Bird Strike Damage Rates for Selected Commercial Jet Aircraft

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Note: This paper is based on presentations made to Bird Strike Committee USA and Bird Strike Committee Canada from 1995–1999.

Since the inception of jet travel, there have been tens of thousands of bird strikes to civil and military aircraft of every size, but only a fraction of these have caused damage to large commercial aircraft. For all but a handful of the most significant events, the reporting of such encounters to national or international aviation authorities is voluntary, making it difficult to determine rates of bird strikes or bird strike damage to particular classes of aircraft. This study of selected bird strike information sources for large commercial jets was conducted in order to more fully understand the frequency and the range of damage that bird strikes can cause and also to compare the rates of bird strike damage to different types of aircraft.

Using principles outlined in chapter six of my book *Understanding Aviation Safety Data*, This paper will address three questions about the effects of bird strikes on large commercial jet aircraft:

1. Do different aircraft models have bird strike and bird strike damage rates?
2. Is bird damage distributed uniformly across the aircraft?
3. Do different aircraft have different levels of resistance to damage?

In order to address these questions, the bird strike damage record of four types of large jet transports—the 737-300/400/500, 747, 757, and 767—was examined for the time period January 1, 1982 to June 30 1993. Any further mention of the 737 in this paper refers only to the 737-300/400/500 models. Information on these aircraft models was drawn from records of the Boeing Company, the Federal Aviation Administration, airline safety publications, and a variety of other aviation industry sources. In order to put the bird damage history of these four aircraft models in perspective, three additional sources of bird strike information from different organizations were included:

1. A bird strike study from U.K. Civil Aviation Authority (CAA) for U.K. registered aircraft from 1984 to 1986;
2. A summary from the International Civil Aviation Organization (ICAO) Bird Strike Information System for the years 1988 to 1992, and
3. A detailed breakdown of bird strike events reported to the ICAO in 1992;

In this study, a **bird damage encounter** refers to a bird strike involving one or more birds that either (1) caused damage to the aircraft that had to be repaired before the next revenue flight or (2) caused a significant effect on the flight such as a rejected takeoff or the malfunction of some aircraft system.

Table 1 summarizes the similarities and differences between the information provided by the three organizations.

Table 1: Comparisons of the Three Bird Strike Data Sources

Characteristics	CAA	ICAO	Boeing
Time Frame	1984-1986	1988-1992	1982- June 1993
Scope	U.K. registered civil aircraft over 5700 kg (12,500 lb) -also includes some executive jets lighter than 5700 kg	Civil aircraft bird strikes voluntarily reported by ICAO member states. About 70% of these strikes were on large jet aircraft over 27,000 kg No more than 49 of the 183 ICAO member states sent reports in a given year.	737-300/400/500, 747, 757, and 767. 100% large jet aircraft over 27,000 kg
Aircraft Flights	1.6 million (estimated)*	No information given	22.1 million
Bird Strikes	1629 total, 1595 to fixed wing aircraft (98%)	25,894 - 99% fixed wing	No information given
Bird Damage Encounters	105-120, about 6.8% of all strikes, 9% of all strikes to jets and 14% of all wide body bird strikes	1464 (estimated from 1992 data), about 5.65 % of all strikes	1265, unknown number of non-damage encounters
Bird Damage Encounter Rates	6.6-7.5 x 10^{-5} per flight	Insufficient information	5.7 x 10^{-5} per flight
Strike Altitude (AGL)	Below 200 ft - 75% Below 800 ft - 85% Below 2500 ft - 92% At cruise - 2%	Below 200 ft - 64% Below 1000 ft - 82% Below 2500 ft - 91% (based on 1992 data)	Incomplete information

* estimates in this chart are based on information contained within that bird strike information source

Based on the ICAO and CAA data on the distribution of bird strikes by altitude, aircraft flights was chosen as the basic unit of exposure because for those bird strikes where the altitude was known, more than 90% occurred below 2500 feet AGL. The CAA data stated that only about 2% of the strikes occurred during cruise. Both studies included larger jets and other aircraft, but neither study explicitly stated whether the relationship applied to the large jet airliners in those studies. However, the detailed 1992 ICAO data implied that about 70% of the aircraft in the bird strike reports were large jets.

Data Limitations

These data sources have a number of common limitations:

Different reporting criteria: Most bird strikes do not significantly affect the aircraft so reporting to aviation authorities, is voluntary so airports, airlines, or national aviation authorities that are effective at reporting strikes are disproportionately represented.

Different levels of details: In addition to those items mentioned in Table 1, the data sources also differed on the amount of damage information. Only the Boeing data allowed detailed analysis of damage by location on the aircraft. Also there was no way to analyze the ICAO and CAA data by specific model or event

Data sources not independent: Many of the Boeing events were certainly included in the ICAO and CAA statistics, but there was no way to measure the level of commonly reported events or to see if bird strike information from specific events was consistent among the three data source.

Assumptions

In this paper's analysis, several assumptions were made about the bird strike information.

1. Bird strike reporting is highly variable and dependent on the ability and willingness of the airline, airport authorities, and national aviation authorities to report these events. Therefore, any identified population of bird strikes or bird strike effects should be considered an minimum estimate of the prevalence of these strikes.
2. Differences in bird strike rates are due in part to the differing levels of effectiveness for the bird strike reporting processes for an airline, government, or aircraft manufacturer.

Question 1: Differences in Aircraft Model Strike Rate and Damage Rate

None of the three data sources provided details of both bird strikes to individual aircraft models and also of the number of flights by aircraft model. The Boeing data included flights by model but did not include the number of bird strikes that did not cause damage.

The details of the Boeing damage encounter data follows in Table 2.

Table 2: Rate of Bird Damage Encounters By Aircraft Model

Model	Damage Encounters	Flights	Rate per Flight
737-3/4/5	384	10M	3.8×10^{-5}
747	599	6.0M	1.0×10^{-4}
757	118	3.0M	3.9×10^{-5}
767	164	3.1M	5.3×10^{-5}
Total	1265	22.1M	5.7×10^{-5}

Table 2 shows that the 747 has a bird damage encounter rate about 2.63 times the size of the 737, 2.56 times that of the 757, and 1.89 times the 767 rate. The obvious conclusion is that this is due to the 747 being a bigger aircraft. On the surface, it would appear that aircraft size has some relation to damage encounter rate and information from the CAA paper would seem to confirm this. The CAA paper indicated that 9% of all bird strikes to large jets resulted in damage while 14% of the strikes to wide bodied jets resulted in damage, a ratio of 1.56 wide body damage encounter events for every one event on all jets. Coincidentally, the ratio of the wide body bird damage encounter rate to the all model rate for the Boeing data is 1.47 to 1.

This information from the Boeing and CAA data do not directly address whether different models have a different bird strike rate. The CAA paper went as far as to say that 1 in 1000 flights results in a bird strike but did not break this down by model. If one were to assume that the overall bird strike rate between wide and standard bodied large jets are the same, then the CAA and Boeing data would support the idea that wide bodied aircraft have a higher conditional probability of damage given a bird strike.

Question 2: Damage Distribution on the Aircraft

Damage to the aircraft is not uniform, but rather concentrated on the engine and nacelle areas. The CAA and ICAO data did not detail damage by section, but the Boeing data provided insight in this area with damage to the engine and nacelles in over 75% of all bird damage encounters. Table 3.1 and 3.2 details the fraction of damage encounters involving the engine and the relative size of the projected frontal area for the four Boeing models and their engine and nacelle areas.

Table 3.1: Bird Damage Encounters - Engine Area

Model	Damage Encounters	Engine Area Encounters	Percent in Engine Area
737-3/4/5	384	297	77.3
747	599	472	78.8
757	118	83	70.3
767	164	118	72.0
Total	1265	970	76.7

Table 3.2: Aircraft and Engine Projected Frontal Areas

Model	Engine/Nacelle Area	Aircraft Frontal Area	% Engine Area
737-3/4/5	$5.1m^2$	$36.7m^2$	13.9
747	$24.7m^2$	$138m^2$	17.9
757	$9.7m^2$	$61.9m^2$	15.7
767	$12.4m^2$	$82.8m^2$	18.1

The fraction of damage encounters involving the engines and nacelles is clearly high relative to their contribution to the projected frontal areas. Three other general areas of the aircraft - wings, fuselage, and empennage - were studied with respect to their involvement in of bird damage encounters, but engines and nacelles were clearly the most likely of the four areas to be damaged in a given bird damage encounter.

Question 3: Differences in Resistance to Damage

This question can be posed as follows: is a given area of different aircraft equally likely to sustain damage from a bird strike given the same exposure to the bird strike hazard? Instead of using aircraft flights as the unit of exposure, a better unit for measuring the differences in damage resistance would be a given surface area being exposed to a specific number of flights. For this paper that measurement would have the units of one square meter of projected aircraft area exposed to one million flights. Alternately, one can define the measurement as one square kilometer of projected aircraft area exposed to one flight (km^2-flight). Table 4.1 shows the exposures and the rate of bird encounter damage events of the four Boeing models. Table 4.2 gives the same information for the engine areas of the four aircraft. The CAA and ICAO data were not detailed enough to allow comparisons with similar jet models.

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Table 4.1: Bird Damage Encounters Per Exposure (km^2-flight)

Model	Flights	Aircraft Frontal Area	Exposure (km^2-flights)	Damage Encounters	Encounters per Exposure (km^2-flight)
737-3/4/5	10M	36.7m^2	367	384	1.05
747	6.0M	138m^2	828	599	0.72
757	3.0M	61.9m^2	185.7	118	0.64
767	3.1M	82.8m^2	256.7	164	0.64

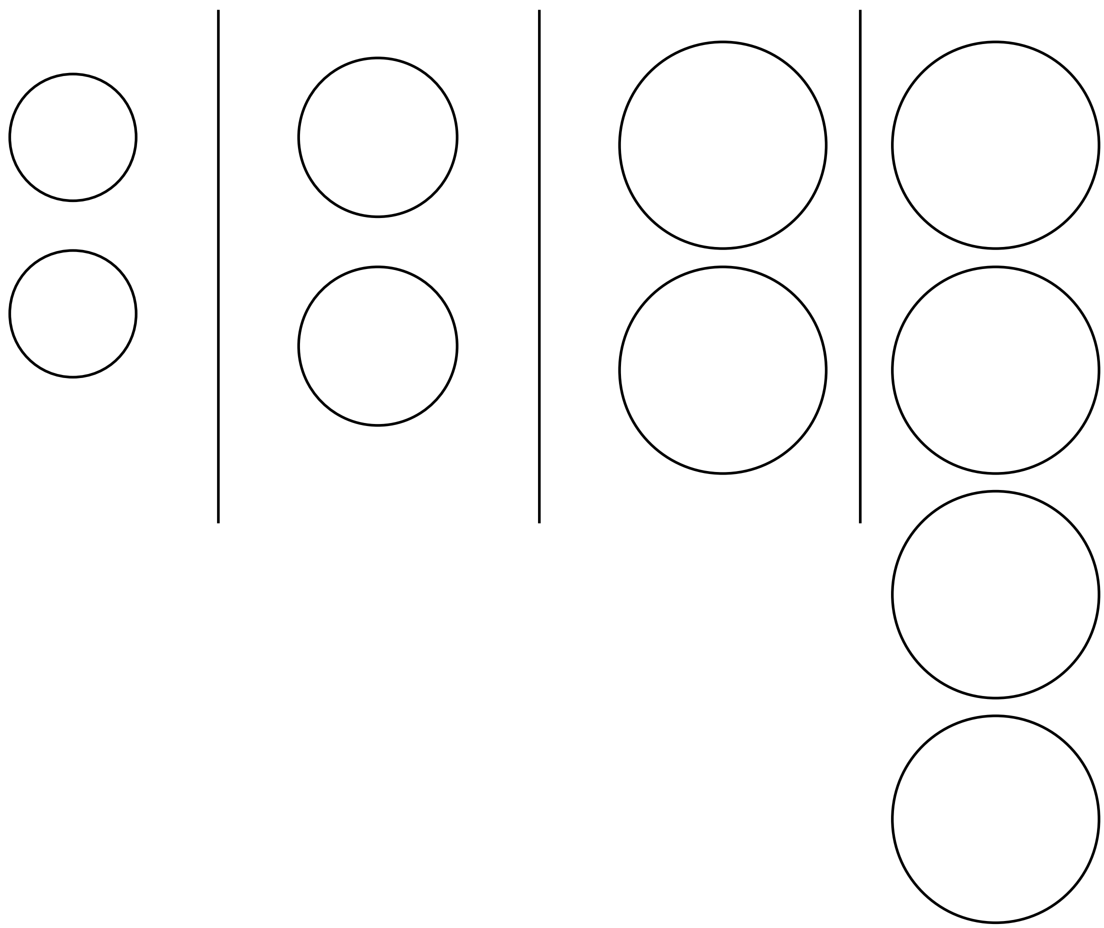
Table 4.2: Engine Area Bird Damage Encounters Per Exposure (km^2-flight)

Model	Flights	Engine Frontal Area	Exposure (km^2-flights)	Damage Encounters	Encounters per Exposure (km^2-flight)
737-3/4/5	10M	5.1m^2	51	297	5.82
747	6.0M	24.7m^2	148.2	472	3.18
757	3.0M	9.7m^2	29.1	83	2.85
767	3.1M	12.4m^2	38.4	118	3.07

Tables 4.1 and 4.2 indicate that the 737 is more prone to damage from bird strike for a given exposure area then the other three aircraft models and that this difference is more pronounced for the engine and nacelle area. While the engine area of the 737 has the lowest resistance to damage from bird strike , any given flight would have much less projected engine area compared to the other three models. Figure 1 graphically illustrates the engine area exposure differences between the four aircraft models by showing the relative size and number of engine nacelle areas of the four Boeing aircraft models studied.

Figure 1: Relative Projected Engine Areas - 737-3/4/5, 757, 767, 747*

737	757	767	747
2 x 2.55m^2	**2 x 4.85m^2**	**2 x 6.19m^2**	**4 x 6.19m^2**



*Note: Figures used to show relative size of the projected area, not actual silhouettes of the engines and nacelles.

Discussion

Although the ICAO and CAA sources were not as detailed as Boeing with respect to the damage caused by bird strikes, some comparisons between the three with respect to bird strike damage are possible. Assuming that the CAA estimates of one bird strike per one thousand flights and that 9% of all bird strikes on jets cause damage are accurate for both the CAA and ICAO studies, the comparisons detailed in Table 5 can be made between the three sources. The strike rate per flight for the three sources are similar, but not exactly comparable because the ICAO and CAA data included aircraft other than large jets.

Table 5: Bird Damage Encounter Rates By Source

Source	Flights (Millions)	Bird Strikes	Damage Encounters	Rate per Flight
Boeing Total	22.1	No information	1265	5.7×10^{-5}
CAA	1.6(estimate)	1595	105-120**	$6.5\text{-}7.5 \times 10^{-5}$
ICAO	26 (estimate)	25,894	1466	5.6×10^{-5}

** CAA study stated that 35 to 40 bird strikes a year caused aircraft damage

Based on the Boeing data, two things that stand out are the prominent role engines play in bird damage events and the different levels of resistance to damage showed by the four Boeing models studied. Overall, the standard bodied aircraft, the 737 and 757, were less likely to have a bird damage encounter during a flight than the wide bodied 747 and 767. This was supported by the CAA finding of wide body aircraft having a greater conditional probability of sustaining damage from a bird strike than do standard body aircraft.

Answers to Questions

Of the three questions initially posed in this paper, the bird strike and bird damage encounter data provided by the three sources was sufficient to address questions two and three and to partially address the first question.

Question 1: Do different aircraft models have different bird strike and bird damage rates?
None of the three sources provided overall bird strike information by aircraft model, so this question could not be answered.

Question 2: Is bird damage distributed uniformly across the aircraft?
The Boeing data best addressed this question and that data clearly showed that engines and nacelles were involved in over three quarters of all bird damage encounters and that the projected area of the engines and nacelles were all less than 20% of the total projected areas of the aircraft studied. The wide bodied 747 and 767 had a higher proportion of engine area damage encounters than the standard body 757 and 737-300/400/500, but the two larger aircraft also had a higher percentage of projected frontal area involving the engine area.

Question 3: Do different aircraft have different levels of resistance to damage?
Question three was not directly answered. Normalizing the bird damage encounter rate for the Boeing aircraft revealed that the 737-300/400/500 had a damage rate noticeably higher than the other three models and that this difference was more pronounced if only the engine and nacelle damage experience was considered. The available information could not show whether the operational environment of the four jet models were similar enough to discount this as a possible explanation of the higher 737 damage rate.

Conclusions

The analysis of the three data sources supports the following findings:

- The derived bird damage encounter rates from the CAA, ICAO, and Boeing data sources are similar
- More than 90% of their reported bird strikes took place below 2500 feet AGL
- Engines and nacelles were involved in over 75% of the bird damage encounters on Boeing aircraft
- Bird damage encounter rates for the Boeing aircraft are directly related to projected area of aircraft and engine areas with the 747 having the highest rate followed by the 767, 757, and 737-300/400/500
- If bird damage encounter rates are computed per million flights of one square meter of exposed aircraft area and engine area, the 737-300/400/500 has a higher damage encounter rate than the 747, 757, and 767
- The CAA and Boeing data suggest that wide bodied aircraft have about a 50% higher conditional probability of a bird damage encounter given a bird strike compared to standard bodied aircraft.

References

Curtis, Todd , *Understanding Aviation Safety Data: Using the Internet and Other Sources to Analyze Air Travel Risk*, SAE, Warrendale, PA, 2000
ICAO, IBIS World Statistics for 1992, Attachment to State Letter AN 4/9.1.1 - 94/51

ICAO, Statistical Data On ICAO Bird Strike Information System: 1988-1992, Attachment to State Letter AN 4/9.1 - 94/80.

John Thorpe, The Civil Aviation Birdstrike Record, Civil Aviation Authority, 1987.