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Study of Bird Ingestions into Small Inlet Area Aircraft Turbine Engines (May 1987-April 1989)

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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 inlet area up to approximately 1400 square inches. This report presents an analysis of the 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, phase of flight, month, location and bird species and weight.

Figure E-1 is an overall summary of the data that were collected during the 2-year period from May 1, 1987, to April 30, 1989. Throughout the world during that time there were approximately 16 million operations by the engines included in the data (ALF502, TFE731, TPE331 and JT15D). This figure includes 24 months of operations for the first three engines and 12 months of operation for the fourth. A total of 210 engine ingestion events were reported during this period. The probability of an engine ingestion event occurring is 1.3×10^{-5} per operation. Thus, the ingestion of a bird is a rare but not impossible occurrence.

Within the United States, the most frequently ingested bird weight is 4 ounces, while outside the United States, the most frequently ingested bird weight is 7.7 ounces. However, birds in the range of 0 to 4 ounces actually outnumber the birds in the range of 4 to 8 ounces. Within the United States, half the ingested birds weigh over 4 ounces, while outside the United States, the median weight is 7.7 ounces. 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, if seasonality exists, these tests as described in Section 3 were not able to detect it.

It was found that ingestions occurred more frequently in the daytime than at night. More than likely this is the result of two factors: fewer aircraft flights at night and more birds flying in the daytime.

No geographic patterns seem to be apparent in the bird ingestions in the United States. The Northeast and Midwest States seem to form a block of states with several ingestions, but no single state in that area had more than five (Ohio, second highest number in the nation). The largest number of ingestions (11) in one state occurred in California. This may be explained by a conjunction of many seabirds and a high level of aircraft activity.

It was determined that the engine ingestions could be described adequately by a Poisson distribution. This made it possible to test hypotheses about the relationship between engine size and ingestion rate. The data are consistent with the hypothesis that ingestion rates are directly related to engine cross section area. 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.

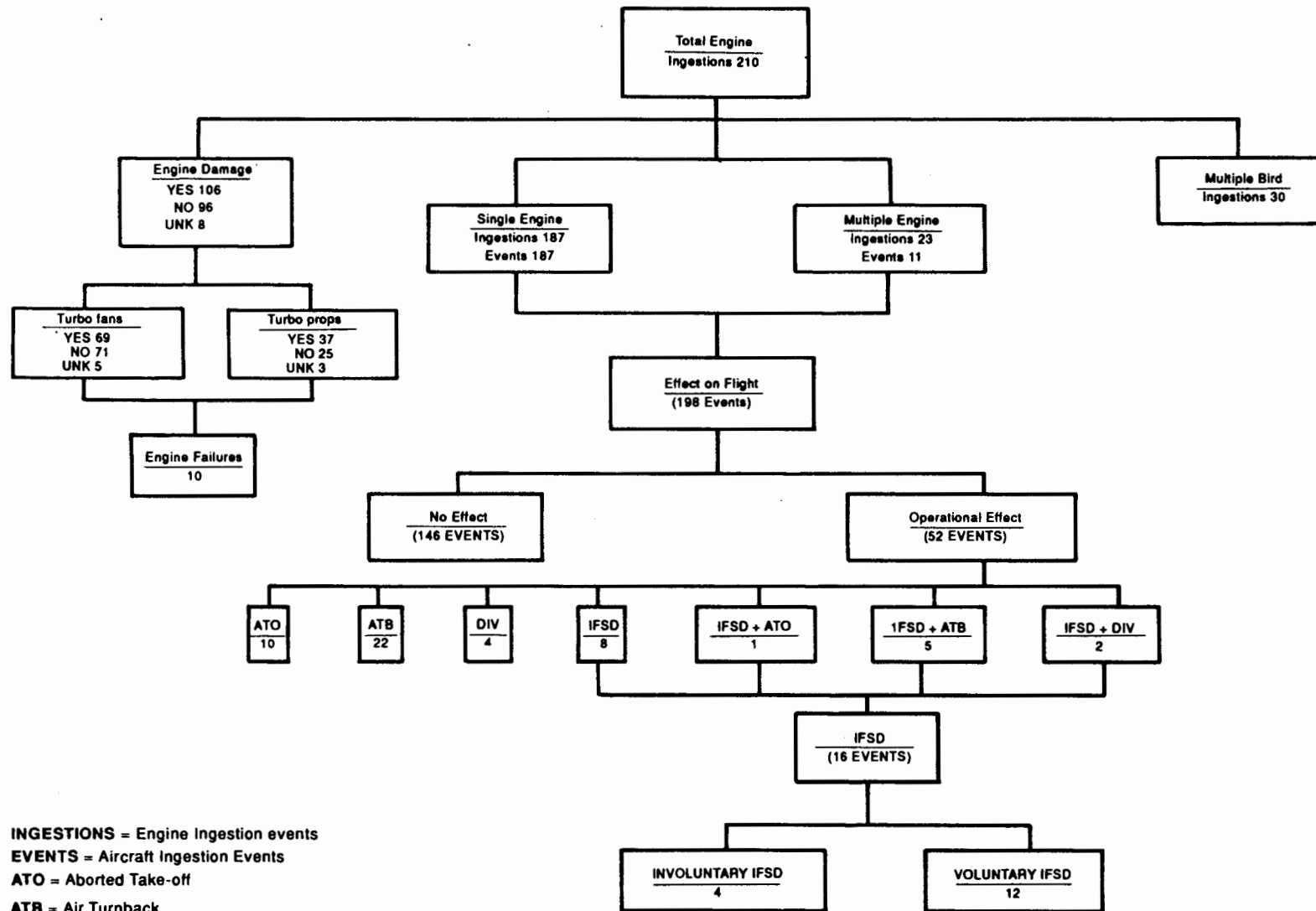


FIGURE E-1. SMALL INLET AREA TURBINE ENGINE BIRD INGESTION STUDY
DATA SUMMARY
(2 YEARS OF DATA, 5/87 TO 4/89)

It was observed that the same number of engine ingestion events occurred in the combined takeoff/climb phases of flight as in the combined approach/landing phases of flight. The ratio of landing events to approach was close to one (55:45), whereas the ratio of takeoff events to climb events exceeded ten (91:9). Less than 5 percent of all ingestion events occurred during taxi or at cruise altitude.

Engine damage occurred in 50 percent of all engine ingestion events, and 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 versus bird-weight curves were computed from the data. Also, the probability of engine damage is greater when the bird ingestion occurs during the takeoff and climb phases of flight than when it occurs during approach and landing. Aircraft airspeed at or above 140 knots also increases the probability of engine damage.

It was determined that 5 percent of all engine bird ingestion events resulted in an engine failure. Four engine failures were caused by birds that weighed more than 4 pounds and two were caused by birds that weighed less than 1/2 pound. Engine failures are also more likely to occur when multiple birds are ingested into an engine.

It was observed that as the level of damage increased, the probability of crew action likewise increased. For turbofan engines, the probability of crew action was 6.6 percent after engine ingestion events in which there was no damage, while probability of crew action was 42 percent after engine ingestion events in which there was severe damage. For the turboprop engine, the probability of crew action for events with no engine damage was 16 percent.

It was found that the probability of ingestion for birds in the weight range from 0 to 4 ounces (the most common range) was 1.98 per million operations. Overall, the probability of ingesting a bird was 13 per million engine operations.

A summary of the most pertinent statistics extracted from the 2 years of data is provided below:

Most Frequently Ingested Bird Weight (oz)

United States	4
Foreign	7.7

Average Bird Weight (oz)

United States	21
Foreign	9.2

Median Bird Weight (oz)

United States	4
Foreign	7.7

Probability of Ingestion per Engine Operation	
Worldwide (all engine types)	1.3×10^{-5}
United States (JT15D engine excluded)	1.04×10^{-5}
Foreign (JT15D engine excluded)	1.922×10^{-5}

Most Commonly Ingested Bird	
United States	Dove
Foreign	Lapwing

Engines Experiencing Moderate/Severe Damage	
Turbofans	41
Turboprops	2

Ingestions During Phase of Flight	
Takeoff and Climb	100
Approach and Landing	100

SECTION 1 INTRODUCTION

1.1 BACKGROUND.

Contention for airspace between birds and airplanes has created a serious bird/aircraft strike hazard. Four past studies [references 1,2,3 and 4] have indicated that birdstrikes to engines are statistically rare events. The probability of a birdstrike during any given flight is extremely low; however, given the number of flights currently taking place, the expected number of birdstrikes becomes significant.

The windshield and the engines 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 occurred on a civilian airplane resulting in the death of the copilot. Ingestion of birds into airplane engines is a safety problem for civil as well as military airplanes for it can cause significant damage to the engine, resulting in degraded engine performance and possibly 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 noncruise phases of flight. Hovey and Skinn [references 2 and 3] 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 birdstrike.

The solution to the problem of engine damage resulting from bird ingestion is similar to that for windshield birdstrike, e.g., either design-consideration of the structure to withstand impact, and/or avoidance of birds. Bird avoidance can be facilitated by either of two approaches: (1) keeping airplanes out of airspaces with large bird concentrations, or (2) removing birds from these regions of airspace. The bird avoidance approach can have various degrees of success or failure for commercial air fleets 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 withstand bird ingestion damage can be accomplished given 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 re-evaluating certification test regulations 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 OBJECTIVE.

The objective of this report is to determine the relationship of bird weight, geographic location, season, 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 four engine types (ALF502, TPE331, TFE731 and JT15D) operating worldwide over a 2-year reporting period from May 1987 through April 1989. 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 as 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 inlet area up to approximately 1400 square inches.

1.3 ORGANIZATION OF REPORT.

Section 2 presents engine hours and operations for the four engines. Section 3 identifies the characteristics 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 discusses data quality. Section 8 provides a summary of the results obtained during this phase of data analysis. Section 9 lists references used in preparation of this report. Section 10 is a glossary of terms. 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, JT15D, and TFE731, only data on engine hours were available. To obtain engine operations, average values of 0.8 operations/hours (TFE731), 0.9 operations/hours (JT15D), and 1.2 operations/hours (TPE331) were provided through the FAA. Numbers of engine operations by month for the ALF502, TFE731, and TPE331 engines are presented in tables 2.1, 2.2 and 2.3, respectively. Because total operations for the TFE731 and TPE331 engines are obtained by using the aforementioned flight hour conversion factors, certain monthly, United States, foreign, and overall total operations in tables 2.2 and 2.3 appear as incorrect sums of individual monthly operations. Rounding error accounts for the arithmetic discrepancies. Figures 2.1, 2.2 and 2.3 are histograms displaying operations by month and engine.

Data for the JT15D were provided only as a total: 872,510 hours for the period May 1, 1988, to April 30, 1989. A conversion factor of 0.9 operations/hours results in a total of 785,259 operations for this engine. No information by month is available for this engine.

TABLE 2.1. HOURS AND OPERATIONS ALF502

<u>Date</u>		<u>United States</u>		<u>Foreign</u>		<u>Total</u>	
Month	Year	Hours	Operations	Hours	Operations	Hours	Operations
MAY87		39290	44167	8275	7538	47565	51705
JUN87		39290	44167	8275	7538	47565	51705
JUL87		46118	53719	10336	8689	56454	62408
AUG87		47163	54699	12139	10130	59302	64829
SEP87		43865	51507	9219	7842	53084	59349
OCT87		46311	52987	12621	9795	58932	62782
NOV87		43550	50574	12377	10205	55927	60779
DEC87		43032	49247	11995	10418	55027	59665
JAN88		46366	50244	10427	10706	56793	60950
FEB88		46366	48185	10184	11922	56550	60107
MAR88		41430	48185	9304	11866	50734	60051
APR88		45168	49224	16300	18364	61468	67588
MAY88		43484	50812	17136	16020	60620	66832
JUN88		43724	50932	21352	19104	65076	70036
JUL88		44040	51086	21956	19408	65996	70494
AUG88		45868	53220	22224	20340	68092	73560
SEP88		41148	47956	23968	22932	65116	70888
OCT88		45200	51656	24284	23148	69484	74804
NOV88		42836	48216	24536	24604	67372	72820
DEC88		43328	48448	25760	24564	69088	73012
JAN89		43748	49212	26654	25851	70402	75063
FEB89		40056	44110	25738	26367	65794	70477
MAR89		30700	48780	32319	33715	63019	82495
APR89		40020	46648	33060	34288	73080	80936
Total		1032101	1187981	430439	415354	1462540	1603335

TABLE 2.2. HOURS AND OPERATIONS TFE731

<u>Date</u>		<u>United States</u>		<u>Foreign</u>		<u>Total</u>	
Month	Year	Hours	Operations	Hours	Operations	Hours	Operations
MAY87		127148	101718	45189	36151	172337	137870
JUN87		128132	102506	46060	36848	174192	139354
JUL87		130058	104046	46028	36822	176086	140869
AUG87		132051	105641	48274	38619	180325	144260
SEP87		131189	104951	46967	37574	178156	142525
OCT87		132677	106142	48595	38876	181272	145018
NOV87		134888	107910	49968	39974	184856	147885
DEC87		135142	108114	51393	41114	186535	149228
JAN88		131583	105266	50585	40468	182168	145734
FEB88		134338	107470	49942	39954	184280	147424
MAR88		140277	112222	52557	42046	192834	154267
APR88		141617	113294	53424	42739	195041	156033
MAY88		132631	106105	49215	39372	181846	145477
JUN88		131509	105207	49084	39267	180593	144474
JUL88		131517	105214	50924	40739	182441	145953
AUG88		131881	105505	51783	41426	183664	146931
SEP88		130933	104746	50872	40698	181805	145444
OCT88		134926	107941	52596	42077	187522	150018
NOV88		144838	115870	54334	43467	199172	159338
DEC88		138015	110412	51316	41053	189331	151465
JAN89		135526	108421	50296	40237	185822	148658
FEB89		142042	113634	51414	41131	193456	154765
MAR89		139941	111953	54156	43325	194097	155278
APR89		148383	118706	56031	44825	204414	163531
Total		3241242	2592994	1211003	968802	4452245	3561796

Note: Detail may not add to total because of rounding.

TABLE 2.3. HOURS AND OPERATIONS TPE331

<u>Date</u>		<u>United States</u>		<u>Foreign</u>		<u>Total</u>	
Month	Year	Hours	Operations	Hours	Operations	Hours	Operations
MAY87		206666	247999	81385	97662	288051	345661
JUN87		211357	253628	89138	106966	300495	360594
JUL87		234047	280856	93231	111877	327278	392734
AUG87		232892	279470	93280	111936	326172	391406
SEP87		232924	279509	95408	114490	328332	393998
OCT87		237444	284933	97521	117025	334965	401958
NOV87		237631	285157	101077	121292	338708	406450
DEC87		230677	276812	95275	114330	325952	391142
JAN88		237817	285380	97319	116783	335136	402163
FEB88		251480	301776	88360	106032	339840	407808
MAR88		250675	300810	93553	112264	344228	413074
APR88		261232	313478	100541	120649	361773	434128
MAY88		249151	298981	116604	139925	365755	438906
JUN88		253131	303757	116706	140047	369837	443804
JUL88		249269	299123	119622	143546	368891	442669
AUG88		250314	300377	120657	144788	370971	445165
SEP88		263965	316758	116854	140225	380819	456983
OCT88		252292	302750	118798	142558	371090	445308
NOV88		255233	306280	120698	144838	375931	451117
DEC88		255934	307121	122375	146850	378309	453971
JAN89		268975	322770	121914	146297	390889	469067
FEB89		259072	310886	122810	147372	381882	458258
MAR89		254644	305573	124848	149818	379492	455390
APR89		266753	320104	126383	151660	393136	471763
Total		5903575	7084288	2574357	3089229	8477932	10173518

Note: Detail may not add to total because of rounding.

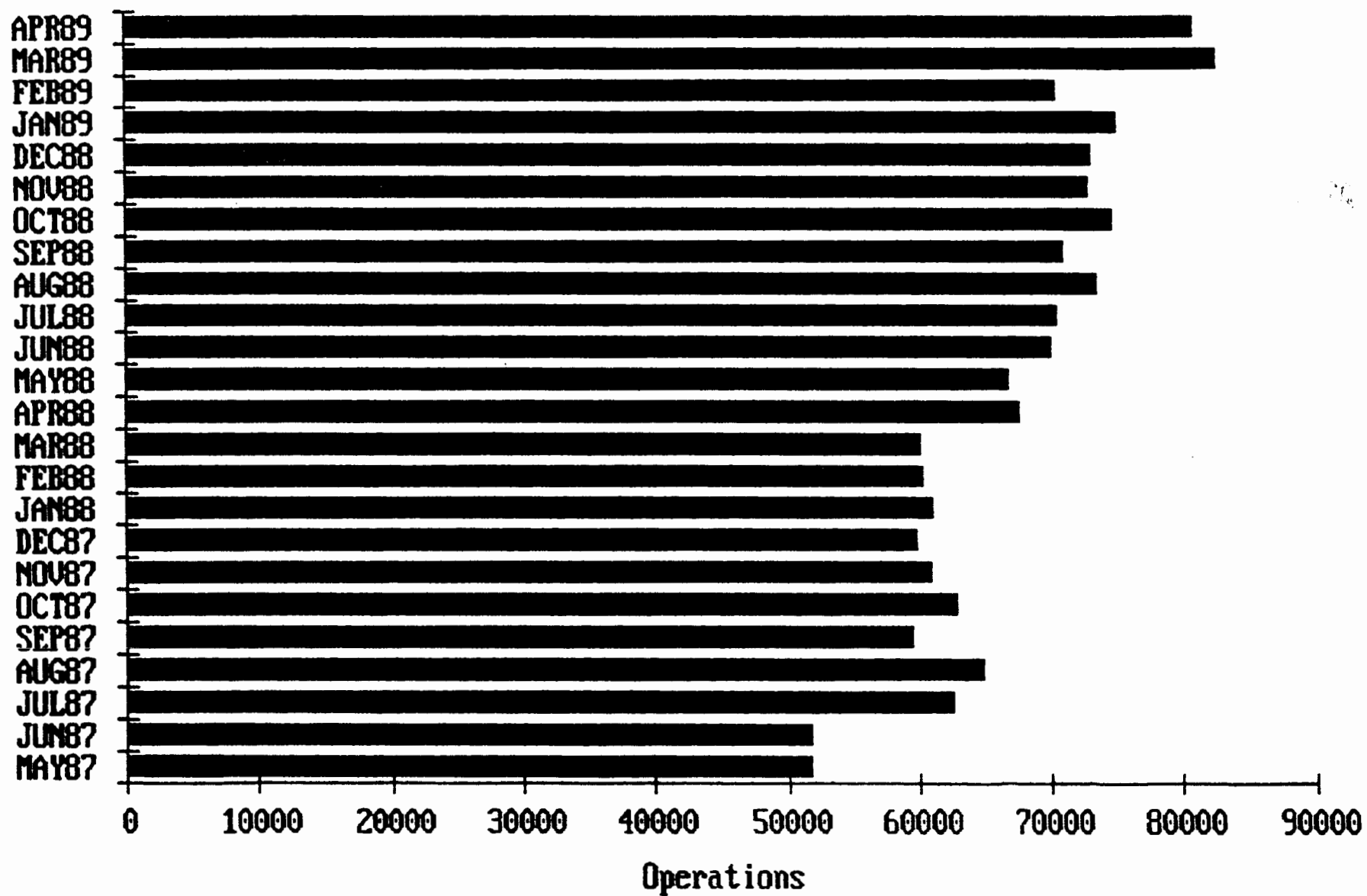


FIGURE 2.1. OPERATIONS, ALF502 ENGINE

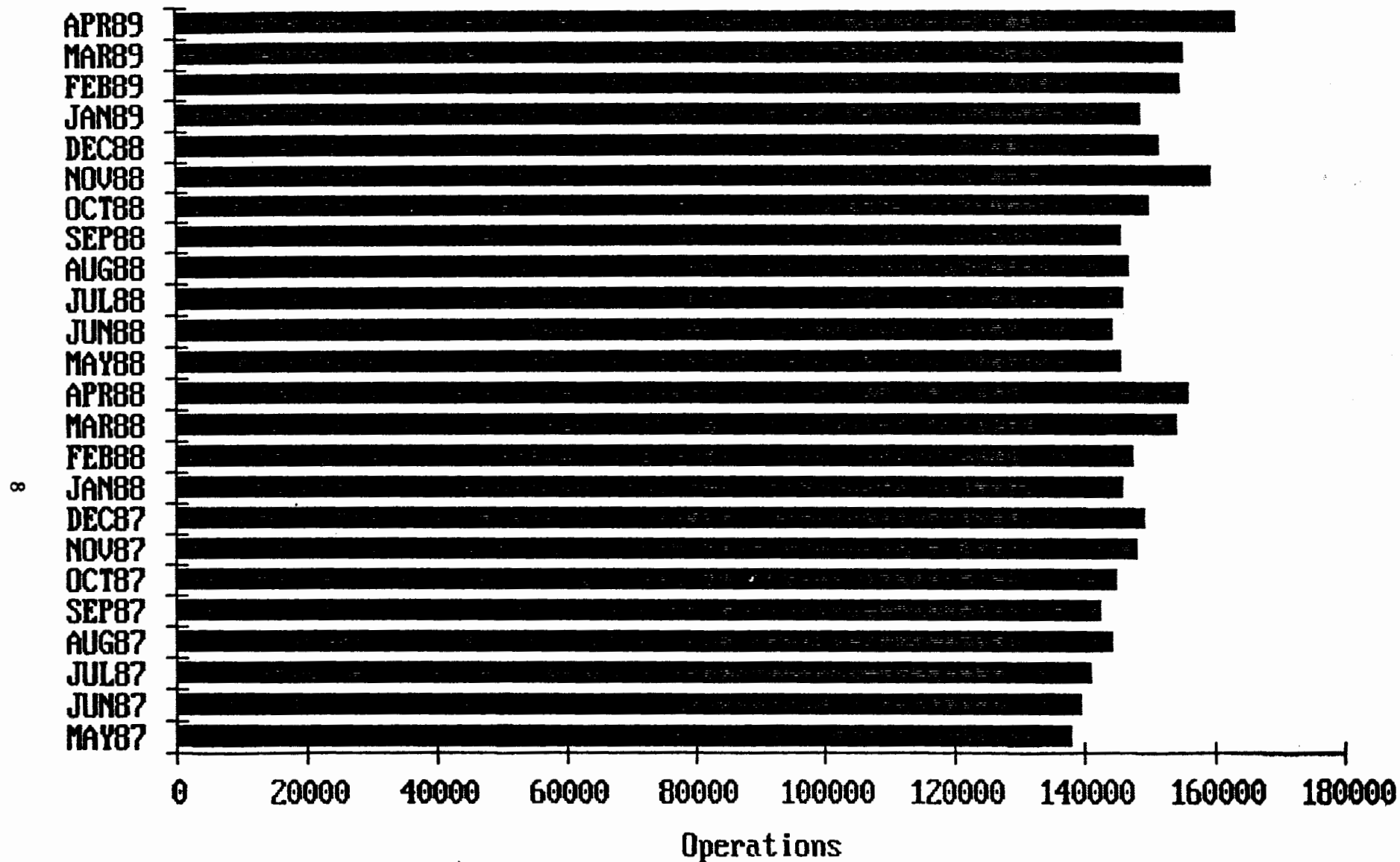


FIGURE 2.2. OPERATIONS, TFE731 ENGINE

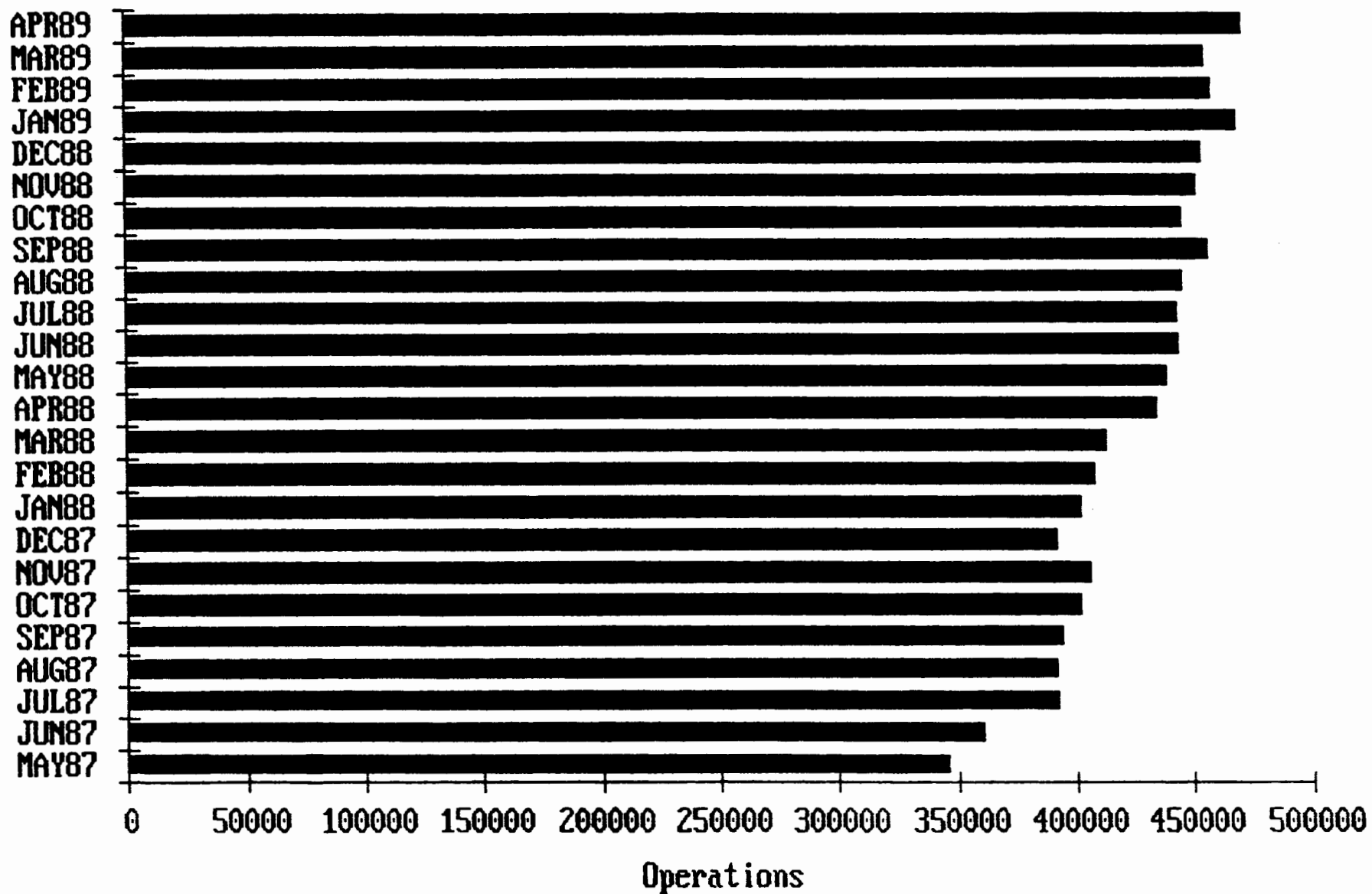


FIGURE 2.3. OPERATIONS, TPE331 ENGINE

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, seasonal trends, time-of-day trends, and geographic location.

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 engine bird ingestion data base is the low bird identification rate. Out of the total of 198 aircraft ingestion events that were recorded, the bird species was positively identified in only 70 events, for a total identification rate of 35.4 percent.

Table 3.2 presents the distribution of weights for the positively identified birds. The numbers in table 3.2 reflect the number of times birds of a given weight were encountered. That is, if more than one bird was ingested in one or more engines, the bird weight was counted once only. Thus the table is not skewed by multiple-bird or multiple-engine ingestions from the same flock of birds. 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 30 cases where multiple birds were ingested into the same engine, and 11 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 bird weights for United States and foreign ingestion events was carried out using the Kolmogorov-Smirnov test. The maximum deviation between the distributions was 0.176. 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 4 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

<u>Latin Name</u>	<u>Common Name</u>	<u>Species</u>	<u>US</u>	<u>Foreign</u>	<u>Unknown</u>	<u>Overall</u>
Gavia	Common loon	1E3	1	0	0	1
Nyctanassa violacea	Yellow-crowned night heron	1I27	1	0	0	1
Chen caerulescens	Snow Goose	2J26	2	0	0	2
Branta canadensis	Canada goose	2J30	2	0	0	2
Anas americana	American wigeon	2J71	1	0	0	1
Anas platyrhynchos	Mallard	2J84	0	1	0	1
Aythya affinis	Lesser scaup	2J125	1	0	0	1
Cathartes aura	Turkey vulture	1K1	1	0	0	1
Haliaeetus indus	Brahminy kite	3K31	0	1	0	1
Falco sparverius	American kestrel	5K26	1	1	0	2
Falco tinnunculus	Eurasian kestrel	5K27	0	1	0	1
Perdix perdix	Hungarian partridge	4L85	0	1	0	1
Phasianus colchicus	Ring-neck pheasant	4L161	1	0	0	1
Gallinula chloropus	Common gallinule	7M112	1	0	0	1
Vanellus vanellus	Common lapwing	5N1	0	5	0	5
Charadrius vociferus	Killdeer	5N33	6	0	0	6
Charadrius mongolus	Mongolian plover	5N45	0	1	0	1
Tringa melanoleuca	Greater yellowlegs	6N19	1	0	0	1
Tringa flavipes	Lesser yellowlegs	6N20	1	0	0	1
Scolopax minor	American woodcock	6N37	1	0	0	1
Larus delawarensis	Ring-billed gull	14N12	3	2	0	5
Larus Canus	Common gull	14N13	1	0	0	1
Larus argentatus	Herring gull	14N14	1	0	0	1
Larus pipixcan	Franklin's gull	14N31	1	0	0	1
Larus ridibundus	Common black-headed gull	14N36	0	1	0	1
Columba livia	Common rock dove	2P1	4	0	0	4
Columba palumbus	Common wood-pigeon	2P9	0	1	0	1
Streptopelia chinensis	Spotted dove	2P65	0	1	0	1
Zenaidura macroura	American mourning dove	2P105	9	0	0	9
Tyto alba	Common barn owl	1S2	1	0	0	1
Asio otus	Northern long-eared owl	2S120	0	1	0	1
Apus melba	Alpine swift	1U52	0	1	0	1
Apus apus	Common swift	1U55	0	1	0	1
Eremophila alpestris	Horned lark	17Z74	2	0	0	2
Hirundo rustica	Barn swallow	18Z37	1	0	0	1
Delichon urbica	Common house martin	18Z69	0	1	0	1
Sturnus vulgaris	Common starling	21Z75	1	0	1	2
Turdus philomelos	Common song thrush	41Z282	0	1	0	1
Agelaius phoeniceus	Red-winged blackbird	64Z54	1	0	0	1
Sturnella magna	Eastern meadowlark	64Z67	1	0	0	1
Passer domesticus	House sparrow	70Z12	1	0	0	1
Passer montanus	Eurasian tree sparrow	70Z23	0	1	0	1
			---	---	---	---
			48	22	1	71

TABLE 3.2. DISTRIBUTION OF BIRD WEIGHTS
(AIRCRAFT INGESTION EVENTS)

Weight (oz)	US	Foreign	Unknown	Total
0 < x ≤ 4	23	8	1	32
4 < x ≤ 8	2	7	0	9
8 < x ≤ 12	3	2	0	5
12 < x ≤ 16	6	4	0	10
16 < x ≤ 20	2	2	0	4
20 < x ≤ 24	1	0	0	1
24 < x ≤ 28	1	0	0	1
32 < x ≤ 36	0	1	0	1
36 < x ≤ 40	2	0	0	2
64 < x ≤ 68	1	0	0	1
88 < x ≤ 92	2	0	0	2
100 < x ≤ 104	1	0	0	1
124 < x ≤ 128	2	0	0	2
Totals	46	24	1	71

(Note: this table includes one bat, not included in table 3.1)

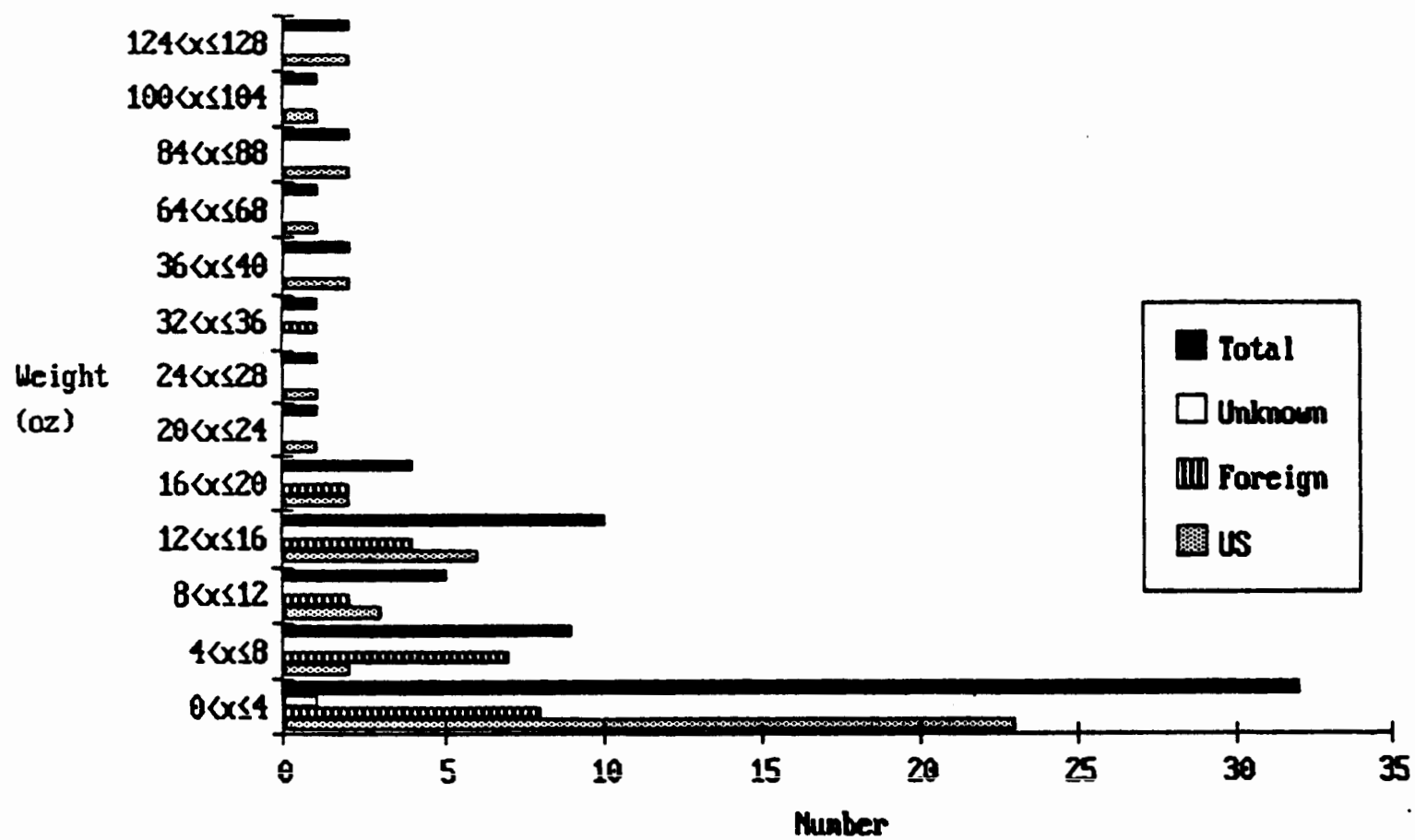


FIGURE 3.1. DISTRIBUTION OF BIRD WEIGHTS

TABLE 3.3. SUMMARY STATISTICS FOR INGESTED BIRD WEIGHTS

<u>Statistic</u>	<u>US</u>	<u>Foreign</u>	<u>Worldwide</u>
Mode	4	7.7	4
Median	4	7.7	7.7
Lower Quartile	3	2	3
Upper Quartile	17	14	16
Interquartile Range	14	12	13
Mean	21.01	9.21	16.77
Standard Deviation	33.20	8.19	27.65

Note: All weights in ounces.

The median is the value which divides the distribution in half. Median weights are 4 ounces in the United States, 7.7 ounces outside the United States, and 7.7 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 17 ounces, while outside the United States the top 25 percent of birds had weights equal to or exceeding 14 ounces. In the United States, 25 percent of the birds weighed 3 ounces or less, while outside the United States the lowest 25 percent of the weights included birds only up to 2 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 14 ounces, while outside the United States it is 12 ounces. Worldwide it is 13 ounces. This simply means that inside and outside the United States, the degree of clustering about the median is nearly the same, even though the medians differ by roughly a factor of two. However, outside the quartiles the spread of bird weights is greater in the United States. This can be seen 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 birds with weights up to 128 ounces.

The mean is obtained by weighting each value in the distribution by the number of times which 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 4 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 16 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. A chi-square value of 4.8 was obtained, comparing the actual numbers of identified birds with the hypothesis that the same fraction of birds were identified regardless of damage level. With 3 degrees of freedom, a value for chi-square of 6.25 would be exceeded with a probability of 10 percent. Hence the hypothesis that the same fraction of birds are identified regardless of the damage level cannot be rejected, and one can conclude that the ingestion events in which bird weight is known are representative of all ingestion events.

Figure 3.2 presents a histogram of ingestions by month for the 2-year period covered by the data. Each bar in figure 3.2 represents the sum of ingestions from its respective month in 2 consecutive years. It is known that the number of ingestions per month should be influenced by seasonality (bird migrations) and by

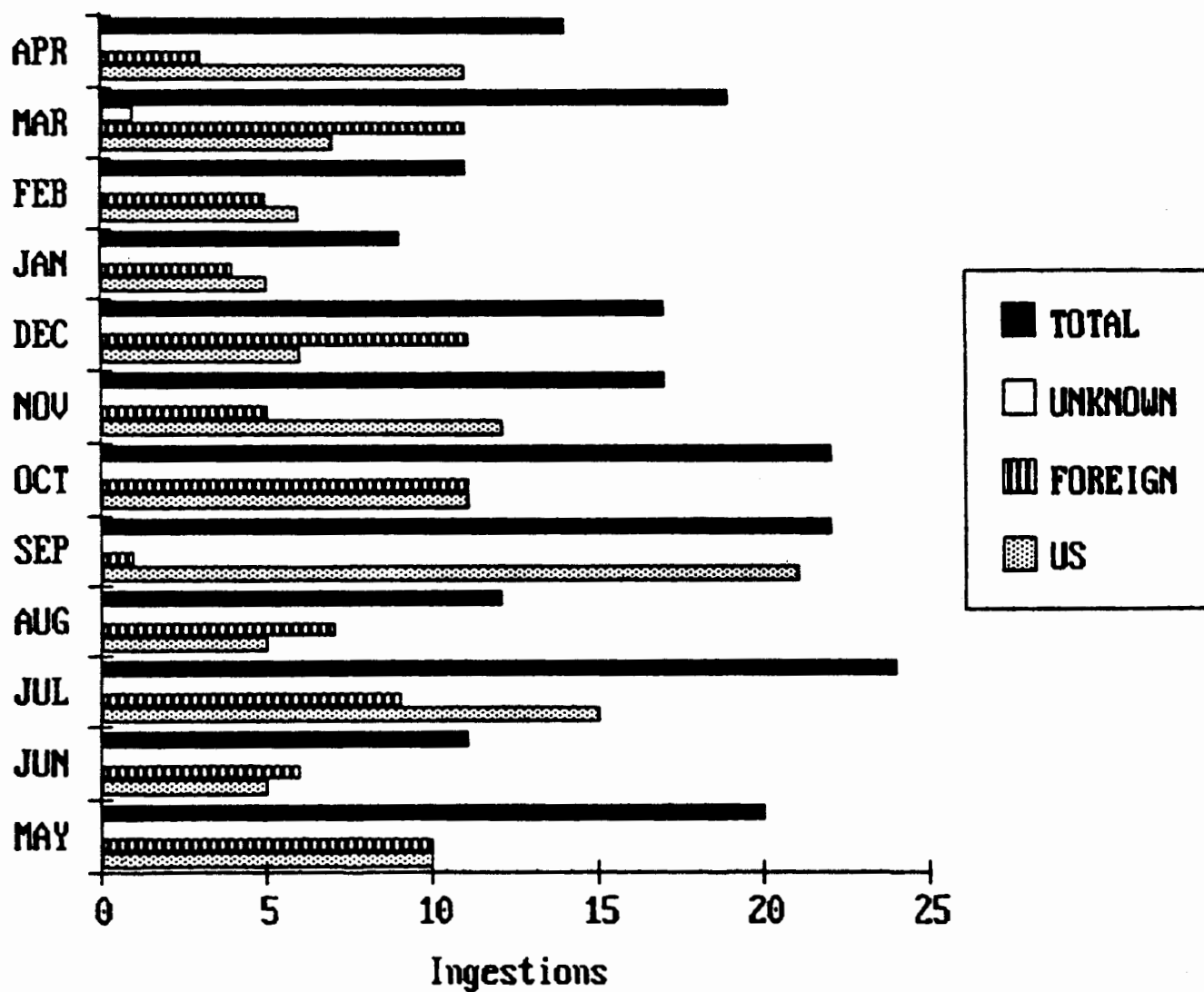


FIGURE 3.2. AIRCRAFT INGESTIONS BY MONTH FOR 2 YEARS

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 normalized to numbers 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-square test was used to test for differences between patterns of monthly ingestions inside and outside the United States (including both hemispheres). The test found a significant difference. However, there is some question of whether this finding should be taken seriously. Nearly half the total value of chi-square came from the months of September, in which the United States had a total of 21 ingestions while there was only one ingestion outside the United States.

A Kolmogorov-Smirnov test was likewise applied to United States versus foreign monthly ingestions. This test found that the difference between the two sets of ingestions was not significant at the 1 percent level. This reinforces the suggestion that the chi-square test result was the result of statistical anomaly, that is, accepting the hypothesis of a difference would be to commit a Type I error.

A chi-square test was applied to the Northern Hemisphere data alone, to detect United States versus foreign differences uncontaminated by differing seasonality in Northern and Southern Hemispheres. The difference between the two was not found to be significant.

Several tests were applied to detect seasonality if it existed.

A chi-square test was used to determine if there were significant departures from a uniform distribution across the months. This test found a significant difference. However, again a significant share of the total chi-square value was accounted for by the months of September alone. Hence this test must be viewed as possibly spurious.

A linear regression was also performed on the Northern Hemisphere ingestions on the months, in sequence, to detect any trends. The slope of the regression was -0.608 and the standard error of the slope was 0.459 . 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 23 percent of the average monthly ingestion rate. At best, this would be only weak evidence for periodicity (seasonality). Moreover, one of the troughs of the second-harmonic fit coincided with the month of the greatest number of ingestions, while one of the peaks of the second-harmonic fit coincided with the month in which ingestions were slightly below average. This result indicates that if seasonality is present in the Northern Hemisphere data, it is buried in the noise.

Figures 3.3, 3.4 and 3.5 present histograms of aircraft ingestion events by time of day for the period covered by the data. Figure 3.3 shows aircraft ingestion events by time of day. A chi-square analysis allows rejection of the hypothesis that number of ingestions is uniformly distributed throughout the day. The actual value of chi-square was 70.1, while a value of 9.4 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, many birds tend to be diurnal and are less likely to be exposed to ingestion at night. Second, 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. Both these factors probably influence the variation by time of day in the number of ingestions.

During all time periods, the number of ingestions in the United States was greater than the number of ingestions outside the United States. However, a chi-square 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. The actual value of chi-square was only 1.91. This value would be exceeded by chance 25 percent of the time. A chi-square value of 9.4 would be required for the difference to be statistically significant at 2.5 percent.

Figure 3.4 shows numbers of aircraft ingestion events in which more than one bird was ingested into the same engine. The total number of events is not sufficient to permit any statistical analysis. However, there were more ingestion events during the morning hours than in any other period of the day.

Figure 3.5 shows numbers of ingestion events in which birds were ingested in more than one engine. There were too few multiple engine ingestion events to permit any statistical analysis. The distribution appears uniform across the day, with the only difference between United States and foreign events being one foreign event of an ingestion during the night.

For some ingestions, time of day was not stated. These are shown as Unknown in figures 3.3, 3.4 and 3.5. Note that the total unknown count in figure 3.3 exceeds the sum of United States and foreign counts by one because the geographic location of one event is also unknown.

The geographic distribution of aircraft ingestion events within the United States is shown in figure 3.6. California had the largest number of aircraft ingestion events with 11. This may be due to a combination of a large coastal bird population and heavy air traffic. The state with the second largest number of aircraft ingestion events was Ohio with 5. However, there appears to be a concentration of events east of the Mississippi and south of the Great Lakes, extending to the Atlantic coast. This is probably the result of heavy air traffic in this region, with many cities, many airports, and frequent operations.

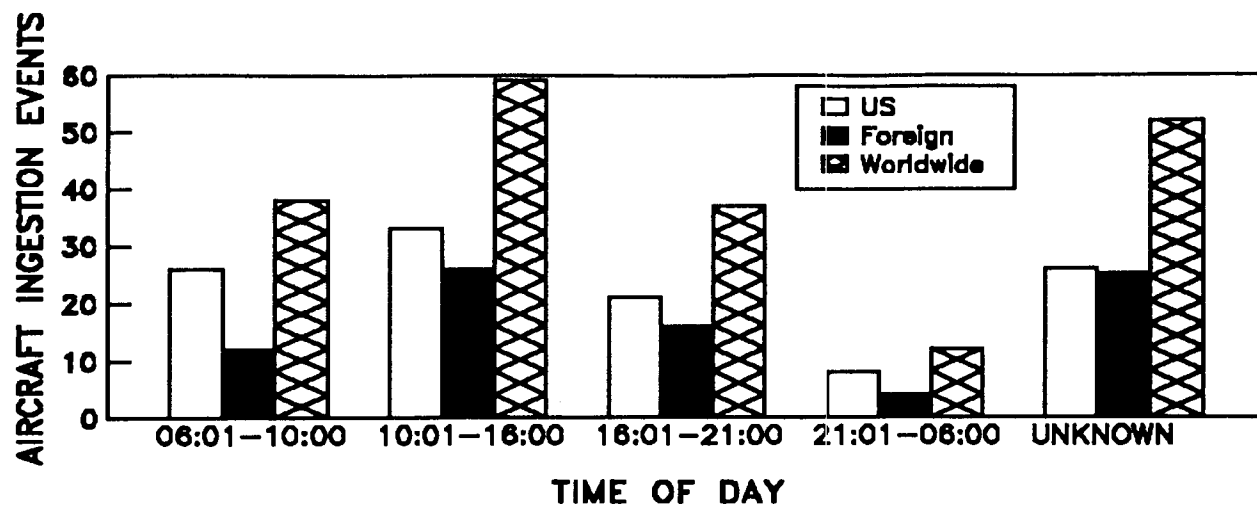


FIGURE 3.3. INGESTIONS BY TIME OF DAY

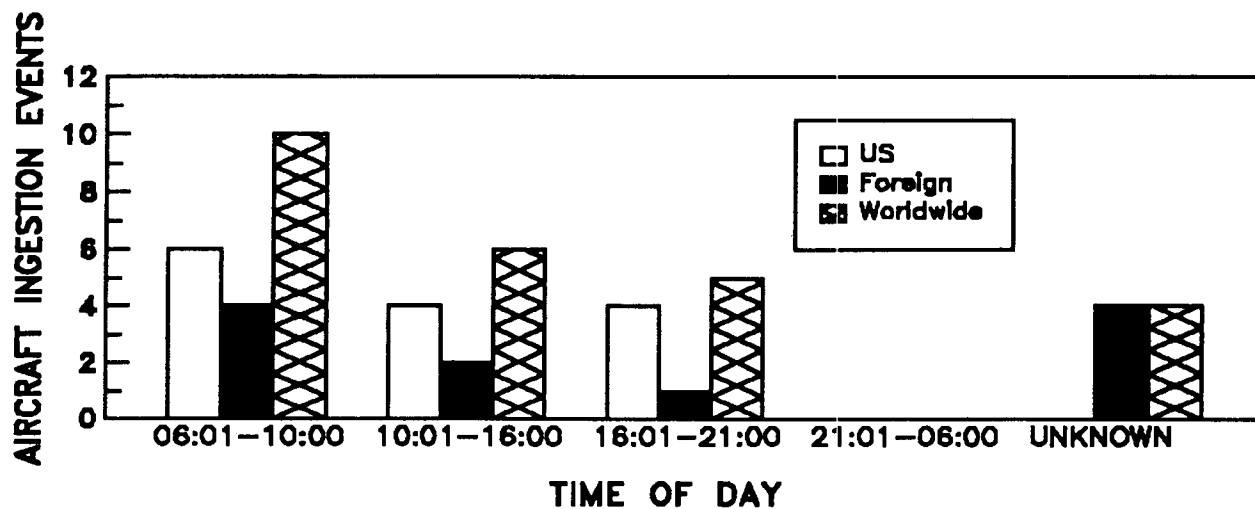


FIGURE 3.4. MULTIPLE BIRD INGESTIONS BY TIME OF DAY

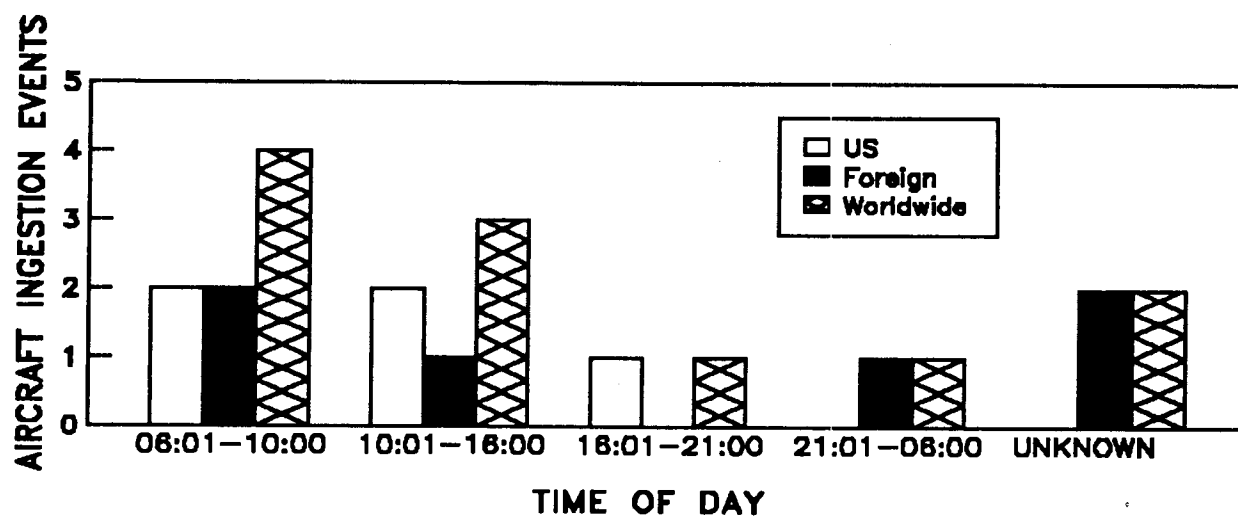


FIGURE 3.5. MULTIPLE ENGINE INGESTIONS BY TIME OF DAY

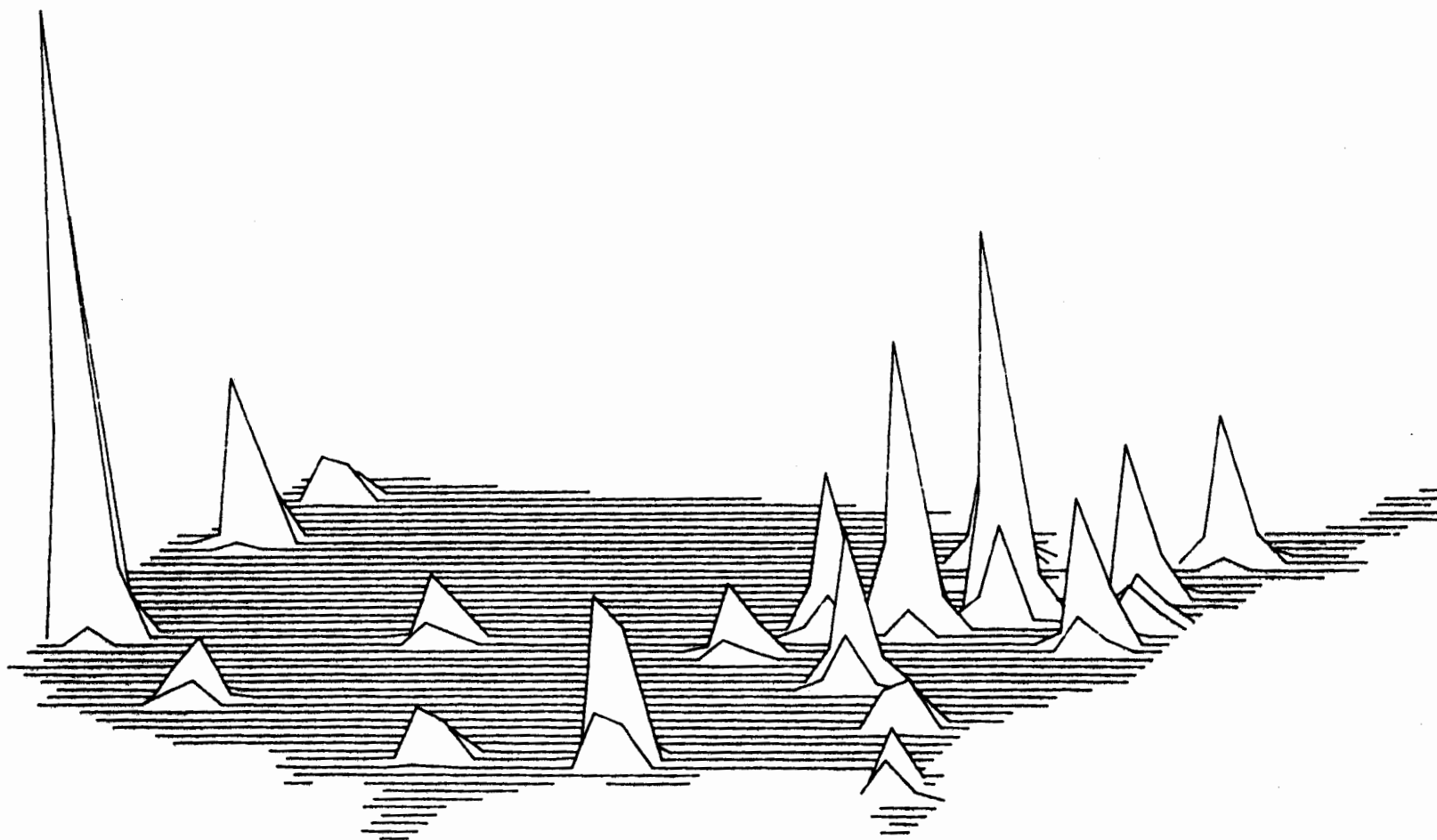


FIGURE 3.6. CONTOUR MAP OF DOMESTIC AIRCRAFT INGESTION EVENTS

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 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 size 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 four 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 Aerospace Industries Association (AIA) uses the inlet throat dimension in analyses involving engines. The analysis of engine dimension will therefore use 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 4.2 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. Note that those ingestion events not specifically identified with a phase of flight were allocated across phases in the same proportions as the identified ingestion events. For the individual engines, the same pattern holds generally, with the exception of the ALF502 which had seven more ingestion incidents during landing than during takeoff. Overall it appears that the takeoff phase poses the highest risk 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 ingestion events.

TABLE 4.1. ENGINE INGESTION RATES

	<u>ALF502</u>	<u>TFE731</u>	<u>TPE331</u>	<u>JT15D</u>	<u>Total</u>
<u>Engine Ingestion Events</u>					
US	34	37	42	6	119
Foreign	29	34	23	4	90
Worldwide	63	72 ¹	65	10	210
<u>Engine Hours</u>					
US	1032101	3241242	5903575		
Foreign	430439	1211003	2574357		
Worldwide	1462540	4452245	8477932	872510	15264327
<u>Engine Ingestion Events/10K Engine Hours</u>					
US	0.329	0.114	0.071		
Foreign	0.674	0.281	0.089		
Worldwide	0.431	0.162	0.077	0.115	0.138
<u>Engine Operations</u>					
US	1187981	2592274	7084288		10864543
Foreign	415354	968802	3089229		4473385
Worldwide	1603335	3561076	10173517	785259	16123187
<u>Engine Ingestion Events 10K Engine Operations</u>					
US	0.286	0.143	0.059		
Foreign	0.698	0.351	0.074		
Worldwide	0.393	0.202	0.064	0.127	0.130
<u>Inlet Area (in units of 10 square feet)</u>					
	0.683	0.3125	0.051	0.215	
<u>Engine Ingestion Events/10K ops/10 sq. ft. Inlet Area</u>					
US	0.419	0.457	1.162		
Foreign	1.022	1.123	1.460		
Worldwide	0.575	0.647	1.253	0.592	0.725
Worldwide (turbofans only)					0.610
<u>Inlet Diameter (ft.)</u>					
	2.949	1.995		1.655	
<u>Engine Ingestion Events/10K ops/ft. inlet diam. (turbofans only)</u>					
US	0.097	0.072			
Foreign	0.237	0.176			
Worldwide	0.133	0.101		0.077	0.110

Note: One operation incident not identified as to location; included here in total but not in specific location.

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

	Engine Ingestion Events	Events per 10K Operations	95% Upper Bound	Events per 10K Operations per 10 sq. ft. Inlet Area
ALF502				
Approach	9	0.056	0.098	0.082
Climb	0	0.000	0.019	0.000
Cruise	0	0.000	0.019	0.000
Landing	28	0.175	0.239	0.256
Takeoff	22	0.137	0.196	0.201
Taxi	4	0.025	0.057	0.037
TFE731				
Approach	12	0.034	0.055	0.108
Climb	4	0.011	0.026	0.036
Cruise	1	0.003	0.013	0.009
Landing	15	0.042	0.065	0.135
Takeoff	38	0.107	0.140	0.341
Taxi	1	0.003	0.013	0.009
JT15D				
Approach	2	0.025	0.080	0.118
Climb	1	0.013	0.060	0.059
Cruise	2	0.025	0.080	0.118
Landing	0	0.000	0.038	0.000
Takeoff	5	0.064	0.134	0.296
Taxi	0	0.000	0.038	0.000
TPE331				
Approach	22	0.022	0.031	0.424
Climb	4	0.004	0.009	0.077
Cruise	1	0.001	0.005	0.019
Landing	12	0.012	0.019	0.231
Takeoff	26	0.026	0.035	0.501
Taxi	0	0.000	0.003	0.000
ALL ENGINES				
Approach	45	0.028	0.036	
Climb	9	0.006	0.010	
Cruise	4	0.002	0.006	
Landing	55	0.034	0.043	
Takeoff	91	0.056	0.067	
Taxi	5	0.003	0.007	

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.

4.2 THE POISSON PROCESS.

The Poisson process is the simplest type of stochastic process that 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 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:

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

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:

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

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 [references 5,6] 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:

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

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:

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

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 [reference 7]. 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 0.065, 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.

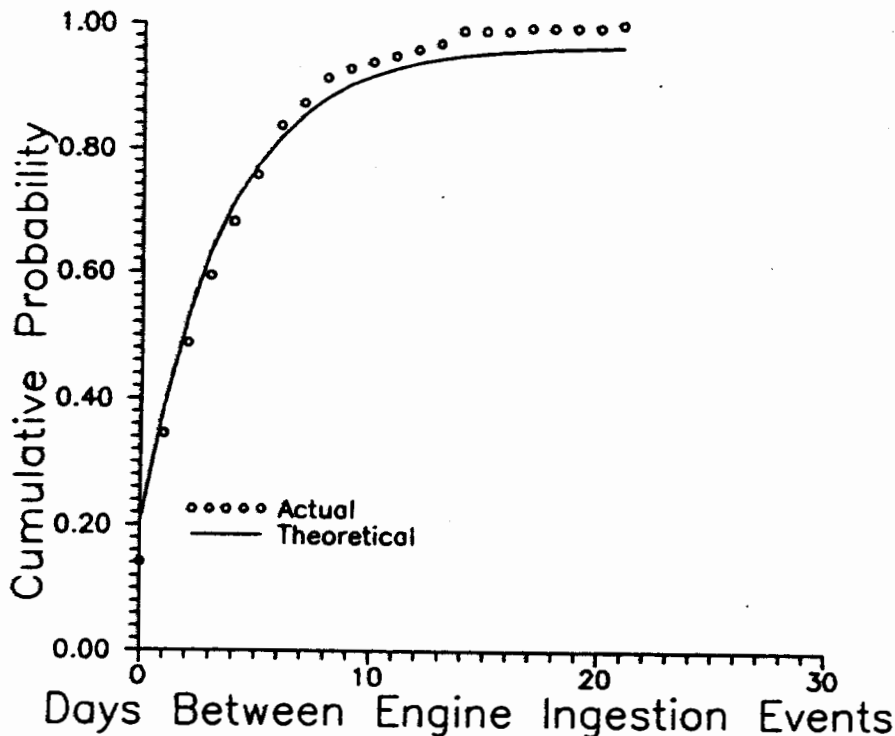


FIGURE 4.1. COMPARISON OF ACTUAL AND THEORETICAL CUMULATIVE DISTRIBUTIONS

4.4 INLET THROAT AREA EFFECT ON INGESTION RATES.

One property of the Poisson process model described in equation 4.3 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.

Because of the difficulty of comparing the inlet throat area for a turboprop engine with the area for a turbofan engine, only turbofan engines are included in this analysis.

The ingestion rate for all turbofan engines in this study is 0.610 engine ingestions/10K operations/10 square ft. inlet area. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-square test is applied to these expected ingestions, the value 0.47 is obtained. The critical value of chi-square for 2 degrees of freedom and probability 0.01 is 9.21. Hence the evidence is strong that the hypothesis of ingestion rate being proportional to engine inlet throat area cannot be rejected.

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 four 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.

Because of the difficulty of defining an engine diameter for turboprop engines, where the inlet is wrapped around the propeller spinner, only turbofan engines are included in this analysis. For the turbofan engines, diameter is computed from the published area and an assumed circular cross section.

The ingestion rate for all turbofan engines in this study is 0.110 per ten thousand operations per foot of engine inlet throat diameter. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-square test is applied to these expected ingestions, the value 4.10 is obtained. By chance, the value 9.21 would be exceeded 1 percent of the time. Thus, strictly speaking, we cannot reject the hypothesis of ingestion rate being proportional to engine inlet throat diameter. However, the evidence for this hypothesis is much weaker than the evidence for ingestions being proportional to engine inlet throat area.

SECTION 5

ENGINE DAMAGE DESCRIPTION

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 and the relationships between engine damage and bird weight, engine damage and phase of flight, engine damage and aircraft airspeed, engine damage and multiple engine and multiple bird involvement. 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. The fourth part describes the engine failures that were due to bird ingestions.

5.1 ENGINE DAMAGE DESCRIPTION.

The types of damage that were identified in the data base were grouped into 14 categories which are defined in table 5.1. During the 2-year data collection period, nine of the damage categories occurred. Tabulations of the occurrences of combinations of damage categories for turbofan engines 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 they were not specifically identified as involving more than two types of damage. The first row of the bottom two rows of table 5.2 indicates the number of times each damage category was the only damage sustained from a bird ingestion. The second presents the number of times each damage category occurred either as the sole damage or in combination with any other damage category

TABLE 5.1. DEFINITION OF ENGINE DAMAGE CATEGORIES

<u>DAMAGE CATEGORY</u>	<u>SEVERITY LEVEL</u>	<u>DAMAGE DEFINITION</u>
TRVSFRAC	Severe	Transverse fracture - fan blade broken chordwise (across) and piece liberated (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 (blade retention mechanism broken).
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. TURBOFAN ENGINE DAMAGE CAUSED BY BIRD INGESTIONS

	LEAD_EDG								
BEN/DEN	2								
		BEN/DEN							
BE/DE>3	1	0							
			BE/DE>3						
TORN<3	1	1	0						
				TORN<3					
BROKEN	0	0	3	0					
					BROKEN				
SHINGLED	0	3	2	0	0				
						SHINGLED			
TRVSFRAC	0	0	0	0	1	0			
							TRVSFRAC		
CORE	2	3	8	1	2	1	1		
								CORE	
NACELLE	0	0	1	0	0	1	0	1	

	LEAD_EDG	BEN/DEN	BE/DE>3	TORN<3	BROKEN	SHINGLED	TRVSFRAC	CORE	NACELLE
ONLY DAMAGE	1	10	16	1	3	0	0	7	2
TOTAL	6	18	27	3	7	5	1	21	4

The amount of data available is not sufficient to make any 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" and "broken," 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). "Broken" appeared by itself in only three of seven cases, or slightly less than half; shingled never occurred by itself, but always in conjunction with other kinds of damage.

The TPE331 turboprop engines did not experience any multiple damage category events. Since turboprop engines have no fan stage and no bypass airflow, a bird that is ingested goes directly into the engine core: For this reason the damage that occurred was almost always core damage. Damage to the engine core occurred in 30 events and to the engine nacelle in 1 event. No further specific damage categories were indicated for the TPE331 turboprop engine. A further description of the damage that occurred may be available in the remarks column of the bird ingestion data base (see appendix B) on an individual event basis. It should be noted that in many of the turboprop engine ingestions a blockage of airflow (i.e., primary fuel nozzle/combustor dome flow area, secondary combustion liner diffusion zones) occurred due to the bird debris and there was minor or no physical engine damage.

Tables 5.3 and 5.4 attempt to establish a relationship between the weight of the ingested bird and the resulting engine damage. Table 5.3 shows the number of engine ingestion events with and without reported damage in each specified bird weight range. The damage summaries in table 5.4 for turbofan engines and table 5.5 for turboprop engines were made by tallying the damage codes from the events shown in table 5.3 in each specified bird weight range.

Since many of the engine ingestion events have multiple damage categories, the total number of damage categories does not equal the number of engine ingestion events. Tables 5.4 and 5.5 also show the damage sustained by those engines that were considered to have failed due to the bird ingestion. See Section 5.4 for more information on engine failure.

The amount of data available is insufficient to draw any correlations between the weight of the ingested bird and the type of damage that occurs. However, tables 5.4 and 5.5 show that the majority of the ingestions (31) in which the bird weighed less than or equal to 8 ounces caused no damage. In comparison, all of the birds ingested that weighed more than 24 ounces caused some engine damage.

The relationship between engine damage, phase of flight, and aircraft airspeed is shown in tables 5.6 and 5.7. Table 5.6 depicts the relationship between engine damage and phase of flight. Of the 156 known phase-of-flight engine ingestion events, 48 percent occurred on takeoff and climb and 5 percent of the engine ingestion events that took place during takeoff and climb resulted in engine damage; in comparison, only 47 percent resulted in damage during approach and landing. This appears to establish a relationship between engine speed (thrust) and bird ingestion engine damage since engine speed would typically be higher during takeoff and climb than during approach and landing. It should be noted that the number of engine failures that occurred during takeoff and climb were only one greater than the engine failures that occurred during approach and landing.

TABLE 5.3. TALLY OF POSITIVELY IDENTIFIED BIRD SPECIES BY WEIGHT RANGE AND ENGINE TYPE

<u>Weight Range (oz.)</u>	<u>Bird Indentifications*</u>	
	<u>Turbofan</u>	<u>Turboprop</u>
$0 < x \leq 8$	41	7
$8 < x \leq 16$	13	2
$16 < x \leq 24$	4	1
$24 < x \leq 32$	0	1
$32 < x \leq 40$	1	2
$x > 40$	6	0
Totals	65	13

*One counted for each engine ingestion event

TABLE 5.4. BIRD INGESTION TURBOFAN DAMAGE SUMMARY

<u>Severity</u>	<u>Damage Category</u>	<u>Bird Weight Range (oz.)</u>					
		(0 < x ≤ 8)	(8 < x ≤ 16)	(16 < x ≤ 24)	(24 < x ≤ 32)	(32 < x ≤ 40)	(x > 40)
	None	27	5	1	0	0	0
	Damage Unknown	1	1	0	0	0	0
	Other	3/1*	4	0	0	0	0
Mild							
	Lead-Edg	0	2	0	0	1	1/1*
	Shingled	1	0	1	0	0	1
	Ben/Den	6/1*	3	0	0	0	1/1*
	Torn 3	1	0	0	0	1	1/1*
	Nacelle	1	1	1	0	0	1
Moderate							
	Be/De > 3	3	2	3	0	0	3/2*
	Torn > 3	0	0	0	0	0	0
	Broken	0	0	0	0	0	2/2*
	Spinner	0	0	0	0	0	0
	Released	0	0	0	0	0	0
Severe							
	Trvs Frac	0	0	0	0	0	1/1*
	Core	3	3	0	0	0	6/4*
	Flange	0	0	0	0	0	0
	Turbine	0	0	0	0	0	0

*Number of occurrences/number of occurrences when engine failed

TABLE 5.5. BIRD INGESTION TURBOPROP DAMAGE SUMMARY

Damage Category	<u>Bird Weight Range (oz.)</u>					
	$(0 < x \leq 8)$	$(8 < x \leq 16)$	$(16 < x \leq 24)$	$(24 < x \leq 32)$	$(32 < x \leq 40)$	$(x > 40)$
None	4	1	1	0	0	0
Damage Unknown	1	0	0	0	1	0
Other	0	0	0	0	1	0
Lead-Edg	0	0	0	0	0	0
Shingled	0	0	0	0	0	0
Ben/Den	0	0	0	0	0	0
Torn < 3	0	0	0	0	0	0
Nacelle	0	0	0	0	0	0
Be/De > 3	0	0	0	0	0	0
Torn > 3	0	0	0	0	0	0
Broken	0	0	0	0	0	0
Spinner	0	0	0	0	0	0
Released	0	0	0	0	0	0
Trvs Frac	0	0	0	0	0	0
Core	2/1*	1	0	1	1	0
Flange	0	0	0	0	0	0
Turbine	0	0	0	0	0	0

*Number of occurrences/number of occurrences when engine failed

TABLE 5.6. PHASE-OF-FLIGHT (POF) ANALYSIS

	Known POF Aircraft Events/ Engine Ingestions (144/156)	Known POF Damaging Aircraft Events/ Engine Ingestions (87/92)	Known POF Engine Failure Ingestions (9)
Takeoff and Climb	68/75	52/56	5
Approaching and Landing	65/70	32/33	4

TABLE 5.7. AIRCRAFT AIRSPEED ANALYSIS

Aircraft Airspeed	Known Speed Engine Ingestions (123)	Known Speed Damaging Engine Ingestions (73)	Known Speed Damaging Engine Ingestions, Takeoff and Climb (42)	Known Speed Damaging Engine Ingestions, Landing and Approach (27)
< 140 Knots	87	50	30	18
≥ 140 Knots	36	23	12	9

Table 5.7 shows the number of engine ingestion events and the number of damaging engine ingestions known to have occurred below 140 knots airspeed and at or above 140 knots. The table also shows the phase of flight that these damaging engine ingestions occurred in those airspeed ranges. There were seven percent more engine ingestions that resulted in engine damage at or above 140 knots airspeed than those that occurred below 140 knots. It is also shown that a greater number of damaging ingestions occurred during takeoff and climb than during approach and landing at both aircraft airspeed ranges.

Multiple engine and multiple bird ingestion events present the greatest safety hazard to aircraft. Table 5.8 shows the number of these events that occurred. Eleven aircraft had bird ingestions into more than one engine during the same event, and four events resulted in damage to more than one engine. There were also four events where multiple birds were ingested into more than one engine, potentially the most hazardous condition an aircraft can encounter.

Table 5.8 also gives the number of engine ingestion events where more than one bird was ingested into the engine. Of the 30 multiple bird engine ingestions that occurred, 77 percent of the ingestions resulted in some engine damage. In comparison, only 46 percent of the engines that ingested a single bird resulted in some engine damage. Ten percent of the multiple bird ingestions resulted in engine failures compared to only four percent of the single bird ingestions.

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 heavier 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. Figure 5.1 illustrates the variation in damage for turbofan engines. For the lowest weight range, there was one case of severe damage and two cases of mild or unspecified damage. All other ingestions resulted in no reported damage. With increasing bird weight, the proportion of ingestion events resulting in severe damage increased, as did the proportion of ingestion events resulting in mild or moderate damage. In the heaviest weight range, there were only four ingestion events (out of 21 total for this weight range) which resulted in no damage.

For the turboprop engine, the situation is somewhat different because of damage definitions that are different from those used for turbofans. Regardless of bird weight, there were no instances of damage being classified as more severe than mild. In 11 ingestion events, including 5 in the highest weight range, damage was limited to mild. There was one ingestion event in the highest weight range which resulted in no damage.

TABLE 5.8. MULTIPLE ENGINE AND MULTIPLE BIRD ANALYSIS

	<u>Aircraft Events/ Engine Ingestions</u>	<u>Damaging Engine Ingestions</u>	<u>Engine Failure Ingestions</u>
Multiple Engine	11/23	12/4*	0
Multiple Bird	26/30	23	3
Single Bird	175/180	83	7

*Aircraft events where more than one engine damaged

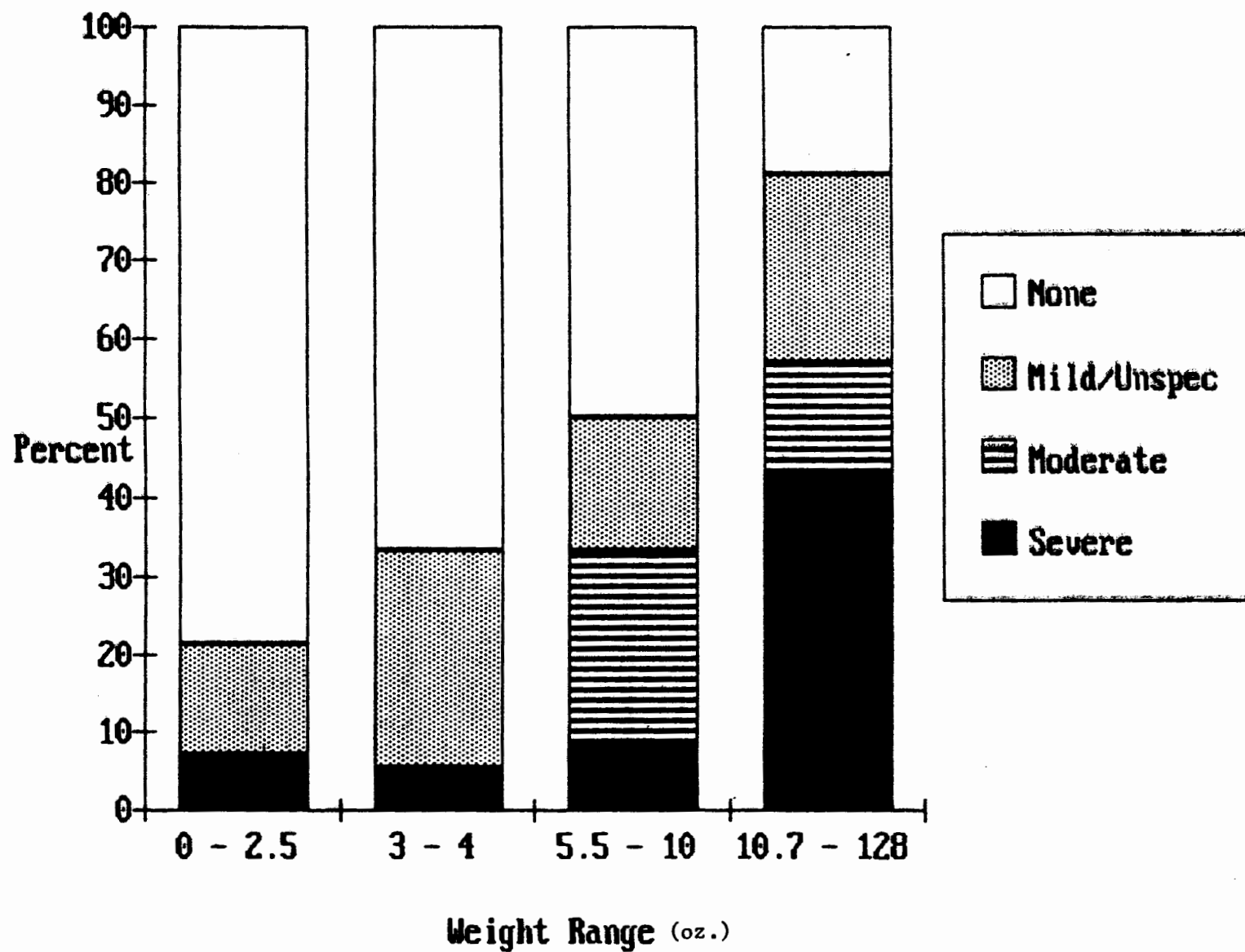


FIGURE 5.1. SERVERITY OF DAMAGE FOR TURBOFAN ENGINES
VERSUS BIRD WEIGHT RANGE

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 use 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, it 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:

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

In this parameterization, w is the bird weight, μ represents the mean logarithm of 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 logarithm of 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 the literature (see references 8 and 9). 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 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 at first, then flattens out. There is a significant probability of damage at 20 ounces, and almost 90 percent probability of damage at 100 ounces.

Figure 5.3 shows the probability of at least moderate damage. The probability of moderate damage does not rise quite as steeply as the probability of any damage. The probability of damage reaches almost 90 percent at weights of 100 ounces.

Figure 5.4 shows the probability of severe damage. The probability of severe damage reaches about 65 percent at a weight of 100 ounces. The rise is much less steep than the two preceding curves, being almost linear.

The sample size appears to be large enough that the estimates of damage probability are reliable. Moreover, 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.

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 was shut down (IFSD) as a result of the ingestion. Table 5.9 presents the conditional probabilities that a crew action is required given the severity of the damage that the engine incurs [P(CA D)]. The probability that a crew action is required increases with the severity of engine damage as would be expected. The third column of table 5.9 contains the upper 95 percent confidence bound on the conditional probabilities presented in the second column.

A crew-initiated in-flight engine shutdown occurred in seven of the 210 engine ingestion events. There was one involuntary in-flight shutdown of a turbofan engine, and three involuntary in-flight shutdowns of a turboprop engine. This corresponds to an estimated conditional probability of an involuntary in-flight shutdown of 0.019 with a 95 percent confidence bound of 4.359×10^{-2} . Given the small sample size, and only 16 total instances of in-flight shutdown, no inferences can be drawn about the causes of in-flight shutdowns.

5.4 ENGINE FAILURE.

Engine failures are important areas to consider when analyzing these engine bird ingestion events. For the purpose of this study an engine failure was considered to have occurred when an engine was not able to produce and maintain usable thrust of at least 50 percent. A transverse fan blade fracture and an involuntary engine in-flight shutdown were considered to be engine failures in all cases. Otherwise, an engineering judgment was made based on the extent of engine damage, effect on flight, phase of flight, and any other factors that may have been provided in the description of the event or investigation summary.

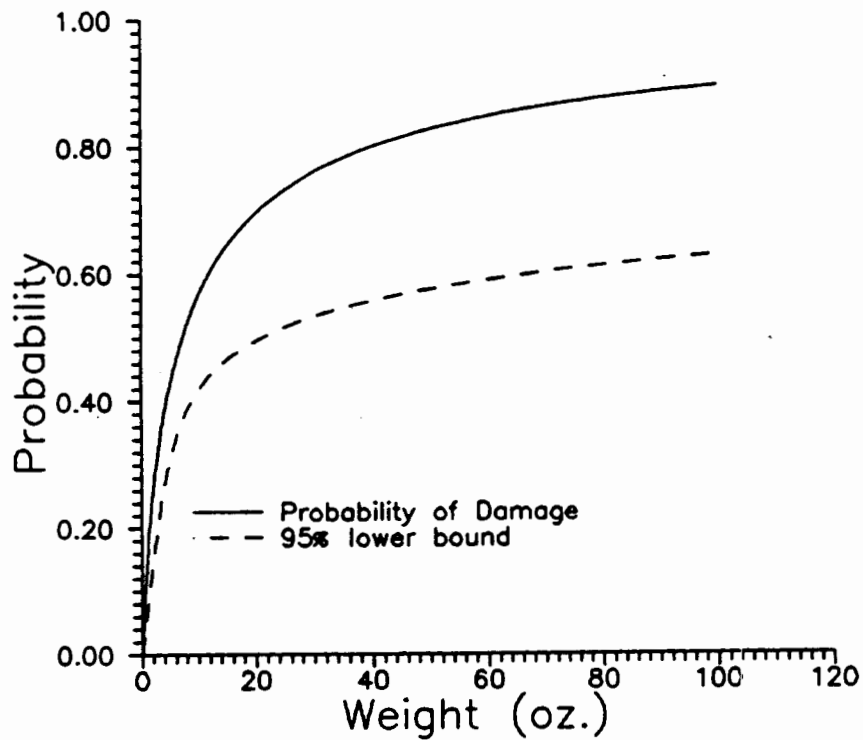


FIGURE 5.2 PROBABILITY OF ANY DAMAGE VERSUS BIRD WEIGHT

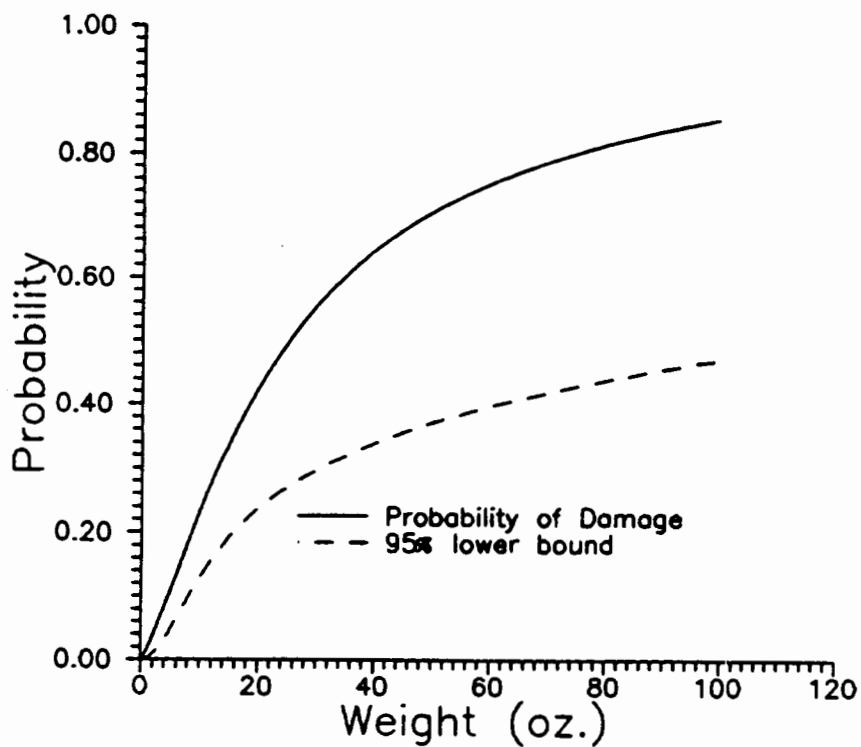


FIGURE 5.3 PROBABILITY OF AT LEAST MODERATE DAMAGE VERSUS BIRD WEIGHT

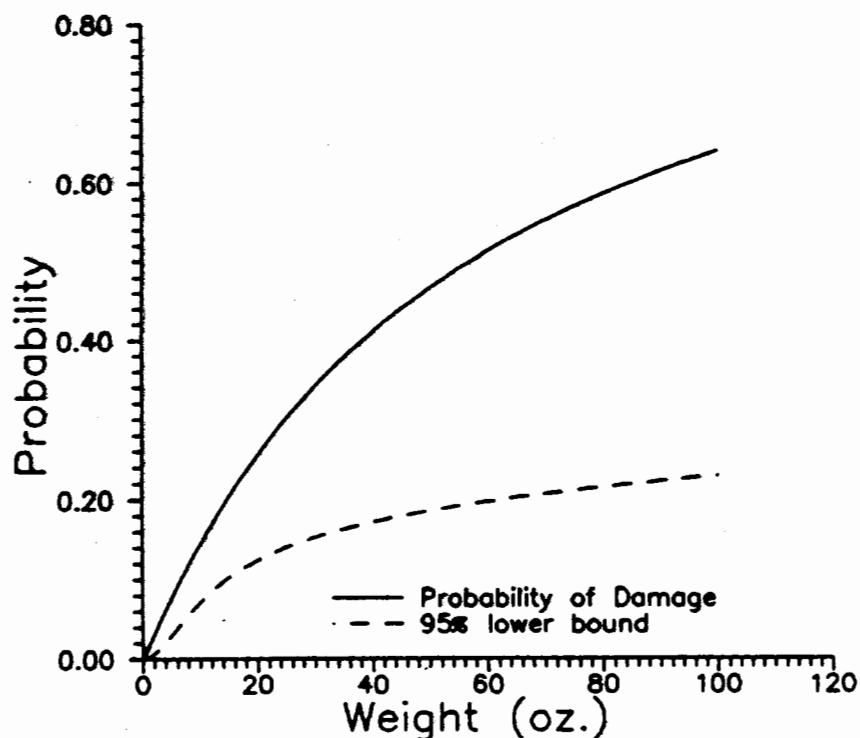


FIGURE 5.4. PROBABILITY OF SEVERE DAMAGE VERSUS BIRD WEIGHT

There were ten ingestion events which resulted in engine failure, ranging from partial power loss, through voluntary shutdown, to involuntary shutdown. The number of cases is too small for any patterns to be apparent. However, some summary is possible. Table 5.10 provides a summary of some of the important data categories for the engine ingestion events that resulted in an engine failure. Overall, five percent of the engine ingestion events resulted in an engine failure. The turbofan engine failure rate was 0.01 failures per ten thousand aircraft operations, and the turboprop engine failure rate was 0.004 failures per ten thousand aircraft operations.

Table 5.10 shows that a voluntary or involuntary in-flight shutdown of the engine occurred in eight of the ten engine failures. There was also a power loss associated with all of the engine failures where there was information reported in the power loss category. The only relationship that appears between the damage codes of these engine failures is that in all but one event there was core damage.

Reviewing the bird threat data for these engine failures shows that seven of the engine failures were caused by the ingestion of a single bird and three were caused by the ingestion of two birds. This is a much higher percentage than the fraction of all ingestion events which involved multiple birds, suggesting that engine failure is more likely in cases of multiple bird ingestion. Also, in four of the six engine failures where the bird weight was known the bird or birds weighed more than four pounds. However, the other two were caused by single birds that weighed less than 8 ounces. Comparing this with the number of engine ingestions where the bird was positively identified (table 5.3) shows that 83

TABLE 5.9. CONDITIONAL PROBABILITY OF CREW ACTION AND IN-FLIGHT SHUTDOWN
GIVEN THE ENGINE DAMAGE SEVERITY

Severity of Engine Damage	Engine Ingestion Events	Instances of Crew Action*	$P(CA D)$	Upper 95% Confidence Bound	Inflight Shutdowns	$P(IFSD D)$	Involuntary Inflight Shutdowns	$P(IIFSD D)$
Turbofans:								
None	76	5	0.066	0.138	0	0.000	0	0.000
Any	69	28	0.406	0.556	5	0.072	1	0.014
Mod/Severe	41	21	0.512	0.738	4	0.098	1	0.024
Severe	19	8	0.421	0.760	3	0.158	1	0.053
Turboprop:								
None	25	4	0.160	0.366	2	0.080	0	0.000
Any	40	15	0.375	0.577	9	0.225	3	0.075
Mod/Severe	2	0	0.000	1.000	1	0.500	0	0.000
Severe	2	0	0.000	1.000	0	0.000	0	0.000

* Crew action includes Aborted Takeoff, Air Turnback, Diversion

IFSD - In flight shutdown

TABLE 5.10. ENGINE FAILURE SUMMARY BY BIRD WEIGHT

<u>Bird (oz.) Weight</u>	<u>Number of Birds</u>	<u>Damage Code</u>	<u>Phase of Flight</u>	<u>Power Loss</u>	<u>In-Flight Shutdown</u>	<u>Crew Action</u>
128	2	A,G,I,K	Takeoff	Flame Out	Yes	ATO
102	1	A,D,G,K	Takeoff	Momentary	No	ATB
88	2	A,B,D,K	Landing	Yes	No	None
64.5	1	A,C,E,K	Takeoff	Compressor	Involuntary	ATB
7.7	1	A,K	Approach	Spool Down	Involuntary	None
1.5	1	A,C,P	Takeoff	-----	Vibes	DIV
---	1	A,D,K,P	Unknown	-----	Yes	---
---	1	A,K	Approach	Flame Out	Involuntary	---
---	1	A,K	Approach	Spool Down	Involuntary	None
---	2	A,K	Takeoff	50%	Voluntary	ATB

Note: A description of the columns and column contents can be found in appendix B.

percent of engine ingestion events, where the bird ingested weighed more than 4 pounds, resulted in engine failures, whereas only four percent of the events, where the bird ingested weighed less than 1/2 pound, resulted in engine failures.

In the six engine failure events in which weight of the ingested birds were known, the average weight was 65.3 ounces, which is much higher than either the median or the mode for ingested bird weights. That is, in cases of engine failure, the ingested bird typically was heavier than the average for all bird ingestion events. Note that the figure given above is for average weight of each ingested bird, not average ingested weight, since some of the engine failure events involved multiple ingestions. This finding is not unexpected, since a heavier bird would be expected to result in greater damage.

The failures were split almost evenly between takeoff (five engine failure events) and approach/landing (four engine failure events). (One event was not identified as to phase of flight.) For the nine engine failure events in which weather conditions are known, the sky was clear (seven cases) or had scattered clouds (two cases). This implies that weather was not a factor in engine failure.

For the nine engine failure events in which lighting conditions were known, two occurred in the dark, one at dawn, and five in light conditions. This implies that illumination was not a factor in engine failures.

The findings on weather and lighting conditions, taken together, imply that lack of visibility was not a factor in the engine failures. This is probably to be expected, since aircraft are not permitted either to land or take off in low visibility conditions, and only one of the engine failures occurred at an altitude above 1000 feet. Thus, the fact that the aircraft were flying at all would imply that visibility was acceptable at low altitude.

A final finding regarding engine failures is that in the seven of nine engine failure events in which engine location is known, the failed engine was located on the right side of the aircraft. This presents a strong contrast with the distribution of engine ingestion events where engine location is known: 98 on the right, 101 on the left, and 3 in the center. That is, for all engine ingestion events, the location is consistent with the hypothesis that engines on the left and on the right are equally likely to ingest birds. The distribution of locations for engine failures has a probability of only 0.10, and is not consistent with that hypothesis. One possible explanation is that pilots, who sit on the left, are able to see and avoid those large birds which seem to be responsible for engine failure. However, given the small number of engine failure events, this possibility is little better than pure speculation. While no convincing explanation can be offered for the discrepancy, it may be significant.

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 all flight phases, multiple bird ingestions, and ingestions where the damage was moderate or severe. Note that one ingestion event was not identified as to location. Therefore the United States and foreign events do not add to the total for all phases.

The overall likelihood of a bird ingestion event in a single operation is about 1.3 in 100,000 thousand. Although this probability is very low, there are sufficient operations per year (over 1.6 million during the period covered by the data) that the expected number of ingestions is roughly 200. Most ingestions occur during takeoff or landing phases, so the probabilities for those phases are larger than for other phases of flight. Multiple bird ingestion events are comparatively rare, and this is reflected in the lower probabilities for these events.

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 randomness of bird identification. 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 an 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 6.4 shows the probability of ingestion by phase of flight for each engine type by region. 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. Note that one ingestion for the TFE731 was not identified as to location. It is included in the world total for all flight phases but not in either United States or foreign ingestions.

TABLE 6.1. ENGINE INGESTION PROBABILITIES

<u>CONDITION</u>	<u>ENGINE INGESTION EVENTS</u>	<u>PROBABILITY OF INGESTION</u>	<u>UPPER 95% CONFIDENCE BOUND</u>
All Phases			
World	210	1.302E-05	1.460E-05
US	113	1.040E-05	1.216E-05
Foreign	86	1.922E-05	2.300E-05
Approach			
World	45	2.791E-06	3.578E-06
US	31	2.853E-06	3.851E-06
Foreign	12	2.683E-06	4.346E-06
Climb			
World	9	5.582E-07	9.741E-07
US	5	4.602E-07	9.676E-07
Foreign	3	6.706E-07	1.733E-06
Cruise			
World	4	2.481E-07	5.677E-07
US	1	9.204E-08	4.366E-07
Foreign	1	2.235E-07	1.060E-06
Landing			
World	55	3.411E-06	4.270E-06
US	24	2.209E-06	3.107E-06
Foreign	31	6.930E-06	9.353E-06
Takeoff			
World	91	5.644E-06	6.719E-06
US	52	4.786E-06	6.030E-06
Foreign	34	7.601E-06	1.012E-05
Taxi			
World	5	3.101E-07	6.520E-07
US	0	0	2.757E-07
Foreign	5	1.118E-06	2.350E-06
Multiple Birds			
World	30	1.861E-06	2.524E-06
US	15	1.381E-06	2.126E-06
Foreign	15	3.353E-06	5.163E-06
Moderate to Severe Damage			
Turbofans			
World	41	6.891E-06	8.941E-06
US	14	3.703E-06	5.790E-06
Foreign	23	1.662E-05	2.354E-05
Turboprops			
World	2	1.966E-07	6.188E-07
US	1	1.412E-07	6.696E-07
Foreign	1	3.237E-07	1.536E-06

Note: JT15D engine excluded in US and Foreign conditions

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

<u>Weight¹</u>	<u>U.S. Events</u>	<u>U.S. Prob</u>	<u>Foreign Events</u>	<u>Foreign Prob</u>	<u>Unknown</u>	<u>Worldwide Events</u>	<u>Worldwide Prob</u>
0<x≤4	23	2.117E-06	8	1.788E-06	1	32	1.985E-06
4<x≤8	2	1.841E-07	7	1.565E-06	0	9	5.582E-07
8<x≤12	3	2.761E-07	2	4.471E-07	0	5	3.101E-07
12<x≤16	6	5.523E-07	4	8.942E-07	0	10	6.202E-07
16<x≤20	2	1.841E-07	2	4.471E-07	0	4	2.481E-07
20<x≤24	1	9.204E-08	0	0	0	1	6.202E-08
28<x≤32	1	9.204E-08	0	0	0	1	6.202E-08
32<x≤36	0	0	1	2.235E-07	0	1	6.202E-08
36<x≤40	2	1.841E-07	0	0	0	2	1.24E-07
64<x≤68	1	9.204E-08	0	0	0	1	6.202E-08
84<x≤88	2	1.841E-07	0	0	0	2	1.24E-07
100<x≤104	1	9.204E-08	0	0	0	1	6.202E-08
124<x≤128	2	1.841E-07	0	0	0	2	1.24E-07

¹ Ounces

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

	ALF502			TFE731			TPE331			JT15D
	U.S.	FOREIGN	WORLDWIDE	U.S.	FOREIGN	WORLDWIDE	U.S.	FOREIGN	WORLDWIDE	WORLDWIDE
Engine Operations:	1,187,981	415,354	1,603,335	2,592,274	968,802	3,561,077	7,084,288	3,089,229	10,173,518	785,259
<u>Bird Wt Range (Oz.)</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>	<u>Prob. of Ingestion</u>
(0 < X ≤ 4)	1.010	0.963	0.998	0.231	0.413	0.309	0.071	---	0.049	---
(4 < X ≤ 8)	---	0.482	0.125	0.077	0.310	0.140	---	0.065	0.020	---
(8 < X ≤ 12)	0.084	0.241	0.125	0.077	0.103	0.084	---	---	---	---
(12 < X ≤ 16)	---	---	---	0.154	0.310	0.197	0.014	0.032	0.020	0.127
(16 < X ≤ 20)	---	0.241	0.062	0.077	---	0.056	---	0.032	0.010	---
(20 < X ≤ 24)	---	---	---	0.039	---	0.028	---	---	---	---
(24 < X ≤ 28)	---	---	---	---	---	---	0.014	---	0.010	---
(32 < X ≤ 36)	---	---	---	---	---	---	---	0.032	0.010	---
(36 < X ≤ 40)	---	---	---	0.039	---	0.028	0.014	---	0.010	---
(64 < X ≤ 68)	0.084	---	0.062	---	---	---	---	---	---	---
(84 < X ≤ 88)	0.084	---	0.062	0.039	---	0.028	---	---	---	---
(100 < X ≤ 104)	---	---	---	0.039	---	0.028	---	---	---	---
(124 < X ≤ 128)	---	---	---	0.077	---	0.056	---	---	---	---
All Events	1.263	1.926	1.435	0.849	1.135	0.955	0.113	0.162	0.128	0.127

* Ingestion probabilities scaled by 10⁶

TABLE 6.4. ENGINE INGESTION PROBABILITIES* BY ENGINE AND LOCATION

	ALF502						TFE731						TPE331						JT15D	
	-----						-----						-----						-----	
	U.S.		FOREIGN		WORLDWIDE		U.S.		FOREIGN		WORLDWIDE		U.S.		FOREIGN		WORLDWIDE		WORLDWIDE	
-----						-----						-----						-----		
Engine Operations:	1,187,981		415,354		1,603,335		2,592,274		968,802		3,561,077		7,084,288		3,089,229		10,173,518		785,259	
-----						-----						-----						-----		
Condition Under Consideration	Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.		Ingestion Evt Prob.	
All Flight Phases	34	2.86	29	6.98	63	3.93	37	1.43	34	3.51	72	2.02	42	0.59	23	0.74	65	0.64	10	1.27
Takeoff And Climb Phases	15	1.26	7	1.69	22	1.37	19	0.73	23	2.37	42	1.18	23	0.32	7	0.23	30	0.29	6	0.76
Approach And Landing Phases	19	1.60	18	4.33	37	2.31	17	0.66	10	1.03	27	0.76	19	0.27	15	0.49	34	0.33	2	0.25
Dual Engine - Single Bird Events	3	0.25	0	--	3	0.19	0	--	1	0.10	1	0.03	0	--	1	0.03	1	0.01	0	--
Multiple Birds - Single Engine Events	1	0.08	1	0.24	2	0.12	9	0.35	4	0.41	13	0.37	2	0.03	2	0.06	4	0.04	0	--
Multiple Birds - Dual Engine Events	1	0.08	1	0.24	2	0.12	1	0.04	2	0.21	3	0.08	0	--	1	0.03	1	0.01	0	--
Moderate Or Severe Damage	3	0.25	2	0.48	5	0.31	11	0.42	21	2.17	32	0.90	1	0.01	1	0.03	2	0.02	4	0.51

*Ingestion probabilities scaled by 10^5

SECTION 7 DATA QUALITY

The interpretations derived from any large set of data are only as good as the data. The use of poor data can lead to invalid and misleading conclusions. The conclusions reached in this report should be interpreted in the context of the sources of the data and the quality of the data. The following paragraphs discuss the sources of data for the first 2 years and the quality of the data as measured by the consistency of the data collected in the first and second years.

7.1 DATA SOURCES.

The data used in this report were collected by the engine manufacturers and supplied to the FAA. The data were in turn supplied to the University of Dayton by the FAA. The method of data collection was a census rather than a survey sample. That is, the goal was to collect information on every bird ingestion event affecting the four engines in the study, during the 2-year period (second year only for the JT15D). A complete census is nearly impossible to achieve under any circumstances; therefore, estimates involving the total number of ingestions, such as ingestion rates, should be viewed as lower bounds. Other than the possibility that some ingestion events escaped the census, there were no known problems which systematically affected the reliability of the data.

7.2 INTERNAL CONSISTENCY.

The data collected during the second year should be consistent with the data collected during the first year, if the two data sets are to be combined. Hence it is necessary to compare the two data sets for consistency. This is done below, with two different tests being applied.

The first test compares the ingestion rates (ingestions per operation) for each engine for the first year and for the two years. Section 4 provided evidence that aircraft ingestion events occur according to a Poisson process so that a Z test can be used to compare the two. According to the properties of a Poisson process, the proportion of events that were recorded in the first year should be equal to the proportion of operations that were conducted in the first year.

The formula for the expected proportion of events in the first year becomes

$$P = O_1 / (O_1 + O_2) \quad (7.1)$$

where O_1 and O_2 are the number of operations for a particular engine in the first and second years, respectively. The proportion of aircraft ingestion events in the first year is used as P along with P as defined above, in the equation for Z

$$Z = (P - P) / \text{SQRT}(P(1 - P)/N) \quad (7.2)$$

where N is the total number of ingestion events for the engine.

The Z statistic defined in equation 7.2 is used to test the null hypothesis that there is no difference between the ingestion rates of a given engine between the first year and the two years taken together. Table 7.1 gives the results of the analysis. Any type of change, either increase or decrease, is important. Hence a two-sided test should be used. The critical value for a two-sided test and 5

TABLE 7.1. COMPARISON OF INGESTION RATES FOR FIRST AND SECOND YEARS

Engine	First Year		Both Years		P	$\hat{P}$	Z
	Events	Operations	Events	Operations			
U.S.							
ALF502	12	596905	34	1187981	0.502	0.353	-1.744
TFE731	23	1279280	37	2592994	0.493	0.622	1.559
TPE331	19	3389810	42	7084288	0.478	0.452	-0.339
Foreign							
ALF502	14	125013	29	415354	0.301	0.483	2.134
TFE731	17	471185	34	968802	0.486	0.500	0.159
TPE331	14	1351306	23	3089229	0.437	0.609	1.656

percent significance is ± 1.96 . As the table shows, only one of the Z values exceeds the ± 1.96 bound. Considering that we have performed six tests, each of which has probability 0.05 of falling "out of bounds" by pure chance, there is actually one chance in four that at least one of the six tests will fall out of bounds by pure chance. The fact that one test did exceed the limit cannot be considered strong evidence that the data are inconsistent from the first to the second year.

Another check on the consistency of the data collection is to compare the birds that were identified in the 2 years. There were too many different species and locations of ingestions, and too few of each species or location, to allow comparisons of those features. However, if the species identifications are reduced to bird weights, the cumulative weight distributions for the first and second years can be compared. Table 7.2 provides the cumulative bird weight distributions for the first and second years, worldwide. The data are plotted in figure 7.1 to provide a visual comparison. As can be seen from both the table and the figure, there are substantial differences between the distributions at the low end.

A statistical measure of the closeness of the cumulative distributions is the Kolmogorov-Smirnov D test. The D statistic is compared to a test value based on the sizes of the two samples. When the D statistic is smaller than the test value, the distributions are considered to be similar at a given significance level.

The maximum difference between the distributions in figure 7.1 is 0.413. For the sample sizes, this maximum difference should be less than 0.387 at a significance level of 0.01. The conclusion is that with a possible chance of error of 1 in 100, the two cumulative distributions are significantly different. Hence by this test, the data in the 2 years are not consistent.

In summary, the tests have found some significant differences between the data sets collected in the first and the second years. However, this need not be attributed to faults in data collection. It might also be due to changes in aircraft operational patterns or to changes in bird habits. The information available is not sufficient to distinguish between these alternative possibilities.

TABLE 7.2. CUMULATIVE DISTRIBUTIONS, FIRST AND SECOND YEARS

<u>Weight (oz)</u>	<u>Year 1</u>	<u>Year 2</u>
4	0.235	0.649
8	0.382	0.757
12	0.471	0.811
16	0.647	0.919
20	0.735	0.946
24	0.765	0.946
28	0.794	0.946
36	0.824	0.946
40	0.853	0.973
68	0.882	0.973
88	0.912	1
104	0.941	1
128	1	1

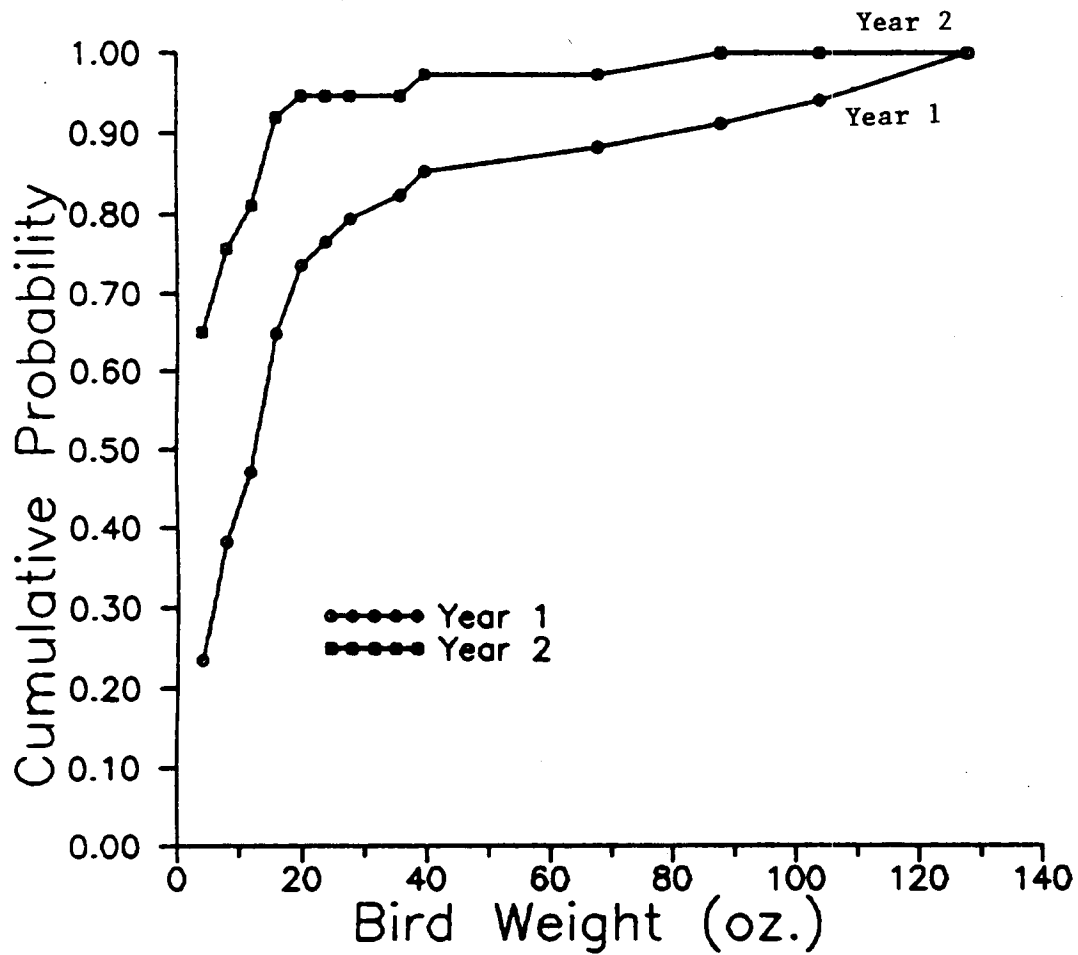


FIGURE 7.1. COMPARISON OF BIRD WEIGHT DISTRIBUTIONS, FIRST AND SECOND YEARS

SECTION 9
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SECTION 10
GLOSSARY OF TERMS

<u>Term</u>	<u>Definition of Term</u>
Ingested Bird	A bird having experienced the process of bird ingestion.
Aircraft Operation	A nonstop aircraft flight from one airport to another (includes 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 Ingestion Event	The simultaneous passage of one or more birds through the inlet of an engine during an engine operation.
Aircraft Ingestion Event	The simultaneous passage of one or more birds through the inlet of one or more engines of an aircraft during an aircraft operation.
Engine Hours	The total running time, measured in hours, of an engine or group of engines during a given period.
Ingestion Rate	Rate at which (aircraft or engine) events occur per flight event. Flight event refers to aircraft or airport operation. The components of ingestion rate are specified whenever this term is used. The influence of engine inlet opening size is not taken into account in this definition.
Normalized Ingestion Rate	Ingestion rate normalized to a given inlet size. Normalization allows statistical comparison of ingestion rates of engines with different inlet opening sizes.

APPENDIX A
ENGINE APPLICATIONS

<u>Engine</u>	<u>Engine Type</u>	<u>Engine Manufacturer</u>	<u>Engine Face Area (in²)</u>	<u>Typical Throat Area (in²)</u>	<u>Typical Aircraft Installation</u>
JT15D	Turbofan	Pratt & Whitney	346	310	Cessna Citation 1 & S2, Mitsubishi/Beech Diamond, Beechjet
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, and 900; Gates Learjet 35A, 55, 55ER, and 55LR; Israel Aircraft Industries Westwind 1124 and Astra 1125; Lockheed Jetstar II; Rockwell/Sabreliner 65; Cessna Citation III
TPE 331	Turboprop	Garrett	72	73	Alaska F & W, Goose; British Aerospace, Jetstream 3, 31, 32; Carstedt, Jetliner 600; CASA 212; Cessna, Conquest 2; Commander 680, 690, 695, Turbocommander; Dornier 228; Fairchild Metro, Metro 2, 3, Merlin 2,3,4, Peacemaker, Porter; Grumman, S2 Tracker; Helitec s 55; IAI, S2 Tracker; Mitsubishi, Marquise, Soltaire, MU-2; Pilatus, Porter; Piper, Cheyenne 400; Short Brothers, Skyvan; Turbobeaver; Volpar, Turbo 18

APPENDIX B
 CONTENTS OF FAA BIRD INGESTION DATA BASE
 SMALL ENGINES
 MAY 1987 - APRIL 1989

This appendix presents the contents of the small engine bird ingestion data base maintained by the FAA. The appendix presents actual data extracted from the FAA data base and used in this report. The data base contents are described below:

<u>COLUMN</u>	<u>DESCRIPTION OF COLUMN CONTENTS</u>
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.
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.
ENGINE	Engine model. (ALF502;JT15D;TFE731) - turbofan engines (TPE331) - turboprop engine
DASH	Engine dash number
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.
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 (blade retention mechanism broken)
- O(1) - TURBINE; turbine damage
- P - OTHER; any damage not previously listed
- Q - UNKNOWN

NOTE: The maximum number of damage codes listed for an engine ingestion event is three. These three damage codes reflect the most severe damage that occurred. There may be other damage that occurred which is less severe that 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.

Turbofan engine damage severity codes:

- 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

Turboprop engine severity codes:

- 1 - extremely severe damage (might jeopardize the airworthiness of the aircraft)

2 - severe damage (substantial damage which does not jeopardize the airworthiness of the aircraft)
 3 - minor damage
 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 a 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
 VLNTRY - voluntary engine shutdown
 OTHER - other reasons, may be listed in remarks
 UNKNOWN - unknown cause for shutdown

POF Phase of flight during which bird ingestion occurred.
 (TAXI;TAKEOFF;CLIMB;CRUISE;APPROACH;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.

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

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.

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

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

EDATE	EVT#	ETIME	SIGN_EVT	AIRCRAFT	ENGINE	DASH	ENG_POS	DMG_CODE	SEVERITY	POW_LOSS	MAX_VIBE	THROTTLE	IFSD	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER
05/03/87	2	18:00:00	MULT BIRDS	FALCON 50	TFE731	3	1 LEFT	A,K	1 NONE			NONE	NO	LANDING					
05/11/87	3	18:45:00	NONE	BAE125	TFE731	5	1 LEFT		9 NONE			NONE	NO	LANDING	0 122		VFR	DUSK	SCATTERED
05/14/87	1	16:30:00	NONE	BAE146	ALF502	R5	4 RIGHT OUTBOARD		9 NONE			NONE	NO	LANDING	25 125		VFR	LIGHT	CLEAR
05/14/87	25	15:30:00	NONE	METRO	TPE331	11U	1 LEFT	A,K	3 YES		YES	NONE	NO	TAKEOFF				LIGHT	CLEAR
05/17/87	4	16:00:00	MULT BIRDS	SABRE 65	TFE731	3R	1 LEFT	A,C,P	3 NONE		NONE	NONE	NO	LANDING	10 90		VFR	LIGHT	CLEAR
05/20/87	7	9:30:00	MULT BIRDS	CON 441	TPE331	8	1 LEFT		9 NONE		NONE	NONE	NO	TAKEOFF				LIGHT	CLEAR
05/22/87	8	5:30:00	NONE	METRO II	TPE331	30W	1 LEFT		9 NONE		NONE	NONE	NO	TAKEOFF	25 125		VFR	LIGHT	CLEAR
05/25/87	5		MULT BIRDS	FALCON 10	TFE731	2	2 RIGHT	A,D	2 NONE			NONE	NO	TAKEOFF	150		VFR	LIGHT	CLEAR
05/25/87	52	15:30:00	NONE	LEAR 35A	TFE731	2		A	4		NONE	NONE	NO	LANDING	100 100		VFR	LIGHT	CLEAR
05/26/87	6		NONE	LEAR 35	TFE731	2	2 RIGHT	A,D	2 NONE		NONE	NONE	NO	APPROACH	200 160		VFR	LIGHT	CLEAR
05/31/87	14		MULT ENG	LEAR 55	TFE731	3A	1 LEFT	A,K	1 NONE		NONE	NONE	NO	TAKEOFF			VFR	LIGHT	CLEAR
05/31/87	14		MULT ENG	LEAR 55	TFE731	3A	2 RIGHT	A,K	1 NONE		NONE	NONE	NO	TAKEOFF	150		IFR	LIGHT	CLEAR
06/17/87	9	14:00:00	NONE	JETSTAR	TFE731	3	1 LEFT OUTBOARD	A,B,E	3 NONE		NONE	NONE	NO	TAKEOFF	150		IFR	LIGHT	CLEAR
06/17/87	10		NONE	BAE146	ALF502	R5	3 RIGHT INBOARD		9 NONE			NONE	NO	TAKEOFF	200 100		VFR	LIGHT	CLEAR
06/21/87	20	21:30:00	NONE	MU-2	TPE331	5	2 RIGHT		9 NONE		NONE	NONE	NO	UNKNOWN					
07/01/87	33		NONE	FALCON 50	TFE731	3	3 RIGHT	A,K	1		NONE	NONE	NO	TAKEOFF	1500 150		VFR	DARK	CLEAR
07/13/87	16	20:45:00	NONE	BAE125-700	TFE731	3R	2 RIGHT	A,D	2 NONE		YES	NONE	NO	UNKNOWN					
07/14/87	17	16:00:00	NONE	FALCON 50	TFE731	3	2 CENTER		9 NONE		NONE	NONE	NO	LANDING	300 117		VFR	DUSK	CLEAR
07/21/87	21	14:00:00	NONE	METRO III	TPE331	11U	1 LEFT	A,X	3 NONE		NONE	NONE	NO	APPROACH	6000 140		VFR	LIGHT	SCATTERED
07/22/87	22	11:30:00	NONE	METRO III	TPE331	11U	2 RIGHT		4 YES		NONE	RETARD	NO	TAKEOFF	0		VFR	LIGHT	SCATTERED
07/27/87	18		NONE	LEAR 35	TFE731	2	1 LEFT	A,C	3 NONE		NONE	NONE	NO	TAKEOFF	0 100		VFR	LIGHT	CLEAR
07/28/87	23	17:30:00	NONE	METRO III	TPE331	11	1 LEFT	A,K	3 YES		NONE	NONE	NO	UNKNOWN			IFR	LIGHT	CLEAR
07/30/87	11	20:00:00	NONE	BAE146	ALF502	R5	2 LEFT INBOARD		9 NONE			NONE	NO	TAKEOFF	0 100		VFR	DAWN	CLEAR
07/31/87	12	8:40:00	NONE	CL600	ALF502	L2	1 LEFT	A,D,H,L	2 NONE		YES	NONE	NO	TAXI	0 0		VFR	DUSK	CLEAR

EDATE	EVT#	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS	WT_02_1	US_INCID	CTY_PRS	AIRPORT	LOCALE	REMARKS
05/03/87		NONE		SEVERAL	SEAGULL*		3	24.0	YES		DTW	DETROIT, MICHIGAN	
05/11/87		NONE	YES	YES	RING-BILLED GULL	14N12	1	17.0	YES		BKL	CLEVELAND, OH	COMP STATORS BENT
05/14/87		NONE	NO	ONE	SPARROW*		1		NO		LEEDS	LEEDS, ENGLAND	
05/14/87		NONE	NO	NO			1		YES		PSC	PASCO, WA	
05/17/87		NONE		FLOCK	MORNING DOVE	2P105	*	4.0	YES		MSY	NEW ORLEANS, LA	1+2STG IMP DAM, 1BENT BLADE
05/20/87		NONE	NO	NO	STARLING*		*	8.0	YES		EVV	EVANSVILLE, INDIANA	COMP STATORS DAMAGED
05/22/87		ATB	NO	ONE	COMMON GULL	14N13	1	15.0	NO		LDK	LINKOPING, SWEDEN	
05/25/87		NONE	NO	SEVERAL	HAWK*		2		NO		LIN	MILANO, ITALY	
05/25/87			NO	ONE	SEAGULL*		1	64.0	NO		PLCH	LONDON, UK	5 F BLOS WERE BENT
05/26/87		NONE	NO		PIGEON*		1	16.0	NO		SCL	SANTIAGO, CHILE	
05/31/87		NONE	NO	SEVERAL	GULL*		1	16.0	NO			THESSALONIKI, GREECE	1 1STG LPC BLD BENT TO FWD SIDE
05/31/87		NONE	NO	SEVERAL	GULL*		1	16.0	NO			THESSALONIKI, GREECE	1 1STG LPC BLD BENT TO FWD SIDE
06/17/87		NONE	YES	YES	HERRING GULL	14N14	1	40.0	YES		SIE	SEA ISLE CITY, NJ	3 F BLOS TIP CURL
06/17/87		NONE	NO	NO			1		NO			OXFORD, ENGLAND	
06/21/87		NONE	NO	NO	DOVE*		1		YES		RDD	REDDING, CA	
07/01/87		NONE	NO	NO			1		NO				
07/13/87		NONE	YES	YES	YELLOW CROWN NIGHT HERON	1I27	1	24.0	YES		MSY	NEW ORLEANS, LA	ODOR, FAN STATOR DAMAGED
07/14/87		NONE	NO	ONE	CHIMNEY SWIFT		1	1.0	YES		STL	ST. LOUIS, MO	
07/21/87		ATO	NO	ONE	SEAGULL*		1	16.0	YES		TVC	TRAVERSE CITY AIRPORT MI	BENT IMP BLD
07/22/87		NONE	NO	YES	MOURNING DOVE	2P105	1	4.0	YES		CWA	WAUSAU, WI	
07/27/87		NONE	NO	NO	KILLDEER	5N33	1	3.0	YES		PHX	PHOENIX, ARIZONA	
07/28/87		ATO	NO	NO	ROCK DOVE	2P1	1	14.0	YES		LAX	LOS ANGELES, CA	IMP DAMAGE
07/30/87		NONE	NO	NO	TREE SPARROW	70223	1	1.0	NO		LANZHO	CHINA	
07/31/87		ATB	YES	ONE	BARHNING KITE	3K31	1	20.0	NO		BAYAN	PENANG, MALAYSIA	12 EXIT GUIDE VANES DAMAGED
07/31/87		NONE	NO	FLOCK	ROCK DOVE	2P1	*	14.0	YES		TOA	TORRANCE, CA	
08/11/87		ATB	NO	SEVERAL	SEAGULL*		2	32.0	NO			VALPARAISO, CHILE	1ST IMP DAMAGE
08/16/87		ATO			RING-BILLED GULL	14N12	1	16.0	NO			LINDSAY, ONTARIO, CANADA	FAN STATOR DAMAGE
08/24/87		DIV	YES	ONE	COMMON WHITE SEAGULL*		1	32.0	NO			DUMFRIES, SCOTLAND	75% IMP VANES BENT/CURLED OVER, ODOR
08/26/87		NONE	NO	NO			1		YES				
09/0													

EDATE	EVT#	ETIME	SIGN_EVT	AIRCRAFT	ENGINE	DASH	ENG_POS	DMG_CODE	SEVERITY	POW_LOSS	HAX_VIBE	THROTTLE	IFSD	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER
12/13/87	65	16:00:00	MULT	ENG-BIRDS	JETSTAR	TFE731	3	2 LEFT INBOARD	A,D,K	1 NONE	NONE	NONE	NO	TAKEDOFF	50	160	VFR	DUSK	OVERCAST
12/13/87	65	16:00:00	MULT	ENG-BIRDS	JETSTAR	TFE731	3	4 RIGHT OUTBOARD	A,D	2 NONE	NONE	NONE	NO	TAKEDOFF	50	160	VFR	DUSK	OVERCAST
12/13/87	65	16:00:00	MULT	ENG-BIRDS	JETSTAR	TFE731	3	3 RIGHT INBOARD	A,D	2 NONE	NONE	NONE	NO	TAKEDOFF	50	160	VFR	DUSK	OVERCAST
12/16/87	98	18:00:00	NONE		BAE125	TFE731	3R	2 RIGHT	A,D	2 NONE	NONE	NONE	NO	APPROACH	1200	160	VFR	DUSK	OVERCAST
12/17/87	71	8:05:00	MULT	ENG-BIRDS	DO 228	TPE331	5	1 LEFT	A,K	3	NONE	RETARD	NO	LANDING	0	80	VFR	LIGHT	CLEAR
12/17/87	71	8:05:00	MULT	ENG-BIRDS	DO 228	TPE331	5	2 RIGHT	A,K	3	NONE	RETARD	NO	LANDING	0	80	VFR	LIGHT	CLEAR
12/30/87	99	16:00:00	NONE		LEAR 35A	TFE731	2	2 RIGHT	A,D,K	1 YES	NONE	NONE	NO	CLIMB	0	80	VFR	LIGHT	CLEAR
01/07/88	162		MULT	ENG-BIRDS	LEAR 35	TFE731	2	2 RIGHT	A,D,G	2 YES	SOME	NONE	NO	TAKEDOFF	0	130	IFR	LIGHT	CLEAR
01/07/88	162		MULT	ENG-BIRDS	LEAR 35	TFE731	2	1 LEFT	A,D,G	2 YES	SOME	NONE	NO	TAKEDOFF	0	130	IFR	LIGHT	OVERCAST
01/13/88	58	10:57:00	INV	POW LOSS	BAE146	ALF502	R5	4 RIGHT OUTBOARD	A,C,E,K	1 COMPRESSOR	NONE	IDLE	NO	INVOLUNTARY	800		VFR	LIGHT	OVERCAST
01/15/88	63	14:00:00	NONE		CITATION 3	TFE731	3B	2 RIGHT	A,C,H	3 NONE	SOME	NONE	NO	TAKEDOFF	110		VFR	LIGHT	CLEAR
01/16/88	59	11:40:00	NONE		BAE146	ALF502	R5	3 RIGHT INBOARD	A,C	3 NONE	NONE	NONE	NO	UNKNOWN			VFR	DARK	CLEAR
01/22/88	77	7:00:00	NONE		COMM 681	TPE331	43BL	2 RIGHT		9 NONE	NONE	NONE	NO	TAKEDOFF	40	100	VFR	DARK	SCATTERED
02/03/88	60	18:40:00	NONE		BAE146	ALF502	R5	1 LEFT OUTBOARD		9 NONE	1.2	IDLE	NO	LANDING	115		VFR	DUSK	CLEAR
02/11/88	68	22:22:00	NONE		BAE125-700	TFE731	3R	2 RIGHT		9 NONE	NONE	NONE	NO	TAKEDOFF	0	120	IFR	DARK	FOG
02/15/88	61	12:30:00	NONE		BAE146	ALF502	R5	1 LEFT OUTBOARD		9 NONE	.6	NONE	NO	TAKEDOFF	120		IFR	LIGHT	CLEAR
02/16/88	78	8:50:00	NONE		DO 228	TPE331	5	2 RIGHT	A,K	3 YES	NONE	CUTOFF	NO	INVOLUNTARY	0	100	VFR	LIGHT	CLEAR
02/18/88	62	6:50:00	MULT	ENG-BIRDS	BAE146	ALF502	R5	3 RIGHT INBOARD		9 NONE	.3	NONE	NO	LANDING	115		VFR	LIGHT	CLEAR
02/18/88	62	6:50:00	MULT	ENG-BIRDS	BAE146	ALF502	R5	1 LEFT OUTBOARD		9 NONE	.3	NONE	NO	LANDING	115		VFR	LIGHT	CLEAR
02/22/88	69	21:00:00	MULT	BIRDS	LEAR 35A	TFE731	2	2 RIGHT	A,B,D,K	1 YES	HIGH	NONE	NO	LANDING	20	120	VFR	DARK	CLEAR
02/22/88	75	11:00:00	NONE		LEAR 35	TFE731	2	2 RIGHT		9 NONE	NONE	NONE	NO	APPROACH	400	140	VFR	LIGHT	CLEAR
03/04/88	85	19:30:00	INV	POW LOSS	HU 2	TPE331	10	1 LEFT	A,K	3 SPOOL DOWN	HIGH	CUT OFF	NO	INVOLUNTARY	100		VFR	DARK	DRY
03/05/88	79	16:45:00	OTHER		METRO	TPE331	11	1 LEFT	A,K,P	2		CUTOFF	NO	INVOLUNTARY					

EDATE	EVT#	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS	WT_OZ_1	US_INCID	CTY_PRS	AIRPORT	LOCALE	REMARKS
12/13/87		ATB	NO	FLOCK	COMMON LAPHING	SN1	*	7.7	NO			COVENTRY, ENGLAND	BYPASS+CORE INLET STATORS, LPC BLOS BENT
12/13/87		ATB	NO	FLOCK	COMMON LAPHING	SN1	*	7.7	NO			COVENTRY, ENGLAND	GUN + VEHICLE BIRD CONTROL
12/13/87		ATB	NO	FLOCK	COMMON LAPHING	SN1	*	7.7	NO			COVENTRY, ENGLAND	GUN + VEHICLE BIRD CONTROL
12/16/87		NONE	NO	NO			1		YES			RICHMOND, VA-BYRD FIELD	FOUR FAN BLADES DAMAGED, 1 AT ROOT
12/17/87		NONE	NO	FLOCK	GULL*		*	8.0	NO		FDH	FRIEDRICHSHAFEN, GERMANY	1 STG IMP BLOS BENT
12/17/87		NONE	NO	FLOCK	SEAGULL*		*	8.0	NO		FDH	FRIEDRICHSHAFEN, GERMANY	IMP SLIGHTLY DAMAGED
12/30/87		NONE	NO	NO			1		NO			CRICIUMA, SOUTHERN BRAZIL	SIX F BLOS TIPS BENT, LPC DAMAGE
01/07/88		DIV	NO	YES	KAIKENE*		*	128.0	NO			USHUAIA, ARGENTINA	6 FAN BLADES BENT AND BROKEN
01/07/88		DIV	NO	YES	KAIKENES*		*	128.0	NO			USHUAIA, ARGENTINA	16 FAN BLADES BENT AND BROKEN
01/13/88		ATB	YES	SEVERAL	TURKEY VULTURE	1K1	1	64.5	YES	OAK-SNH	OAK	SAN FRANCISCO, OAK., CA	ALL COMP STAGES DAMAGED, ENG FLAMED OUT
01/15/88		ATB	NO	ONE			1		YES		SLN	SALINA, KS	3 FAN BLADES BENT
01/16/88		NONE	NO				1		YES	LAX-SAN		CA	FOUND ON GRD INSPEC., 2 FAN BLADES BENT
01/22/88		DIV	NO	SEVERAL	DOVE*		1		YES			JACKSONVILLE, FL	
02/03/88		NONE	NO	NO	DOVE*		1		NO		JAX	BULAWAYO, ZIMBABWE	
02/11/88		NONE	NO	NO			1		YES	HRE-BUQ	BUQ	TAMPA, FL	MINOR CORE DAMAGE REMAINED IN SERVICE
02/15/88		NONE	NO	ONE	SHALLOW*		1		NO		KAB-HKM	KAB	
02/16/88		ATB		FLOCK	CROW*		1		NO			MATABELELAND, AFRICA	BIRD WENT THROUGH BYPASS
02/18/88		NONE	NO	FLOCK	HOUSE MARTIN	18269	1	0.6	NO	HRE-MSV	MSV	BAGDORA, BENGAL, INDIA	TQ MOMENTARILY DROPPED BELOW 60%
02/18/88		NONE	NO	FLOCK	HOUSE MARTIN	18269	2	0.6	NO	HRE-MSV	MSV	MASVINGO, ZIMBABWE	BIRD WENT THROUGH BYPASS
02/22/88		NONE	NO	SEVERAL	SNOW GOOSE	2J26	2	88.0	YES		HOU	MASVINGO, ZIMBABWE	ONE BIRD INTO CORE, ONE THROUGH BYPASS
02/22/88		NONE	NO	NO	SPARROW*		1		YES		FHA	HOUSTON, TEX	STGS 1 THRU 4,LPC+HPC BLOS NICKED
03/04/88		NONE	NO	NO	LAPHING	SN1	1	7.7	NO		LAG	SIERRA VISTA, AZ	
03/05/88		NONE	NO	NO			1		YES		PDX	PARIS, FRANCE	STG 1 AND 2 IMP DAMAGE
03/09/88		ATO	NO	NO			1		YES		ISP	PORTLAND, OR	1STG IMP BENT+1 BROKEN BLD,2STG VANE DAM
03/10/88		NONE	YES	SEVERAL	SPARROW*		1		YES		ASE	RONKOKOMA, NY	CHG IN ENG NOISE, 2 BENT IMP BLOS
03/14/88		NONE	NO	SEVERAL	WOOD PIGEON	2P9	1	18.0	NO	DEN-ASE	ASE	ASPEN, COL	
03/22/88		NONE	NO	ONE	RING BILLED GULL	14N12	1	16.0	NO				

EDATE	EVT#	ETIME	SIGN_EVT	AIRCRAFT	ENGINE	DASH	ENG_POS	DMG_CODE	SEVERITY	POW_LOSS	MAX_VIBE	THROTTLE	IFSD	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER
07/16/88	107		NONE	BAE146	ALF502	R5	3 RIGHT INBOARD		9	NONE			NO	UNKNOWN					
07/18/88	108	10:00:00	MULT ENG	BAE146	ALF502	R5	3 RIGHT INBOARD	A,K	1	NONE			NO	LANDING		210	IFR	DARK	DRIZZLE
07/18/88	108	10:00:00	MULT ENG	BAE146	ALF502	R5	4 RIGHT OUTBOARD		9	NONE			NO	LANDING		210	IFR	DARK	DRIZZLE
07/19/88	117	15:00:00	NONE	FALCON 10	TFE731	2	2 RIGHT		9	NONE	NONE	NONE	NO	LANDING		0 50		LIGHT	SCATTERED
07/21/88	118	20:40:00	NONE	LEAR 35	TFE731	2	2 RIGHT		9	NONE	NONE	NONE	NO	UNKNOWN		980 120	VFR	LIGHT	CLEAR
07/21/88	128	21:15:00	MULT ENG	MU-2	TPE331	6A	1 LEFT		9	NONE	NONE	NONE	NO	TAKEOFF			IFR	DARK	SCATTERED
07/21/88	128	21:15:00	MULT ENG	MU-2	TPE331	6A	2 RIGHT		9	NONE	NONE	NONE	NO	TAKEOFF			IFR	DARK	SCATTERED
07/25/88	109		NONE	BAE146	ALF502	R5	3 RIGHT INBOARD		9	NONE			NO	UNKNOWN				LIGHT	CLEAR
07/29/88	124		MULT BIRDS	LEAR 35A	TFE731	2	1 LEFT	A,D	2	NONE	NONE	NONE	NO	LANDING			IFR	LIGHT	CLEAR
08/04/88	123	15:00:00	OTHER	JS 31	TPE331	12UAR	2 RIGHT	A,K,P	2	YES	NONE	NONE	NO	APPROACH		200 120	VFR	LIGHT	BROKEN
08/09/88	143	15:30:00	INV POW LOSS	DO 228	TPE331	5	2 RIGHT	A,K	3	SPOOL DOWN	NONE	CUTOFF	NO	INVOLUNTARY APPROACH		200 105	VFR	LIGHT	CLEAR
08/09/88	197		NONE	BAE146	ALF502		4 RIGHT OUTBOARD		9					UNKNOWN					
08/16/88	125	7:55:00	MULT BIRDS	LEAR 35	TFE731	2	2 RIGHT	A,C,K	1		NONE	RETARD	NO	TAKEOFF		0 120	IFR	LIGHT	SCATTERED
08/22/88	199		NONE	JS 3103	TPE331	10U	1 LEFT		9					APPROACH					
08/23/88	202		NONE	JS 3101	TPE331	10U	1 LEFT		9					UNKNOWN					
08/25/88	129	17:15:00	NONE	METRO II	TPE331	10UA	1 LEFT	A,K	3		SOME		NO	TAKEOFF		0 95	VFR	LIGHT	CLEAR
08/31/88	126	12:00:00	NONE	LEAR 36A	TFE731	2	1 LEFT	A,B	3	NONE	NONE	NONE	NO	TAKEOFF		3 120	VFR	LIGHT	CLEAR
09/07/88	133	19:35:00	MULT ENG	BAE146	ALF502	R5	3 RIGHT INBOARD		9	NONE			NO	TAKEOFF				DARK	CLEAR
09/07/88	133	19:35:00	MULT ENG	BAE146	ALF502	R5	1 LEFT OUTBOARD		9	NONE			NO	TAKEOFF				DARK	CLEAR
09/13/88	127	17:00:00	MULT BIRDS	CITATION 3	TFE731	3BR	2 RIGHT	A,C,K	1	YES	NONE		NO	TAKEOFF		50 130		LIGHT	CLEAR
09/15/88	134		NONE	BAE146	ALF502	R5	2 LEFT INBOARD		9	NONE			NO	UNKNOWN					
09/15/88	135		NONE	BAE146	ALF502	R5	1 LEFT OUTBOARD		9	NONE			NO	UNKNOWN					
09/22/88	130	13:36:00	NONE	JS 3101	TPE331	10UG	1 LEFT	A,L	9	NONE	NONE		NO	APPROACH		100 125	VFR	LIGHT	CLEAR
09/22/88	137		NONE	CL600	ALF502	L-2C	1 LEFT		9	NO			NO	UNKNOWN					
09/23/88																			

EDATE	EVT#	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS	WT_OZ_1	US_INCID	CTY_PRS	AIRPORT	LOCALE	REMARKS
07/16/88		NONE	NO		KILLDEER	5N33	1	3.0	YES		FMS	BAERFIELD, FT WAYNE, IND	
07/18/88			YES		KILLDEER	5N33	1	3.0	YES	CRW-ORD	ORD	CHICAGO, ILL-OHARE	FOUND DURING GROUND INSPECTION
07/18/88			YES		LESSER YELLOWLEGS	6N20	1	3.0	YES	CRW-ORD	ORD	CHICAGO, ILL-OHARE	SEVERAL 1ST STG COMP BLOS BENT
07/19/88		NONE	NO	NO	EURASIAN KESTREL	5K27	1	8.0	NO		LBG	LE BOURGET, FRANCE	
07/21/88		NONE	NO	YES			1		YES		PTK	PONTIAC, MI	
07/21/88		NONE	NO	NO	GRAY FACED BUZZARD*			14.0	NO			MIYAKO, JAPAN	
07/21/88		NONE	NO	NO	GRAY FACED BUZZARD*			14.0	NO			MIYAKO, JAPAN	
07/25/88		NONE	NO		AMERICAN KESTREL	5K26	1	3.5	YES	ORD-FWA		ILL-IND	TORQUE DROPPED 6% THEN RECOVERED
07/29/88		NONE	NO	NO	GULL*		*		NO			MILANO-LINATE, ITALY	FOUND DURING GROUND INSPECTION
08/04/88		NONE	YES	FLOCK	WOOD PIGEON*		1	24.0	NO			CAMBELL TOWN, UK	
08/09/88		NONE	NO	ONE	SEAGULL*		1	24.0	NO		GHT	WESTERLAND, GERMANY	1 IMP BLD FAILED, 3 IMP BLOS BENT
08/09/88							1		YES			CHICAGO, IL	2-1STG IMP BLOS BENT, DEBRIS IN F NOZZLE
08/16/88		NONE			GULL*		*		NO		LDK	LINDKOPING, SWEDEN	FOUND ON GRD INSPEC, DEBRIS ON INTAKE
08/22/88							1		YES		PHL	PHILA, PA	
08/23/88							1		YES				
08/25/88		ATO	NO	ONE			1		YES		TUP	TUPELO, MS	ENGINE REMOVED FOR INSPEC, BENT PROP TIP
08/31/88		ATB	NO	ONE	GULL*		1		NO		NCE	NICE, FRANCE	1-1STG IMP BLD BENT
09/07/88		ATB	YES	SEVERAL	HORNED LARK	17274	1	1.5	YES		ROA	ROANOKE, VA	1 FAN BLADE LE CORNER SLIGHTLY BENT
09/07/88		ATB	YES	SEVERAL	HORNED LARK	17274	1	1.5	YES		ROA	ROANOKE, VA	
09/13/88		NONE	NO	SEVERAL	ROCK DOVE	2P1	2	14.0	YES		BUR	BURBANK, CA	
09/15/88		NONE	NO	NO			1		YES			WASHINGTON, D.C.	3 BENT F BLADES, 6 DAMAGED CORE STATORS
09/15/88				NO			1		YES		FWA	FT. WAYNE, IND	FOUND DURING GROUND INSPECTION
09/22/88		NONE	NO	NO	GULL*		1		YES		YKM	YAKIMA, WA	FOUND DURING GROUND INSPECTION
09/23/88		NONE	NO	YES	HORNED LARK	17274	1	1.5	YES		TUP	TETERBORO, NJ	COWLING DAMAGE
09/24/88		NONE	NO	ONE	SPARROW OR STARLING*		1		YES		PDX	TUPELO, MISS	
09/27/88		NONE	NO	NO			1		YES	CCR-SMF	CCR	PORTLAND, OR	EGT RISE
09/29/88			NO	ONE	OWL*		1	64.0	YES		DEM	CONCORD, CA	
09/30/88		NONE		ONE	GULL*		1		YES		SBA	DENVER, CO	FOUND DURING GROUND INSPECTION AT SMF
10/06/88							1		YES			SANTA BARBARA, CA	PRECAUTIONARY SHUTDOWN, PROP SPIN DAMAGE
10/08/88		NONE	NO	ONE	CORMORAN*		4		NO		NCE	DAYTON, OH	BENT IMP BLOS
10/11/88		ATB	NO		AMERICAN WOODCOCK	6N37	1	6.0	YES		PHL	NICE, FRANCE	FOUND ON GRD INSPEC
10/15/88		ATO	NO	SEVERAL	HAWK*		1	32.0	NO		EDLP	PHILA, PA	PRECAUTIONARY IFSD, FAN STATOR DAMAGE
10/19/88							1		YES			PADERBORN, GERMANY	12 FAN BLADES B

EDATE	EVT#	ETIME	SIGN_EVT	AIRCRAFT	ENGINE	DASH	ENG_POS	DNG_CODE	SEVERITY	POW_LOSS	MAX_VIBE	THROTTLE	IFSD	POF	ALTITUDE	SPEED	FL_RULES	LT_CONDS	WEATHER
01/02/89	177	14:00:00	NONE	BAE125	TFE731	3	1 LEFT	A,D	2				NO	TAKEOFF	50		VFR		
01/08/89	170	16:00:00	NONE	LEAR 35A	TFE731	2	1 LEFT	A,D,P	2	NONE	NONE	RETARD	NO	TAKEOFF	30	160	VFR	LIGHT	BROKEN OVERCAST
01/29/89	185		NONE	METRO	TPE331	3U	2 RIGHT	A,K	3	NONE	NONE		NO	LANDING					
01/30/89	178	12:00:00	NONE	WESTWIND	TFE731	3	2 RIGHT	A	4	NONE	NONE	RETARD	NO	TAKEOFF	50		VFR	LIGHT	CLEAR
02/07/89	175	11:44:00	NONE	BAE146	ALF502	R5	4 RIGHT OUTBOARD		9	NONE			NO	UNKNOWN				LIGHT	CLEAR
02/21/89	179	16:10:00	NONE	BAE125-800	TFE731	5R	2 RIGHT		9	NONE	NONE		NO	APPROACH	800	250	VFR	LIGHT	CLEAR
02/22/89	174	16:30:00	NONE	CESSNA 550	JT15D	4	UNK		9				NO	TAKEOFF				DAY	
02/28/89	176	18:01:00	MULT BIRDS	BAE146	ALF502	R5	2 LEFT INBOARD	A,K,L	1	COMPRESSOR			NO	APPROACH	800	170		DUSK	
03/06/89	180		NONE	BAE146	ALF502	R5	4 RIGHT OUTBOARD		9	NONE			NO	UNKNOWN					
03/07/89	181		NONE	BAE146	ALF502	R5	1 LEFT OUTBOARD		9	NONE			NO	UNKNOWN					
03/16/89	182		NONE	BAE146	ALF502	R5			9				NO	UNKNOWN					
03/16/89	186		NONE	LEAR 35A	TFE731	2		A,D,K,P	1				YES	UNKNOWN					
03/17/89	183	15:15:00	NONE	BAE146	ALF502	R5	1 LEFT OUTBOARD		9	COMPRESSOR		IDLE	NO	APPROACH	50	110	VFR	LIGHT	CLEAR
03/20/89	187	12:30:00	NONE	LEAR 55	TFE731	3A	1 LEFT	A	4	NONE	NONE		NO	APPROACH	1400	140	VFR	LIGHT	CLEAR
03/21/89	184	13:00:00	NONE	BAE146	ALF502	R5	3 RIGHT INBOARD	A,K	1	NONE			NO	UNKNOWN			VFR	LIGHT	CLEAR
03/24/89	191		NONE		TFE731				9					UNKNOWN					
03/24/89	192		NONE		TFE731				9					UNKNOWN					
04/02/89	198	15:30:00	NONE	FAIRCHILD	TPE331	11		A	4					TAKEOFF					
04/07/89	193	14:15:00	NONE	METRO	TPE331	11U	1 LEFT	A	4	YES			NO	CLIMB	300		VFR	LIGHT	CLEAR
04/10/89	194		NONE	JS 3101	TPE331	10UF	1 LEFT		9	NONE	NONE		NO	UNKNOWN			IFR	LIGHT	CLOUDY
04/12/89	189		NONE	BAE146	ALF502	R5	3 RIGHT INBOARD		9	NONE			NO	UNKNOWN				LIGHT	
04/13/89	195	18:30:00	NONE	COMM	TPE331	5	2 RIGHT	A	4	YES	NONE		YES	LANDING	25	105	VFR	DUSK	CLEAR
04/26/89	190		NONE	BAE146	ALF502	R5	1 LEFT OUTBOARD		9	NONE			NO	UNKNOWN			IFR	LIGHT	CLEAR
04/26/89	196	10:00:00	NONE	JS 3101	TPE331	10UG	1 LEFT	A	4	YES	NONE		NO	TAKEOFF	100	120	IFR	LIGHT	OVERCAST

EDATE	EVTS	CREW_AC	CREW_AL	BIRD_SEE	BIRD_NAM	BIRD_SPE	#_BIRDS	WT_OZ_1	US_INCID	CTY_PRS	AIRPORT	LOCALE	REMARKS
01/02/89	DIV				GULL*		1		NO			VICTORIA, CANADA	
01/08/89	ATB	NO		ONE	BUZZARD*		1		NO		GIG	RIO DE JANEIRO	DEBRIS IN CORE AND BYPASS
01/29/89					MAGPIE*		1	40.0	NO			MOUNT GAMBIER, AUSTRALIA	FAN EXIT GUIDE VANES BROKEN
01/30/89	ATB	NO		YES	ROCK DOVE	2P1	1	14.0	YES		SHV	SHREVEPORT, LA	1ST IMP BLADE BENT, 1ST DIFF VANES BENT
02/07/89					MOURNING DOVE	2P105	1	4.0	YES		ORD	CHICAGO, IL-OHARE	
02/21/89	NONE	NO		YES	GULL*		1		NO			CHESTER, ENGLAND	FOUND ON GRD INSPEC
02/22/89	NONE						1		YES			MONROE, TX	
02/28/89		YES		FLOCK	SNOW GOOSE	2J26	*	88.0	YES	TX-OK	TX	SACRAMENTO, CA	DAMAGE TO 1 STG COMP BLADES
03/06/89					MOURNING DOVE	2P105	1	4.0	YES	SNA-SMF	SMF	FORT WAYNE, IN	FOUND ON GRD INSPEC
03/07/89							1		NO				
03/16/89							1		NO			BUDAPEST, HUNGARY	
03/16/89		NO		NO			1		NO			BRAZIL	
03/17/89	NONE	NO		YES	GULL*		1		NO			OXFORDSHIRE, ENGLAND	FAN BYPASS STATORS EXITED FAN EXHAUST
03/20/89	NONE	NO			REDTAIL HAWK*		1	50.0	YES		POU	HAPPINGER, FL	ENG REMOVED TO CLEAN OUT BIRD DEBRIS
03/21/89		YES		NO			1		NO			CARATHA, AUSTRALIA	FOUND ON GRD, 8,1ST STG COMP BLOS BENT
03/24/89					COMMON STARLING	21275	1	3.0	UNK				
03/24/89					HOUSE SPARROW	70212	1	1.0	YES				
04/02/89					GULL*		1		YES				
04/07/89	ATB	NO		NO	GULL*		1		YES		LAX	LOS ANGELES, CA	ENGINE CHANGE, AIRCRAFT SA227AC
04/10/89	NONE	NO		NO	MOURNING DOVE	2P105	1	4.0	YES		LAX	LOS ANGELES, CA	
04/12/89							1		NO			DAYTON, OH	
04/13/89	NONE	NO		ONE	RING-NECKED PHERSANT	4L161	1	40.0	YES		LWS	BENSON, ENGLAND	FOUND ON GRD INSPEC
04/26/89	NONE			NO	MONGOLIAN PLOVER	5N45	1	2.0	NO			LEWISTON, ID	
04/26/89	ATB	NO		YES	STARLING	21275	1	3.0	YES		DAY	BEIJING-LANZHOU, CHINA	
												VANDALIA, OH	

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 cannot be rejected and is then tentatively accepted. (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 that 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 there is 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 one 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, using the hypothesized mean rather than the sample mean in the computation. 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 degrees 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-square 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.