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Study of Bird Ingestions into Small Inlet Area, Aircraft Turbine Engines

(May 1987 - April 1988)

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INTERIM REPORT

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16. Abstract

The Federal Aviation Administration (FAA) Technical Center initiated a study in May 1987 to determine the numbers, sizes, and types of birds which are being ingested into small inlet area turbofan and turbine engines and to determine what damage, if any, results. Bird ingestion data are being collected for the ALF502, TFE731, and TPE331 engines. This report analyzes the first of 2 years of data collection. The first year extends from May 1, 1987 through April 30, 1988.

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EXECUTIVE SUMMARY

An investigation was initiated by the Federal Aviation Administration (FAA) Technical Center in May 1987 to determine the numbers, weight, and species of birds which are ingested into small inlet area turbofan and turboprop engines during worldwide service operation and to determine what damage, if any, results. Small inlet area engines are defined as those engines having an air inlet area up to approximately 1400 square inches. This report presents an analysis of the first of 2 years of data. The purpose of the analysis is to assist the FAA in evaluating certification test requirements for such engines. In particular, this report presents information concerning ingestion events as related to time of day, month, location, and bird weight.

These data cover the period from May 1 1987 to April 30 1988. Throughout the world during that time there were approximately 7.2 million engine operations by the engines included in the data. Ninety-seven engine ingestion events were reported during this period.

Within the United Sates, the most frequently ingested bird has a weight of 4 ounces, while outside the United States the most frequently ingested bird weight is 7.7 ounces. Within the United States, half the ingested birds weigh 14 ounces or more, while outside the United States bird weights as low as 8 ounces are in the top half of the weight range. Bird weights are based on identification of bird species.

Most bird ingestions occurred in the northern hemisphere. Several tests were made to detect seasonal patterns in these data. However, the sample size is too small to make it evident if seasonal patterns are present.

It was found that ingestions occured more frequently in the daytime than at night. This is probably the result of two factors: fewer flights at night, and more birds flying in the daytime.

It was determined that the engine ingestions could be described adequately by a Poisson distribution. This made it possible to test hypotheses concerning the relationship between engine size and ingestion rate. It was determined that ingestion rates are related to engine size, but it was not possible to determine whether number of ingestions was related to engine inlet cross sectional area or to engine inlet diameter. It was determined that the ingestion experience of the turboprop engine was different from that of the turbofan engines, but the reasons for this difference could not be determined.

It was observed that most ingestions take place during takeoff and climb, with important but lesser numbers of ingestions occurring during approach and landing. It was not the case that there was a threshold bird weight such that smaller birds did no damage and larger birds always caused damage. Instead, the probability of damage increased with bird weight. However, in some events small birds caused damage, while in other events larger birds caused no damage at all. Probability-of-damage curves were computed from the data.

It was observed that as the level of damage increased, the probability of crew action likewise increased. A crew action is defined as an aborted takeoff, air turnback, or diversion. The probability of crew action was only 14 percent after

engine ingestion events in which there was no damage, while the probability of crew action was 48 percent after engine ingestion events in which there was severe damage.

It was found that the probability of ingestion for birds that weighed less than or equal to 4 ounces (the most common range) was 2.22 per million engine operations. Overall, the probability of ingesting a bird was 13.5 per million engine operations.

The following is a summary of the most pertinent statistics extracted from the first year of data:

Engine Ingestion Events	97
Aircraft Ingestion Events	89
Most Frequently Ingested Bird Weight (oz) (mode)	
United States	4.0
Foreign	7.7
Average Bird Weight (oz)	
United States	19.0
Foreign	13.3
Median Bird Weight (oz)	
United States	14
Foreign	7.7
Probability of an Engine Ingestion Event Per Engine Operation	
Worldwide	1.35×10^{-5}
United States	1.03×10^{-5}
Foreign	2.21×10^{-5}
Most Commonly Ingested Bird	
United States	Dove
Foreign	Gull/Lapwing
Engines Experiencing Moderate/Severe Damage	37
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SECTION 1

INTRODUCTION

1.1 BACKGROUND

Contention for airspace between birds and airplanes has created a serious bird/aircraft strike hazard. Two past studies [references 1 and 2] have indicated that birdstrikes on airplanes are statistically rare events. The probability of a birdstrike during any given flight is extremely low; however, given the large number of flights currently taking place, the expected number of birdstrikes becomes significant.

The windshield and the engine are particularly vulnerable to the birdstrike threat. Although penetration of the windshield by a bird is primarily a concern for military airplanes operating at high speeds in a low-altitude environment, such a penetration has occurred on a civilian airplane resulting in the death of the co-pilot. Ingestion of birds into airplane engines is a problem for commercial as well as military jet airplanes for it can cause significant damage to the engine resulting in degraded engine performance and possible failure.

In his study of bird ingestions on commercial flights, Frings [reference 1] indicated that nearly all bird ingestion events have occurred in the vicinity of airports during the non-cruise phase of flight. Hovey and Skinn [reference 2] reached similar conclusions. This is understandable because these phases of flight naturally occur closer to the ground where bird concentrations are higher, resulting in a higher probability of birdstrikes.

The solution to the problem of engine damage resulting from bird ingestion are similar to those for a windshield birdstrike, e.g., either design of the structure to withstand impact, or avoidance of birds. Bird avoidance can be facilitated by either of two approaches: (1) keeping airplanes out of airspaces with large bird concentrations, and (2) removing birds from these regions of airspace. Neither bird avoidance approach is well suited to civilian aircraft because flight schedules place airplanes in specific areas at specific times and the effectiveness of airport bird control programs (if any) varies from airport to airport and country to country.

Structural design of engines to minimize bird ingestion damage can be accomplished provided that realistic requirements with respect to bird sizes and numbers can be identified. Bird ingestion data for various sizes of turbofan and turboprop engines are currently being collected by several engine manufacturers. Statistical evaluation of bird ingestion data from these data collection efforts and previous bird ingestion studies will be useful in reevaluating the certification test requirements laid out in FAA regulation 14 CFR 33.77. As a result, future engines can be designed to withstand more realistic bird threats.

1.2 OBJECTIVES

The objective of this report is to determine the relationship of bird weight, time of day, phase of flight, and engine type to the frequency of bird ingestion events and the extent of engine damage resulting from the ingested birds. A statistical analysis was conducted of reported bird ingestion data experienced by commercial and general aviation aircraft equipped with any of three engine types (ALF502, TPE331, TFE731) operating worldwide over a 1-year reporting period from May 1987 through April 1988. The analysis was used to summarize the bird ingestion damage experienced by these engines. The findings of the analysis will be used to determine the adequacy of the bird ingestion test criteria, specified in FAA regulation 14 CFR 33.77 for this class of small inlet area engines. Small inlet area engines are being defined as those engines having an air inlet area up to approximately 1400 square inches.

1.3 ORGANIZATION OF REPORT

Section 2 discusses engine operations. Section 3 identifies the characteristics and behavior of bird species that have been ingested and reliably identified. Section 4 describes bird ingestion rates by location, engine type, and phase of flight. Section 5 summarizes engine damage resulting from bird ingestions. Section 6 examines the probabilities of various bird ingestion events. Section 7 provides a summary of the results obtained during this phase of data analysis. Section 8 lists references utilized in preparation of this report. Appendix A provides information about size and use of the engines covered in this report. Appendix B provides the original data used in the analysis. Appendix C discusses the methods of statistical analysis used in the report, particularly hypothesis testing.

SECTION 2

ENGINE OPERATIONS

The number of engine operations is required to determine bird ingestion rates. Operations data that have been used to generate bird ingestion rates throughout the report are provided to aid in understanding this section. The reader should refer to the Glossary of Terms for definitions of the terms used.

For the ALF502, data on engine hours and engine operations were available from the manufacturer through the FAA. For the TPE331 and the TFE731, only data on engine hours were available. To obtain engine operations, average values of 0.8 operations/hr (TFE731) and 1.2 operations/hr (TPE331) were provided by the FAA. Number of engine operations by month and engine type are presented in table 2.1. Figure 2.1 is a histogram displaying operations by month and engine. Note that the level of usage of the TPE 331 is much higher than that of the other two engines.

TABLE 2.1. ENGINE HOURS AND OPERATIONS BY MONTH AND ENGINE TYPE

	TOTAL HOURS	TOTAL OPERATIONS	US HOURS	US OPERATONS	FOREIGN HOURS	FOREIGN OPERATIONS
<u>ALF502</u>						
MAY87	47565	51705	39290	44167	8275	7538
JUN87	47565	51705	39290	44167	8275	7538
JUL87	56454	62408	46118	53719	10336	8689
AUG87	59302	64829	47163	54699	12139	10130
SEP87	53084	59349	43865	51507	9219	7842
OCT87	58932	62782	46311	52987	12621	9795
NOV87	55927	60779	43550	50574	12377	10205
DEC87	55027	59665	43032	49247	11995	10418
JAN88	56793	60950	46366	50244	10427	10706
FEB88	56550	60107	46366	48185	10184	11922
MAR88	50734	60051	41430	48185	9304	11866
APR88	61468	67588	45168	49224	16300	18364
TOTALS	659401	721918	527949	596905	131452	125013
<u>TFE731</u>						
MAY87	172337	137870	127148	101718	45189	36151
JUN87	174192	139354	128132	102506	46060	36848
JUL87	176086	140869	130058	104046	46028	36822
AUG87	180325	144260	132051	105641	48274	38619
SEP87	178156	142525	131189	104951	46967	37574
OCT87	181272	145018	132677	106142	48595	38876
NOV87	184856	147885	134888	107910	49968	39974
DEC87	186535	149228	135142	108114	51393	41114
JAN88	182168	145734	131583	105266	50585	40468
FEB88	184280	147424	134338	107470	49942	39954
MAR88	192834	154267	140277	112222	52557	42046
APR88	195041	156033	141617	113294	53424	42739
TOTALS	2188082	1750466	1599100	1279280	588982	471186
<u>TPE331</u>						
MAY87	288051	345661	206666	247999	81385	97662
JUN87	300495	360594	211357	253628	89138	106966
JUL87	327278	392734	234047	280856	93231	111877
AUG87	326172	391406	232892	279470	93280	111936
SEP87	328332	393998	232924	279509	95408	114490
OCT87	334965	401958	237444	284933	97521	117025
NOV87	338708	406450	237631	285157	101077	121292
DEC87	325952	391142	230677	276812	95275	114330
JAN88	335136	402163	237817	285380	97319	116783
FEB88	339840	407808	251480	301776	88360	106032
MAR88	344228	413074	250675	300810	93553	112264
APR88	361773	434128	261232	313478	100541	120649
TOTALS	3950930	4741116	2824842	3389810	1126088	1351306

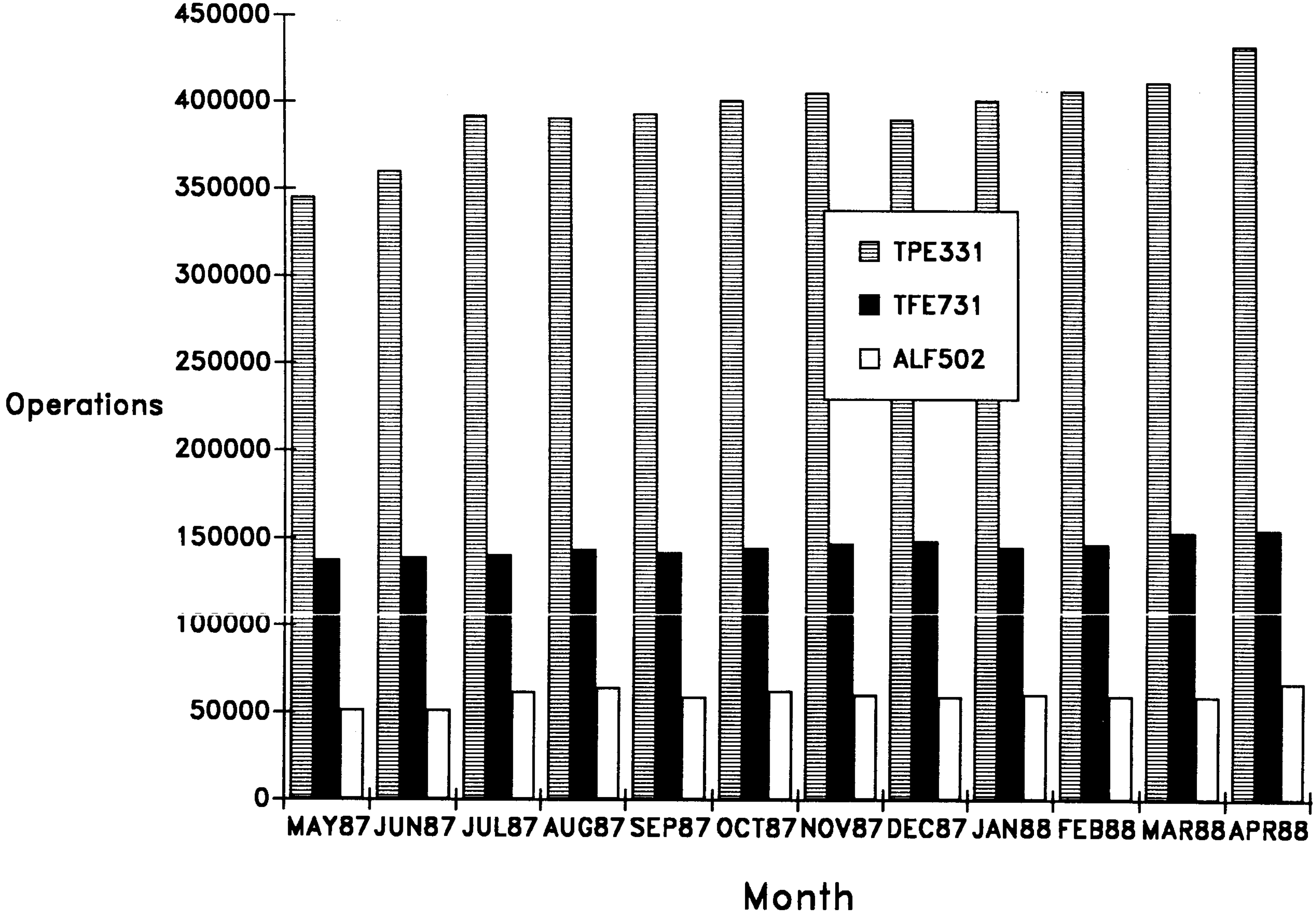

Figure 2.1. Engine Operations by Month and Engine Type

SECTION 3

CHARACTERISTICS OF INGESTED BIRDS

The purpose of this section is to provide a description of the birds that were ingested during the period covered by the data, and to provide an analysis of the extent of the bird ingestion threat. The bird related features that are described in this section include species, weight, and distribution of ingestions by time of day, by month, and geographic region.

Table 3.1 provides a tally of all the species that were positively identified by an ornithologist during the period covered by the data. The species are listed by order and family. One of the disappointing features of the small engines bird ingestion data base is the low bird identification rate. Out of the total of 89 aircraft ingestion events that were recorded, the bird species was positively identified only 32 times.

Table 3.2 presents the distribution of weights for the positively identified birds. The numbers in table 3.2 represent the total number of ingested birds. It should be noted that 2 was used as the number of birds when the exact number of positively identified ingested birds was unknown for a multiple bird ingestion event. The bird weights are derived from the species identification and when possible are adjusted for the age and sex of the ingested bird. Figure 3.1 presents the same data in the form of a histogram.

There were 20 cases where multiple birds were ingested into the same engine, and 7 cases where bird ingestions occurred in multiple engines during the same event. These cases, of multiple bird ingestions and multiple engine events, are important from a safety standpoint. However, the data contain too few cases to allow any conclusions to be drawn.

A comparison of the distribution of ingested bird weights for United States and foreign ingestion events was carried out utilizing the Kolmogorov-Smirnov test. The maximum deviation between the distributions was 0.32. By chance, a deviation of 0.39 would be exceeded five times in a hundred. Hence at a significance level of 0.05, the hypothesis that the weights of ingested birds in the United States and outside the United States are the same cannot be rejected. (For a brief explanation of statistical terms see appendix C.)

Summary statistics calculated from the raw data for the United States, foreign and worldwide bird weight distributions are presented in table 3.3. The statistics presented are the mode, the median, and the mean. These three statistics each represent an attempt to identify a "typical" member of a distribution. The mode is the most common value in the distribution, the median is the value which splits the distribution into two equal halves, and the mean is weighted by each value appearing in the distribution, as well as the number of times it appears.

The mode is a relevant measure of the bird ingestion problem. It represents the weight which will be encountered most frequently. In the United States, the modal weight is 4 ounces, while outside the United States the modal weight is 7.7 ounces. Worldwide the modal weight is also 7.7 ounces. These modal weights correspond to the most frequently encountered species in each case. It is possible to have multimodal distributions, but the weight distributions of birds ingested during the period covered by the data turned out to be unimodal.

TABLE 3.1. TALLY OF POSITIVELY IDENTIFIED BIRD SPECIES BROKEN DOWN BY US, FOREIGN, AND OVERALL

BIRD_SPE	BIRDNAME	LATIN	FOREIGN	U.S.	WORLD
14N10	Black-tailed gull	Larus crassirostris	0	1	1
14N12	Ring-billed gull	Larus delawarensis	2	0	2
14N14	Herring gull	Larus argentatus	0	1	1
14N31	Franklin's gull	Larus pipixcan	0	1	1
14N36	Common black-headed gull	Larus ridibundus	2	0	2
18Z69	Common house martin	Delichon urbica	1	0	1
1E3	Common loon	Gavia immer	0	1	1
1I27	Yellow-crowned night-heron	Nyctanassa violacea	0	1	1
1K1	Turkey Vulture	Cathartes aura	0	1	1
2J26	Snow goose	Chen caerulescens	0	1	1
2J30	Canada goose	Branta canadensis	0	2	2
2J84	Mallard	Anas platyrhynchos	1	0	1
2P1	Common rock dove	Columba livia	0	2	2
2P105	American mourning dove	Zenaida macroura	0	4	4
2P9	Common wood-pigeon	Pterocles gutturalis	1	0	1
3K31	Brahminy Kite	Haliastur indus	1	0	1
4L85	Hungarian partridge	Perdix perdix	1	0	1
5N1	Common lapwing	Vanellus vanellus	4	0	4
5N33	Killdeer	Charadrius vociferus	0	1	1
64Z54	Red-winged blackbird	Agelaius phoeniceus	0	1	1
6N19	Greater yellowlegs	Tringa melanoleuca	0	1	1
70Z23	Eurasian tree sparrow	Passer montanus	1	0	1
			14	18	32

TABLE 3.2. WEIGHT DISTRIBUTION OF BIRDS BY LOCATION FOR ENGINE INGESTION EVENTS

Weight Interval	US	FOREIGN	TOTAL
$0 < x \leq 4$	12	4	16
$4 < x \leq 8$	1	10	11
$8 < x \leq 12$	1	1	2
$12 < x \leq 16$	3	4	7
$16 < x \leq 20$	1	2	3
$20 < x \leq 24$	2	0	2
$32 < x \leq 36$	0	1	1
$36 < x \leq 40$	1	0	1
$64 < x \leq 68$	1	0	1
$84 < x \leq 88$	2	0	2
$100 < x \leq 104$	1	0	1
$124 < x \leq 128$	3	0	3
Total	28	22	50

Note: all weights in ounces

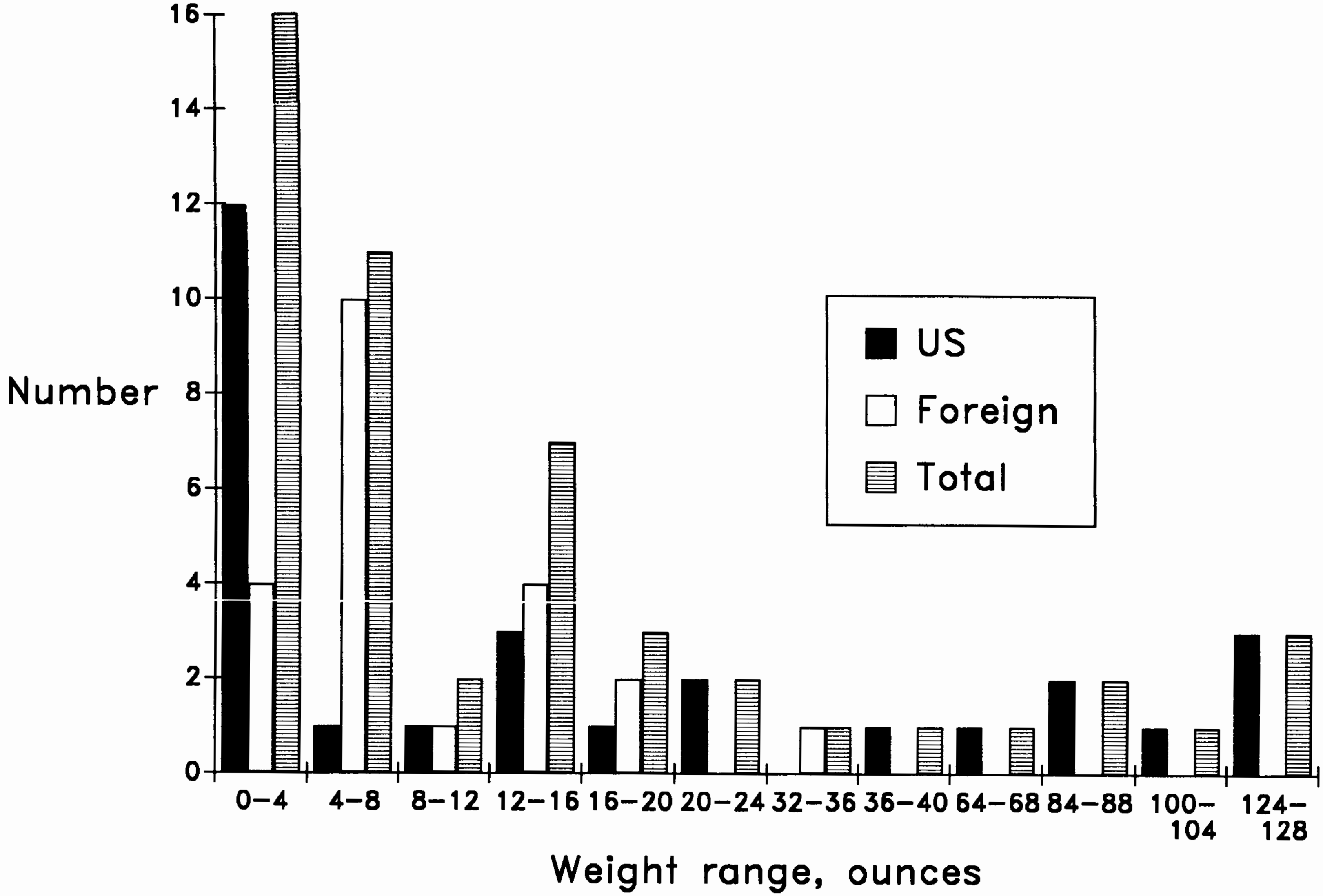

Figure 3.1 Engine Ingestions by Weight

TABLE 3.3. SUMMARY STATISTICS FOR INGESTED BIRD WEIGHTS

Statistic	US	Foreign	Worldwide
Mode	4	7.7	7.7
Median	14	7.7	7.7
Lower Quartile	4	7.7	4
Upper Quartile	64.5	15	18
Interquartile Range	60.5	7.3	16
Mean	33.0	10.2	23.0
Standard Deviation	44.5	8.02	25.3

Note: all weights in ounces

The median is the value which divides the distribution in half. Median weights are 14 ounces in the United States, 7.7 ounces outside the United States, and 7.7 ounces worldwide. The quartiles divide the upper and lower halves of a distribution in half. Each is a value one-quarter of the way in from the end of the distribution. In the United States, 25 percent of the birds had weight equal to or exceeding 64.5 ounces (4 pounds), while outside the United States the top 25 percent of birds had weights equal to or exceeding 15 ounces. In the United States, 25 percent of the birds weighed 4 ounces or less, while outside the United States the lowest 25 percent of the weights included birds up to 7.7 ounces. The interquartile range (IQR) is the distance between the upper and lower quartiles -- the "middle half" of the distribution. It is a measure of the dispersion of values in the distribution. In the United States the IQR is 60.5 ounces, while outside the United States it is 7.3 ounces. This simply means that outside the United States the weights of ingested birds are more closely clustered about the median weight than are the weights of birds ingested in the United States. In the United States, the birds at the upper end of the distribution weighed more than did the birds at the upper end of the distribution outside the United States. This can be seen clearly from table 3.2, which shows that outside the United States the weight of ingested birds did not exceed 36 ounces, while in the United States there were eight with a weight exceeding 36 ounces.

The mean is obtained by weighting each value in the distribution by the number of times it occurs. Moreover, it is a function of the sum of all the values in the distribution. The mean tends to be influenced by extreme values. In the case of the bird weight distributions, the mean is influenced by the high values, and thus overestimates the weight of the "typical" ingested bird. The mean would be a relevant measure of ingested bird weight if damage were related to the cumulative weight of all birds ingested by a single engine since it does depend upon the total weight of the ingested birds. However, since bird ingestion is such a rare event, the mean is not a particularly useful measure of ingested bird weight.

From the standpoint of descriptive statistics, then, the important results from table 3.3 are that the most frequently ingested birds weigh 7.7 ounces, but 50 percent of all ingested birds weigh 7.7 ounces or more, and fully 25 percent of all ingested birds weigh more than 18 ounces.

One issue which might be raised is the extent to which the ingestion events in which the bird weight is known are representative of all ingestion events. It might be hypothesized that the bird species is more likely to be identified (and therefore the weight known) in those cases in which greater damage has been incurred, while bird weight is less likely to be known if lesser or no damage occurred. The chi-square test was applied to this hypothesis. In 96 of the 97 engine ingestion events, damage severity was specified. In 37 of these events, bird species was also identified. Thus overall, bird species was identified in 38.5 percent of the ingestion events in which damage severity was also specified. This overall percentage was compared with the percentage of cases in which bird species was identified for each of the damage categories. The value of chi-squared for this comparison was 0.073. By chance, a chi-squared value of 11.3 would be exceeded one time in a hundred (with three degrees of freedom). The actual value for the comparison is much smaller than the critical value. Hence the hypothesis that bird species is equally likely to be identified for all damage categories cannot be rejected at the 0.01 level.

Figure 3.2 presents a histogram of ingestions by month for the period covered by the data. It is known that the number of ingestions per month should be influenced by seasonality (bird migrations) and by number of operations. However, the effects of these factors could not be separately identified in the data. Since ingestion locations were known, the numbers of ingestions could be categorized as United States or foreign, and also as Northern or Southern Hemisphere. Numbers of engine operations could be separated only into United States or foreign. Hence ingestions in either hemisphere could not be corrected for number of operations.

The variation in number of ingestions from month to month is not only highly volatile but appears random. Several tests for randomness, trend, or seasonality were applied.

A chi-squared test was used to test for differences between patterns of monthly ingestions inside and outside the United States (including both hemispheres). The test found no significant difference between United States and foreign monthly ingestion patterns.

A Kolmogorov-Smirnov test was likewise applied to United States versus foreign monthly ingestions. This test showed that with probability 20 percent, differences as great as those found could be expected by chance alone. This reinforces the chi-squared test and shows that the hypothesis of no difference cannot be rejected.

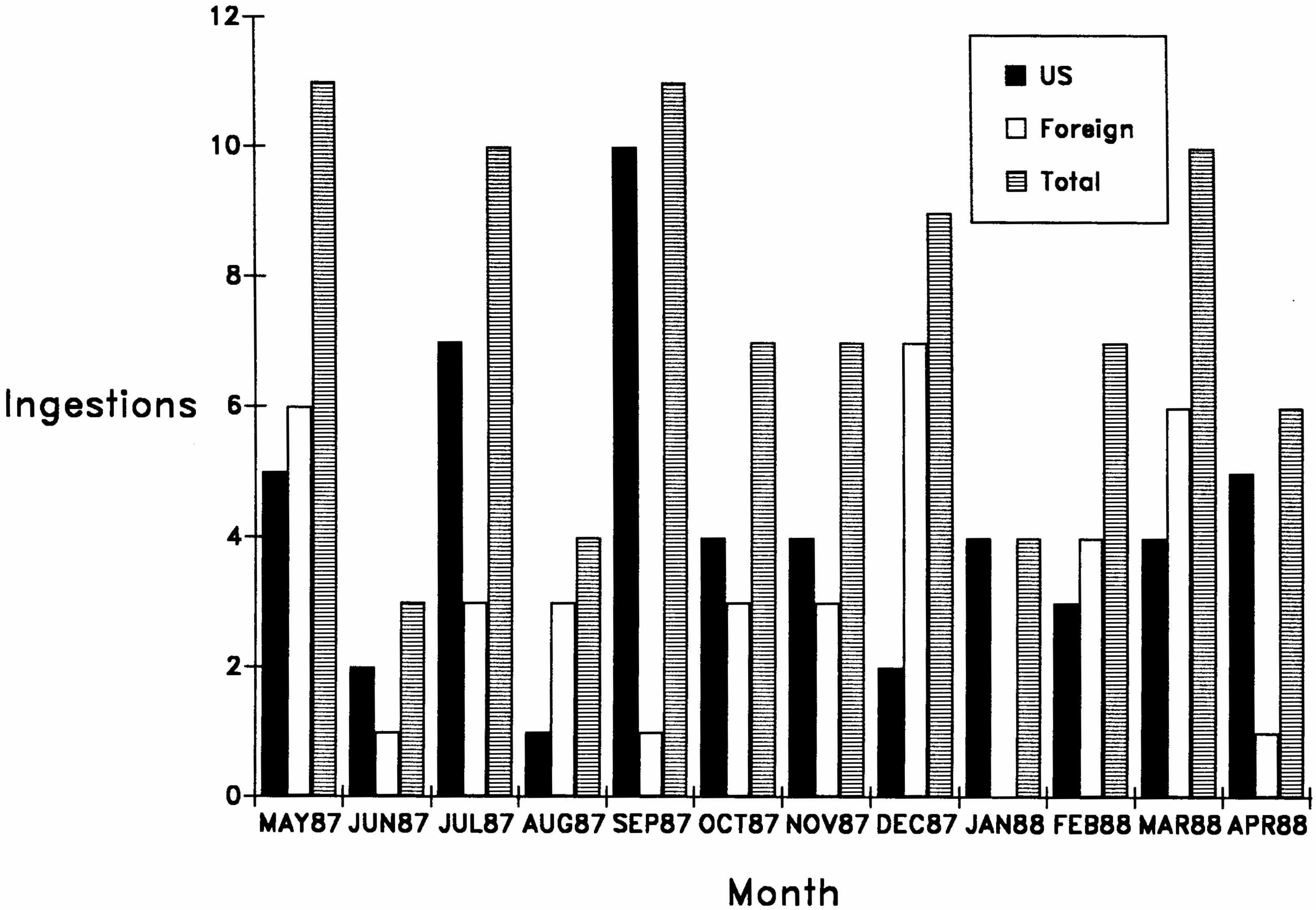

Figure 3.2 Aircraft Ingestions by Month

A chi-squared test was run on the Northern Hemisphere data alone. This also showed no significant departure from chance in the month-to-month variations.

A linear regression was performed of the number of Northern Hemisphere ingestions on the months in sequence. The slope of the regression was 0.16, but the standard error of the regression was 0.24. Hence the slope was not significantly different from zero. On the basis of this test, the hypothesis of no trend in the data cannot be rejected.

A Fourier analysis of the month-to-month variation in ingestions in the Northern Hemisphere was carried out, in an attempt to find periodicity in the data. The magnitude of the second harmonic (two peaks and two troughs) was only 25 percent of the average monthly ingestion rate. At best, this would be only weak evidence for periodicity (seasonality). Moreover, one of the highest numbers of ingestions in the actual data occurred during a trough of the fitted Fourier series, while one of the lowest numbers of ingestions occurred at a peak of the fitted Fourier series. This result indicates that if seasonality is present in the Northern Hemishpere data, it is buried in the noise.

Figures 3.3a, 3.3b, and 3.3c present histograms of ingestion of time of day for the period covered by the data. Figure 3.3a shows all ingestion events by time of day. A chi-squared analysis allows rejection of the hypothesis that number of ingestions is uniformly distributed throughout the day. The actual value of chi-squared was 10.3, while a value of 7.4 would be exceeded by chance only 2.5 percent of the time. The variation in number of ingestions by time of day can be explained by either or both of two factors. First, most aircraft operations occur in the middle of the day, with fewest at night. Numbers of analysis allows rejection of the hypothesis that number of ingestions is uniformly distributed throughout the day. The actual value of chi-squared was 10.3, while a value of 7.4 would be exceeded by chance only 2.5 percent of the time. The variation in number of ingestions by time of day can be explained by either or both of two factors. First, most aircraft operations occur in the middle of the day, with fewest at night. Numbers of operations in the morning and the evening are intermediate between the midday and night levels. Second, many birds tend to be diurnal and are less likely to be exposed to ingestion at night. Both these factors probably influence the variation by time of day in the number of ingestions.

During most time periods, the number of ingestions in the United States was greater than the number outside the United States. However, a chi-squared test showed that there was no significant difference in the patterns of ingestions in the United States and outside the United States by time of day.

Figure 3.3b shows numbers of ingestion events in which more than one bird was ingested into the same engine. These events were more frequent in the United States than outside the United States, but the numbers are too small to permit any statistical tests.

Figure 3.3c shows numbers of ingestion events in which birds were ingested in more than one engine. The sample size is too small to permit any statistical tests.

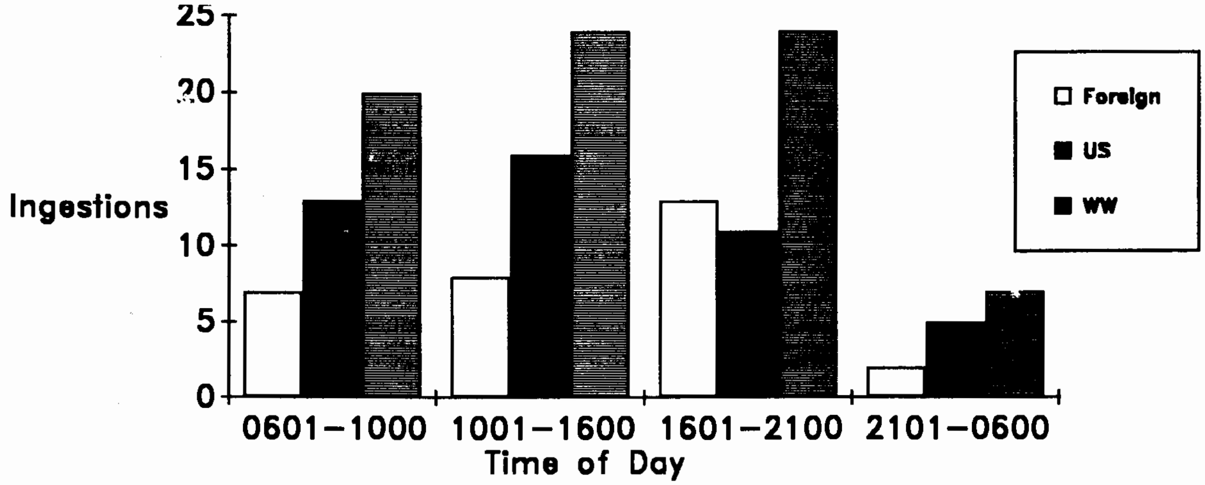

Figure 3.3a. Aircraft Ingestions by Time Of Day

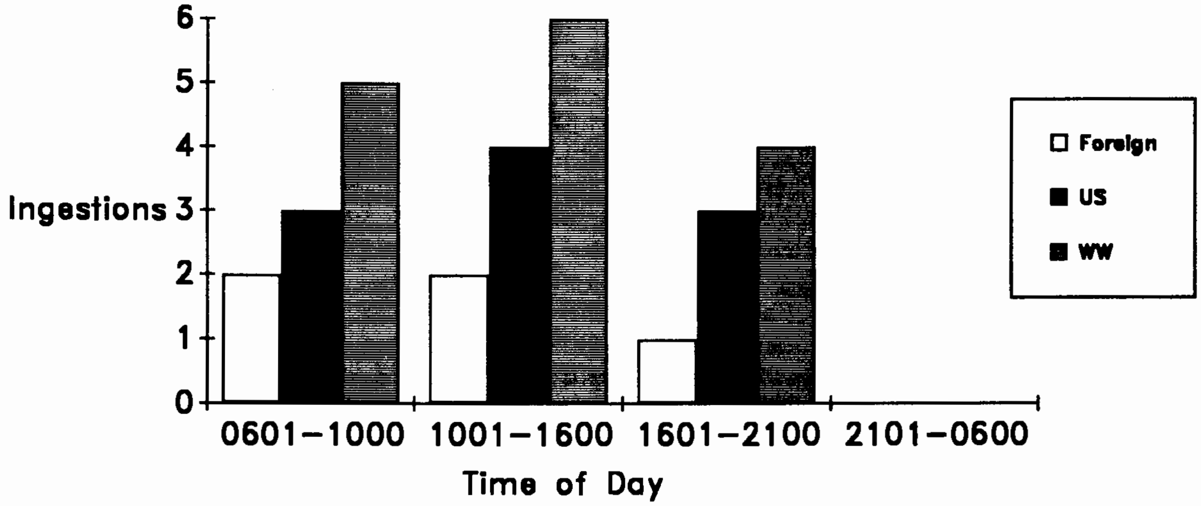

Figure 3.3b. Multiple Bird Ingestions

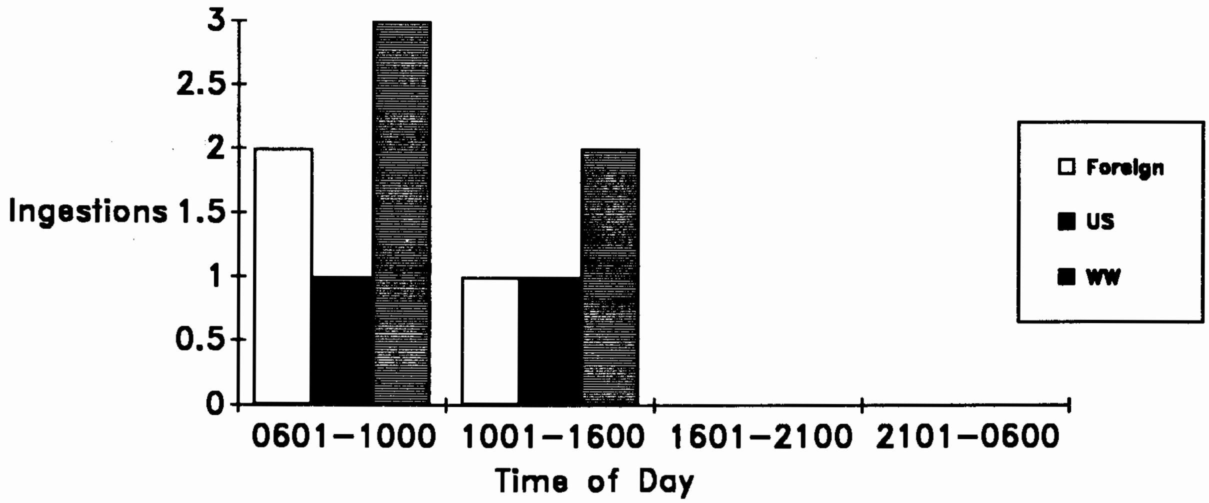

Figure 3.3c. Multiple Engine Ingestions

Figure 3.4 is a map showing the number of engine ingestion events by state within the U.S. Only two airports had more than one ingestion incident during the period covered by the data, and these had only two incidents each. Only one state had more than two ingestions, and this was at several airports with one ingestion each. The data are not adequate to identify any patterns among the ingestion events.

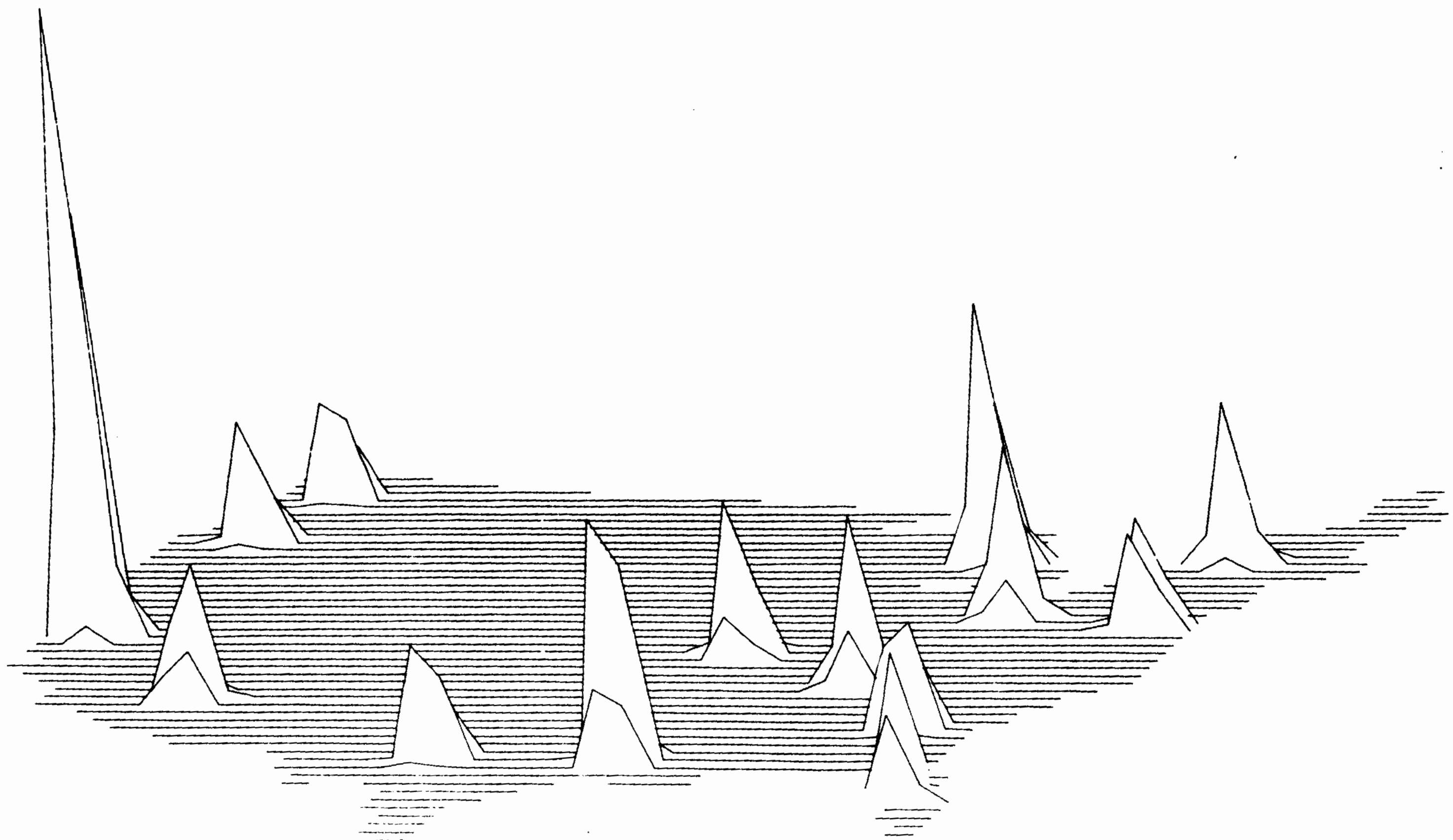

FIGURE 3.4. CONTOUR MAP OF DOMESTIC AIRCRAFT INGESTION EVENTS

SECTION 4

INGESTION RATES

This section describes the rates at which bird ingestions occurred during the period covered by the data. While the term "rate" usually implies occurrences per unit time, in this case it refers to occurrences per engine operation or per aircraft operation. The Poisson distribution is commonly used to describe how events are randomly distributed in time and the bird ingestion data are shown to agree with the assumption of a Poisson process. The first part of this section provides the estimates of the basic ingestion rates. The second part describes the Poisson distribution and how it relates to the bird ingestion events. The final parts discuss statistical analysis based on the assumption that bird ingestions follow a Poisson process.

4.1 INGESTION RATE ESTIMATES

This section provides a general description of ingestion rates broken down by location, by engine, and by phase of flight. The rates are given in terms of ingestions per 10,000 engine operations and have been adjusted for differences in inlet area of the engine where appropriate. A more detailed statistical analysis of ingestion rates is presented in subsequent sections, using statistical techniques for Poisson processes.

Table 4.1 presents engine ingestion rate data for each of the three small engines. The data presented include number of ingestions, rate per 10K operations, rate per 10K operations normalized to a 10-square-foot inlet area, and rate per 10K operations normalized to a 1-foot engine diameter. The inlet dimensions for each engine inlet model are given in appendix A. The Aerospace Industries Association (AIA) uses the inlet throat dimension in analyses involving engines. The analysis of engine dimension will therefore use the throat dimension. A discussion of inlet area and inlet diameter effects on ingestion rates is given in Sections 4.4 and 4.5.

These rates were calculated using the reported and estimated data on operations presented earlier in this report.

TABLE 4.1. ENGINE INGESTION RATE ESTIMATES

	ALF502	TFE731	TPE331	Total
Engine Ingestion Events				
Worldwide	26	38	33	97
United States	12	23	19	54
Foreign	14	15	14	43
Hours				
Worldwide	659401	2188082	3950930	6798413
United States	527949	1599100	2824842	4951891
Foreign	131452	588982	1126088	1846522
Engine Ingestion Events/10K hrs.				
Worldwide	0.394	0.174	0.084	0.143
United States	0.227	0.144	0.067	0.109
Foreign	1.065	0.255	0.124	0.233
Operations				
Worldwide	721918	1750466	4741116	7213500
United States	596905	1279280	3389810	5265995
Foreign	125013	471186	1351306	1947505
Engine Ingestion Events 10K ops.				
Worldwide	0.360	0.217	0.070	0.134
United States	0.201	0.180	0.056	0.103
Foreign	1.120	0.318	0.104	0.221
Engine Ingestion Events/10K ops/10 sq.ft. of engine area				
Worldwide	0.527	0.695	1.373	0.757
United States	0.294	0.575	1.106	0.551
Foreign	1.639	1.019	2.043	1.428
Engine Ingestion Events/10K ops/ft. of engine diameter				
Worldwide	0.012	0.011	0.020	0.013
United States	0.007	0.009	0.016	0.010
Foreign	0.038	0.016	0.029	0.024

Table 4.2 presents data on engine ingestion events and rates by phase of flight for all engines and for each engine separately. The 95 percent Upper Confidence Bound on Ingestions per 10,000 operations is also given (e.g., the bounds are 95 percent likely to contain the true value, allowing for sampling fluctuation). Overall, most ingestion events occurred during takeoff, followed by the landing and approach phases. For the individual engines, the same pattern holds generally, with the exception of the ALF502, which had one more ingestion incident during landing than during takeoff. Overall it appears that the takeoff phase is the riskiest from the standpoint of rate of bird ingestions. Note that because of the small sample size, some phases of flight were not represented among the ingestions.

This pattern is commonly found in birdstrike and bird ingestion studies. It arises from the fact that airports are typically located in desirable bird environs (vacant land, often near bodies of water). Since the birds congregate around airports there is a greater chance of striking or ingesting a bird during the phases of flight that take place close to the airports. An additional factor contributing to higher ingestion rates in the flight phases close to the ground is the fact that civilian aircraft usually cruise at altitudes well above bird flight routes.

Note that for some ingestion events, the phase of flight was not reported. Hence the rates given in table 4.2 represent slight underestimates of the true rates.

TABLE 4.2. ENGINE INGESTION EVENTS AND RATES BY PHASE OF FLIGHT

	Engine Ingestion Events	Events Per 10K Operatons	95% Upper Bound	Events Per 10K Operations Per 10 sq ft	Events Per 10K Operations per ft diam
ALF502					
Approach	0	0.000	0.042	0.000	0.000
Climb	0	0.000	0.042	0.000	0.000
Cruise	0	0.000	0.042	0.000	0.000
Landing	8	0.111	0.200	0.162	0.038
Takeoff	6	0.083	0.160	0.122	0.028
Taxi	1	0.014	0.066	0.020	0.005
Unknown	11	0.152	0.250	0.223	0.052
Total	26	0.360	0.500	0.527	0.122
TFE731					
Approach	6	0.034	0.068	0.110	0.017
Climb	2	0.011	0.036	0.037	0.006
Cruise	1	0.006	0.027	0.018	0.003
Landing	7	0.040	0.075	0.128	0.020
Takeoff	20	0.114	0.161	0.366	0.057
Taxi	0	0.000	0.017	0.000	0.000
Unknown	2	0.011	0.036	0.037	0.006
Total	38	0.217	0.285	0.695	0.109
TPE331					
Approach	8	0.017	0.030	0.333	0.048
Climb	3	0.006	0.016	0.125	0.018
Cruise	1	0.002	0.101	0.042	0.006
Landing	8	0.017	0.030	0.333	0.048
Takeoff	12	0.025	0.041	0.499	0.072
Taxi	0	0.000	0.006	0.000	0.000
Unknown	1	0.002	0.010	0.042	0.006
Total	33	0.070	0.093	1.373	0.197
AllEng					
Approach	14	0.019	0.030		
Climb	5	0.007	0.015		
Cruise	2	0.003	0.009		
Landing	23	0.032	0.045		
Takeoff	38	0.053	0.069		
Taxi	1	0.001	0.007		
Unknown	14	0.019	0.030		
Total	97	0.134	0.159		

4.2 THE POISSON PROCESS

The Poisson process is the simplest type of stochastic process which describes how events are distributed in time. The Poisson process is here taken to govern ingestion events, and the times at which these events occur are random. In a Poisson process the events are distributed somewhat evenly in time so that it appears that the times at which the events occurred form a uniform distribution. This section describes some of the properties of Poisson processes that will be useful in describing bird ingestions and in testing hypotheses about bird ingestion rates.

The basis of a Poisson process is a description of the probability distribution of the number of events that occur in a given time interval. The formula for the probability of n events in an interval of length T is:

$$P(X(T)=n) = \frac{e^{-\lambda T}(\lambda T)^n}{n!} \qquad 4.1$$

In this equation, the parameter λ is the mean rate at which events occur. Therefore the mean number of events in the time interval of length T is λT. Since hours of operation are not a significant measure of exposure to birdstrikes (the entire cruise portion of the flight is usually at altitudes above those at which birds are found), the time scale used will be number of engine operations rather than hours. Ingestion rates are typically reported in events per 10,000 operations which implies the use of operations as the time scale in a Poisson process.

One way in which the formula for the Poisson distribution can be derived is as the limiting distribution of the binomial distribution for large sample sizes. If the probability of a bird ingestion is the same from flight to flight then the number of ingestions in a large number of flights has a binomial distribution. If the probability of ingestion is p and the number of flights is N then the probability that n ingestions occur in the N flights is:

$$P(X(N)=n) = \binom{N}{n} p^n (1-p)^{(N-n)} \qquad 4.2$$

The binomial probabilities in equation 4.2 can be approximated by a Poisson distribution with mean Np for large values of N. That is, the single flight probability of an ingestion, p, replaces λ in equation 4.1. Past studies [2,3,4] of birdstrikes have used the hypothesis that the probability of a birdstrike is proportional to the cross sectional area of the aircraft. Applying the same hypothesis to engines implies that the bird ingestion rate should be proportional to the cross sectional area of the engine.

The inlet area effect can be incorporated into the Poisson process model by letting the parameter λ represent the ingestion rate per unit area. The probability of n ingestions in N operations for an engine with inlet area A is:

$$P(X(N)=n) = \frac{e^{-\lambda AN}(\lambda AN)^n}{n!} \qquad 4.3$$

The hypothesis that ingestion rates should be proportional to engine cross section area assumes that birds take no evasive action when approached by an aircraft. That is, the hypothesis assumes that the engine goes through a flock of birds like a cookie-cutter. In reality, birds tuck their wings and drop when they perceive a threat. Hence the critical engine dimension may be engine diameter (vertical height), not cross section area. In that case, the probability of n ingestions in N operations for an engine with engine diameter D is:

$$P(X(N)=n) = \frac{e^{-\lambda DN}(\lambda DN)^n}{n!} \qquad 4.4$$

4.3 VALIDITY OF THE POISSON PROCESS MODEL FOR BIRD INGESTION

The applicability of the Poisson process model can be tested by analyzing the times between ingestions. The interarrival times in a Poisson process are random variables that have independent exponential distributions and the mean time between arrivals is the reciprocal of the ingestion rate. The validity of the Poisson process model can be tested by applying a goodness of fit (GOF) test for the exponential distribution to the times between ingestions.

The GOF test for the exponential distribution is a modified Kolmogorov-Smirnov (K-S) test comparing the observed cumulative distribution function (CDF) to the predicted exponential CDF based on the sample mean. The K-S test uses the test statistic D defined as the maximum vertical distance between the observed and predicted CDFs. A modification to the critical values for the test statistic is required when the predicted CDF is derived from the mean of the sample. The critical values for the modified K-S test were computed by Lilliefors [5]. He presents tables of critical values for sample sizes up to 30, and formulas for approximating the critical values for larger sample sizes.

Because of the small sample size, ingestions for all engines were treated together. A visual comparison of the observed versus theoretical CDFs is presented in figure 4.1. The actual value of D obtained from the observed and theoretical CDFs was 0.054, while the critical value for a probability of 0.01 is 0.133. Hence the hypothesis of an exponential distribution for interarrival times cannot be rejected at the 0.01 level of significance. The use of a Poisson process to model bird ingestions is appropriate based on the results of this test.

4.4 INLET THROAT AREA EFFECT ON INGESTION RATES

One property of the Poisson process model described in equation 4.3 of Section 4.2 is that ingestion rates should be proportional to the inlet area of the engine. (Physically, this can be thought of as relating ingestions to the volume swept out by the engine during a flight.) The dimension effect can be investigated for the sample of small engines by comparing actual ingestions with those predicted on the assumption that ingestions will be proportional to both number of operations and inlet throat area.

The ingestion rate for all engines is 0.757/10K operations/10 sq. ft. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-squared test is applied to these expected

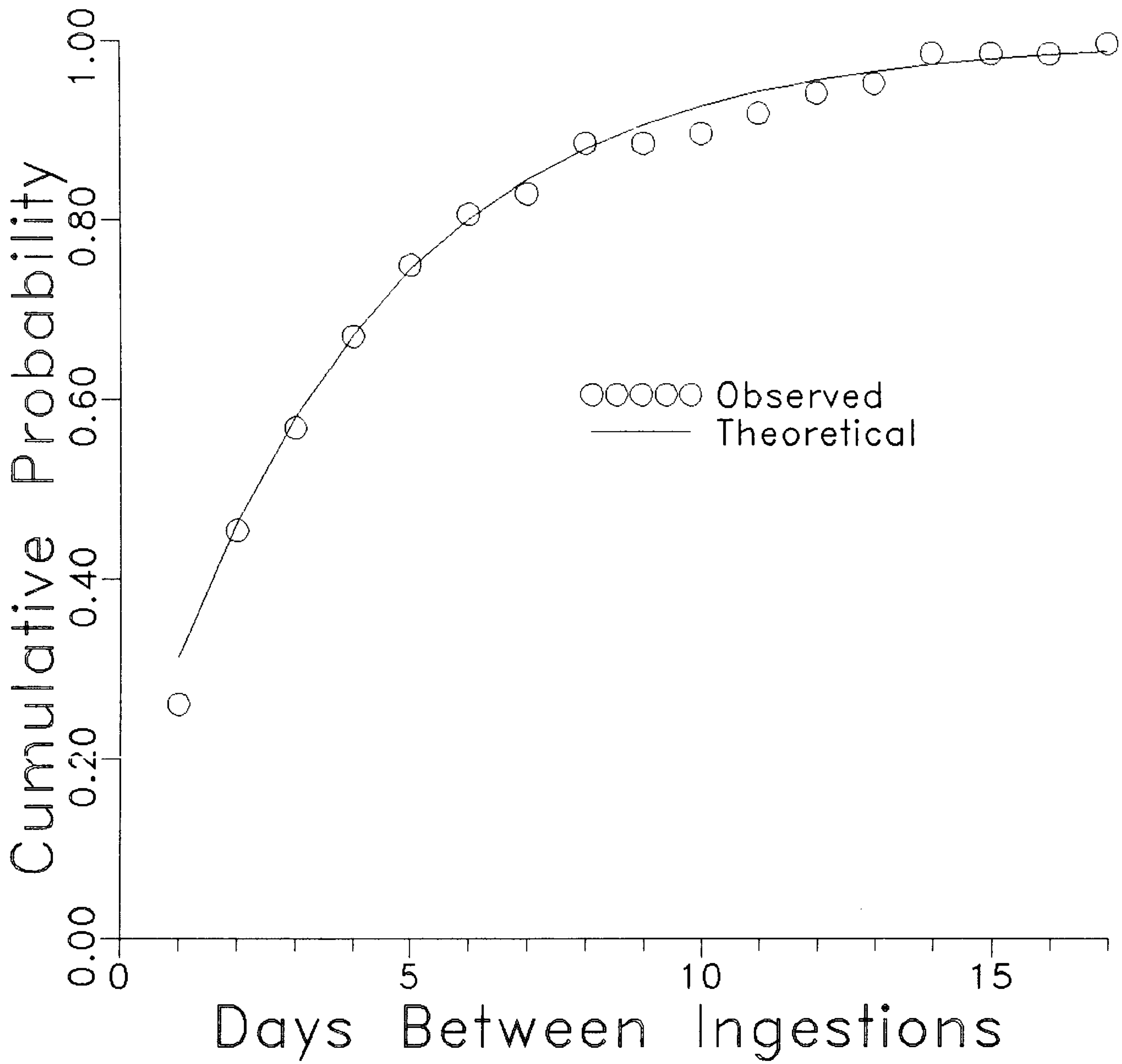

Figure 4.1 Comparison of Observed and Theoretical Cumulative Distribution Functions

ingestions, the value 15.76 is obtained. The critical value of chi-squared for 2 d.f. and probability 0.05 is 10.6. Hence the hypothesis that ingestions are proportional to inlet throat area must be rejected at the 0.005 level. That is, in rejecting the hypothesis, we are taking a risk of only one chance in 200 of making a mistake due to random variation in the data.

4.5 INLET THROAT DIAMETER EFFECT ON INGESTION RATES

As noted above, it may be the case that engine ingestion events are related to engine inlet throat diameter rather than inlet throat area. Under the area hypothesis, an engine of twice the diameter would be expected to ingest 4 times as many birds. Under the diameter hypothesis, an engine of twice the diameter would be expected to ingest only twice as many birds. The results of testing the diameter hypothesis are presented here.

Definition of the diameter for the engines is not straightforward. The ALF502 and TFE731 have circular cross sections, and computation of a diameter is not particularly difficult. However, the TPE331 has an air inlet which is wrapped around the propeller shaft, and which can be roughly approximated by the region between two concentric half-circles. The diameter for the TPE331 was taken as the difference between the radii of the two half-circles (e.g., the radial distance separating them).

The ingestion rate for all engines is 0.013 per thousand operations per foot of engine diameter. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-squared test is applied to these expected ingestions, the value 6.87 is obtained. By chance, the value 5.99 would be exceeded 5 percent of the time, and the value 7.38 would be exceeded 2.5 percent of the time. Hence we have a borderline situation. If we are willing to accept one chance in twenty of making a mistake due to random fluctuation of the data, we would reject the hypothesis that ingestions are related to diameter. If, however, we adopt the more stringent requirement that the risk of falsely rejecting the hypothesis be held to one chance in forty or fewer, we cannot reject the hypothesis that ingestions are related to diameter.

4.6 DISCUSSION OF DIMENSION EFFECTS

From examination of table 4.2, we see that whether ingestions are normalized by engine area or by engine diameter, the results for the ALF502 and the TFE731 are comparatively close together. It is the TPE331 which deviates markedly from the other two. It is probably the TPE331 which is responsible for the large values of chi-squared, resulting in rejection of the two hypotheses.

If we omit the TPE331 from the analysis, we can compare only the two turbofan engines. Repeating the chi-squared test on the ingestions without normalization, for only the ALF502 and the TFE731, the difference is significant at the 5 percent level. That is, with only one chance in twenty of being wrong through randomness in the data, we can reject the hypothesis that there is no difference between the engines.

This allows yet another possibility. The chi-squared test is very robust, in that it is insensitive to the actual probability distribution governing the fluctuations in the data. It can thus be applied to a wide variety of situations. However, it is not a particularly powerful test. That is, it is not capable of detecting small differences when those differences are real. If we restrict ourselves to only the case of two engines, a more powerful test is possible.

The two engines had a total of 64 ingestions between them. We can examine the actual split of ingestions between the engine types, and compare it with the split expected under whatever hypothesis we are testing. Then we determine the probability of getting the observed deviation from the expected split. This is done by treating each ingestion as a Bernoulli trial, with ingestion by one engine as a "success" and ingestion by the other engine as a "failure." It does not matter which engine we take as "success," because the computations are identical in either case. We then sum the "tail" of the Binomial distribution which includes the actual number of ingestions. That is, if the observed number of ingestions is greater than the expected number, we sum the upper tail, starting with the observed number. We do the converse if the observed number is fewer than expected. The result is to determine the probability of finding a deviation from expected which is as great or greater than the observed deviation. The hope is that this more powerful test will reject one hypothesis while failing to reject the other.

The results are as follows:

	No Normalization	Normalize to Area	Normalize to Diameter
Actual ingestions	38	38	38
Expected ingestions	45	34	40
Probability of observed deviation or greater	0.04	0.191	0.346

With no normalization, the deviation of observed from expected is a very low-probability event. This is consistent with the results of the chi-squared test, which led us to conclude that there is a real difference between the engines in probability of ingestion per operation. For the two cases of normalization, the deviation of observed ingestions from expected ingestions is a fairly high-probability event (1 in 5 for area; 1 in 3 for diameter). Put another way, the deviations after normalization could readily be ascribed to randomness in the data, since a fairly powerful test failed to reject either of the hypotheses.

This leaves us with a problem. Apparently the number of ingestions is somehow related to engine dimensions, but neither the hypothesis relating ingestions to area nor the hypothesis relating ingestions to diameter can be rejected on the basis of the data from the turbofan engines. These two hypotheses are quite different, since the diameter hypothesis predicts that the ALF502 should have about 25 percent more ingestions than the TFE731 for the same number of operations, while the area hypothesis predicts that the ALF502 should have over twice as many ingestions as the TFE731 for the same number of operations. The available data are simply not sufficient to distinguish between these two hypotheses. Moreover, inclusion of the TPE331 in any analysis is likely to weaken the conclusions, since defining its area or diameter in ways compatible with the two turbofan engines is difficult.

4.7 DISCUSSION OF LOCATION EFFECTS

It might also be hypothesized that bird ingestion rate would be influenced by engine location: wing-mounted vs. tail-mounted. Since most ingestions occur during takeoff and landing, times when the aircraft has a marked nose-high attitude, it would be plausible to expect that tail-mounted engines would be shielded from ingestions by the wings and fuselage. Thus tail-mounted engines would be hypothesized to have fewer ingestions than wing-mounted engines, all other things being equal. Unfortunately, it turns out that almost all the ALF502 engines are wing-mounted, and almost all the TFE731 engines are tail-mounted. Thus engine type is confounded with engine location. It has already been demonstrated that there is a statistically significant difference between the ingestion rates for the two engines, a difference which is reduced but not eliminated by normalizing for dimension. However, it is not possible to test separately for the location effect, because of the confounding of location with engine type. It can only be suggested that location is a possible explanation for some or all of the differences remaining after normalization for dimension.

SECTION 5

ENGINE DAMAGE

Knowledge of the type of damage imposed by a well defined bird ingestion threat is useful in refining bird certification criteria that could lead to improved engine design. This section describes the information available on engine damage. The first part of this section provides descriptions of the types of damage incurred during the period covered by the data. The second part describes the statistical analysis of the relationship between bird weight and the likelihood of damage occurring in an ingestion. The third part describes any unusual crew actions taken as a result of the ingestions.

5.1 ENGINE DAMAGE DESCRIPTION

The types of damage that were identified in the data base were grouped into 11 categories which are defined in table 5.1. Tabulations of the occurrences of combinations of damage categories are presented in table 5.2. The triangular top portion of the table provides tallies of co-occurrences for all pairs of damage categories. The number in the top portion of the table represents the number of events in which both the row damage and the column damage occurred. The events in which more than two types of damage occurred were included in the tallies of the top portion of table 5.2, but were not specifically identified as involving more than two types of damage.

The amount of data available is insufficient to make strong statements about correlations between types of damage. From the lower portion of the table, it can be seen that with the exception of "shingled," when a given type of damage occurred, in half or more of the cases it was the only type which occurred (i.e., conditional probability of no other damage exceeds 0.50) (by contrast, "shingled" never occurred alone but always in combination with some other type of damage).

TABLE 5.1. DEFINITION OF ENGINE DAMAGE CATEGORY CODES

DAMAGE CATEGORY	SEVERITY LEVEL	DAMAGE DESCRIPTION
TRVSFRAC	Severe	Transverse fracture - a fan blade broken or torn and/or a piece missing (includes secondary hard object damage).
CORE	Severe	Bent/broken compressor blades/vanes, blade/vane clash, blocked/disrupted airflow in low, intermediate, and high pressure compressors.
FLANGE	Severe	Flange separations.
TURBINE	Severe	Turbine damage.
BE/DE>3	Moderate	More than three fan blades bent or dented.
TORN>3	Moderate	More than three torn fan blades.
BROKEN	Moderate	Broken fan blades, leading edge and/or tip pieces missing, other blades also dented.
SPINNER	Moderate	Dented, broken, or cracked spinner (includes spinner cap).
RELEASED	Moderate	Released (walked) fan blades.
TORN<3	Mild	Three or fewer torn fan blades.
SHINGLED	Mild	Shingled (twisted) fan blades.
NACELLE	Mild	Dents and/or punctures to the engine enclosure (includes cowl).
LEAD_EDG	Mild	Leading edge distortion/curl.
BEN/DEN	Mild	One to three fan blades bent or dented.

TABLE 5.2. TYPES OF DAMAGE CAUSED BY BIRD INGESTIONS

	BEN/DEN	BE/DE>3	TORN<3	TORN>3	BROKEN	SHINGLED	NACELLE
BE/DE>3	0						
TORN<3	1	0					
TORN>3	0	1	0				
BROKEN	0	0	0	0			
SHINGLED	1	2	0	1	0		
NACELLE	0	1	0	0	0	0	
CORE	2	1	1	0	0	0	0

	BEN/DEN	BE/DE>3	TORN<3	TORN>3	BROKEN	SHINGLED	NACELLE	CORE
ONLY DAMAGE	8	8	1	0	1	0	1	22
TOTAL	11	12	2	1	1	3	2	25

5.2 PROBABILITY OF DAMAGE

One of the key questions which inspired the bird ingestion survey is the issue of what weight bird should be simulated in certification testing. Two of the main issues in deciding what the certification bird weight should be are (1) the likelihood of ingesting a bird of that weight or larger and (2) the likelihood that damage will result from ingesting a bird of the certification weight. The issue of bird weights is discussed in Sections 3 and 7 while the probability of damage is the topic of this section. In general, the heavier the bird ingested, the greater the engine damage. However, the problem of relating bird weight to engine damage is made more complicated by the fact that in a few cases small birds caused considerable engine damage, while in other cases large birds were ingested with no engine damage. This is illustrated in figure 5.1, which shows the percentage of each damage category by bird weight intervals. Birds with weight below 4 ounces caused no instances of severe damage. As bird weight increases, the proportion of instances with no damage tends to decrease, and the proportion of instances with moderate or severe damage tends to increase.

This situation is similar to bioassay experiments, in which a continuous variable (dose size) produces a discontinuous result (cure/no cure; cancer/no cancer; etc.). In such experiments, it is usually found that a small dose produces the effect in a few experimental subjects, while a large dose produces the effect in many subjects. It would be more convenient, of course, if there were a threshold dose such that below the threshold, no experimental subjects showed any effect, while above the threshold all experimental subjects showed the effect. Since there is no such unique threshold, the bioassay experiments are then analyzed in terms of the probability that a given dose size will produce the response.

We have chosen to utilize the same method of analysis for the bird ingestion data, because it has the same characteristics as bioassay data: a small "dose" may cause damage, but the likelihood of damage is greater with larger "doses." Our approach is to compute the probability of damage (POD) as a function of bird weight. The key elements are that the probability of success for a Bernoulli trial is related to a continuous stimulus variable. In bird ingestion the Bernoulli trial is whether or not damage occurs and the stimulus variable is the weight of the ingested bird.

Linear logistic analysis is the most commonly used method of analyzing the dosage-response type of data. It is used not only in bioassay experiments, but in transportation studies involving choice of transportation mode. It has also been used successfully in relating the probability of transparencies breaking as a function of projectile size in dealing with the problem of propwash blown gravel breaking helicopter windshields. In that case, the transparency is sometimes broken by small stones, yet in other cases survives impact by large stones. Nevertheless, heavier stones have a greater probability of breaking the transparency. The logistic distribution function serves as the basis for the linear logistic analysis. There are several ways in which the logistic distribution function can be parameterized. The one we used is given by:

$$POD(w) = 1/(1+\exp[-(\pi/\sqrt{3})\ (w-\mu)/\sigma]) \qquad 5.1$$

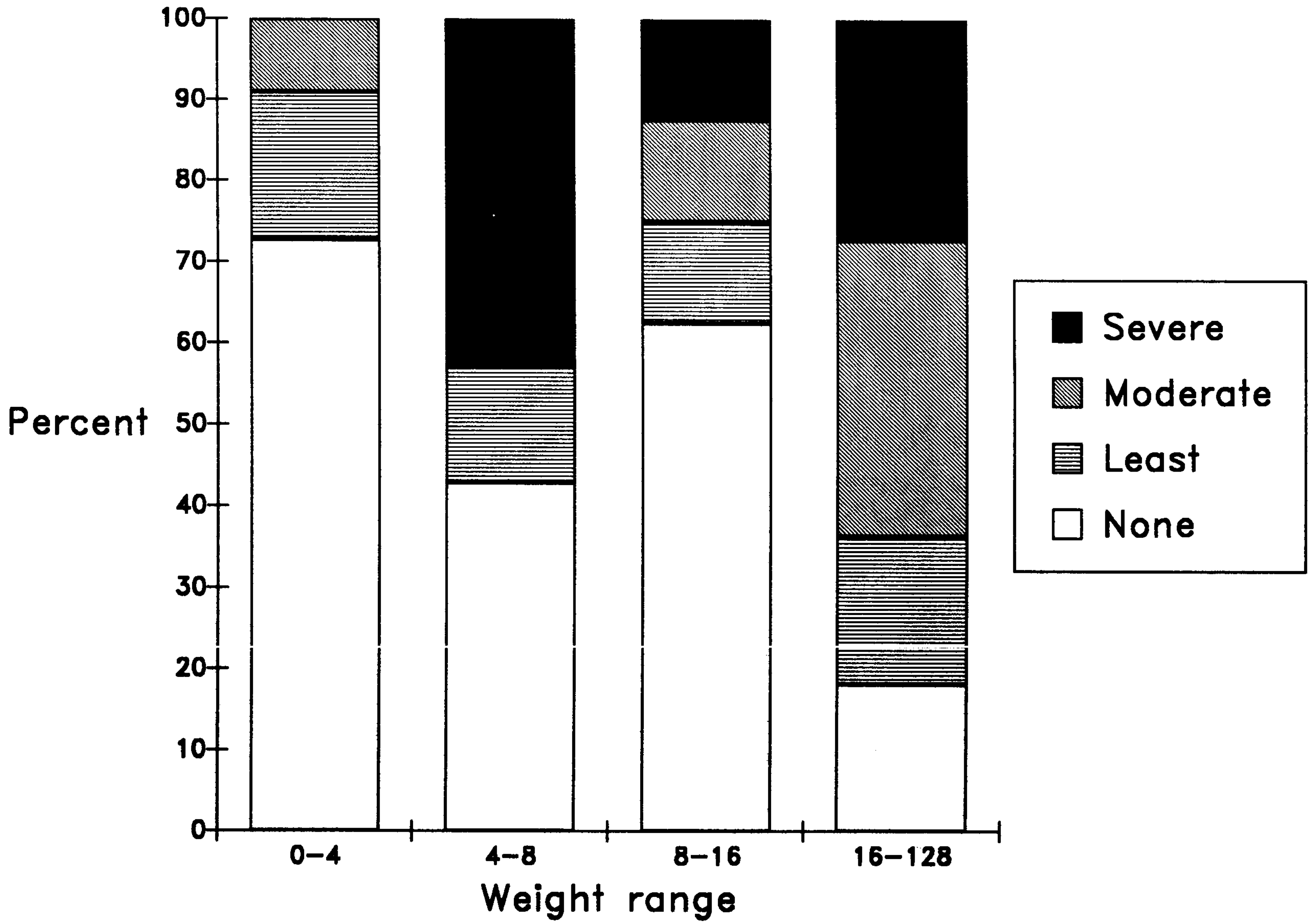

Figure 5.1 Proportion of Damage Categories Versus Bird Weight

In this parameterization, w is the bird weight, μ represents the mean bird weight and σ is a parameter that is related to the steepness of the POD function. This parameterization is selected because of its similarity to the usual parameterization of the familiar Normal probability distribution. The logistic probability density is symmetrical about the mean μ. Therefore μ is not only the mean, it is also the median and the mode of the distribution. In particular, it is the bird weight with a 50 percent chance of causing damage.

The estimation of the function given in equation 5.1 has been extensively studied and the methods have been described in literature [6,7]. The method of maximum likelihood provides the best estimates for the type of data in the bird ingestion study since there are only a few ingestions at each weight. The software for estimating the parameters of equation 5.1 has been developed and extensively tested at the UDRI and verified by researchers at other institutions.

The types of damage were categorized as mild, moderate, or severe in table 5.1 by the FAA (actual data are presented in appendix B). Three distinct analyses were conducted based on the severity ratings. The three analyses estimated the probability of any damage at all, the probability of at least moderate damage, and the probability of severe damage. Figures 5.2, 5.3, and 5.4 show the estimated POD functions along with confidence bounds on the POD functions for the analyses.

Figure 5.2 shows the probability of any damage occurring and includes all three severity levels as positive responses, including unspecified damage levels. The probability of any damage occurring rises steeply, reaching 30 percent at about 10 ounces, and 50 percent at about 15 ounces. This means that birds at the median weight and above have at least a 25 percent probability of causing some damage, and birds in the upper quartile have at least a 50 percent probability of causing some damage. The curve rises more slowly above bird weights of 20 ounces, and reaches 90 percent only above 90 ounces. The distance between the curve for probability of damage and the lower 95 percent bound on the probability is quite wide. This implies a fairly weak relationship between bird weight and degree of damage. The probable reason for this apparently weak relationship is the small amount of data available. It is reasonable to assume that a greater amount of data would result in the lower confidence bound lying closer to the estimated probability curve.

Figure 5.3 shows the probability of at least moderate damage. The probability of moderate damage does not rise as steeply as the probability of any damage. The probability of moderate damage reaches 50 percent at just over 20 ounces. It does not reach 80 percent until bird weight exceeds 120 ounces. The confidence bound shown in figure 5.3 is even farther from the probability curve than in figure 5.2. This may also be due in part to the small sample size.

Figure 5.4 shows the probability of severe damage. The sample size was too low to permit calculation of a lower confidence bound. The probability of severe damage reaches 20 percent at 20 ounces, but rises only slowly after that, reaching 40 percent at 140 ounces.

The small sample size makes the estimates of probability of damage somewhat unreliable. However, as shown in Section 3, there seems to be no relationship between severity of engine damage and the likelihood that bird weight was determined (through identification of species). Hence there is no reason to believe that the estimates of probability of damage are biased either upward or downward from this cause.

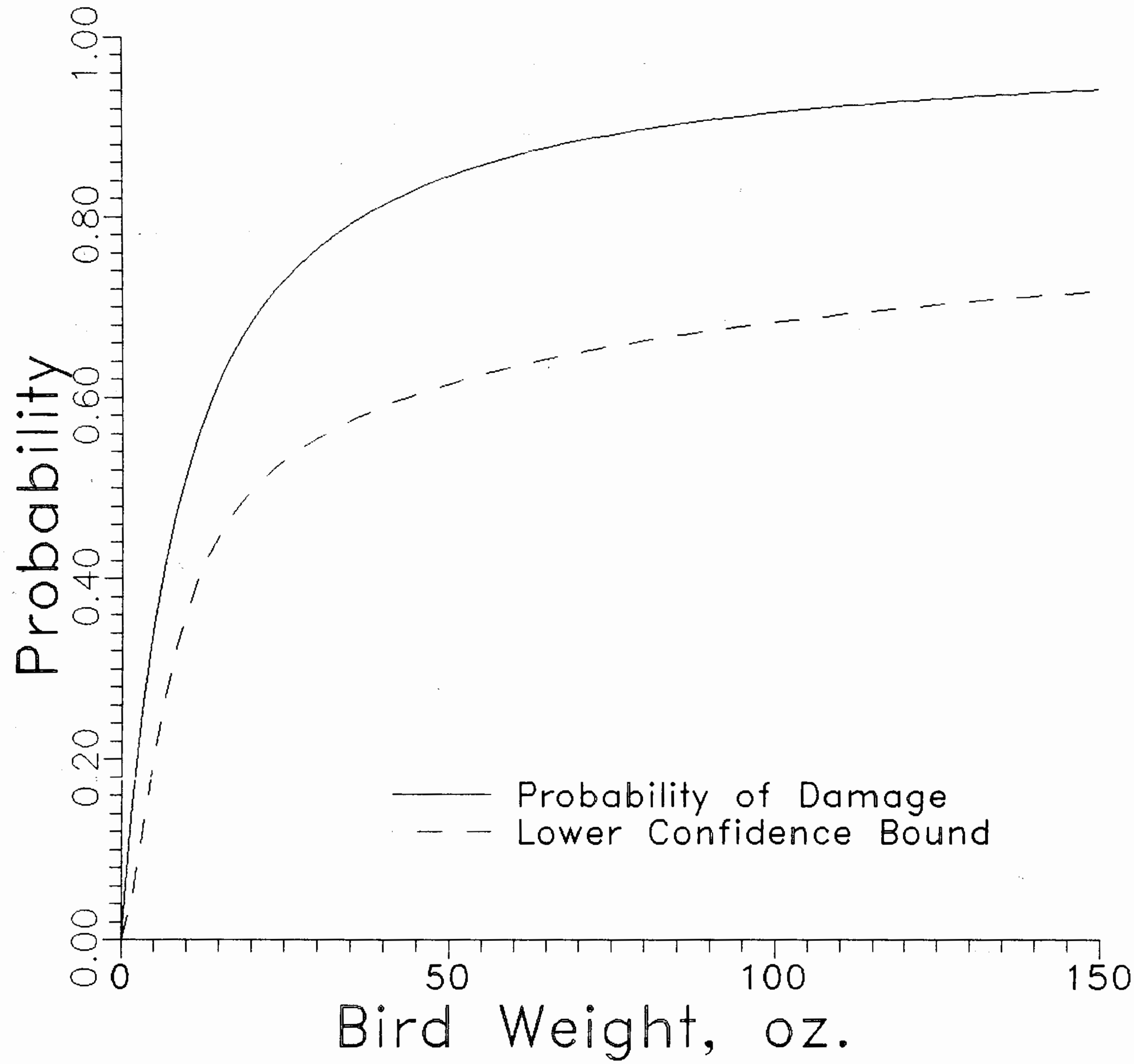

Figure 5.2 Probability of Any Damage Versus Bird Weight

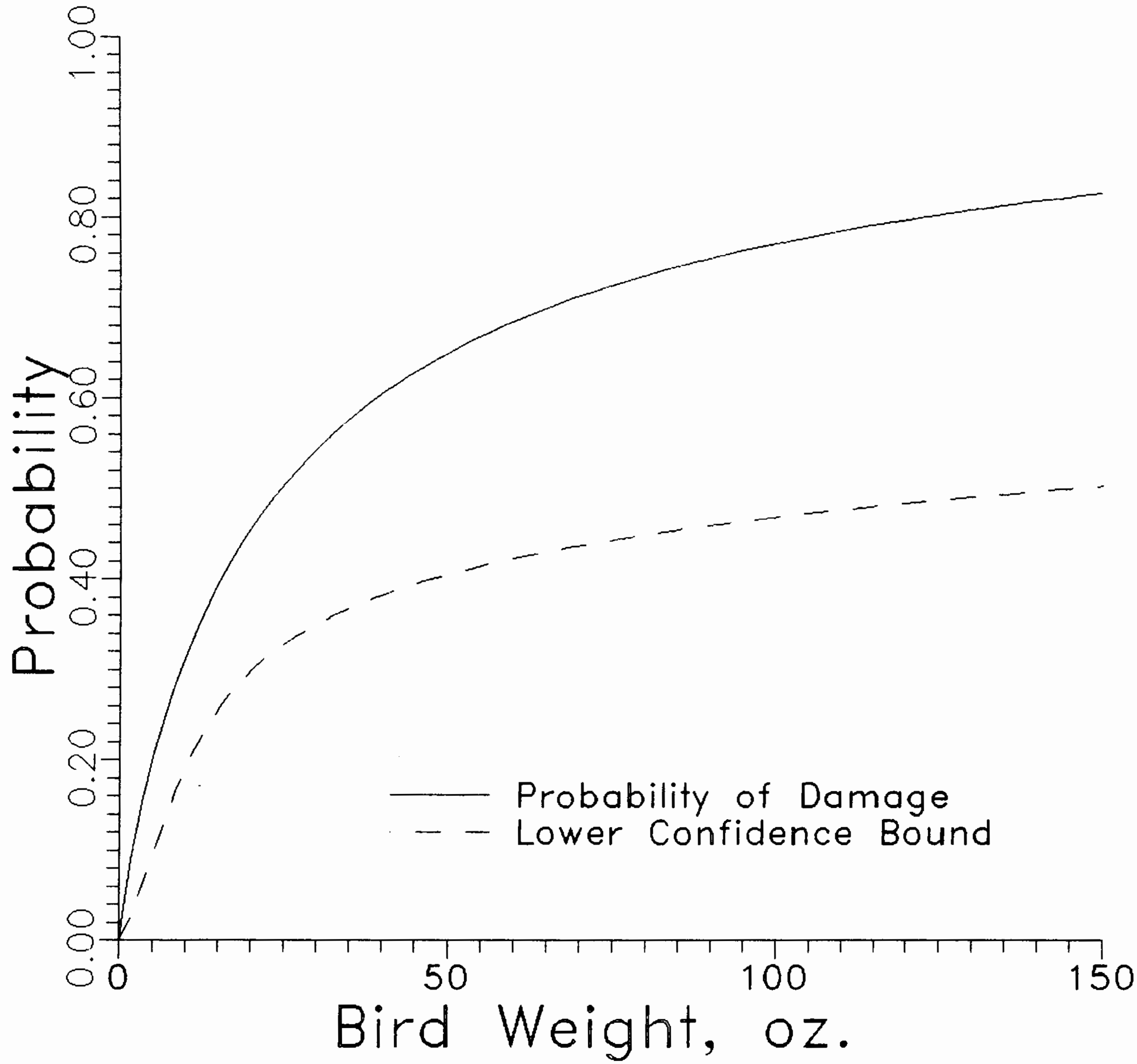

Figure 5.3 Probability of At Least Moderate Damage Versus Bird Weight

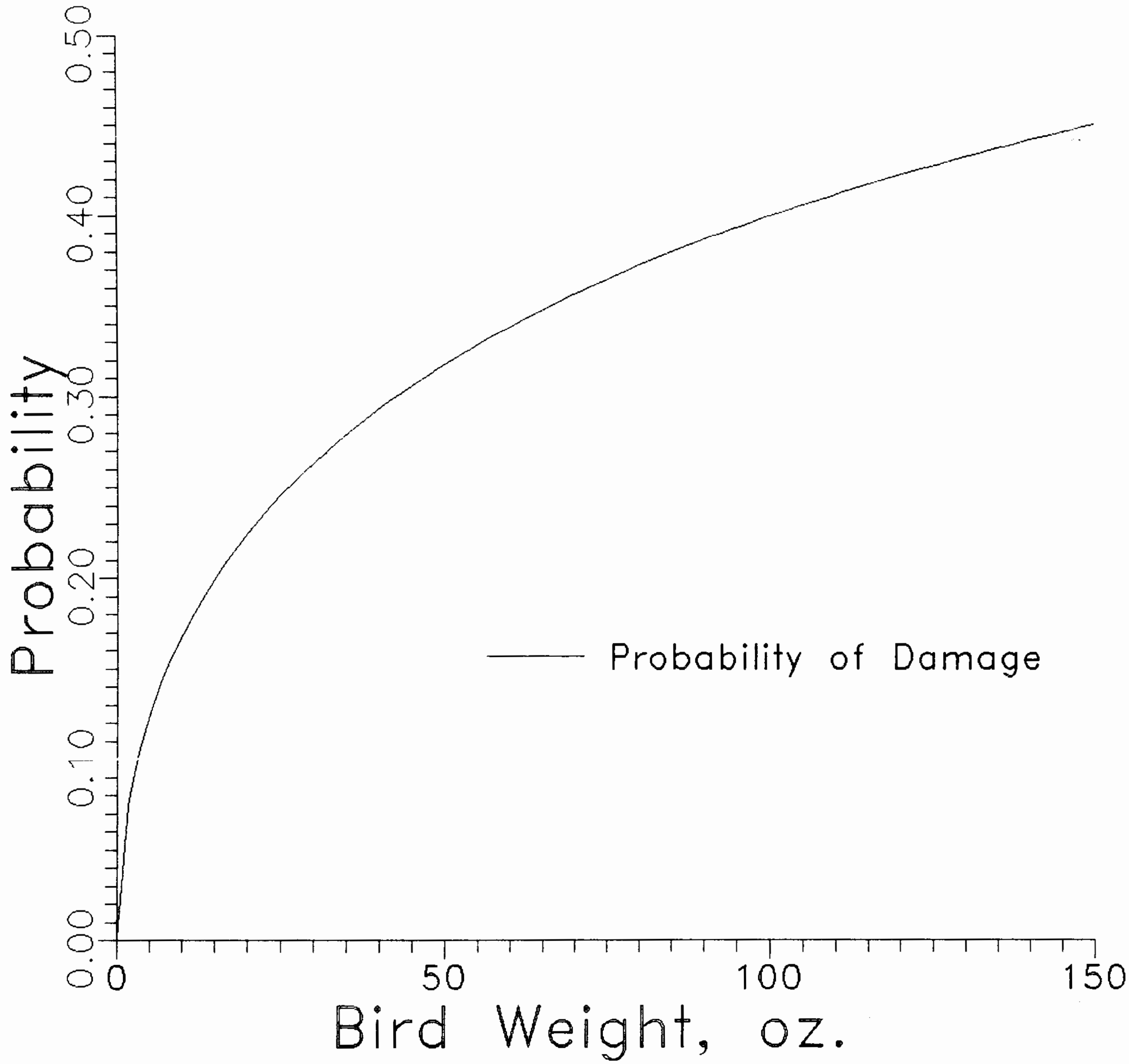

Figure 5.4 Probability of Severe Damage Versus Bird Weight

5.3 CREW ACTION DESCRIPTION

Two other factors that relate to the severity of engine damage are whether or not a crew action is required (aborted takeoff (ATO), air turnback (ATB), or diversion (DIV)) and whether or not the engine shut down (IFSD) as a result of the ingestion. Table 5.3 presents the conditional probabilities that a crew action is required given the severity of the damage that the engine incurs [P(CA²D)]. The probability that a crew action is required increases with the severity of engine damage as would be expected. The third column of table 5.3 contains the upper 95 percent confidence bound on the conditional probabilities presented in the second column.

A crew-initiated voluntary in-flight engine shutdown occurred in three of the 97 engine ingestion events. This corresponds to an estimated conditional probability of a voluntary in-flight engine shutdown of 0.031 with a 95 percent confidence bound of 0.079. An involuntary in-flight engine shutdown occurred in four of the 97 engine ingestion events when there was a loss of engine power. This corresponds to an estimated conditional probability of an involuntary in-flight shutdown of 0.041 with a 95 percent confidence bound of 0.108.

TABLE 5.3. CONDITIONAL PROBABILITY OF UNUSUAL CREW ACTION GIVEN THE ENGINE DAMAGE SEVERITY

Severity of Engine Damage	Number of Events	Instances of Crew Action*	P(CA|D)	Upper 95% Confidence Bound	Inflight Shutdowns	P(IFSD|D)	Involuntary Inflight Shutdowns	P(IIFSD|D)
None	44	6	0.14	0.27	0	0.00	0	0.000
Any	53	19	0.37	0.54	8	0.15	4	0.077
Mod/Severe	37	17	0.46	0.66	6	0.16	3	0.081
Severe	25	11	0.44	0.73	6	0.24	3	0.120

* Crew action includes Aborted Takeoff, Air Turnback, Diversion

SECTION 6

PROBABILITY ESTIMATES

This section provides a summary of the probabilities of various engine ingestion events. The probability of an event is a measure of the likelihood that the event will occur. The probabilities in this section are calculated on a per engine operation basis and present information similar to the ingestion rates. The ingestion rates that were presented in Section 4 were calculated on the basis of 10,000 engine operations. In that section, it was shown that the ingestions did follow a Poisson distribution. As a consequence of the Poisson distribution, the ingestion rate per engine operation is equal to the probability of ingestion for a single operation. This section provides more details on the probabilities of various categories of bird ingestion events.

Table 6.1 provides the estimated probabilities and 95 percent confidence bounds for the entire small engine population for various bird ingestion events including:

- any ingestion
- takeoff and climb ingestions
- approach and landing ingestions
- moderate/severe damage ingestions (all phases)

The overall likelihood of an engine ingestion event in a single engine operation is slightly more than one in one-hundred thousand. Although this probability is very low, there are sufficient operations per year (over 7.2 million during the period covered by the data) that the expected number of ingestions is roughly one hundred. Most ingestions occur during takeoff or landing phases, so the probabilities for those phases are larg#r than for other phases of flight. Multiple engine ingestion events and multiple bird ingestion events are comparatively rare, and this is reflected in the lower probabilities for these events.

As shown in Section 4.4, the hypothesis that ingestions are proportional to engine dimensions (either cross section area or diameter) cannot be rejected on the basis of the data. The ALF502 engine has the largest cross section, and as expected it has the largest number of ingestions per operation.

Table 6.2 shows the probability of ingestion by bird weight range and location. This is computed by multiplying the overall probability of ingestion per operation for each of the regions (United States, foreign, worldwide) by the frequency of each bird weight range. The validity of this calculation is dependent on the birds actually identified being representative of all those ingested (i.e., whether an ingested bird is identified is treated as a random event). As discussed in Section 3, there appears to be no reason to believe that the probability of a bird being identified is correlated with degree of engine damage, hence the assumption of randomness appears justified.

Table 6.3 shows the probability of ingestion by bird weight range for each engine type and region (United States, foreign, worldwide). As with table 6.2, this is computed by multiplying the overall probability of ingestion per operation for each of the regions, computed separately for each engine type, by the frequency of each bird weight range. The same caveat applies as to randomness of bird identifications.

TABLE 6.1. ENGINE INGESTION PROBABILITIES

CONDITION	ENGINE INGESTION EVENTS	PROBABILITY OF INGESTION	UPPER 95% CONFIDENCE BOUND
All Flight Phases			
World	97	1.345E-05	1.592E-05
US	54	1.025E-05	1.286E-05
Foreign	43	2.208E-05	2.847E-05
Takeoff & Climb			
World	43	5.961E-06	7.687E-06
US	25	4.747E-06	6.630E-06
Foreign	18	9.243E-06	1.371E-05
Approach & Landing			
World	37	5.129E-06	6.748E-06
US	20	3.798E-06	5.519E-06
Foreign	17	8.729E-06	1.309E-05
Multiple Birds			
World	22	3.050E-06	4.355E-06
US	12	2.279E-06	3.692E-06
Foreign	10	5.135E-06	8.710E-06
Moderate/Severe Damage			
World	37	5.129E-06	6.748E-06
US	17	3.228E-06	9.842E-06
Foreign	20	1.027E-05	1.492E-05

TABLE 6.2. PROBABILITY OF AN ENGINE INGESTION EVENT* VS. BIRD WEIGHT

Interval	U.S.	FOREIGN	WORLDWIDE
$0 < x \leq 4$	0.228	0.205	0.222
$4 < x \leq 8$	0.019	0.514	0.153
$8 < x \leq 12$	0.019	0.051	0.028
$12 < x \leq 16$	0.057	0.205	0.097
$16 < x \leq 20$	0.019	0.103	0.042
$20 < x \leq 24$	0.038		0.028
$32 < x \leq 36$		0.051	0.014
$36 < x \leq 40$	0.019		0.014
$64 < x \leq 68$	0.019		0.014
$84 < x \leq 88$	0.038		0.028
$100 < x \leq 104$	0.019		0.014
$124 < x \leq 128$	0.057		0.042

* Scaled by 10^5

TABLE 6.3. PROBABILITIES OF AN ENGINE INGESTION EVENT* AS A FUNCTION OF BIRD WEIGHT, LOCATION, AND ENGINE TYPE

	ALF502			TFE731			TPE331		
	U.S.	FOREIGN	WORLDWIDE	U.S.	FOREIGN	WORLDWIDE	U.S.	FOREIGN	WORLDWIDE
Engine Operations:	596,949	125,013	721,918	1,279,280	471,186	1,750,466	3,389,810	1,351,306	4,741,116
Bird Wt. Range (oz)	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion	Prob. of Ingestion
0 < x ≤ 4	1.173	3.200	1.524	0.235	---	0.171	0.059	---	0.042
4 < x ≤ 8	---	---	---	0.078	1.273	0.400	---	0.222	0.063
8 < x ≤ 12	---	0.800	0.139	0.078	0.212	0.114	---	---	---
12 < x ≤ 16	---	---	---	0.156	0.637	0.286	0.030	0.074	0.042
16 < x ≤ 20	---	0.800	0.139	0.078	---	0.057	---	0.074	0.021
20 < x ≤ 24	---	---	---	0.156	---	0.114	---	---	---
32 < x ≤ 36	---	---	---	---	---	---	---	0.074	0.021
36 < x ≤ 40	---	---	---	0.078	---	0.057	---	---	---
64 < x ≤ 68	0.168	---	0.139	---	---	---	---	---	---
84 < x ≤ 88	---	---	---	0.156	---	0.114	---	---	---
100 < x ≤ 104	---	---	---	0.078	---	0.057	---	---	---
124 < x ≤ 128	---	---	---	0.235	---	0.171	---	---	---
All Events	1.341	4.800	1.939	1.329	2.122	1.542	0.089	0.444	0.190

* Ingestion probabilities scaled by 10^5

Table 6.4 shows the probability of ingestion by weight range for various flight conditions, by engine type and by region (United States, foreign, worldwide). It also shows the probability of multiple bird ingestions in the same engine, the probability of multiple engine ingestions, and the probability of moderate or severe damage. The table is computed by dividing the number of engine ingestion events in each of the conditions by the number of operations for the particular engine type in each region.

TABLE 6.4. ENGINE INGESTION PROBABILITITES* BY ENGINE AND LOCATION

	ALF502						TFE731						TPE331					
	U.S.		FOREIGN		WORLDWIDE		U.S.		FOREIGN		WORLDWIDE		U.S.		FOREIGN		WORLDWIDE	
Engine Operations:	596,905		125,013		721,918		1,279,280		471,186		1,750,466		3,389,810		1,351,306		4,741,116	
Condition Under Consideration	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.	Ingestion Evt	Ingestion Prob.
All Flight Phases	12	2.01	14	11.20	26	3.60	23	1.80	15	3.18	38	2.17	19	0.56	14	1.04	33	0.70
Takeoff and Climb Phases	3	0.50	3	2.40	6	0.83	11	0.86	11	2.33	22	1.26	11	0.32	4	0.30	15	0.32
Approach and Landing Phases	3	0.50	5	4.00	8	1.11	10	0.78	3	0.64	13	0.74	7	0.21	9	0.67	16	0.34
Dual Engine - Single Bird Events	1	0.17	0	--	1	0.14	0	--	1	0.21	1	0.06	0	--	0	--	0	--
Multiple Birds- Single Eng. Events	0	--	0	--	0	--	7	0.55	1	0.21	8	0.46	1	0.03	2	0.15	3	0.06
Multiple Birds - Dual Engine Events	1	0.17	1	0.80	2	0.28	1	0.08	1	0.21	2	0.11	0	--	1	0.07	1	0.02
Moderate or Severe Damage	2	0.34	1	0.80	3	0.42	6	0.47	9	1.91	15	0.86	9	0.27	10	0.74	19	0.40

* Ingestion probabilities scaled by 10^5

SECTION 7

CONCLUSIONS

The goal of the bird ingestion investigation is to provide data to define the nature and extent of the bird ingestion threat. Collecting information on bird ingestions is extremely difficult because of the large number of organizations that must cooperate to collect complete and accurate bird ingestion data. The sparseness of information obtained during the collection period makes it difficult to draw inferences on the nature of the bird ingestion threat. This section summarizes conclusions from the data collected.

Bird Descriptions

Gulls, doves and lapwings are the birds most often ingested.

The identification rate does not seem to vary with degree of engine damage.

Ingestions are least likely to occur at night. Although seasonality in ingestions is a plausible hypotheses, the data were insufficient to verify it.

Ingestion Rates

Ingestion events can be modeled as a Poisson process.

Ingestion rates are related to the engine dimensions (i.e., when actual ingestion rates are normalized for engine area or diameter, the differences among engines are reduced). Unfortunately, the data were not sufficient to distinguish between an area-dependence and a diameter-dependence.

Engine Damage

There does not appear to be correlation among different types of engine damage. However, any real correlations may have been obscured by the small sample size.

The probability of damage increases with the weight of the bird that is ingested.

Probabilities of Ingestion

Bird ingestions are more likely during the takeoff and landing phases of aircraft operation.

SECTION 8

REFERENCES

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SECTION 9

GLOSSARY

Term	Definition of Term
Engine Ingestion Event	Process whereby one or more birds pass through the engine inlet during engine operation.
Ingested Bird	A bird having experienced the process of engine ingestion event.
Aircraft Ingestion Event	Simultaneous ingestion of one or more birds into one or more engines of an aircraft.
Airport Operation	Takeoff (departure) from an airport or a landing (arrival) at an airport.
Aircraft Operation	A nonstop aircraft flight from one airport to another. (Includes time from taxi-out from departure airport through taxi-in at arrival airport.)
Engine Operation	The participation of each engine of an aircraft in an aircraft operation (e.g., a twin engine aircraft would, ideally, experience two engine operations for each aircraft operation).
Engine Hours	The total running time, measured in hours of an engine or group of engines during a given period.
Ingestion Rate	The number of aircraft or engine ingestion events per flight event. Flight event refers to aircraft, engine or airport operation. The components of ingestion rate are specified when used in the report. The influence of engine inlet area is not considered.
Normalized Ingestion Rate	Ingestion rate adjusted to a given nominal area. Allows statistical comparison of ingestion rates of engines with different inlet areas.

APPENDIX A

ENGINE APPLICATIONS

Engine	Engine Type	Engine Manufacturer	Engine Face Area (in^2)	Typical Throat Area (in^2)	Typical Aircraft Installation
ALF 502	Turbofan	Textron-Lycoming	1276	984	Canadair Challenger CL-600, British Aerospace 146
TFE 731	Turbofan	Garrett	625	450	British Aerospace 125-700 & 125-800; Dassault-Breguet Falcon 10, 100, 50 & 900; Gates Learjet 35A, 36A, 55, 55ER & 55LR; Israel Aircraft Industries Westwind 1 & 2, Astra; Lockheed Jetstar II; Rockwell/Sabreliner 65; Cessna Citation III
TPE 331	Turboprop	Garrett	72	73	British Aerospace Jetstream 31; CASA 212; Dornier 228; Cessna Conquest II; Swearingen/Fairchild Metro and Merlin 3, 4, 4C, & 300; Mitsubishi MU-2, Solitaire & Marquise; Omac Inc. Model 1; Piper Cheyenne 400 LS; Rockwell 840, 900, 980 & 1000 TurboCommander

APPENDIX B
CONTENTS OF FAA SMALL INLET AREA TURBINE ENGINE BIRD INGESTION DATA BASE
MAY 1987 - APRIL 1988

This appendix presents the contents of small inlet area engine bird ingestion data base maintained by the FAA. The appendix presents actual data extracted from the FAA database and used in this report. When the null symbol -0- appears in any data position it indicates that the data are unknown. The data base contents are described below:

COLUMN	DESCRIPTION OF COLUMN CONTENTS
EDATE	Date(mm/dd/yyyy) of ingestion event.
EVT#	FAA ingestion event sequence number reflecting order in which events were entered into the FAA bird ingestion data base.
ENG_POS	Engine position of engine ingesting bird. Since each engine ingestion event has a unique record in the data base, duplicate event numbers indicate multiple engine ingestion events. This column provides record uniqueness in such cases.
ETIME	Local time of bird ingestion.
SIGN_EVT	Significant event factors. AIRWRTHY - engine related airworthiness effects INV POS LOSS - involuntary power loss MULT BIRDS - multiple birds in 1 engine MULT ENG - multiple engine ingestion (1 bird in each engine) MULT ENG-BIRDS - multiple engine ingestion and 1 or both engines sustained multiple bird ingestion TRVS FRAC - transverse fan blade fracture OTHER - other significant factor, may be reported in narrative remarks NONE - no significant factor noted
AIRCRAFT	Aircraft type.
POF	Phase of flight during which bird ingestion occurred. (TAXI;TAKEOFF;CLIMB;CRUISE;DESCENT;LANDING;UNKNOWN)
ALTITUDE	Altitude (ft. AGL) at time of bird ingestion.
SPEED	Air speed (knots) at time of bird ingestion.
FL_RULES	Flight rules in effect at time of bird ingestion. IFR - instrument flight rules VFR - visual flight rules UNK - unknown

LT_COND Light conditions at time of bird ingestion.
(DARK;LIGHT;DAWN;DUSK;etc.)

WEATHER Weather conditions at time of bird ingestion.

CREW_AC Crew action taken in response to bird ingestion.
ATO - aborted takeoff
ATB - air turnback
DIV - diversion
UNK - unknown
NONE - no crew action taken
N/A - not applicable
OTHER - some action taken, may be specified in narrative remarks

CREW_AL Indicates whether crew alerted to presence of birds at time of bird ingestion.
(YES;NO;UNKNOWN)

BIRD_SEE Indicates whether ingested bird(s) seen prior to ingestion
NO - not seen
YES - seen
SEVERAL - 2 to 10 birds observed
FLOCK - more than 10 birds observed

BIRD_NAM Common bird name. Trailing asterisk (*) implies bird not positively identified as such.

BIRD_SPE Species of positively identified bird. Alphanumeric identification code which conforms to Edward's† convention.

#_BIRDS Number of birds ingested. An asterisk (*) implies more than one bird but the exact count is unknown.

WT_OZ_1 Weight (oz.) of first ingested bird.

CTY_PRS Scheduled city pairs of aircraft operation.
(from code:to code) 3 letter city airport code.

AIRPORT Airport at which bird ingestion event occurred.
3 letter city airport code.

LOCALE Nearest town, state, country, etc.

US_INCID Indicates whether bird ingestion occurred within United States boundaries.
(YES;NO)

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† Edwards, E.P., "A Coded List of Birds of the World," IBSN:911882-04-9, 1974.

ENGINE Engine model.

DASH Engine dash number.

DMG_CODE Letter codes summarizing engine damage resulting from the bird ingestion. This column does not exist in the actual FAA data base, but was developed by the contractor to compress 17 YES/NO damage fields into a single column. A letter code appears for damage columns whose values are YES. Each page of damage information contains a legend identifying the damage type. In the explanation of damage codes below, a number in parentheses indicates the damage severity code which is further explained in the SEVERITY column. The data base column name is given in the explanation of the damage code.

- A(4) - ENG_DAM; engine damaged due to bird ingestion
- B(3) - LEAD_EDG; leading edge distortion/curl, minor fan blades
- C(3) - BEN/DEN; 1 to 3 fan blades bent or dented
- D(2) - BE/DE 3; more than 3 fan blades bent or dented
- E(3) - TORN 3; 1 to 3 fan blades torn
- F(2) - TORN 3; more than 3 fan blades torn
- G(2) - BROKEN; broken fan blade(s). leading edge and/or tip pieces missing; other blades also dented
- H(3) - SHINGLED; shingled (twisted) fan blades
- I(1) - TRVSFRAC; transverse fracture - a fan blade broken chordwise (across) and the piece liberated (includes secondary hard object damage)
- J(2) - SPINNER; dented, broken, or cracked spinner (includes spinner cap)
- K(1) - CORE; bent/broken compressor blades/vanes, blade/vane clash, blocked/disrupted airflow in low, intermediate, and high pressure compressors
- L(3) - NACELLE; dents and/or punctures to the engine enclosure (includes cowl)
- M(1) - FLANGE; flange separations
- N(2) - RELEASED; released (walked) fan blades
- O(1) - TURBINE; turbine damage
- P - OTHER; any damage not previously listed
- Q - UNKNOWN

NOTE: For any engine ingestion event the maximum number of damage codes is three. These three damage codes reflect the most severe damage that occurred. There may be other damage that occurred which was less severe, and may be listed in the remarks column.

SEVERITY Numeric code indicating the severity of engine damage resulting from the bird ingestion. This column does not exist in the actual FAA data base, but was developed by the contractor as a result of an analysis of reported damage in the data base. The lower the severity code, the more severe the damage. The severity rating assigned to a flight is determined as the lowest severity rating attained by any of the damage categories. The corresponding severity ratings for each damage category were given in parentheses in the DMG_CODE discussion above.

1 - most severe damage (damage is known)
2 - moderately severe damage (damage is known)

3 - least severe damage (damage is known)
4 - damage indicated, but not specified
9 - no damage reported

POW_LOSS Degree of power loss as a result of bird ingestion
NONE - no power loss
EPR DEC - engine pressure ratio decrease
SPOOL DOWN - engine spooled down
N1 CHANGE - N1 rotor change
N2 CHANGE - N2 rotor change
COMPRESSOR - compressor surge/stall
UNKNOWN - unknown whether power loss occurred

MAX_VIBE Maximum vibration reported as a dimensionless unit.

THROTTLE Voluntary throttle change by crew in response to bird ingestion.
ADVANCE - voluntary throttle advance
RETARD - voluntary throttle retard
IDLE - voluntary throttle retard to idle
CUTOFF voluntary throttle retard to cutoff
NONE - no voluntary throttle change

IFSD Indicate whether voluntary in-flight shutdown occurred in response to bird ingestion.
NO - no shutdown
VIBES - shutdown due to vibrations
STAL/SURG - shutdown due to compressor stall/surge
HI EGT - shutdown due to high exhaust gas temperature
EPR - shutdown due to incorrect engine pressure ratio
INVLNTRY - involuntary engine shutdown
PARAMTRS - shutdown due to incorrect engine parameters
OTHER - other reasons, may be listed in remarks
UNKNOWN - unknown cause for shutdown

REMARKS Narrative description providing additional information concerning some aspect of the ingestion.

CONTENTS OF FAA SMALL INLET AREA TURBINE ENGINE BIRD INGESTION DATABASE

EDATE	EVT#	ENG_POS	ETIME	SIGN_EVT	AIRCRAFT	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS
05/03/1987	2	1 LEFT	13:00:00	MULT BIRDS	FALCON 50	LANDING	0	122	VFR	DUSK	SCATTERED	NONE	-0-	SEVERAL	SEAGULL*	-0-	3
05/11/1987	3	1 LEFT	16:45:00	NONE	BAE125	LANDING	25	125	VFR	LIGHT	CLEAR	NONE	YES	YES	RING-BILLED GULL	14N10	1
05/14/1987	1	4 RIGHT OUTBOARD	16:30:00	NONE	BAE146	TAKEOFF	-0-	-0-	-0-	LIGHT	CLEAR	NONE	NO	ONE	SPARROW*	-0-	1
05/14/1987	25	1 LEFT	15:30:00	NONE	METRO	LANDING	10	90	VFR	LIGHT	CLEAR	NONE	NO	NO	-0-	-0-	1
05/17/1987	4	1 LEFT	16:00:00	MULT BIRDS	SABRE 65	TAKEOFF	-0-	-0-	VFR	LIGHT	CLEAR	NONE	-0-	FLOCK	MORNING DOVE	2P105	*
05/20/1987	7	1 LEFT	9:30:00	MULT BIRDS	CON 441	TAKEOFF	25	125	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	STARLING*	-0-	*
05/22/1987	8	1 LEFT	5:30:00	NONE	METRO II	TAKEOFF	150	-0-	VFR	LIGHT	CLEAR	ATB	NO	ONE	COMMON GULL	14N36	1
05/25/1987	5	2 RIGHT	-0-	MULT BIRDS	FALCON 10	LANDING	100	100	VFR	LIGHT	CLEAR	NONE	NO	SEVERAL	HAWK*	-0-	*
05/25/1987	52	-0-	15:30:00	NONE	LEAR 35A	APPROACH	200	160	VFR	LIGHT	CLEAR	-0-	NO	ONE	SEAGULL*	-0-	1
05/26/1987	6	2 RIGHT	-0-	NONE	LEAR 35	TAKEOFF	-0-	-0-	VFR	LIGHT	CLEAR	NONE	NO	-0-	PIGEON*	-0-	1
05/31/1987	14	1 LEFT	-0-	MULT ENG	LEAR 55	TAKEOFF	150	-0-	IFR	LIGHT	CLEAR	NONE	NO	SEVERAL	SEAGULL*	-0-	1
05/31/1987	14	2 RIGHT	-0-	MULT ENG	LEAR 55	TAKEOFF	150	-0-	IFR	LIGHT	CLEAR	NONE	NO	SEVERAL	SEAGULL*	-0-	1
06/17/1987	9	1 LEFT OUTBOARD	14:00:00	NONE	JETSTAR	TAKEOFF	200	100	VFR	LIGHT	CLEAR	NONE	YES	YES	SEAGULL	14N14	1
06/17/1987	10	3 RIGHT INBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	-0-	NONE	NO	NO	-0-	-0-	-0-
06/21/1987	20	2 RIGHT	21:30:00	NONE	MU-2	TAKEOFF	1500	150	VFR	DARK	CLEAR	NONE	NO	NO	DOVE*	-0-	1
07/01/1987	33	3 RIGHT	-0-	NONE	FALCON 50	UNKNOWN	-0-	-0-	-0-	-0-	-0-	NONE	NO	NO	-0-	-0-	-0-
07/13/1987	16	2 RIGHT	20:45:00	MULT BIRDS	BAE125-700	LANDING	300	117	VFR	DUSK	CLEAR	NONE	YES	YES	YELLOW CROWN NIGHT HERON	1I27	2
07/14/1987	17	2 CENTER	16:00:00	NONE	FALCON 50	APPROACH	6000	140	VFR	LIGHT	SCATTERED	NONE	NO	ONE	CHIMNEY SWIFT	-0-	1
07/21/1987	21	1 LEFT	14:00:00	NONE	METRO III	TAKEOFF	0	-0-	VFR	LIGHT	SCATTERED	ATO	NO	ONE	SEAGULL*	-0-	1
07/22/1987	22	2 RIGHT	11:30:00	NONE	METRO III	TAKEOFF	0	100	VFR	LIGHT	CLEAR	NONE	NO	YES	MOURNING DOVE	2P105	1
07/27/1987	18	1 LEFT	-0-	NONE	LEAR 35	UNKNOWN	-0-	-0-	IFR	LIGHT	CLEAR	NONE	NO	NO	KILLDEER	5N33	1
07/28/1987	23	1 LEFT	17:30:00	NONE	METRO III	TAKEOFF	0	100	VFR	DAWN	CLEAR	ATO	NO	NO	ROCK DOVE	2P1	1
07/30/1987	11	2 LEFT INBOARD	20:00:00	NONE	BAE146	TAXI	0	0	VFR	DUSK	CLEAR	NONE	NO	NO	TREE SPARROW	70Z23	1
07/31/1987	12	1 LEFT	8:40:00	NONE	CL600	TAKEOFF	35	140	VFR	LIGHT	CLEAR	ATB	YES	ONE	BARHMING KITE	3K31	1
07/31/1987	19	1 LEFT	9:14:00	MULT BIRDS	LEAR 35	TAKEOFF	0	120	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	ROCK DOVE	2P1	*
08/11/1987	26	1 LEFT	11:00:00	MULT BIRDS	CASA 212	CLIMB	800	110	VFR	LIGHT	RAIN	ATB	NO	SEVERAL	SEAGULL*	-0-	2
08/16/1987	24	1 LEFT	17:00:00	NONE	LEAR 35A	TAKEOFF	-0-	-V1	VFR	LIGHT	CLEAR	ATO	-0-	-0-	RING-BILLED GULL	14N12	1
08/24/1987	38	2 RIGHT	11:00:00	NONE	JS 31	CRUISE	450	180	VFR	LIGHT	CLEAR	DIV	YES	ONE	COMMON WHITE SEAGULL*	-0-	1
08/26/1987	13	1 LEFT OUTBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	-0-	NONE	NO	NO	-0-	-0-	-0-
09/09/1987	34	2 RIGHT	8:50:00	NONE	LEAR 55	TAKEOFF	0	110	VFR	LIGHT	OVERCAST	NONE	NO	ONE	GREATER YELLOWLEGS	6N19	1
09/10/1987	35	1 LEFT	14:30:00	MULT BIRDS	LEAR 35	TAKEOFF	0	128	VFR	LIGHT	CLEAR	NONE	NO	YES	SPARROW*	-0-	*
09/10/1987	37	2 RIGHT	8:45:00	MULT ENG-BIRDS	CITATION	LANDING	240	150	VFR	LIGHT	CLEAR	NONE	NO	YES	STARLING*	-0-	1
09/10/1987	37	1 LEFT	8:45:00	MULT ENG-BIRDS	CITATION	LANDING	240	150	VFR	LIGHT	CLEAR	NONE	NO	YES	STARLING*	-0-	2
09/12/1987	27	2 LEFT INBOARD	15:00:00	MULT ENG	BAE146	TAKEOFF	100	120	VFR	LIGHT	CLEAR	ATB	NO	FLOCK	MOURNING DOVE	2P105	1
09/12/1987	27	3 RIGHT INBOARD	15:00:00	MULT ENG	BAE146	TAKEOFF	100	120	VFR	LIGHT	CLEAR	ATB	NO	FLOCK	MOURNING DOVE	2P105	1
09/14/1987	28	1 LEFT OUTBOARD	8:55:00	NONE	BAE146	LANDING	0	85	VFR	LIGHT	CLEAR	NONE	NO	ONE	-0-	-0-	-0-
09/16/1987	39	2 RIGHT	12:00:00	NONE	JS 3101	LANDING	-0-	-0-	VFR	LIGHT	SCATTERED	NONE	NO	ONE	-0-	-0-	1
09/18/1987	40	1 LEFT	9:30:00	NONE	JS 3101	APPROACH	100	125	VFR	LIGHT	OVERCAST	NONE	NO	ONE	MOURNING DOVE	2P105	1
09/20/1987	36	1 LEFT	12:00:00	MULT BIRDS	BAE125-700	TAKEOFF	30	125	VFR	LIGHT	OVERCAST	ATB	YES	YES	CANADA GOOSE	2J30	2
09/22/1987	41	1 LEFT	-0-	NONE	METRO	CLIMB	-0-	-0-	-0-	DARK	-0-	ATB	NO	-0-	-0-	-0-	-0-
09/22/1987	44	2 RIGHT	-0-	NONE	METRO 4	CLIMB	-0-	-0-	VFR	DARK	CLEAR	NONE	NO	NO	SEAGULL*	-0-	-0-
09/28/1987	42	2 RIGHT	13:00:00	NONE	JS 3101	TAKEOFF	320	120	IFR	LIGHT	CLEAR	NONE	NO	NO	-0-	-0-	1
10/01/1987	45	2 RIGHT	9:45:00	NONE	JS 31	APPROACH	200	120	VFR	LIGHT	CLEAR	NONE	NO	ONE	-0-	-0-	1
10/05/1987	29	3 RIGHT INBOARD	13:30:00	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	LIGHT	SCATTERED	NONE	-0-	NO	-0-	-0-	-0-
10/08/1987	30	2 LEFT INBOARD	19:45:00	NONE	BAE146	LANDING	200	-0-	-0-	DARK	SCATTERED	NONE	YES	ONE	COMMON LAPWING	5N1	1
10/13/1987	43	2 RIGHT	9:00:00	NONE	LEAR 35	TAKEOFF	20	130	VFR	LIGHT	OVERCAST	ATB	NO	NO	SEAGULL*	-0-	1
10/13/1987	46	2 RIGHT	22:00:00	NONE	BAE 3101	APPROACH	-0-	120	IFR	DARK	CLEAR	NONE	NO	NO	-0-	-0-	1
10/27/1987	47	2 RIGHT	20:00:00	NONE	JS 3101	APPROACH	2000	150	VFR	DARK	CLEAR	-0-	NO	NO	OWL*	-0-	1
10/30/1987	55	1 LEFT	12:00:00	NONE	METRO 3	LANDING	0	80	VFR	LIGHT	SCATTERED	NONE	NO	FLOCK	SEAGULL*	-0-	-0-
11/02/1987	50	2 RIGHT	8:15:00	NONE	CITATION3	CRUISE	2500	250	VFR	LIGHT	CLEAR	NONE	NO	NO	-0-	-0-	1
11/04/1987	31	3 RIGHT INBOARD	14:55:00	MULT ENG-BIRDS	BAE146	LANDING	-0-	-0-	VFR	LIGHT	SCATTERED	NONE	YES	SEVERAL	REDWINGED BLACKBIRD	64Z54	*
11/04/1987	31	4 RIGHT OUTBOARD	14:55:00	MULT ENG-BIRDS	BAE146	LANDING	-0-	-0-	VFR	LIGHT	SCATTERED	NONE	YES	SEVERAL	REDWINGED BLACKBIRD	64Z54	*
11/06/1987	51	1 LEFT	7:30:00	NONE	METRO	TAKEOFF	900	110	VFR	LIGHT	CLEAR	ATB	NO	ONE	SEAGULL*	-0-	1
11/11/1987	56	1 LEFT	12:05:00	NONE	JS 31	LANDING	0	90	-0-	LIGHT	OVERCAST	NONE	NO	ONE	MALLARD	2J84	1
11/19/1987	53	2 RIGHT	9:15:00	NONE	BAE125-800	TAKEOFF	0	120	VMC	LIGHT	OVERCAST	NONE	YES	ONE	BLACK-HEADED GULL	14N36	1
11/23/1987	57	2 RIGHT	19:30:00	NONE	METRO III	APPROACH	30	-0-	IFR	DUSK	CLEAR	NONE	NO	FLOCK	SEAGULL *	-0-	1
11/29/1987	32	1 LEFT OUTBOARD	17:00:00	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	DUSK	-0-	NONE	-0-	-0-	-0-	-0-	-0-

EDATE	WT_OZ_1	CTY_PRS	AIRPORT	LOCALE	US_INCID	ENGINE	DASH	DMG_CODE	SEVERITY	POW_LOSS	MAX_VIBE	THROTTLE	IFSD	REMARKS
05/03/1987	24.	-0-	DTW	DETROIT, MICHIGAN	YES	TFE731	3	A,P	4	NONE	-0-	NONE	NO	-0-
05/11/1987	17.	-0-	BKL	CLEVELAND, OH	YES	TFE731	5	-0-	-0-	NONE	-0-	NONE	NO	-0-
05/14/1987	-0-	-0-	LEEDS	LEEDS, ENGLAND	NO	ALF502	R5	-0-	-0-	NONE	-0-	NONE	NO	-0-
05/14/1987	-0-	-0-	PSC	PASCO, WA	YES	TPE331	11U	A,K	1	YES	YES	-0-	NO	-0-
05/17/1987	4.	-0-	MSY	NEW ORLEANS, LA	YES	TFE731	3R	A,C	3	NONE	NONE	NONE	NO	-0-
05/20/1987	8.	-0-	EVV	EVANSVILLE, INDIANA	YES	TPE331	8	-0-	-0-	NONE	-0-	NONE	NO	-0-
05/22/1987	15.	-0-	LDK	LINKOPING, SWEDEN	NO	TPE331	3UW	-0-	-0-	NONE	NONE	NONE	NO	-0-
05/25/1987	-0-	-0-	LIN	MILANO, ITALY	NO	TFE731	2	A,D	2	NONE	-0-	NONE	NO	-0-
05/25/1987	64.	-0-	PLCH	LONDON, UK	NO	TFE731	2	A	4	-0-	NONE	-0-	NO	-0-
05/26/1987	16.	-0-	SCL	SANTIAGO, CHILE	NO	TFE731	2	A,D	2	NONE	NONE	NONE	NO	-0-
05/31/1987	16.	-0-	-0-	THESSALONIKI, GREECE	NO	TFE731	3A	A,K	1	NONE	NONE	NONE	NO	-0-
05/31/1987	16.	-0-	-0-	THESSALONIKI, GREECE	NO	TFE731	3A	A,K	1	NONE	NONE	NONE	NO	-0-
06/17/1987	40.	-0-	SIE	SEA ISLE CITY, NJ	YES	TFE731	3	A,E	3	NONE	NONE	NONE	NO	-0-
06/17/1987	-0-	-0-	-0-	OXFORD, ENGLAND	NO	ALF502	R5	-0-	-0-	NONE	-0-	NONE	NO	-0-
06/21/1987	-0-	-0-	RDD	REDDING, CA	YES	TPE331	5	-0-	-0-	NONE	NONE	NONE	NO	-0-
07/01/1987	-0-	-0-	-0-	-0-	NO	TFE731	3	A,K	1	-0-	NONE	-0-	NO	ODOR,DMAGED VANES ON COMP INLET STATOR
07/13/1987	24.	-0-	MSY	NEW ORLEANS, LA	YES	TFE731	3R	A,D	2	NONE	YES	NONE	NO	-0-
07/14/1987	1.	-0-	STL	ST. LOUIS, MO	YES	TFE731	3	-0-	-0-	NONE	NONE	NONE	NO	-0-
07/21/1987	16.	-0-	TVC	TRAVERSE CITY AIRPORT, MI	YES	TPE331	11U	A,K	1	NONE	NONE	RETARD	NO	BENT COMPRESSOR BLADE
07/22/1987	4.	-0-	CWA	WAUSAU, WI	YES	TPE331	11U	-0-	-0-	YES	NONE	-0-	NO	-0-
07/27/1987	3.	-0-	PHX	PHOENIX, ARIZONA	YES	TFE731	2	A,C	3	NONE	NONE	NONE	NO	-0-
07/28/1987	14.	-0-	LAX	LOS ANGELES, CA	YES	TPE331	11	A,K	1	YES	NONE	-0-	NO	-0-
07/30/1987	1.	-0-	LANZHO	CHINA	NO	ALF502	R5	-0-	-0-	NONE	-0-	NONE	NO	-0-
07/31/1987	20.	-0-	BAYAN	PENANG, MALAYSIA	NO	ALF502	L2	A,D,L	2	NONE	-0-	NONE	NO	-0-
07/31/1987	14.	-0-	TOA	TORRANCE, CA	YES	TFE731	2	-0-	-0-	NONE	NONE	NONE	NO	-0-
08/11/1987	32.	-0-	-0-	VALPARAISO,CHILE NAVALBASE	NO	TPE331	5	A,K	1	NONE	NONE	NONE	NO	-0-
08/16/1987	16.	-0-	-0-	LINDSAY, ONTARIO, CANADA	NO	TFE731	3A	A,C,P	3	-0-	HIGH	-0-	-0-	STATOR DAMAGE
08/24/1987	32.	-0-	-0-	DUMFRIES, SCOTLAND	NO	TPE331	10UG	A,K,P	1	YES	-0-	-0-	YES	75% VANES BENT/CURLED OVER, BURNT SMELL
08/26/1987	-0-	-0-	-0-	-0-	YES	ALF502	R5	-0-	-0-	-0-	-0-	NONE	NO	-0-
09/09/1987	6.6	-0-	FLD	BEDFORD, MA	YES	TFE731	3AR	A,C	3	NONE	NONE	NONE	NO	FOUL ODOR
09/10/1987	7.7	-0-	-0-	SHIDELY, SARATOGA, WY	YES	TFE731	2B	-0-	-0-	NONE	NONE	NONE	NO	-0-
09/10/1987	4.	-0-	GRR	GRAND RAPIDS, MI	YES	TFE731	3	A,D	2	NONE	NONE	NONE	NO	-0-
09/10/1987	4.	GRR	GRR	GRAND RAPIDS, MI	YES	TFE731	3	-0-	-0-	NONE	NONE	NONE	NO	-0-
09/12/1987	4.	CNH-IAD	CMH	COLOMBUS, OHIO	YES	ALF502	R5	-0-	-0-	NONE	-0-	NONE	NO	-0-
09/12/1987	4.	CMH-IAD	CMH	COLOMBUS, OHIO	YES	ALF502	R5	A,D	2	NONE	-0-	NONE	NO	-0-
09/14/1987	-0-	POL-HOR	HORTA	AZORES, PORTUGAL	NO	ALF502	R5	-0-	-0-	NONE	NONE	SHUT OFF	NO	-0-
09/16/1987	-0-	-0-	ATL	ATLANTA, GA	YES	TPE331	10UF	-0-	-0-	NONE	NONE	NONE	NO	-0-
09/18/1987	4.	-0-	-0-	VANDALIA, OHIO	YES	TPE331	10UF	-0-	-0-	NONE	NONE	NONE	NO	-0-
09/20/1987	128.	-0-	-0-	WATERBURY, OXFORD, CONN	YES	TFE731	3R	A,D,F,H	2	NONE	MINOR	NONE	NO	-0-
09/22/1987	-0-	-0-	-0-	MANION AIRPORT, ILL	YES	TPE331	10	A,K	1	YES	-0-	ADVANCE	NO	PM INGESTION
09/22/1987	-0-	-0-	-0-	VICTORIA, LA	YES	TPE331	11U	A,K	1	-0-	NONE	NONE	NO	PM
09/28/1987	-0-	-0-	-0-	MIDDLETOWN, MD	YES	TPE331	10UG	A,P	4	YES	NONE	NONE	NO	FUEL NOZZLES AND COMBUSTOR CAN CLOGGED
10/01/1987	-0-	-0-	MEM	MEMPHIS, TENN	YES	TPE331	10UG	-0-	-0-	-0-	-0-	NONE	NO	FUEL NOZZLES REMOVED FOR CLEANING
10/05/1987	-0-	YKM-PSC	-0-	PASCO, WASHINGTON	YES	ALF502	R5	A,C	3	NONE	-0-	NONE	NO	-0-
10/08/1987	7.7	PWK-PWK	PWK	AYRESHIRE, SCOTLAND	NO	ALF502	R5	-0-	-0-	NONE	NONE	NONE	NO	-0-
10/13/1987	16.	-0-	CVT	CHESTER, UK	NO	TFE731	2	A,D,H	2	NONE	NONE	NONE	NO	5 FAN BLADES+1ST STAGE COMPRESSOR DAMAGE
10/13/1987	-0-	-0-	-0-	ERIE, PA	YES	TPE331	10UG	-0-	-0-	NONE	NONE	NONE	NO	-0-
10/27/1987	-0-	-0-	-0-	MEMPHIS, TENN	YES	TPE331	10	A,K	1	SPOOL DOWN	NONE	CUTOFF	YES	FLAME OUT, COMPRESSOR BLADES BENT
10/30/1987	-0-	-0-	-0-	SCHIPOL INT., AMSTERDAM	NO	TPE331	11U	-0-	-0-	NONE	NONE	NONE	NO	PROPELLOR DAMAGE
11/02/1987	-0-	-0-	FRG	QUEEN, NY	YES	TFE731	3B	-0-	-0-	NONE	NONE	NONE	NO	SLIGHT NICK ON A FAN BLADE
11/04/1987	2.	LAX-CCR	CCR	CONTRA COSTA, CONCORD CA	YES	ALF502	R5	-0-	-0-	NONE	NONE	NONE	NO	-0-
11/04/1987	2.	LAX-CCR	CCR	CONTRA COSTA, CONCORD CA	YES	ALF502	R5	-0-	-0-	NONE	NONE	NONE	NO	-0-
11/06/1987	32.	-0-	SBA	SANTA BARBARA, CA	YES	TPE331	11U	A,K	1	NONE	HIGH	CUTOFF	VIBES	-0-
11/11/1987	36.	-0-	-0-	DUNSFOLD, ENGLAND	NO	TPE331	10UF	A,K	1	NONE	NONE	NONE	NO	1 ST. 1 VANE LE TIP CURL
11/19/1987	10.	-0-	EDVE	BRAUNSHWEIG, FRG	NO	TFE731	5R	A,D	2	NONE	NONE	NONE	NO	4 FAN BLADES AND STATOR DAMAGED
11/23/1987	8.	-0-	BSL	BASLE, SWITZERLAND	NO	TPE331	11U	-0-	-0-	NONE	NONE	NONE	NO	-0-
11/29/1987	-0-	SNA-SJC	-0-	SAN JOSE, CA	YES	ALF502	R5	-0-	-0-	NONE	NONE	NONE	NO	FOUND ON POSTFLIGHT INSPECTION

EDATE	EVT#	ENG_POS	ETIME	SIGN_EVT	AIRCRAFT	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS
12/03/1987	54	2 RIGHT	-0-	NONE	FALCON 10	APPROACH	4000	190	VFR	DARK	CLEAR	NONE	NO	SEVERAL	FRANKLIN'S GULL	14N31	1
12/05/1987	64	2 RIGHT	19:00:00	NONE	TCOMM 6958	APPROACH	150	130	VFR	DUSK	CLEAR	NONE	NO	NO	-0-	-0-	1
12/10/1987	48	3 RIGHT INBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	-0-	NONE	NO	NO	-0-	-0-	-0-
12/11/1987	49	1 LEFT OUTBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	-0-	NONE	NO	NO	-0-	-0-	-0-
12/11/1987	70	2 RIGHT	18:30:00	MULT BIRDS	JS 31	TAKEOFF	0	80	IFR	DARK	OVERCAST	ATO	NO	NO	COMMON LAPWING	5N1	*
12/13/1987	65	3 RIGHT INBOARD	16:00:00	MULT ENG-BIRDS	JETSTAR	TAKEOFF	50	160	VFR	DUSK	OVERCAST	ATB	NO	FLOCK	COMMON LAPWING	5N1	*
12/13/1987	65	2 LEFT INBOARD	16:00:00	MULT ENG-BIRDS	JETSTAR	TAKEOFF	50	160	VFR	DUSK	OVERCAST	ATB	NO	FLOCK	COMMON LAPWING	5N1	*
12/13/1987	65	4 RIGHT OUTBOARD	16:00:00	MULT ENG-BIRDS	JETSTAR	TAKEOFF	50	160	VFR	DUSK	OVERCAST	ATB	NO	FLOCK	COMMON LAPWING	5N1	*
12/16/1987	98	2 RIGHT	18:00:00	NONE	BAE125	APPROACH	1200	160	VFR	DUSK	CLEAR	NONE	NO	NO	-0-	-0-	1
12/17/1987	71	1 LEFT	8:05:00	MULT ENG-BIRDS	DO 228	LANDING	0	80	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	SEAGULL*	-0-	*
12/17/1987	71	2 RIGHT	8:05:00	MULT ENG-BIRDS	DO 228	LANDING	0	80	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	SEAGULL*	-0-	*
12/30/1987	99	2 RIGHT	16:00:00	NONE	LEAR 35A	CLIMB	-0-	-0-	VFR	LIGHT	CLEAR	NONE	NO	NO	-0-	-0-	1
01/13/1988	58	4 RIGHT OUTBOARD	10:57:00	INV POW LOSS	BAE146	TAKEOFF	800	-0-	VFR	LIGHT	CLEAR	ATB	YES	SEVERAL	TURKEY VULTURE	1K1	1
01/15/1988	63	2 RIGHT	14:00:00	NONE	CITATION 3	TAKEOFF	-0-	110	VFR	LIGHT	CLEAR	ATB	NO	ONE	-0-	-0-	1
01/16/1988	59	3 RIGHT INBOARD	11:40:00	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	DARK	CLEAR	NONE	NO	-0-	-0-	-0-	-0-
01/22/1988	77	2 RIGHT	7:00:00	NONE	COMM 681	TAKEOFF	40	100	VFR	DAWN	SCATTERED	DIV	NO	SEVERAL	DOVE*	-0-	1
02/03/1988	60	1 LEFT OUTBOARD	18:40:00	NONE	BAE146	LANDING	-0-	115	VFR	DUSK	CLEAR	NONE	NO	NO	DOVE*	-0-	-0-
02/11/1988	68	2 RIGHT	22:22:00	NONE	BAE125-700	TAKEOFF	0	120	IFR	DARK	FOG	NONE	NO	NO	-0-	-0-	1
02/15/1988	61	1 LEFT OUTBOARD	12:30:00	NONE	BAE146	TAKEOFF	-0-	120	IFR	LIGHT	CLEAR	NONE	NO	ONE	SWALLOW*	-0-	1
02/16/1988	78	2 RIGHT	8:50:00	NONE	DO 228	TAKEOFF	0	100	VFR	LIGHT	CLEAR	ATB	-0-	FLOCK	CROW*	-0-	1
02/18/1988	62	3 RIGHT INBOARD	6:50:00	MULT ENG-BIRDS	BAE146	LANDING	-0-	115	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	HOUSE MARTIN	18Z69	1
02/18/1988	62	1 LEFT OUTBOARD	6:50:00	MULT ENG-BIRDS	BAE146	LANDING	-0-	115	VFR	LIGHT	CLEAR	NONE	NO	FLOCK	HOUSE MARTIN	18Z69	2
02/22/1988	69	2 RIGHT	21:00:00	MULT BIRDS	LEAR 35A	LANDING	20	120	VFR	DARK	CLEAR	NONE	NO	SEVERAL	SNOW GOOSE	2J26	2
02/22/1988	75	2 RIGHT	11:00:00	NONE	LEAR 35	APPROACH	400	140	VFR	LIGHT	CLEAR	NONE	NO	NO	SPARROW*	-0-	1
03/04/1988	85	1 LEFT	19:30:00	INV POW LOSS	MU 2	APPROACH	100	-0-	-0-	DARK	DRY	NONE	NO	NO	LAPWING	5N1	1
03/05/1988	79	1 LEFT	16:45:00	NONE	METRO	APPROACH	1000	160	-0-	DUSK	OVERCAST	NONE	NO	NO	-0-	-0-	1
03/09/1988	80	2 RIGHT	7:00:00	NONE	DO 228	TAKEOFF	0	70	VFR	LIGHT	CLEAR	ATO	NO	NO	-0-	-0-	1
03/10/1988	72	2 LEFT INBOARD	9:45:00	NONE	BAE146	LANDING	0	80	VFR	LIGHT	CLEAR	NONE	YES	SEVERAL	SPARROW*	-0-	1
03/14/1988	86	2 RIGHT	15:00:00	NONE	DO 228	LANDING	0	70	VFR	LIGHT	SCATTERED	NONE	NO	SEVERAL	WOOD PIGEON	2P9	1
03/22/1988	76	2 RIGHT	20:40:00	NONE	BAE125-700	APPROACH	2000	130	IFR	DARK	SNOW	NONE	NO	ONE	RING BILLED GULL	14N12	1
03/22/1988	83	2 RIGHT	10:15:00	NONE	LEAR C21A	TAKEOFF	0	95	-0-	LIGHT	SCATTERED	ATO	NO	ONE	GRAY PARTRIDGE	4L85	1
03/23/1988	87	1 LEFT	19:55:00	NONE	METRO	UNKNOWN	600	130	-0-	LIGHT	SCATTERED	NONE	YES	YES	AMERICAN WIGEON	2J71	1
03/25/1988	73	1 LEFT OUTBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	CLEAR	NONE	-0-	NO	SPARROW*	-0-	-0-
03/29/1988	74	2 LEFT INBOARD	21:00:00	NONE	BAE146	UNKNOWN	-0-	-0-	VFR	DARK	-0-	NONE	YES	YES	-0-	-0-	1
04/04/1988	92	2 RIGHT	6:45:00	MULT BIRDS	FALCON 10	TAKEOFF	0	100	VFR	LIGHT	SCATTERED	ATO	NO	NO	CANADA GOOSE	2J30	2
04/09/1988	84	2 RIGHT	10:15:00	NONE	WESTWIND	TAKEOFF	300	160	-0-	LIGHT	CLEAR	ATB	NO	TWO	IMMATURE COMMON LOON	1E3	1
04/12/1988	100	2 RIGHT	8:30:00	NONE	WESTW 1124	CLIMB	3000	170	VFR	LIGHT	CLEAR	NONE	NO	SEVERAL	SEAGULL*	-0-	1
04/18/1988	102	2 RIGHT	17:00:00	NONE	CASA 212	LANDING	0	80	VFR	LIGHT	CLEAR	NONE	NO	YES	QUELTENE*	-0-	1
04/25/1988	81	2 LEFT INBOARD	-0-	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
04/27/1988	82	4 RIGHT OUTBOARD	22:00:00	NONE	BAE146	UNKNOWN	-0-	-0-	-0-	DARK	CLEAR	NONE	NO	-0-	-0-	-0-	-0-

EDATE	WT_OZ_1	CTY_PRS	AIRPORT	LOCALE	US_INCID	ENGINE	DASH	DMG_CODE	SEVERITY	POW_LOSS	MAX_VIBE	THROTTLE	IFSD	REMARKS
12/03/1987	9.	-0-	MKC	KANAS CITY, MO	YES	TFE731	2	-0-	-0-	NONE	-0-	NONE	NO	-0-
12/05/1987	-0-	-0-	HLP	JAKARTA, INDONESIA	NO	TPE331	10R	A,K	1	NONE	NONE	NONE	NO	IMPELLER BLADES DAMAGED
12/10/1987	-0-	-0-	-0-	-0-	NO	ALF502	R5	A,C	3	NONE	NONE	-0-	NO	FOUND DURING ROUTINE INSPECTION
12/11/1987	-0-	-0-	HARARE	AFRICA	NO	ALF502	R5	-0-	-0-	NONE	NONE	-0-	NO	-0-
12/11/1987	7.7	-0-	-0-	WOODFORD, ENGLAND	NO	TPE331	10UF	A,K	1	YES	SOME	NONE	NO	TORGUE FLICKED BACK,IMPELLOR+CORE DAMAGE
12/13/1987	7.7	-0-	-0-	COVENTRY, ENGLAND	NO	TFE731	3	A,D,K	1	NONE	NONE	NONE	NO	GUN + VEHICLE BIRD CONTROL
12/13/1987	7.7	-0-	-0-	COVENTRY, ENGLAND	NO	TFE731	3	-0-	-0-	NONE	NONE	NONE	NO	GUN + VEHICLE BIRD CONTROL IN EFFECT
12/13/1987	7.7	-0-	-0-	COVENTRY, ENGLAND	NO	TFE731	3	-0-	-0-	NONE	NONE	NONE	NO	GUN + VEHICLE BIRD CONTROL
12/16/1987	-0-	-0-	-0-	RICHMOND, VA-BYRD FIELD	YES	TFE731	3R	A,D	2	NONE	NONE	NONE	NO	FOUR FAN BLADES DAMAGED
12/17/1987	8.	-0-	FDH	FRIEDRICHSHAFEN, GERMANY	NO	TPE331	5	A,K	1	-0-	NONE	RETARD	NO	-0-
12/17/1987	8.	-0-	FDH	FRIEDRICHSHAFEN, GERMANY	NO	TPE331	5	A,K	1	-0-	NONE	RETARD	NO	IMPELLOR SLIGHTLY DAMAGED
12/30/1987	-0-	-0-	-0-	CRICIUMA, SOUTHERN BRAZIL	NO	TFE731	2	A,D	2	YES	NONE	NONE	NO	SIX F BLDS TIPS BENT, LPC DAMAGE
01/13/1988	64.5	OAK-SNA	OAK	SAN FRANSICO, OAK., CA	YES	ALF502	R5	A,C,E,K	1	COMPRESSOR	-0-	IDLE	INVOLUNTARY	ALL COMP STAGES DAMAGED, ENG FLAMED OUT
01/15/1988	-0-	-0-	SLN	SALINA, KS	YES	TFE731	3B	A,C,H	3	NONE	SOME	NONE	NO	3 FAN BLADES BENT
01/16/1988	-0-	LAX-SAN	-0-	CA	YES	ALF502	R5	A,C	3	NONE	-0-	-0-	NO	FOUND ON GRD INSPEC., 2 FAN BLADES BENT
01/22/1988	-0-	-0-	JAX	JACKSONVILLE, FL	YES	TPE331	43BL	-0-	-0-	NONE	NONE	NONE	NO	-0-
02/03/1988	-0-	HRE-BUQ	BUQ	BULAAWAYO, ZIMBABWE	NO	ALF502	R5	-0-	-0-	NONE	1.2	IDLE	NO	MINOR CORE DAMAGE REMAINED IN SERVICE
02/11/1988	-0-	-0-	-0-	TAMPA, FL	YES	TFE731	3R	-0-	-0-	NONE	NONE	NONE	NO	-0-
02/15/1988	-0-	KAB-WKM	KAB	MATABELELAND, AFRICA	NO	ALF502	R5	-0-	-0-	NONE	.6	-0-	NO	BIRD WENT THROUGH BYPASS
02/16/1988	-0-	-0-	-0-	BAGDORA, BENGAL, INDIA	NO	TPE331	5	A,K	1	YES	NONE	CUTOFF	VOLUNTARY	TQ DROPPED BELOW 60%, ENGINE WHISTLE
02/18/1988	0.6	HRE-MSV	MSV	MASVINGO, ZIMBABWE	NO	ALF502	R5	-0-	-0-	NONE	.3	-0-	NO	BIRD WENT THROUGH BYPASS
02/18/1988	0.6	HRE-MSV	MSV	MASVINGO, ZIMBABWE	NO	ALF502	R5	-0-	-0-	NONE	.3	-0-	NO	ONE BIRD INTO CORE, ONE THROUGH BYPASS
02/22/1988	88.	-0-	HOU	HOUSTON, TEX	YES	TFE731	2	A,C,K	1	YES	HIGH	NONE	NO	-0-
02/22/1988	-0-	-0-	FHA	SIERRA VISTA, AZ	YES	TFE731	2	-0-	-0-	NONE	NONE	NONE	NO	-0-
03/04/1988	7.7	-0-	LBG	PARIS, FRANCE	NO	TPE331	10	A,K	1	SPOOL DOWN	HIGH	CUT OFF	INVOLUNTARY	PILOT SHUT DOWN ENGINE IN EMERGENCY
03/05/1988	-0-	-0-	PDX	PORTLAND, OR	YES	TPE331	11	A	4	-0-	-0-	CUTOFF	VOLUNTARY	SQUEALER BIRD CONTROL IN EFFECT
03/09/1988	-0-	-0-	ISP	RONKOKOMA, NY	YES	TPE331	5	A,K	1	NONE	-0-	IDLE	NO	CHANGE IN ENGINE NOISE LEVEL
03/10/1988	-0-	DEN-ASE	ASE	ASPEN, COL	YES	ALF502	R3A	-0-	-0-	NONE	.2	NONE	NO	-0-
03/14/1988	18.	-0-	-0-	SUFFOLK, ENGLAND	NO	TPE331	5	-0-	-0-	YES	YES	-0-	NO	IPSWICH AIRPORT, RPM DROPPED TO 40 %
03/22/1988	16.	-0-	CYYZ	TORONTO, CANADA	NO	TFE731	3R	-0-	-0-	NONE	-0-	NONE	NO	-0-
03/22/1988	14.	-0-	-0-	RAMSTEIN AIR BASE, GERMANY	NO	TFE731	2	-0-	-0-	NONE	NONE	RETARD	NO	-0-
03/23/1988	28.	-0-	HON	HURON, SD	YES	TPE331	11U	A,K	1	NONE	NONE	NONE	NO	LPC IMPELLOR BLADE CORNER PIECE BROKEN
03/25/1988	-0-	BEJ-LAN	-0-	HOHHOT, CHINA	NO	ALF502	R5	-0-	-0-	NONE	-0-	-0-	NO	-0-
03/29/1988	-0-	-0-	-0-	ISLAMABAD, PAKISTAN	NO	ALF502	R5	-0-	-0-	NONE	-0-	-0-	NO	-0-
04/04/1988	128.	-0-	PWK	WHEELING,IL	YES	TFE731	2	A	4	FLAME OUT	HIGH	-0-	YES	-0-
04/09/1988	102.	-0-	-0-	CELBURNE, TX	YES	TFE731	3	A,G	2	MOMENTARY	SMALL	NONE	NO	N2 INCREASE,N2+TEMP DECREASE MOMENTARILY
04/12/1988	12.	-0-	-0-	MERTLE BEACH, SC	YES	TFE731	3	A,C	3	YES	NONE	-0-	NO	EGT UP 20 DEG C, SEVERAL BENT F BLADES
04/18/1988	96.	-0-	-0-	RANCAQUA, SANTIAGO, CHILE	NO	TPE331	5	A,K	1	YES	HIGH	-0-	NO	ONE IMPELLER BLADE BENT
04/25/1988	-0-	-0-	-0-	CA	YES	ALF502	R5	-0-	-0-	NONE	-0-	-0-	NO	FOUND DURING GROUND INSPECTION
04/27/1988	-0-	-0-	IAD	WASHINGTON, DC-DULLES	YES	ALF502	R5	A,L	3	NONE	-0-	-0-	NO	FOUND ON GROUND INSPECTION

APPENDIX C

STATISTICAL METHODS USED

Statistical analyses are based on an underlying probabilistic model of the process that gave rise to the data. For example, to provide the basis for comparing the weights of ingested birds in the United States and overseas, it is necessary to hypothesize an underlying random distribution of bird weights. That is, the analyst hypothesizes that there is a population of birds, that these birds have different weights, and that the ingestion process "picked" birds from this population in such a way that all birds had equal chances of being selected (this is really the meaning of "random").

Statistical analyses are somewhat more sophisticated than descriptive data analyses and more care is required to ensure that the methods are appropriate for the data. Statistical analysis is basically formalized inductive reasoning. Hypotheses about bird ingestion hazards are evaluated for consistency with the data that have been collected. Statistical analysis provides the rules for quantifying the level of consistency between the data and a given hypothesis, and thereby forms the basis for objective and unbiased decisions. The process is known formally as statistical hypothesis testing and a brief outline of the procedure is presented here.

The basis of a statistical hypothesis test is the hypothesis, which is a formal statement about a relationship in the data. If the data are found to be inconsistent with the hypothesis, then the hypothesis is rejected. Conversely, if the data are consistent with the hypothesis, the hypothesis <u>cannot be rejected</u>, and is then tentatively <u>accepted</u>. (Note that a tentatively accepted hypothesis may have to be rejected on the basis of later data, hence failure to reject is not the same as proof of validity. By contrast, a hypothesis which is rejected is unlikely to be "accepted" on the basis of later data.)

For instance, in comparing the weight distributions of United States ingestions versus foreign ingestions, one hypothesis is that there is no difference in the sizes of the birds ingested in the two regions. However, because of randomness in the ingestion process, it would be very surprising if the data on bird weights were identical for the two regions. The purpose of the statistical analysis, then, is to determine whether the data are consistent with the hypothesis, despite the occurrence of random variation.

The rules for deciding whether to accept or reject the hypothesis are based on the possible errors that could be made. A type I error refers to the situation in which the hypothesis is true but we reject it. A type II error occurs when the hypothesis is false but we fail to reject it (we accept it).

The goal of the statistician is to minimize the likelihood of both types of errors. Unfortunately the likelihood of a type I error is reciprocally linked to the likelihood of a type II error so that lowering the likelihood of either type of error raises the likelihood of the other type error.

Since only one of the errors can be fully controlled, it has become standard practice to control the likelihood of a type I error, and accept whatever probability of a type II error results. The likelihood of a type I error is called the "significance level" of the test. The test hypothesis is chosen so that it should be accepted unless thereis strong evidence that it is not true. If the data appear to present strong evidence that the hypothesis is false, then the hypothesis is rejected. With likelihood equal to the significance level, this rejection is a mistake caused by randomness in the data.

For instance, if we hypothesize that there is no difference in the weight distributions of birds ingested in the United States and overseas, we would then select a statistical test which has a low significance level (such as 1 percent). That is, the probability of falsely rejecting the hypothesis is controlled to be 1 percent. If the test showed the data to be inconsistent with the hypothesis, then we would consider ourselves safe in rejecting the hypothesis.

Another aspect of evaluating the efficiency of a statistical test is its ability to detect when the test hypothesis is false. This ability is called the power of the test and is defined to be the probability of rejecting the test hypothesis when it is false and should be rejected. Generally there are many alternatives to the test hypothesis. For instance, one alternative to the hypothesis of equality of bird weight distributions inside and outside the United States is that birds outside the United States are heavier than those inside. Yet another alternative hypothesis is that birds outside the United States are lighter than those inside the United States. A test which was very powerful under the first hypothesis might be very weak under the second hypothesis. The power of a test is therefore a function of the specific alternative hypothesis being considered.

A variation on the statistical hypothesis test is the calculation of a confidence interval for a parameter such as the overall probability of ingestion (POI). The POI is computed by dividing the number of ingestion events by the number of opportunities for an ingestion event. However, because of randomness, the actual number of ingestions might be more or fewer than the number associated with the "true" POI. Since we have made no specific hypothesis about the POI, we use a confidence interval to describe the range of probabilities which is consistent with the data. The confidence level associated with a confidence interval is the likelihood that the true value of the parameter (in this case the POI) is contained within the interval. The confidence level thus amounts to 1 minus the significance level of a hypothesis test.

In determining whether the data are consistent with a particular hypothesis, we must sometimes account for "degrees of freedom". Suppose that a population can be described by two parameters. For illustrative purposes we can use the mean and standard deviation. Note in particular that the mean is used to compute the standard deviation. Suppose we have a hypothesis that a certain population has specific values for the two parameters. We could test the hypothesis by collecting a sample of, say, 10 items from the population. We would compute the sample mean, and use a statistical test to compare this with the hypothesized mean. In addition, we would compute a standard deviation from the sample data, <u>using the hypothesized mean rather than the sample mean in the computation</u>. We would then use a statistical test to compare the computed standard deviation with the hypothesized standard deviation. In both cases, we would reject the hypothesis if the statistical test showed there was "too much" difference between the computed and hypothesized values. In computing the two "statistics", we would have used the 10 independent sample values. The tests would then be said to have 10° of freedom.

Suppose, alternatively, that we have no hypothesis about the mean, but we wish to estimate the standard deviation. We could again collect a sample of 10 items. We would compute the mean from the sample, and use this computed mean in the computation of the standard deviation. In statistical parlance, we have "used up one degree of freedom" by so doing. The standard deviation no longer involves 10 independent items. Once the sample mean is fixed, then only 9 items can be picked independently. The value for the 10th is already determined by the first 9, since it must be such as to produce the fixed mean.

A similar situation arises in chi-squared tests. For instance, suppose an overall rate is to be compared with a rate in each of several categories. An instance of this is computing an overall ingestion rate per operation, and comparing this with individual engine ingestion rates. Computing the overall rate uses up one degree of freedom, reducing the degrees of freedom available to determine the power of the test in distinguishing genuine differences among the categories.

In general, then, when an estimate of one parameter involves another parameter, which itself must be estimated from the sample, we lose degrees of freedom. The consequence is that the statistical test is less effective. For a given likelihood of a type I error, there is a higher likelihood of a type II error (the test has lower power) than would be the case if more degrees of freedom were available. In all cases in the report where this issue is relevant, the number of degrees of freedom of the statistical test is stated.

In the report, the term "Bernoulli trial" is used. This refers to a situation ("trial") in which only two outcomes are possible: heads/tails, success/failure, damage/no damage, etc.

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