). Engines with inlets $<2.5m^2$ were not required to address this rule since the statistical analyses showed that the MFB rule in place would provide adequate capability against the LFB due to the shorter fan blades in these smaller engines.

## The Hudson River Effect

During Phase II, which collected industry ingestion data through 2000, it was agreed that the ingestion database should be updated every 10 years. However, the Hudson Event, which occurred approximately seven years after that committee finished its work, caused a revisit of the LFB rule effectiveness, and drove a different look at the data.

Since the introduction of the high-bypass turbofan, the primary aim of the rules was to ensure fan blade integrity and enable continued thrust production. While core ingestion had always been considered, it was believed that the MFB core ingestion requirement, combined with the statistically remote probability of significant core ingestion into two engines simultaneously, gave adequate safety margins.

However, in the Hudson Event, large portions of geese were ingested into the core of both engines, causing massive damage in each compressor, and leaving little available thrust. The fan blades looked relatively unscathed, and would have produced sufficient thrust for safe flight had the cores continued to produce power. During the investigation, it was noted that the §33.76 core ingestion requirement was effectively defined at the fan blade critical conditions of low bird speed and high rotor speed, which would result in lower bird mass ingested into the core. The conditions for the Hudson Event, however, included higher climb speed with lower fan speeds. Current third generation wide-chord fans can probably prevent most core ingestion at the defined certification test conditions.

## Database Update History

The commercial aviation industry engine manufacturers established a database of bird ingestion events specific to their products beginning in 1969. The database collected information that included additional powerplant related data beyond that obtained by the FAA database in order to better understand and analyze the bird strike damage tolerance of each engine model, and to verify product bird ingestion performance relative to their certification requirements. The database was updated by different committees as noted earlier with data from participating engine manufacturers, both U.S. and European, up through January 1999.

The first bird ingestion specific data collection effort was done by the FAA, following a recommendation made by the National Transportation Safety Board after the 1975 ONA DC-10 accident at JFK in 1975. The FAA responded by reviewing the available data on bird ingestion events during the period from 1969 to 1980, and concluded that the resulting database was not adequate to fully define the bird ingestion hazard. An FAA Technical Study was initiated in 1981 for a 26-month period to create an improved database that would more accurately determine the hazard, and determine whether ingestion certification standards needed revision.

To provide a better understanding of the threat bird ingestion posed to aircraft engines, the first concerted aerospace industry task was initiated to document the commercial airplane engine ingestions that occurred from 1968 to 1988 (Phase I). There was also an intermediate update of some of the data to 1995. The result of this industry study was the development of the MFB ingestion regulations.

The second industry database update covered the period from 1968-1999[1] (Phase II). This study encompassed two periods of FAA sponsored bird data collection and significantly increased the total number of reported bird ingestions; however, damaging strike reports were not noticeably affected. The collection and analysis was performed in response to comments on §33.77 amendments which suggested an update to the 1995 data that was employed for those amendments. The resulting rule revisions that were developed focused on the LFB threat, and included analytical projections of LFB populations out to the year 2010.

The third and most recent industry database update covered the period from January 2000 through January 2009[2] (Phase III). This was instigated in response to both the Hudson River accident, and a continued upward trend in populations of LFBs. (The data collection intentionally included January 2009 to incorporate the Hudson accident.) This update also extracted information related to core ingestion findings, which was not

[1] Study of Bird Ingestions into Aircraft Turbine Engines (December 1968 – December 1999), Chester M. Lewis and Terrance G. Tritz, report DOT/FAA/AR-TN03/60, September 2003.
[2] Turbofan Bird Ingestion Regulation Engine Harmonization Working Group Report, February 19, 2015.

considered in detail in prior database reviews. This review of core ingestion data identified a need for greater specificity on the effects attributed to the core ingestion as a separate issue from fan blade effects, in order to improve understanding of engine behavior in service.

## Database Update Process

The bird ingestion data collection effort is a time-intensive process. As noted above, each manufacturer collects bird ingestion information on each individual report as soon as practical after the event occurrence, utilizing whatever resources are available to them, including field service representatives at the airlines and engine maintenance facilities, strike report data from both domestic and foreign government sources, and web sourced aerospace information sources. For many reasons, it is generally challenging to obtain specific information on the engine immediately after a strike occurs, and the engine manufacturer ("OEM") often needs to follow-up with its sources to populate the desired database fields for each strike report. These follow-up efforts are challenging because of the highly temporal nature of the bird strike findings; the remains are often removed and discarded, engines are cleaned, damaged hardware is replaced and not documented, photos are not taken or not saved, crew recollections fade, and flight data recorders are overwritten. So each strike data point comes with a time investment on the part of the engine OEM (as it also does for the FAA Wildlife Strike Database managers), to determine the level of damage, the bird impact energy involved (i.e., bird size, aircraft speed, and engine power setting), whether there was core ingestion, and any effect on power/thrust production. This effort was expended on many of the over 11,000 bird strike entries contained in the most recent database update.

To obtain a full understanding of the strike statistics, it is necessary to combine all of the separate engine manufacturers' data to determine how the engines perform across the various commercial fleets. This then allows an assessment of the threat of bird ingestion to the safety of the flying public. To accomplish this, an airframe manufacturer acted as an independent party to collect and scrub each engine manufacturer’s data. Prior to submitting their engine data, each engine OEM reviewed all of the data records to verify the completeness and integrity of the input, and did further research on events with incomplete information to determine if additional data had been made available after the strike was initially entered. The airframe OEM then combined and sanitized the data, removing any elements that associated the engine manufacturer with individual events. The combined data was screened to cull obvious conflicts in terms of data type or interpretation between engine OEM submissions, and the engine OEMs then revised their datasets as necessary to obtain one harmonious database.

Once the industry database was complete, the airframe company performed a variety of statistical analyses and tests on the data for thorough review by the industry team to determine fleet performance relative to intended safety objectives, and to identify potential improvements in test requirements. As the industry team worked to interpret the information conveyed by the statistical analysis, additional analysis techniques were applied to ensure a solid understanding of what was working, and what opportunities for meaningful improvement should be investigated and recommended.

**Regulatory Update Process**

Usually, a rule update is made to address a demonstrated or perceived threat that has caused accidents or incidents, and that is not considered to be addressed by existing regulations. As noted above, the bird ingestion regulations have changed several times over the last 40 years for different reasons.

With the bird ingestion database updated by the AIA committee, FAA ARAC requested the Transport Airplane and Engine subcommittee (TAE) to review current regulations, identify shortfalls, and make recommendations for rule changes to address any deficiencies found. The TAE established the Bird Rule Engine Harmonization Working Group (EHWG) in March 2013 to review and report back by March 31, 2015.

Since it is impossible to aim for zero events, the goal for working groups addressing "common cause" threats – i.e., something that can affect multiple engines – is to ensure the rule will provide "freedom from multi-engine power loss events at a rate of 1E–8 per aircraft cycle." This goal is based on the §25.1309 requirement that major failure conditions are improbable, and catastrophic failures extremely improbable.

The EHWG reviewed the previous Phase II database work and recommendations, and then assessed the new data that had been added. Various operational, statistical and ingestion simulations were performed, incorporating the conditions of the Hudson Event, and the recommendations by the NTSB. One key difference in this later work was the detailed consideration of core ingestion. The MFB core ingestion requirement, combined with the remote probability of ingesting significant amounts of bird into the cores of multiple engines, has always been sufficient to meet safety goals. However, the emphasis on fan blade capability in both the MFB and LFB tests, and the introduction of modern wide-chord fan blades, has resulted in excellent fan blade robustness such that, when the database was analyzed, indicated that power loss due to core ingestion was becoming a more significant factor.

Although the number of ingestions typically increases yearly, so do aircraft movements, meaning that rates per flight are not necessarily increasing. Also, the data showed that ingestion rates of large birds are not increasing – this as a result of successful efforts at bird control around airports. Another fact revealed by the data is that so far, changes to the rules have worked well. Current engines are far more robust than earlier generations by orders of magnitude, so bird control efforts and engine technology improvements are combining to result in significantly improved safety.

Predicting that the safety goal will be achieved requires statistically combining the probability of multi-engine ingestion with the likelihood that, given an ingestion of a bird, the engine will lose >50% thrust/power. Since aircraft are certified to fly with one engine inoperative, if two engines ingest birds, but can still produce >50% of rated takeoff thrust, it is equivalent to a single engine being inoperative. The MFB and LFB regulations require this level of continued thrust production for 20 minutes, with throttle excursions to demonstrate engine operability. Thus, the aircraft will have sufficient thrust to do a safe air turn back after an event during takeoff.  The analyses showed that, just as in the LFB Phase II work, the safety goal was predicted to be met. However, the EHWG members believed that a change to core ingestion requirements would enhance safety even further, and so they worked on an appropriate modification.

Since the EHWG comprises engine and aircraft OEMs, agencies, and other members, achieving a consensus opinion can sometimes be difficult.  In cases where individual members may disagree with the majority, those members can write a "minority opinion" in the group recommendations.  In this latest EHWG, everyone agreed on the recommendations, and no minority opinions were issued.

Once the EHWG work is completed, a report is submitted to TAE and, if approved, submitted to ARAC.  Once accepted by ARAC, the FAA considers the recommendations, and decides what changes to propose in the rule.  Once a Notice of Proposed Rule Making (NPRM) is issued, it usually takes approximately one year to receive comments, disposition them and then issue the final new rule.

## EHWG Recommendation

The key conclusion from the EHWG was that the current core ingestion criteria defined by the existing CFR’s did not adequately challenge the core section of engines with modern wide-chord fan blades relative to the most likely core-specific threat expected in service. As a result, the industry recommended that an additional core ingestion demonstration of the MFB test at a climb condition reflecting the highest typically allowed aircraft speed (defined as 250 KIAS), and the lowest climb fan rotor speed expected to occur during the initial climb phase. The combination of high aircraft speed and low rotor speed will increase the amount of bird material that can enter the core. In addition, the bird should be targeted to maximize the amount of material ingested into the core at that condition. The industry unanimously supported the additional requirement to show engine core capability, and the FAA is currently evaluating the recommendation for possible rule change proposals.

## Conclusion

Jet engine certification rule changes are not considered lightly. The task of developing bird ingestion rule recommendations to the regulatory authorities requires extensive work up front to identify and collect all available relevant data, to ensure the validity of the data, and then to perform detailed analyses in order to understand what changes, if any, are likely to bring the most improvement to the safety objective. The recent bird ingestion rule efforts are expected to further contribute to the maintenance of industry and regulatory safety goals with respect to the bird ingestion threat.

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# USAir 1549 January 15, 2009 – What's Happened Since?

2009

January 15th ditching of USAir 1549 in Hudson

2009 -2012

In advance of NTSB final report, FAA requested an industry updated bird ingestion database / analysis in anticipation of rulemaking activities. Task completed November 2012

2010

NTSB published safety recommendations in 2010, three were engine related

1 – Modify CFR flocking bird test conditions to lower engine rotor speed

2 – Require Large Flocking Bird test on smaller engines than currently cited

3 – Include core ingestion of Large Flocking Bird

2012 -2015

FAA ARAC request to TAE for rulemaking study and recommendations. Analysis and rule modification recommendations provided February 19, 2015.

# Brief Bird Engine Ingestion Regulation History

| | | |
|---|---|---|
| <1974 | AC33-1 | All FOD requirements,, birds, tire, gravel, weather.<br>“Recommended” several medium 1-2 lbs. birds at takeoff power and climb speed with “desired” 5 minute run-on. |
| 1974 | FAR 33-77<br>Amendment 6 | Similar to AC, small & medium flocking birds with run-on requirement<br>Medium birds established at 1.5 lbs. |

# November 12, 1975 - Overseas National DC-10 Accident Motivated Flocking Bird Rule Update in 1984

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| 1984 | FAR 33-77<br>Amendment 10 | Up to eight 1.5# birds at V2 and T/O power with run-on <25% power loss<br>Large (4#) bird critical target at V2 and T/O engine power with safe shutdown |

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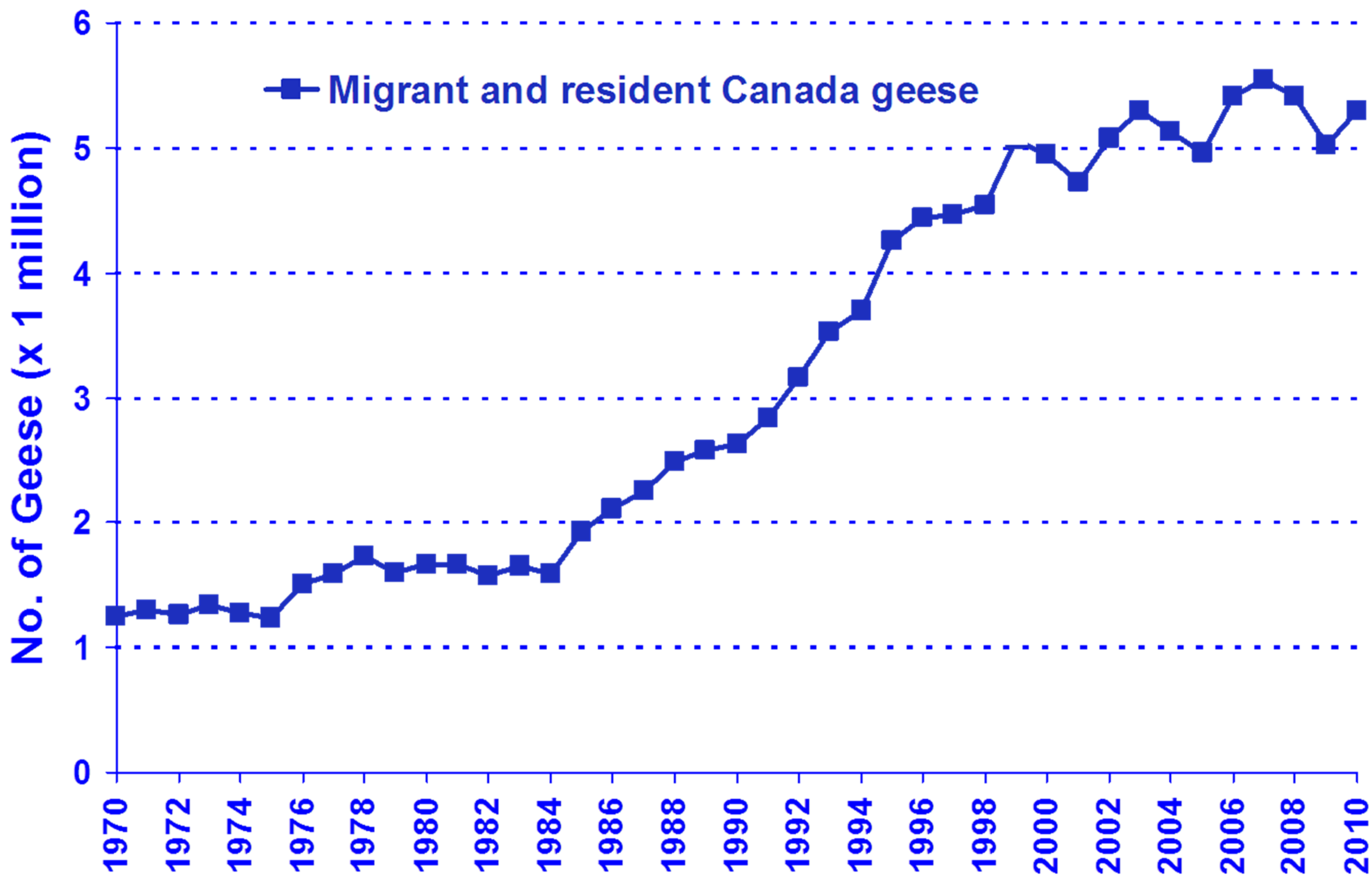
| 2000 | FAR33-76<br>Amendment 20 | Separate rule from 33-77, based upon inlet throat area<br>Medium 1.5# and large 2.5# flocking bird, run-on changed to 20 minutes with flight profile and 25% max thrust loss.<br>Large bird 4#, 6# or 8# based on inlet area, safe shutdown |

# Large Flocking Bird Population Trend & High By-Pass Engines Motivated Regulation Update in 1990's



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| 2007 | FAR 33-76<br>Amendment 24 | Added Large Flocking Bird 4.1#, 4.6# and 5.5#<br>Run-on for 20 minutes with flight profile and 50% max thrust loss. |

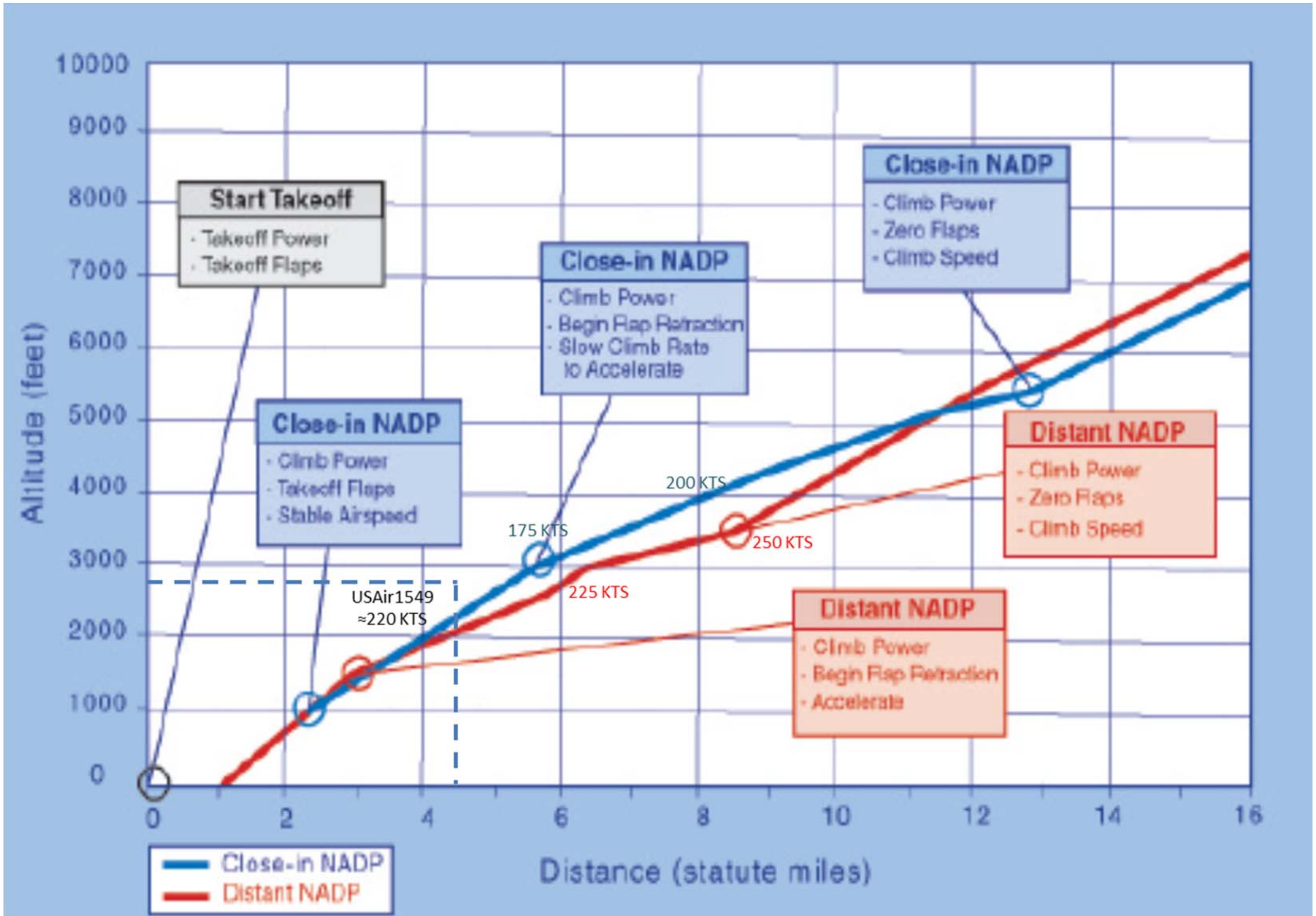
# The Hudson River Effect

The current bird ingestion certification criteria considered the primary threat to continued power production was impact damage to the fan blade airfoils.

- Fan rotor speed set at 100% certified Take Off (<1500’, >V1) speed for MFB
- Bird speed established via analysis to provide greatest impact energy at fan
  - Typically close to V1
- Core ingestion used criteria same as above but bird targeted at core inlet
  - All birds ingested as flock within 1 second

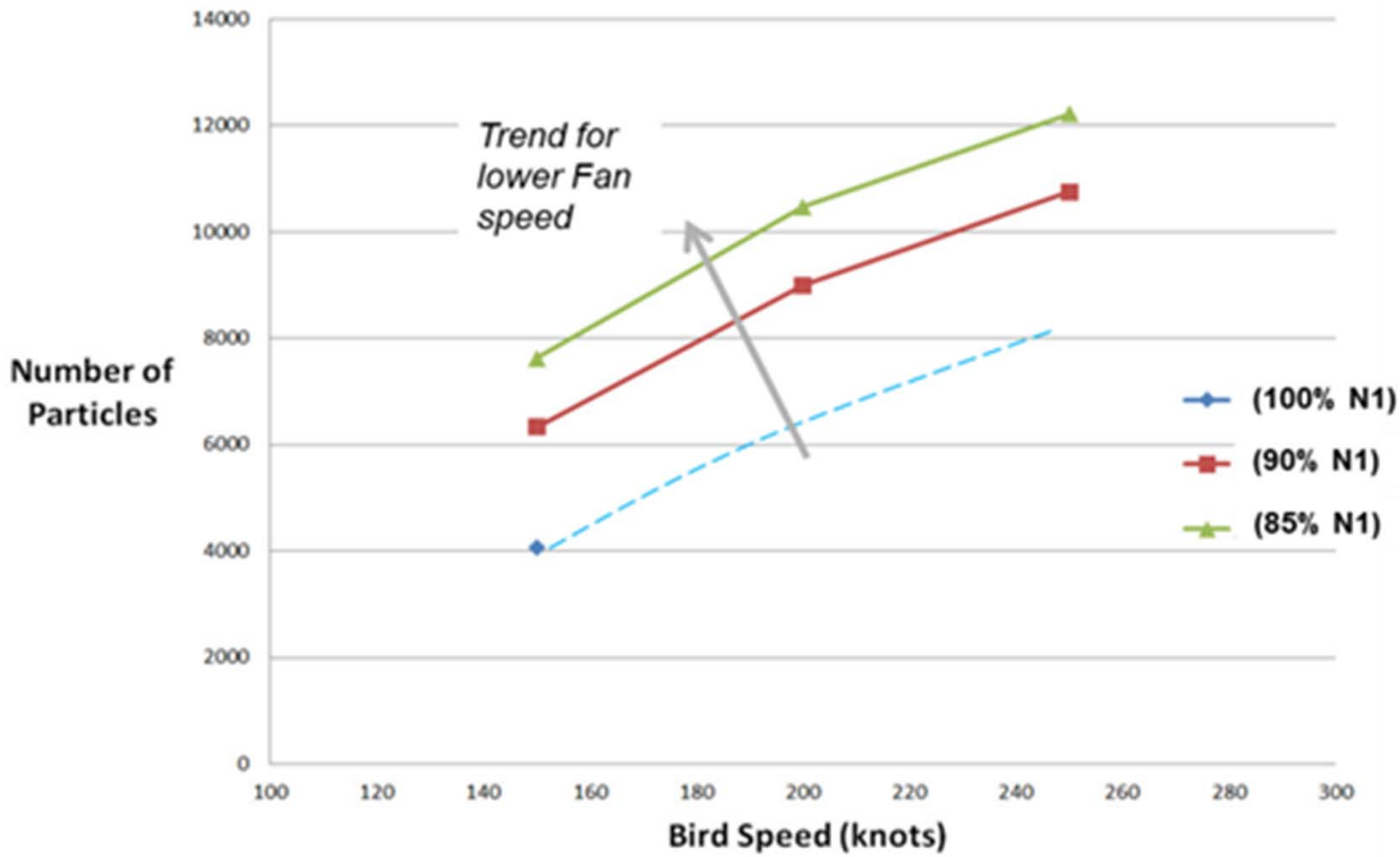
# Hudson River Effect

USAir ingestion occurred at conditions outside of certification test conditions
Climb profile = higher aircraft speed and lower fan rotor speed than Take Off



# The Hudson River Effect

Industry analysis shows bird core ingestion to be a function of fan rotor and bird speeds.



# The Hudson River Effect

- Takeoff fan rotor speeds maximize core bird rejection
- Modern wide-chord fan airfoils increase core bird rejection
- Low bird speed increases core bird rejection

Result :

Very high core bird rejection at current certification criteria

for the Medium Flocking Bird rule

# What Is Ingestion Data Telling Us About Current Threats?

Data collection and quality review with statistical analysis conducted using data from January 2000 through January 2009 (captures USAir event)

Over 11,000 data points covering global ingestion data with engine specific inputs (engine response, physical damage, impact on power production, etc.)

Data analysis targeted towards ingestion and powerloss rates for each bird size class, engine positions, phase of flight, …

Data shows fleet is currently meeting safety objectives for bird ingestions.

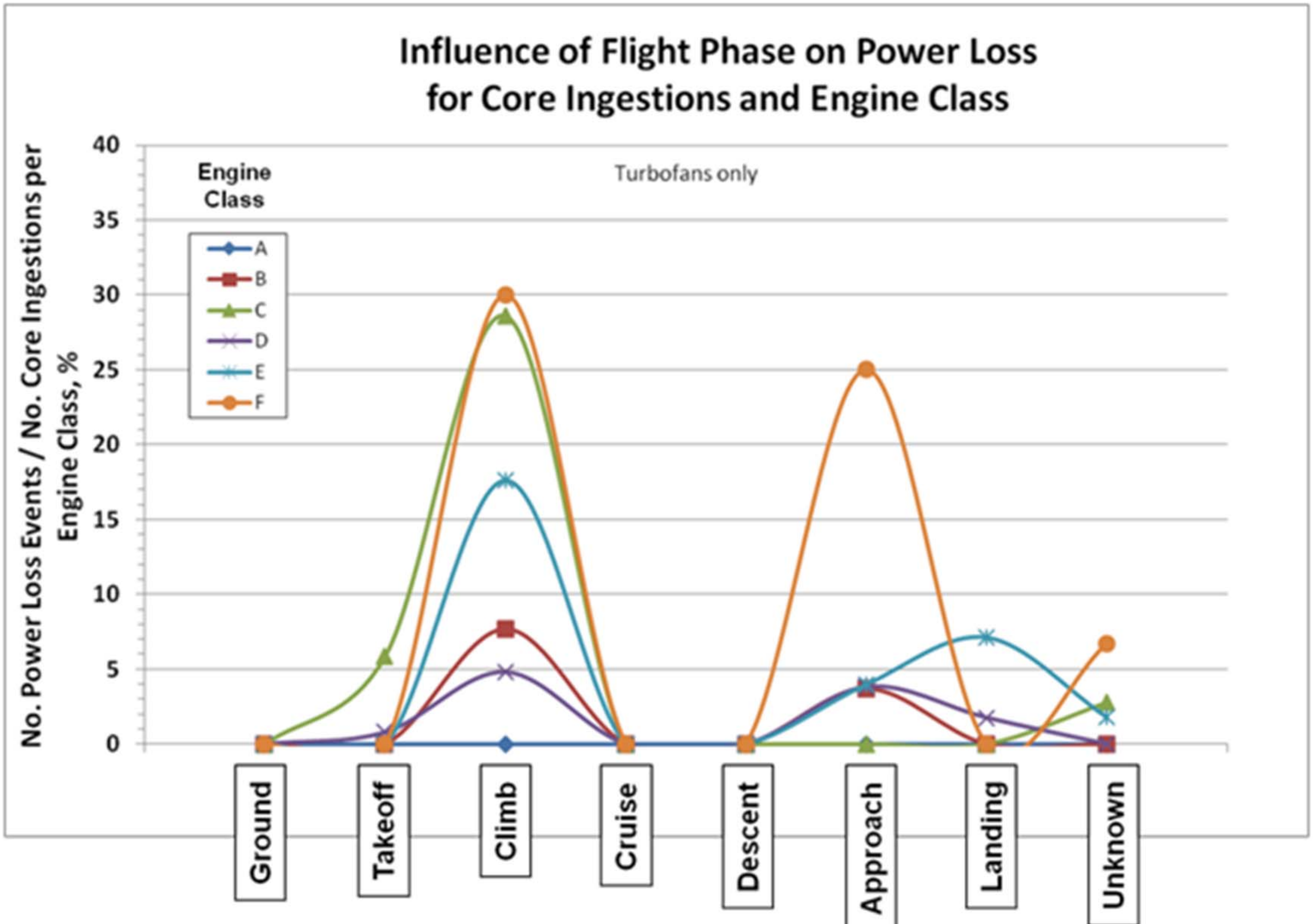
Previous bird regulation amendments improved engine capability relative to powerloss from bird ingestion.

Climb, and to a lesser extent Approach, are the flight phases which are now the most likely to result in a powerloss event.

Bird targeting is a factor in amount of bird material entering the core

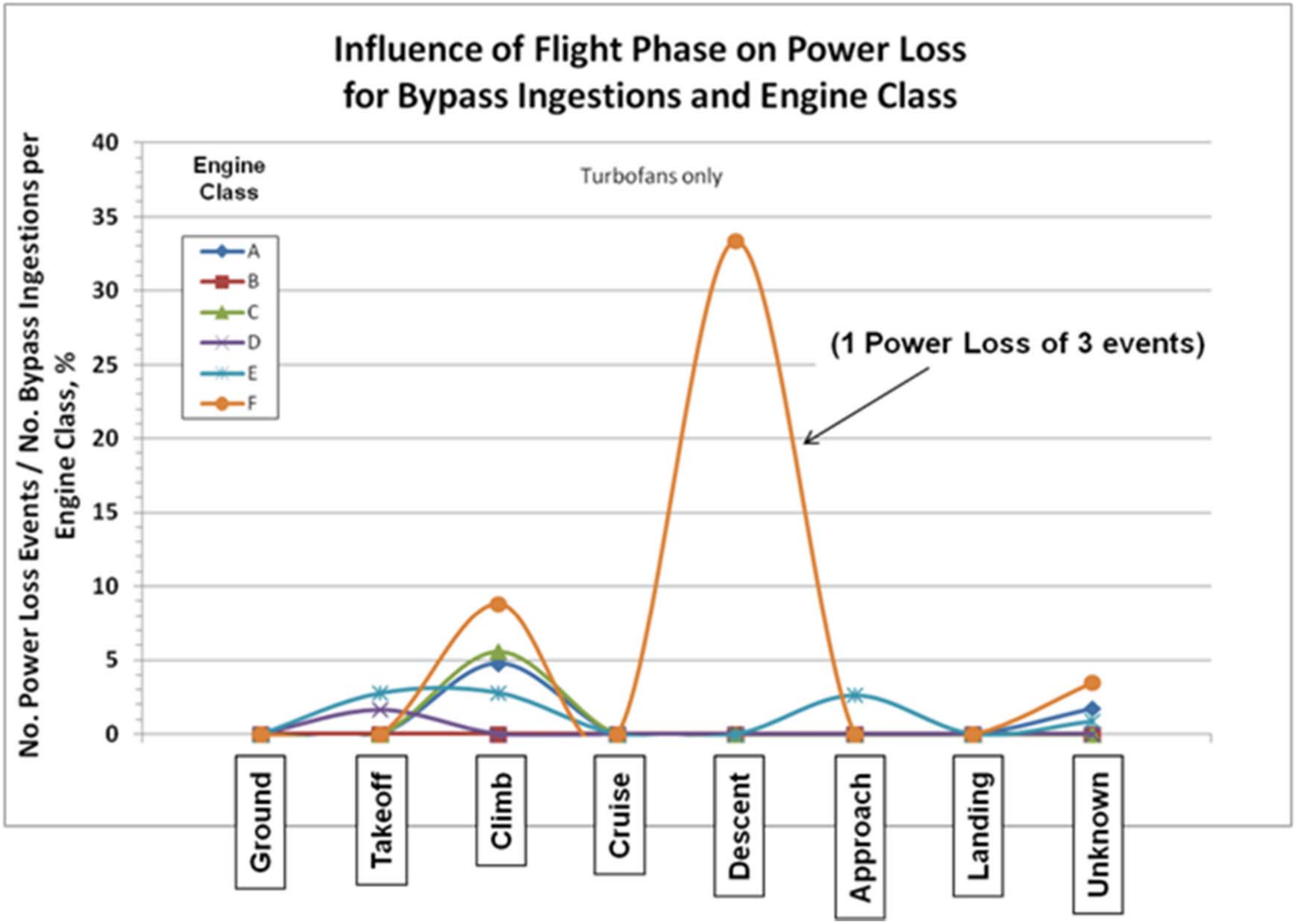
# Flight Phase vs. Powerloss

## Core Ingestion / Climb Greatest Opportunity



# Flight Phase vs. Powerloss

## Core Ingestion / Approach Much Less Likely

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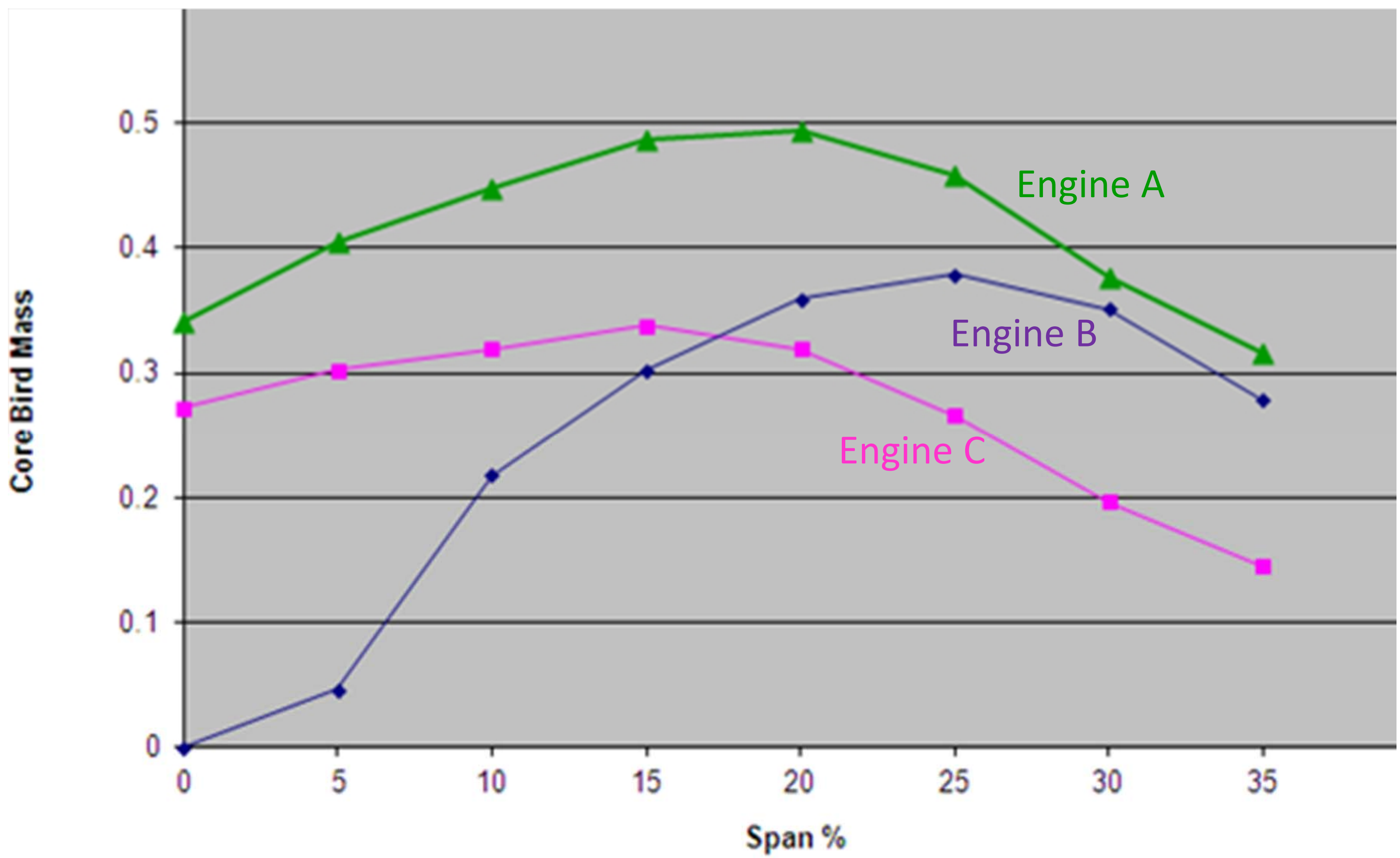
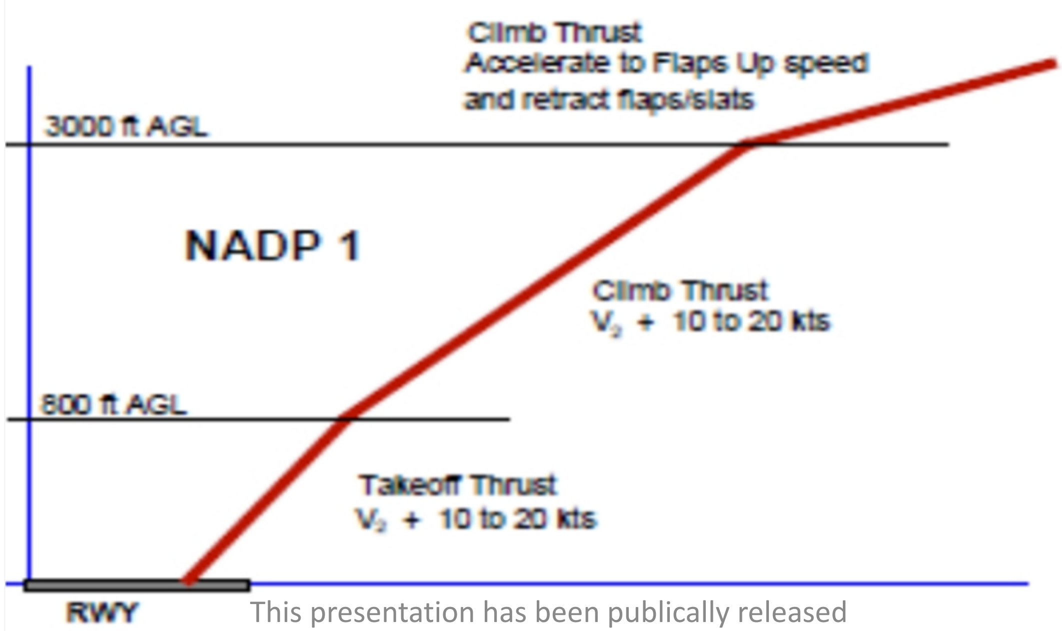
# Bird Ingestion Core Location vs. Quantity Ingested

## Maximum Core Ingestion a Function of Engine Model Specific Targeting



# Appropriate Core Bird Speed and Engine Fan Speed

- The most appropriate flight speed to evaluate MFB core capability is the maximum aircraft speed that is normally used in service at the altitudes which birds are likely to be encountered.
- According to a USDA report, more than 91% of the bird strikes to aircraft occurred below 3,000’ altitude.
- Based on ICAO standard Noise Abatement Departure Profiles and service data from airframe manufacturers and the International Airline Pilots Association, expected flight speeds on commercial aircraft at altitudes from 0-3000’ AGL range between 150 and 250 knots indicated airspeed.



# Rule Recommendations

- Current core ingestion criteria does not adequately challenge the core section of the engines on modern wide-chord fan blades.
- Recommended an additional core ingestion demonstration of the Medium Flocking Bird at a climb condition.
- Bird speed to maximum aircraft speed allowed under 10,000’ Altitude, or 250 KIAS.
- Fan rotor speed to be lowest fan rotor speed expected during initial climb phase.
- Bird to be targeted to maximize the amount of material entering the core
- Engine must demonstrate continued operational capability via an engine run-on demonstration after the ingestion event.

# Acknowledgement

Working Group Members:

Les McVey (General Electric Aviation) WG Co-Chair
Chris Demers (Pratt & Whitney) WG Co-Chair
Alan Strom (FAA-ANE Standards) FAA Representative
Angus Abrams (EASA)
Amy Anderson (FAA-Airports)
John Barton (SNECMA)
Mark Beauregard (Pratt & Whitney Canada)
Walter Drew (Airbus Industries)
Tom Dwier (Cessna)
Ken Knopp (FAA)
Brian Lesko (Air Line Pilots Association)
Dr. Julian Reed (Rolls Royce)
Russ Repp (Honeywell)
Terry Tritz & Anna Raensteam (Boeing)
DC Yuh (Transport Canada)

# In Conclusion

Jet engine certification rule changes are not considered lightly.

The task of developing bird ingestion rule recommendations to the regulatory authorities requires extensive work up front to identify and collect all available relevant data to

1. ensure the validity of the data
2. perform detailed analyses in order to understand what rule changes, if any, are likely to bring the most improvement to safety performance
3. verify any rule recommendations are both achievable and will improve safety of flight
4. Continue monitoring of bird ingestion data going forward

The recent bird ingestion rule recommendations are expected to further contribute to the maintenance of industry and regulatory safety goals with respect to the bird ingestion threat.