MULTI-ENGINE BIRD STRIKES TO TURBINE-POWERED AIRCRAFT

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Abstract

The aviation safety hazard posed by the possibility of multi-engine bird strikes to turbofan- and turbojet-powered air carrier aircraft has been the subject of much recent debate and study. An Aviation Rule Advisory Committee (ARAC) convened by the U.S. Federal Aviation Administration (FAA) in 2001 studied the threat posed by large (weight > 1.15 kg.) flocking birds. Early in the process, there were questions raised as to the inadequacy of the database used by the ARAC group. Based on the strike records in the database, the ARAC group released their recommendations for ingestion standards of large flocking birds in 2002: For engines with an inlet throat area <2.5 m^2 – no large bird ingestion test: For engines with an inlet throat area >2.5 <3.50 m^2 – one 1.85 kg bird: For engines with an inlet throat area >3.5 <3.9 m^2 – one 2.10 kg bird: And for engines with an inlet throat area >3.9 m^2 – one 2.5 kg bird. To reexamine this issue, we analyzed bird/engine strike reports involving turbofan- and turbojet-powered aircraft (N=6,470, 1 January I990 — 28 February 2005) from the FAA National Wildlife Aircraft Strike Database. We found 312 instances of multi-engine bird strikes, 215 of these reports involved both engines on twin-engine aircraft. There were 83 reports of multiple engine damage; 70 of these reports involved both engines on a twin-engine aircraft. There were 139 (121 air carrier aircraft and 18 business jet aircraft) reports of single or multiple-engine ingestion events involving birds with a mass greater than 1.2 kg. There were 109 events that involved only 1 engine and 30 involved 2 or more engines, of which 24 involved both engines on a twin-engine aircraft. We believe these data indicate that the threat of multi-engine strikes and damage posed by flocking birds is more serious than the ARAC's recommendations would indicate, especially when combined with increases in populations of many large flocking-bird species in recent years and the increasing dominance of 2-engine aircraft in the worldwide commercial aviation fleet. We recommend that the FAA not accept the ARAC recommendations at this time, and re-initiate an analysis of this issue using a more complete worldwide dataset of strike events that has been checked for errors and harmonized for consistency.

Key words: aircraft engine, ARAC, aviation safety, bird strike, damage, database, FAA, ingestion.

1. Introduction

The aviation safety hazard posed by the possibility of multi-engine bird/aircraft engine strikes to turbofan- and turbojet-powered air carrier aircraft has been the subject of much recent debate and study (MacKinnon et al. 2001).

Cognizant of the increasing threat to aircraft posed by bird strikes, the Federal Aviation Administration (FAA) adopted new regulations to address more clearly the overall bird ingestion threat in September 2000 (Title 14, Code of Federal Regulations, part 33.76).

Comments to the Notice of Proposed Rule Making contended that the threat from large flocking birds (over 1.15 kg [2.5 lbs] mass) was not covered by the existing certification requirements, and that

increasing population of large flocking birds could expand the threat posed by these birds. In response to these comments, the FAA convened and tasked an Aviation Rule Advisory Committee (ARAC) to review available bird ingestion data for large flocking birds and to provide recommendations for rule making. The ARAC task was approved 24 May 2001.

As part of the ARAC project, the historical bird threat and resulting impact on flight safety for the 30-year period – 1969 to 1999 – was reviewed. The ARAC reported that, "The data collected represented the worldwide non-military service experience of small, medium, and large, 2, 3 and 4 turbofan- and turbojet-engine aircraft in service during that time, excluding aircraft manufactured or flown in the former Soviet Union and Eastern European-block countries.[1]"

The ARAC looked at, "over 325 million aircraft departures and approximately 340 events involving ingestions of large flocking birds (over 1.15 kg [2.5 lbs mass]).[1]" They concluded that, "The occurrence of loss of power on more than two engines [emphasis added] are predicted to be extremely improbable based on the results of the data studied.[1]" The results of the ARAC study are summarized in Table 1.

The ARAC's recommendation for ingestion standards of large flocking birds was released 12 July 2002. They are summarized in Table 2.

2. Background for reexamination of multi-engine bird strike issue

The senior author did not become involved in the ARAC review until relatively late in the process. However, from the start of his involvement with the ARAC, the senior author, as well as the junior author, had 5 concerns about the study's underlying rationales:

1: Because of problems inherent in compiling accurate bird strike records, especially when the data are extracted from a number of databases, questions were raised as to the accuracy of the data used by the ARAC. One group of experts looked at the data and in the first 100 records sampled found errors in every record.

2: During a large part of the ARAC's sampling period (1960s-1980s), many populations of large flocking birds were at all time-lows. Currently, because of environmental protection and conservation programs, many of these same populations are experiencing strong population growth and are at all-time highs (Sauer et al. 2004, Dolbeer and Eschenfelder 2003).

3: Early recommendations made by the ARAC seemed to place the blame for the increased threat of multi-engine ingestions primarily on the increasing populations of large flocking birds, rather than on both the increase in bird populations and the increase in air carrier aircraft numbers (i.e., Bird Ingestion Phase II Task Group, Advanced Recommendation, Feb 2001).

4: Commercial air carriers are replacing their older three- or four-engine aircraft fleets with more efficient and quieter, two-engine aircraft. In 1969, only 25 percent of the 2,100 USA passenger aircraft had two engines. It is estimated that by 2008 the fleet will contain about 7,000 aircraft, and 90 percent will have two engines (Cleary and Dolbeer 1999).

5: Further, research has indicated that birds are less able to detect and avoid modern jet aircraft with quieter engines (Chapter 3, International Civil Aviation Organization 1993) than older aircraft with noisier (Chapter 2) engines (Burger 1983, Kelly et al. 1999). Noisier (Chapter 2) aircraft engines will be phased out by 2005, further exacerbating the risk of a serious strike.

Therefore, increasing large flocking bird populations coupled with increasing numbers of quieter, twin-engine air carrier aircraft can only magnify the risk of bird/engine strikes involving both engines.

3. Analysis of the FAA's National Wildlife Aircraft Strike Database

Because of the previously mentioned concerns and the ARAC's recommendations, we undertook an independent analysis of the FAA's National Wildlife Aircraft Strike Database (FAA database) for the period 1 January 1990 to 28 February 2005. An analysis of the number and characteristics of strike

[1] Aviation Rule Advisory Committee, Transport Airplane and Engine Issues Group, Engine Harmonization Working Group, Bird Ingestion Phase II, Recommendation for rulemaking (NPRM). Final EHWG product to be forwarded to TAIEG. July 12, 2002.

events from this time period (1990-2005) is more appropriate than an analysis of data from the 1960s - 1980s to examine conditions facing the commercial aircraft fleet in the immediate years to come. Furthermore, the FAA database has been systematically error-checked and analyzed on a regular basis since 1995, with detailed analytical reports prepared annually that evaluate and summarize all strike data since 1990 (Cleary et al. 2005)..

As of 28 February 2005, the FAA database contained 67,880 records – 59,604 for civil aircraft, and 8,276 for military aircraft (Table 3). The military records were excluded from this study.

Of the 59,604 strike reports for civil aircraft, 1,500 involved mammals and 58,104 involved bird strikes (Table 4). Mammal data were also excluded from this analysis.

There were 7,973 strike reports involving bird/engine strikes that provided information concerning the type of engine on the aircraft. Of the 7,973 reports, 100 involved turbojet aircraft and 6,470 involved turbofan aircraft (Table 5).

All of the data analysis that follows involves only bird strikes to turbojet- or turbofan-powered USA civil aircraft. Therefore, we will not continually repeat the phrase "turbofan- or turbojet-powered USA civil aircraft."

Of the 6,567[2] reports of aircraft with single or multiple-engine bird strikes (report indicated 1 or more engines was struck by 1 or more birds but birds were not necessarily ingested into engine), 6,255 reports involved strikes to a single engine in which 2,303 engines were damaged. There were 312 reports indicating more than 1 engine on a single aircraft had been struck. Of the 312 strikes, 251 involved both engines on a twin-engine aircraft. There were 83 reports of multiple engine damage on a single aircraft. These included 70 reports of both engines on a twin-engine aircraft being damaged as a result of a bird strike (Table 6).

There were 3,117 reports of aircraft with single or multiple-engine ingestions involving 1 or more birds (report indicate 1 or more birds were actually ingested into the engine), of which 2,919 reports indicated the strike involved a single engine, and 198 involved 2 or more engines. There were 164 strikes to both engines on a twin-engine aircraft, 59 of these resulted in damage to both engines (Table 7).

Realizing that 2 or more bird must be involved in a strike to result in multiple engine damage, the focus was narrowed to the number of reports of aircraft with single and multiple-engine ingestions and engine damage involving 2 or more birds. There were 731 reports that met these criteria; 550 involved single engine ingestions that resulted in damage to 349 engines; 181 strikes involved multiple engine ingestions, 65 of these engines were damaged. There were 153 reports of ingestions to both engines on twin-engine aircraft, approximately one-third of these (56) reported damage to both engines on a twin-engine aircraft (Table 8).

There were 263 events involving 2 or more birds with a known mass exceeding 900 grams. Two-hundred of these events involved a single engine and 63 events involving 2 or more engines. There were 56 strikes involving 2 or more engines on the same aircraft, 52 involved both engines on a twin-engine aircraft, 21 of those strikes resulted in damage to both engines (Table 9).

Because the ARAC was concerned mainly with large flocking birds (over 1.15 kg [2.5 lbs] mass), reports of single and multiple-engine strikes, engine damage and engine ingestions involving 2 or more birds with a mass greater than 1.2 kg[3] were then examined.

There were 139 reports of single and multiple-engines ingestions and engine damage involving birds with a mass greater than 1.2 kg. There were 109 events that involved only 1 engine, 30 involved 2 or more engines, and 24 involved both engines on a twin-engine aircraft. Of the 139 aircraft involved, 121 were air carrier aircraft and 18 were business jet aircraft. Of these 139 events, there were reports of 105 instances of damage to 1 or more engines. There were 91 reports of damage to a single engine and 11 reports of damage to 2 or more engines; 8 of the 11 involved both engines on a twin-engine aircraft. Of these 105 aircraft, 91 were air carrier aircraft and 14 were business jet aircraft (Table 10).

[2] There were 3 reports of the engine suffering secondary strikes. The engine was not directly struck by the bird(s). They were excluded from this study.

[3] There were no reports of bird/engine strikes involving identified birds with masses between 1.11 kg and 1.21 kg.

Bird strikes to other aircraft parts can exacerbate an already precarious situation when 1 or more engines on an aircraft have been damaged. For those engine bird-ingestion events involving 2 or more birds with a mass greater than 1.2 kg and 1 or more engines being damaged, there were 28 reports of damage to 1 other aircraft part; 24 of these events occurred when only 1 engine had been damaged and 4 events occurred when 2 or more engines had been damaged. There were15 reports of damage to 2 or more parts; 13 occurred when a single engine had been damaged and 2 occurred when 2 or more engines had been damaged (Table 11).

Finally, we looked at the effect on flight of aircraft involved in engine strikes with 2 or more large flocking birds, when at least 1 engine was damaged and 1 or more birds were ingested. There were 104 reports that provided this information; 94 involved damage to 1 engine and 10 involved damage to 2 or more engines. The most commonly reported negative effects on flight were: Engine shut down (24); Precautionary landing (19) (Table 12).

4. Conclusions

For the 15-year period, 1990 – 2004, the FAA database contained 3,117 reports of strikes where 1 or more bird(s) were ingested into 1 or more engines. There were 1,129 reports where the bird was identified and the bird's mass was known or could be assigned and 1,988 reports where the species of the bird was not identified. There were 319 (28% of the identified birds) ingestion events involving identified birds with a mass greater than 1.2 kg. If we assume a similar distribution of events among the known and unknown birds, then there were an additional 557 (28% of the 1,988 unknown birds) ingestion events involving 1 or more birds with a mass greater than 1.2 kg, for a projected total of 876 such events. In contrast, for the 30-year period, 1969 – 1999, the ARAC only found 340 ingestion events worldwide involving birds with a mass greater than 1.15 kg.

There were 105 (9 % of the 1,129 ingestion reports with known birds) reports of ingestion events involving 2 or more known birds with masses greater than 1.2 kg that resulted in damage to 1 or more engines on the aircraft. Again, assuming a similar distribution of events among the known and unknown birds, there were an additional 179 (9% of the unknown birds) ingestion events involving 2 or more birds with a mass greater than 1.2 kg, that resulted in damage to 1 or more engines, for a projected total of 284 such events.

There were 8 reports of reports of ingestion events involving 2 or more known birds with masses greater than 1.2 kg that resulted in damage to both engines on a twin-engine aircraft; 6 (0.5% of the known birds) of the 8 aircraft involved were air carrier aircraft. Making the same assumption of a similar distribution of events among the known and unknown birds, there were an additional 10 (0.5% of the unknown birds) twin-engine air carrier aircraft ingestion events involving 2 or more birds with a mass greater than 1.2 kg that resulted in damage to both engines, for a projected total of 16 such events.

Finally, if we assume that only 20 percent of all strikes in the USA are reported (Cleary et al. 2005, Wright and Dolbeer 2005) and there is no difference in the reporting rates for minor and major strike events, there were 80 twin-engine air carrier aircraft ingestions events involving 2 or more birds with a mass greater than 1.2 kg that resulted in damage to both engines, between 1 January 1990 and 28 February 2005. We believe this number to be high, and represents the projected upper limit for the occurrence of such events. The actual number of these 2-engine damage events should lie some where between the 2 extremes of 17 and 80.

We believe these bird ingestion data from 1990-2005 in the USA indicate that the threat of multi-engine strikes and danger posed by large flocking birds is more serious than the ARAC's recommendations, based on an older (1969-1999), less harmonized dataset, would indicate. Combined with the continued increases in populations of large flocking birds and quieter, 2-engine air carrier aircraft, there are enough concerns to warrant rejection of the ARAC's recommendations and a re-initiation of the analysis of this issue using a more complete worldwide dataset of strike events that has been checked for errors and harmonized for consistency. This will involve additional study and may result in producing different requirements and parameters for measuring the effects of bird strikes to turbofan-powered engines.

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Table 1. Summery of Aviation Rule Advisory Committee, Engine Hazard working Group statements concerning occurrences of multi–engine ingestions events for large flocking birds[a].

Engine inlet throat area.	Bird weight ranges (kg)			
	<1.15 kg	>1.15 – <1.5 kg	>1.5 – <3.65 kg	>3.65 kg
	Has a multi–engine ingestion event occurred?			
> 3.9m^2	?	No	No	No
3.5–3.9m^2	?	Yes	Yes	No
2.5–3.5 m^2	?	Yes	No	No
1.35–2.5m^2	?	No	No	No
0.4–1.35m^2	?	Yes	Yes	No
< 0.4m^2	Yes	No	No	No

[a] ARAC consider “large flocking birds” as those having a mass >1.15 kg

Table 2. Recommended engine ingestion standards for large flocking birds made by ARAC Engine Hazard Working Group, 12 July 2002. Ingestion is at a bird velocity of 200 knots.

Engine inlet throat area m^2 (in^2)	Bird Quantity	Bird mass/weight kg. (lbs.)
<2.5 (3,875)	None	–
>2.5 < 3.5 (5,425)	1	1.85 kg. (4.08 lbs.)
>3.5 <3.9 (6,045)	1	2.10 kg. (4.63 lbs.)
>3.9 (6,045)	1	2.50 kg. (5.51 lbs.)

Table 3. The number of wildlife/aircraft strike reports involving USA civil aircraft and USA military aircraft if the strike occurred at a civil field or joint use facility, 1 January 1990 – 28 February 2005.

Aircraft type	No. reports in database
Civilian	59,604
Military	8,276
Total	67,880

Table 4. The number of wildlife/aircraft strike reports for USA civil aircraft, indicating ≥1 birds or mammals struck ≥1 engines, 1 January 1990 – 28 February 2005.

Species	No. reports in database	No. (%) of reports indicating ≥1 engines struck
Mammals	1,500	135 (9)
Birds	58,104	7,973 (14)
Total	59,604	8,108

Table 5. Number of reports identifying the type of civil aircraft engine involved in bird/engine strikes by type of engine, USA, 1 January 1990 – 28 February 2005.

Engine type	No. reports in database
Turbofan	6,470
Turboprop	1,003
Reciprocating	316
Turbojet	100
Turboshaft (helicopter)	18
Unknown	66
Total reports	7,973

Table 6. Number of reports of turbojet- or turbofan-powered civil aircraft with single and multiple-engine bird strikes and engine damage, USA, 1 January 1990 – 28 February 2005.

	No. of reports with engine(s):	
Number of engines struck or damaged	Struck	Damaged
Single	6,255	2,303
Multiple	312	83
2	298 (251)[a]	82 (70)[a]
3	9(4)[b]	1
4	5(5)[c]	0
Total	6,567	2,386

[a] Values in parentheses are number of incidents with 2 engines struck or damaged that involved aircraft with 2 engines.

[b] Values in parentheses are number of incidents with 3 engines struck or damaged that involved aircraft with 3 engines.

[c] Values in parentheses are number of incidents with 4 engines struck or damaged that involved aircraft with 4 engines

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Table 7. Number of reports of turbojet- or turbofan-powered civil aircraft with single and multiple-engine bird ingestions and engine damage involving >1 bird, USA, 1 January 1990 – 28 February 2005.

	No. of reports with engine(s):	
Number of engines ingesting birds or damaged	Ingesting bird(s)	Damaged
Single	2,919	1,423
Multiple	198	70
2	189(164)[a]	69(59)[a]
3	7(3)[b]	1
4	2(2)[c]	0
Total	3,117	1,493

[a] Values in parentheses are number of incidents with 2 engines ingesting birds or damaged that involved aircraft with 2 engines.

[b] Values in parentheses are number of incidents with 3 engines ingesting birds or damaged that involved aircraft with 3 engines.

[c] Values in parentheses are number of incidents with 4 engines ingesting birds or damaged that involved aircraft with 4 engines.

Table 8. Number of reports of turbojet- or turbofan-powered civil aircraft with single and multiple-engine bird ingestions and engine damage involving $\geq$2 birds, USA, 1 January 1990 – 28 February 2005.

	No. of reports with engine(s):	
Number of engines ingesting bird(s) or damaged	Ingesting bird(s)	Damaged
Single	550	349
Multiple	181	65
2	173(153)[a]	64(56)[a]
3	6(2)[b]	1
4	2(2)[c]	0
Total	731	414

[a] Values in parentheses are number of incidents with 2 engines ingesting birds or damaged that involved aircraft with 2 engines.

[b] Values in parentheses are number of incidents with 3 engines ingesting birds or damaged that involved aircraft with 3 engines.

[c] Values in parentheses are number of incidents with 4 engines ingesting birds or damaged that involved aircraft with 4 engines.

Table 9. Number of reports of turbojet- or turbofan-powered civil aircraft with single and multiple-engine bird ingestions and engine damage involving ≥2 birds massing ≥ 900 g, USA, 1 January 1990 – 28 February 2005.

	No. of reports with engine(s):	
Number of engines ingesting bird(s) or damaged	Ingesting bird(s)	Damaged
Single	200	160
Multiple	63	25
2	56(52)[a]	25(21)[a]
3	4(1)[b]	0
4	1(1)[c]	0
Total	263	185

[a] Values in parentheses are number of incidents with 2 engines ingesting birds or damaged that involved aircraft with 2 engines.

[b] Values in parentheses are number of incidents with 3 engines ingesting birds or damaged that involved aircraft with 3 engines.

[c] Values in parentheses are number of incidents with 4 engines ingesting birds or damaged that involved aircraft with 4 engines.

Table 10. Number of reports of turbojet- or turbofan-powered civil aircraft with single and multiple-engine bird ingestions and engine damage involving ≥2 birds with masses ≥1.2 kg, USA, 1 January 1990 – 28 February 2005.

	No. of reports with engine(s):	
Number of engines ingesting bird(s) or damaged	Ingesting bird(s)	Damaged
Single	109	94
Multiple	30	11
2	28 (24)[a]	11(8)[a]
3	1(0)[b]	
4	1(1)[c]	
Total	139[d]	105[e]

[a] Values in parentheses are number of incidents with 2 engines ingesting birds or damaged that involved aircraft with 2 engines.

[b] Values in parentheses are number of incidents with 3 engines ingesting birds or damaged that involved aircraft with 3 engines.

[c] Values in parentheses are number of incidents with 4 engines ingesting birds or damaged that involved aircraft with 4 engines.

[d] 121 air carrier aircraft and 18 business jet aircraft.

[e] 91 air carrier aircraft and 14 business jet aircraft.

Table 11. Number of strike reports involving ≥2 birds with masses >1.2 kg ingested into 1 or more engines for turbojet- or turbofan-powered civil aircraft with ≥1 engines damaged, plus damage to 1 or more other aircraft components, USA, 1 January 1990 – 28 February 2005.

Number of engines damaged	No. of non-engine parts damaged:	
	1	≥2
Single	24	13
Multiple	4 (3)[a]	2(1)[a]
Total	28	15

[a] Values in parentheses are number of incidents with 2 engines damaged that involved twin-engine aircraft.

Table 12. Number of reports indicating effect on the flight of turbojet- or turbofan-powered civil aircraft following bird ingestions into ≥1 engines/engine strikes by ≥2 birds with masses ≥1.2 kg, when ≥1 engines were damaged, USA, 1 January 1990 – 28 February 2005.

	No. of engines damaged	
Reported effect on flight of aircraft	1	>2
None	24(22)[a]	5(4)[a]
Aborted takeoff	8(7)[a]	0
Engine shut down	24(18)[a]	1
Precautionary landing	19(17)[a]	2(2)[a]
Other	9(8)[a]	1
Not reported	10(7)[a]	1(1)[a]
Total	94	10

[a] Values in parentheses are number of incidents that involved twin-engine aircraft.