DEVELOPMENT OF AIRCRAFT WINDSHIELDS TO RESIST IMPACT WITH BIRDS IN FLIGHT PART I

COLLISION OF BIRDS WITH AIRCRAFT IN SCHEDULED COMMERCIAL OPERATIONS IN THE CONTINENTAL UNITED STATES

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Part I

COLLISION OF BIRDS WITH AIRCRAFT IN SCHEDULED COMMERCIAL OPERATIONS IN THE CONTINENTAL UNITED STATES

SUMMARY

This report covers the analysis of 473 records of collision of birds with aircraft in scheduled operations from a period previous to 1942 through 1946 Most of the reported collisions occurred in the continental United States, but some data are given for Canada and Central and South America

The data show that a bird collision on scheduled aircraft occurs each 759,000 miles of operation, which in 1946 corresponded to an average period of 0.89 days

The type of bird most commonly struck by aircraft is the duck Gulls and buzzards also are frequently hit in more limited geographical locations All birds are struck most frequently during migratory seasons, and at low elevations above ground.

More than one-fourth of all recorded bird strikes occur on the airplane windshield, of which about one-third result in severe damage. Approximately one-fourth of all strikes result in severe local damage to some portion of the aircraft structure.

INTRODUCTION

During the past several years increasing concern has been felt by the aircraft industry and governmental organizations interested in safety of commercial air carrier operations regarding collisions of aircraft with birds in flight This feeling has been accentuated by an apparently increasing number of such accidents which result in appreciable damage to the airplane or injury to the pilot, and by consideration of probable increasing future hazards associated with larger and higher speed commercial aircraft

As a result of such interest the Civil Aeronautics Administration in 1942 undertook a development program concerning means of improving impact resistance of aircraft windshields. In addition, the CAA started to accumulate data regarding the frequency and conditions of such collisions in order to learn the extent of this hazard

Data in this connection were obtained on special questionaire forms furnished by the Air Transport Association and filled out by the various airline operators for each occurrence. Further data were obtained from accident records of the Civil Aeronautics Board, and directly from airline operators. It is the purpose of this report to summarize and analyze the data which have been obtained through December, 1946

Acknowledgement is made to the Air Transport Association and to the various air carrier operators through whose cooperation the principal data utilized herein were obtained

GENERAL SCOPE AND ACCURACY OF DATA

As this report is a statistical study of the frequency and conditions of collisions of commercial aircraft with birds, it is of importance to consider the limitations and possible inaccuracies of the data obtained.

Before 1942, data were available only from formal reports made to the Civil Aeronautics Administration involving interruptions to scheduled flights Such data were incomplete, and of such small number as to preclude statistical investigation

In 1942 accumulation of data from the airline operators, through the Air Transport Association, began, and resulted in a more complete reporting of bird strike occurrences However, certain limitations even in these data are evident. The principal limitations may be listed as follows

(1) A tendency apparently exists in reporting bird collisions, particularly in the earlier data, to neglect strikes which do not

damage the airplane, or which do not occur in the vicinity of the windshield.

(2) All of the data desired for each bird strike were not reported in each instance, so that analysis of the various factors cannot be based on all the accidents reported, and the various factors cannot be completely correlated. For example, the type of bird struck and the airspeed at which the strike occurred were not given in all cases. The form distributed to the airlines had no space specifically allotted to statement of altitude at the time of strike.

(3) The various airlines did not report the occurrence of bird strikes with the same degree of thoroughness. This is evident from the data obtained, and from checks made of sources other than the reports furnished directly by the various companies. It is indicated that reasonably complete data were obtained only from one airline operator designated as Airline "A".

(4) The data obtained, with few exceptions, involve the Douglas DC-3 airplane so that possible effects of different windshield arrangements cannot be distinguished.

(5) Some data have been obtained concerning bird collisions with military aircraft, and in foreign operations of domestic airlines. The former data have not been included in this report, and the latter data are noted where used.

The number of bird strikes reported by various domestic airline operators for each year from 1942 through 1946 is shown in Tables I(a) and I(b). It is noted that a total of 473 airplane collisions were reported, of which 408 occurred in the United States, 8 in Canada, and 57 in Central and South America and the Carribean area. Of the 408 collisions occurring in the United States, 221 were reported by Airline "A" whose operations cover approximately 20 per cent of the total revenue miles flown.

It is noted that a general increase in the number of reported strikes occurs in the later years. The trend indicated may be attributed both to an increase in the air miles flown and to some increase in the proportion of strikes reported. In the case of some airlines, there appears a marked decrease in the number of strikes for certain years. It is probable that such decrease was caused by failure to prepare formal bird collision reports for that period.

FREQUENCY OF COLLISIONS RELATED TO REVENUE MILES FLOWN AND SEASON OF YEAR

One of the most significant results which it is desirable to obtain from bird collision statistics is a knowledge of the average frequency at which such collisions occur, or the average number of revenue miles flown for each bird strike. However, the present data cannot be used in its entirety for such a determination because of its known incompleteness. As the data obtained from Airline "A" are known to be reasonably complete, and as the revenue miles flown by this airline are approximately one-fifth of the total miles flown by all domestic airlines, the data obtained from Airline "A" represent a good statistical sample of all air carrier operations These data, therefore, were utilized to determine bird collision frequency, and are plotted in Fig. 1.

In applying Airline "A" data to other airline operations, the possibility exists that the airline taken as a sample might operate in regions of the country where probability of bird strikes is greater or less than the average probability for the entire country. However, as Airline "A" operates entirely across the continent, it is believed that the sample used is reasonably representative of all operations

It is seen from Fig. 1 that the average expectation of a bird strike on an airplane in scheduled air carrier operations is one strike for each 759,000 miles of flight. During the year 1946 a total of 309,592,647 miles were flown by all operators on scheduled flights, so that 759,000 miles covered an average period of 0 89 days. It may be concluded that during 1946 bird strikes on air carrier aircraft occurred at an average rate of about eight per week, and a total of 408 strikes occurred during the year on all air lines, although a total of only 99 strikes were reported.

As will be discussed in later sections of this report, a large proportion of the bird collisions involve small birds and strikes on portions of the aircraft which are not especially vulnerable. Further, a majority of strikes on the windshield, which is considered the most hazardous location for collision, do not cause serious damage. Therefore, the frequency of bird strikes involving possible serious hazard to the aircraft is considerably less than the

TABLE I(a)

REPORTED BIRD COLLISIONS WITH AIRCRAFT IN SCHEDULED OPERATION IN UNITED STATES

AIRLINE	NUMBER OF REPORTED COLLISIONS						
	BEFORE 1942	1942	1943	1944	1945	1946	5-YEAR TOTAL
A	1	39	29	37	57	58	221
B	2	10	5	22	14	28	81
C	3	13	12	11	--	--	39
D	1	7	4	2	10	8	32
E	--	--	2	3	1	--	6
All Others	7	4	6	10	5	5	37
TOTAL	14	73	58	85	87	99	416 *

* Including eight bird strikes occurring in southwestern Canada

TABLE I(b)

REPORTED BIRD COLLISIONS WITH DOMESTIC AIRLINE AIRCRAFT IN SCHEDULED OPERATIONS IN CENTRAL AND SOUTH AMERICA AND IN THE CARRIBEAN AREA

AIRLINE	NUMBER OF REPORTED COLLISIONS						
	BEFORE 1942	1942	1943	1944	1945	1946	5-YEAR TOTAL
F	1	5	8	5	16	11	46
All Others	6	--	--	3	1	1	11
TOTAL	7	5	8	8	17	12	57

frequency of all bird strikes on the airplane

A further significant factor shown in Fig. 1 is the large variation in frequency of bird collisions with the season of year The greatest collision frequency occurs during the spring and fall seasons at a time when migration of birds is at a maximum During September and October bird strikes are about ten times as frequent for a given number of miles flown as in December when the strike frequency is at a minimum, and strikes occur during these months at about twice the average annual frequency Forty-six per cent of the total collisions occur in September, October and November, and 29 per cent occur in March April and May

It is of further interest and significance that the seasonal variation of frequency of bird strikes corresponds closely to the density of bird movements For example, the migration

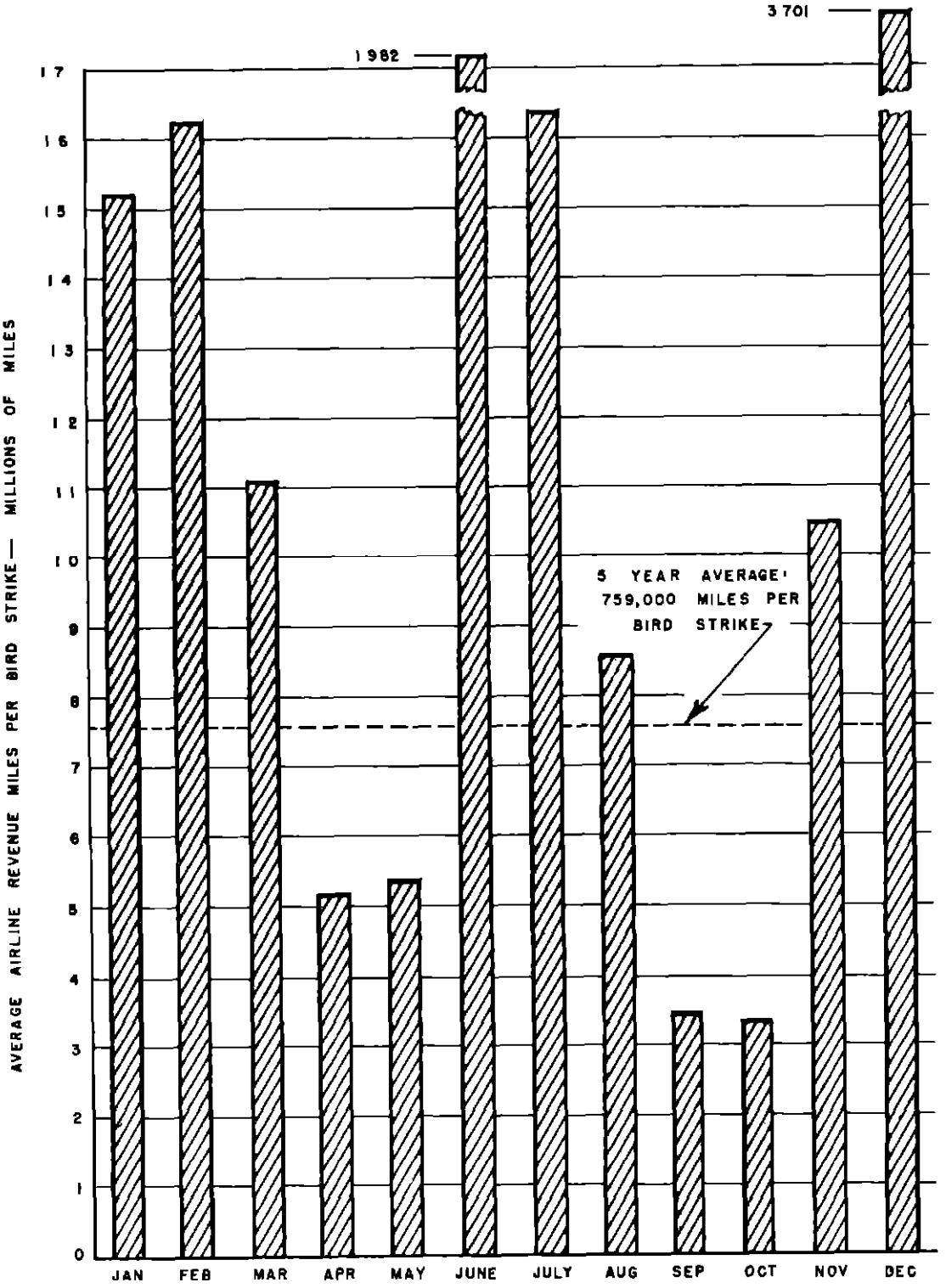

Fig 1 Average Monthly Bird Strike Frequency For Five Years, 1942-1946, Compiled From Reports Submitted by Airline "A"

of birds during the fall season is greater than the spring migration because of the large number of young birds after the breeding period, and because of the considerable mortality of birds during the winter season from natural causes and from hunting The movement of birds during December is small, with some increased movement occurring in January [1] These points are reflected exactly in the bird collision data

It may be assumed that the frequency of bird strikes related to revenue miles flown, which has been existent over the past five years, will remain at the same level in the future, and that commercial air traffic will increase in the amount commonly predicted In 1947, anticipating 350 million airline revenue miles, bird strikes may be expected on an average of about nine per week In 1950, anticipating 440 million revenue miles of flight, strikes will occur at a rate of about 12 per week It also may be anticipated that with greater aircraft cruising speeds, the severity of damage suffered in such collisions will increase

ALTITUDE OF BIRD STRIKES

The altitudes above local ground-level at which bird collisions have occurred are shown in Fig 2 This figure is based upon records of 107 collisions where the altitude of the airplane at the time of the strike was reported

In a number of collision reports no specific altitude was given, but the phase of operation was given as "landing" or "take-off" Such strikes were classified in the grouping for 0 to 2000 feet above local ground elevation

The data in Fig 2 show that approximately two-thirds of all collisions occur less than 2000 feet above the local ground elevation, and that more than 95 per cent of all collisions occur at an altitude less than 6000 feet above the local ground elevation However, bird

[1] F C Lincoln - "Airline Network of Migratory Birds," The Airline Pilot, Vol 2, No 9, October, 1942

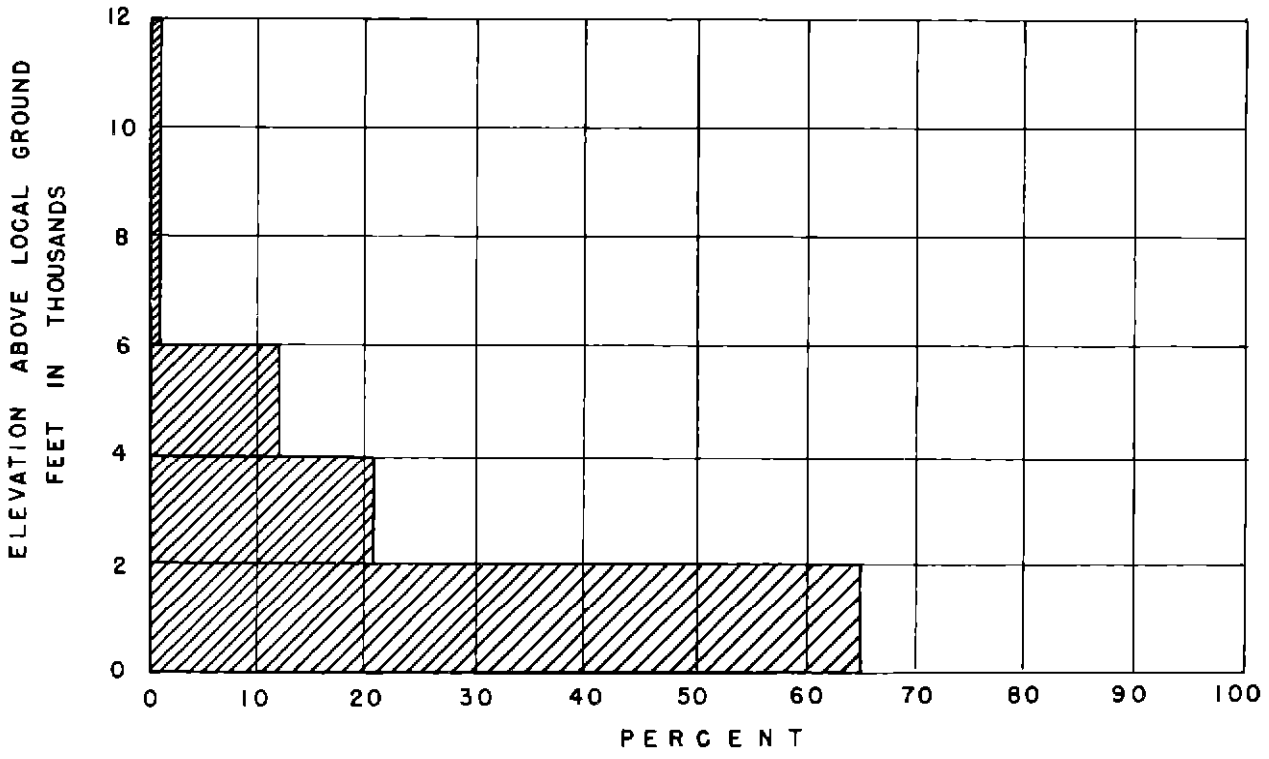

Fig 2 Frequency of Bird Strikes as Effected by Elevation Above Local Ground

strikes have been experienced at altitudes above sea-level as great as 12,000 feet, and consideration must be given to the fact that collisions at all higher altitudes involve greater flight speeds and possibly greater potential hazard than at the 0 to 2000 foot level

The trend shown in Fig 2 for increase in collision frequency with decrease in altitude above ground is in general agreement with the known altitude distribution of bird density It has been shown that the largest number of bird flights occur at altitudes above ground of less than 4000 feet [1] However, it is possible that the data plotted in Fig 2 do not present an accurate picture of potential collision hazards at the higher altitudes If it were feasible to weight these data, to take into consideration the known decrease in aircraft traffic density at the higher altitudes, the possibility of collision at such altitudes might be shown to be somewhat greater than that indicated Past commercial operations at altitudes greater than 12,000 feet above sea-level have been extremely limited, and the possibility of strikes at such altitudes is not excluded by the present results

TYPES OF BIRDS INVOLVED IN AIRCRAFT COLLISIONS

Fig 3 shows the frequency of striking various types of birds, as listed in 188 bird collision reports in which the type of bird was identified Table II shows the average and maximum weights of some of the various types of birds involved

As shown in Fig 3, the greatest portion of recorded bird strikes involve ducks, gulls, and buzzards, with only small numbers of each of 16 other types of birds listed

The weights of various bird types shown in Table II vary over wide ranges according to particular species For example, ducks

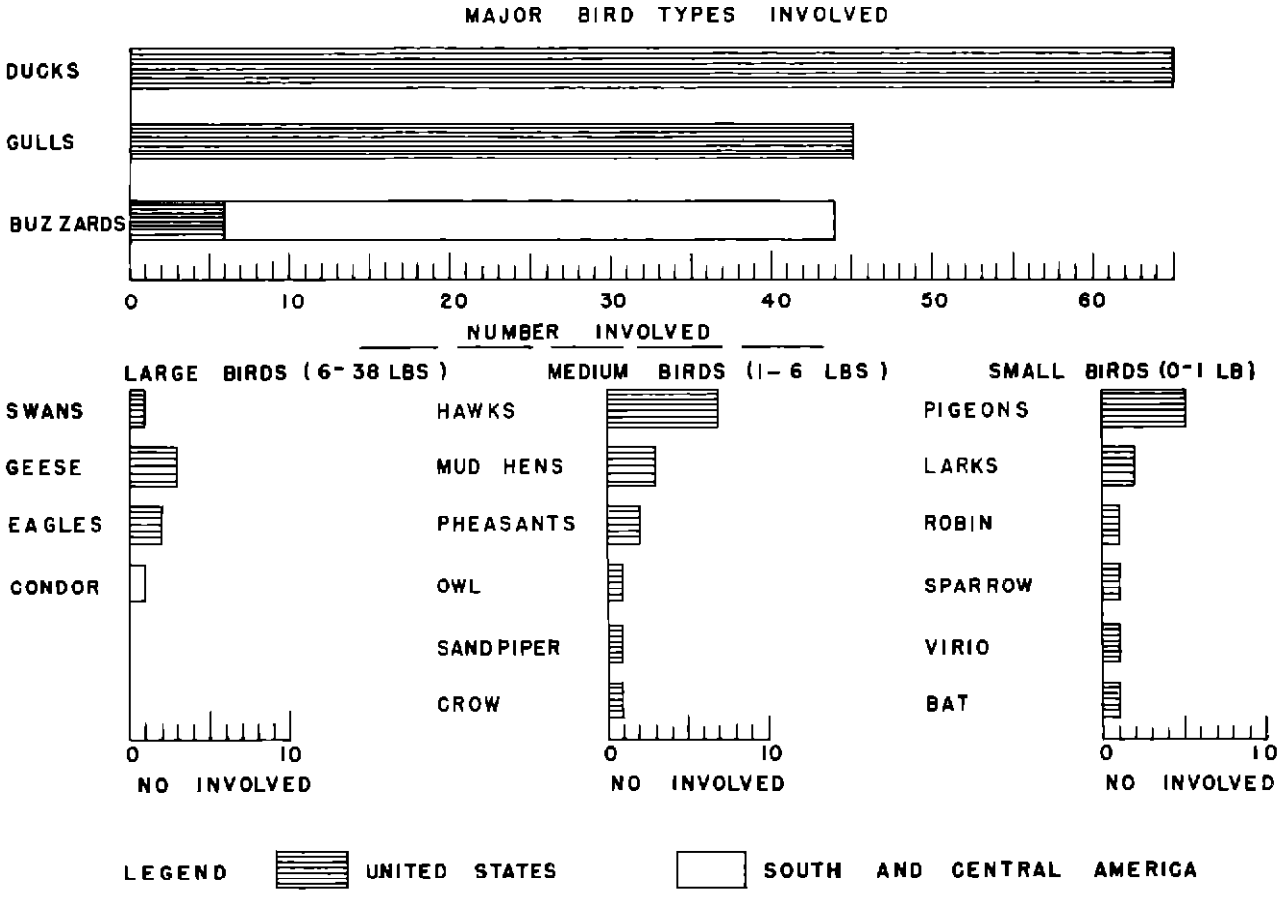

Fig 3 Relative Frequencies of Bird Strikes Involving Various Types of Identified Birds

TABLE II

WEIGHT OF BIRD TYPES INVOLVED IN AIRCRAFT COLLISIONS

	MALE Average lb - oz.	FEMALE Average lb. - oz.	MAXIMUM lb - oz.
DUCKS, Bufflehead	0 - 15.6	0 - 11.3	1 - 5
Black	2 - 11.8	2 - 6.0	3 - 13
Wood	1 - 8.7	1 - 6.9	2 - 0
American Eider	4 - 6.7	3 - 6	4 - 10
Pacific Eider	5 - 11.9	5 - 7	6 - 6
GULLS, Herring	2 - 10 5	2 - 4 7	3 - 0
Great Black	3 lb. to 4 lb		5 - 0
BUZZARD (Vulture) Turkey	4 lb. 8 oz.		
HAWKS, Goshawk	2 lb. to 3 lb		4 - 8
Red Shouldered	1 lb. - 12 oz.		2 - 6
Broad Winged	1 lb. - 8 oz		1 - 10
DOVES (Pigeons) Common Pigeon	0 lb. - 9 1 oz.		0 - 14
Eastern Mourning	0 - 4.6	0 - 4.4	0 - 6
Band Tailed	0 - 12.3	0 - 12.8	0 - 15 5
MUD HEN, Coot	1 - 4.2	1 - 1.4	1 - 10
EAGLE, Bald	8 lb. to 10 lb.		13 - 0
Golden	9 lb. to 11 lb.		14 - 0
GEESE, Cackling	4 - 6.7	2 - 15.5	5 - 9
Common Canada	8 - 5.6	7 - 4.5	13 - 12
Greater Snow	7 - 5	6 - 2 4	10 - 7
SWAN, Trumpeter	27 - 14.5	22 - 9	38 - 0
Whistling	15 - 12.8	13 - 10.2	18 - 10
OWL, Great Horned	4 lb.		6 - 0
Barred	2 lb.		3 - 0

Data furnished by the Fish and Wild Life Service, U. S Department of Interior.

vary from less than one pound to more than 5-1/2 lb in average weight of different species. Similar wide variations are obtained with gulls and hawks In most bird collisions only the general type of bird can be identified, if identification at all is possible, and only a few cases exist where accurate knowledge of bird weight was obtained

It may be concluded that the greatest portion of recorded bird strikes involve types of birds with average weights in a 1 to 5-1/2 lb range and with maximum weights of 6 to 6-1/2 lb.

Of the 188 strikes involving identified birds occurring in North and South America, a total of seven birds, or 3 7 per cent of those

identified, were of heavy-weight types These include swans, geese, eagles, and condor with maximum weight as high as 38 lb In 149 strikes occurring in the United States involving identified birds, six birds or 4.0 per cent were of the heavy-weight type However, the proportion of such heavy birds among the total identified birds probably is greater than their proportion among all birds involved in airplane collision

The values given in Fig 3 for the number of buzzards struck show the number involved in domestic airline collisions and in foreign operations of a domestic airline in South and Central America and in the Carribean area It is apparent that most collisions involving buzzards occur in the tropical and semi-tropical regions of South and Central America

The bird strike reports also show that about 75 per cent of all strikes reported for Central and South America involve buzzards It is not apparent whether these figures represent a true condition, or whether collisions involving small birds generally were less noticeable and were not reported

In Fig 4 are shown the number of collisions each month involving ducks and gulls compared with the total number of bird strikes for each month over the five-year period. There is a general agreement between the three curves In particular, the data for gulls, which are known to be migratory birds but which are usually associated with collisions occurring in landing and take-off phases of flight, follow this characteristic seasonal variation The curve for gulls, in addition, shows a peak in July which can be explained by the known large movement of young gulls during this period

The total absence of collisions involving ducks during June and July for this entire five-year period is of especial interest. It is known that movement of ducks is small during the summer months following the breeding season.

A total of 38 collisions, or about 8 per cent of the total number of collisions reported, were of an especially hazardous nature in that in each case an entire flock of birds was involved. In some cases as many as six birds struck different portions of the airplane simultaneously. In most such cases the flocks consisted of ducks and gulls In one case a flock of swans was hit

The number of flocks of different bird types involved in aircraft collision was as follows

Ducks	14	Hawks	1
Gulls	11	Pigeons	1
Swans	1	Shore Birds	1
Buzzards	1	Unidentified	7
Pheasants	1		

Of five collisions, where penetration of the windshield by birds caused bodily injury to airplane personnel, two involved collision with flocks

TYPE OF BIRD RELATED TO AIRPLANE VELOCITY AND ALTITUDE

The relationship between the various types of birds involved in aircraft strikes and the velocity of the airplane and its altitude above local ground level at the time of collision is of importance in connection with the general conditions of flight under which strikes involving large birds may be expected

In Fig 5, based upon 86 bird strike records, the number of birds of the principal identified types which were struck within the three speed ranges of 50 to 100, 100 to 150, and 150 to 200 mph is shown These air-speed ranges associated with the DC-3 airplane can be approximately correlated as follows to the phases of flight

50 to 100 mph	landing and take-off run speeds
100 to 150 mph	climbing after take-off and making approach before landing
150 to 200 mph	cruising and descending speeds

As indicated in Fig. 5, collision records show that most of the high speed (150 to 200 mph) collisions occur with ducks and that most of the low speed (50 to 100 mph) collisions occur with gulls At intermediate speeds (100 to 150 mph) the maximum total number of bird strikes occurred In this intermediate range, strikes involving gulls are slightly greater in number than strikes involving ducks It is of interest to note that only a small number of gull strikes occurred in the 150 to 200 mph range, and that no buzzards were struck

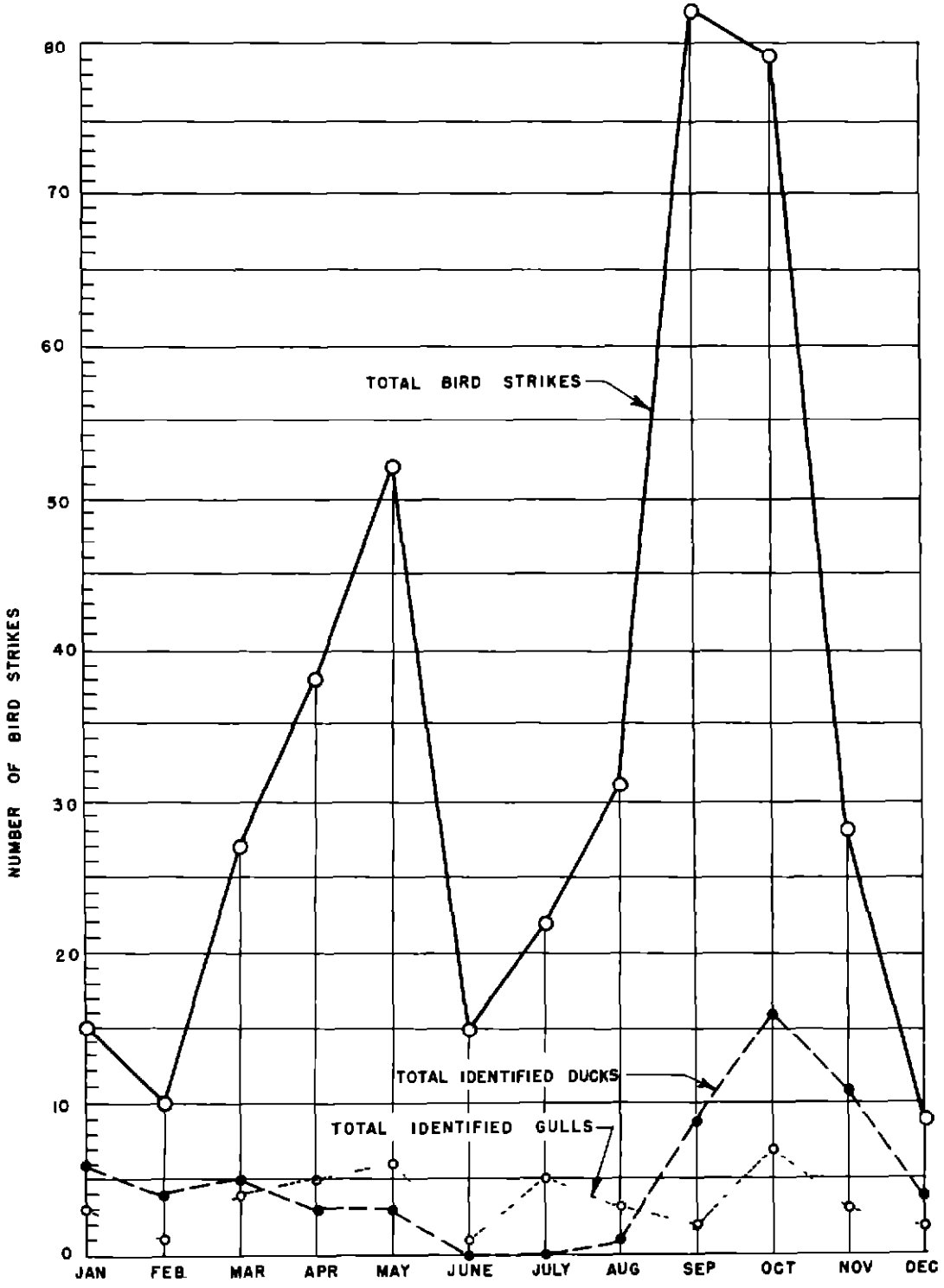

Fig 4 Total Monthly Number of Bird Collisions For Five Year Period, 1942-1946, Involving Ducks, Gulls, and All Birds

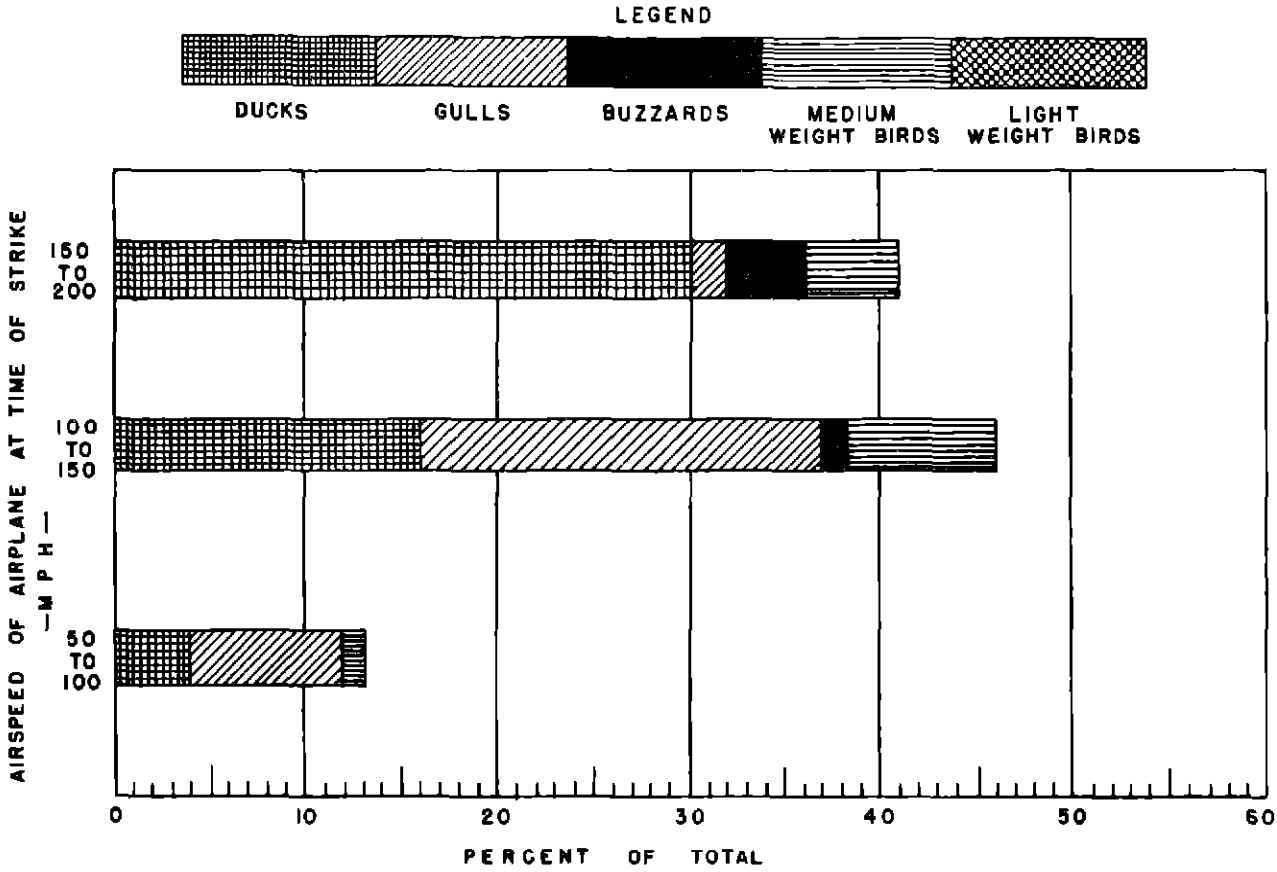

Fig 5 Identified Bird Types Struck at Various Aircraft Velocities

at 50 to 100 mph

Related data are shown in Fig 6 for 64 bird strikes in which both the type of bird and altitude of the airplane above local ground level are known This figure shows that the greatest number of most identified bird varieties are struck by aircraft at altitudes less than 2000 feet above local ground level, and that at this level gulls are most commonly struck At elevations above ground level between 2000 and 4000 feet, all types of birds except the very small species are struck, ducks being the most commonly hit

Above 4000 feet the identified types struck consist only of ducks Because of the limited number of such data, the possibility of hitting other types of birds at high altitudes should not be excluded

In general the data shown in Fig 6 indicate that ducks may be hit at any altitude up to 10,000 feet above local ground level, but most commonly at low levels, that other common types of birds may be hit at altitudes below 4000 feet and especially below 2000 feet, and that gulls are the type of bird most commonly hit at low levels

LOCATION AND SEVERITY OF STRIKES ON AIRPLANE

Data obtained from 473 bird strike reports involving 488 birds are shown in Fig 7 in connection with the location and severity of the strikes upon the aircraft structure As indicated previously, practically all of the data obtained concern the Douglas DC-3 airplane, with only a few strikes involving Douglas DC-4 and other airplanes

In Fig 7 are shown the relative proportions of all strikes which occur separately on the wing, windshield, fuselage, engine and propeller, landing lights, and on miscellaneous parts such as antenna masts, icing indicators, tail structure, etc The windshield strikes are separated from the general fuselage strikes, and the landing light strikes are

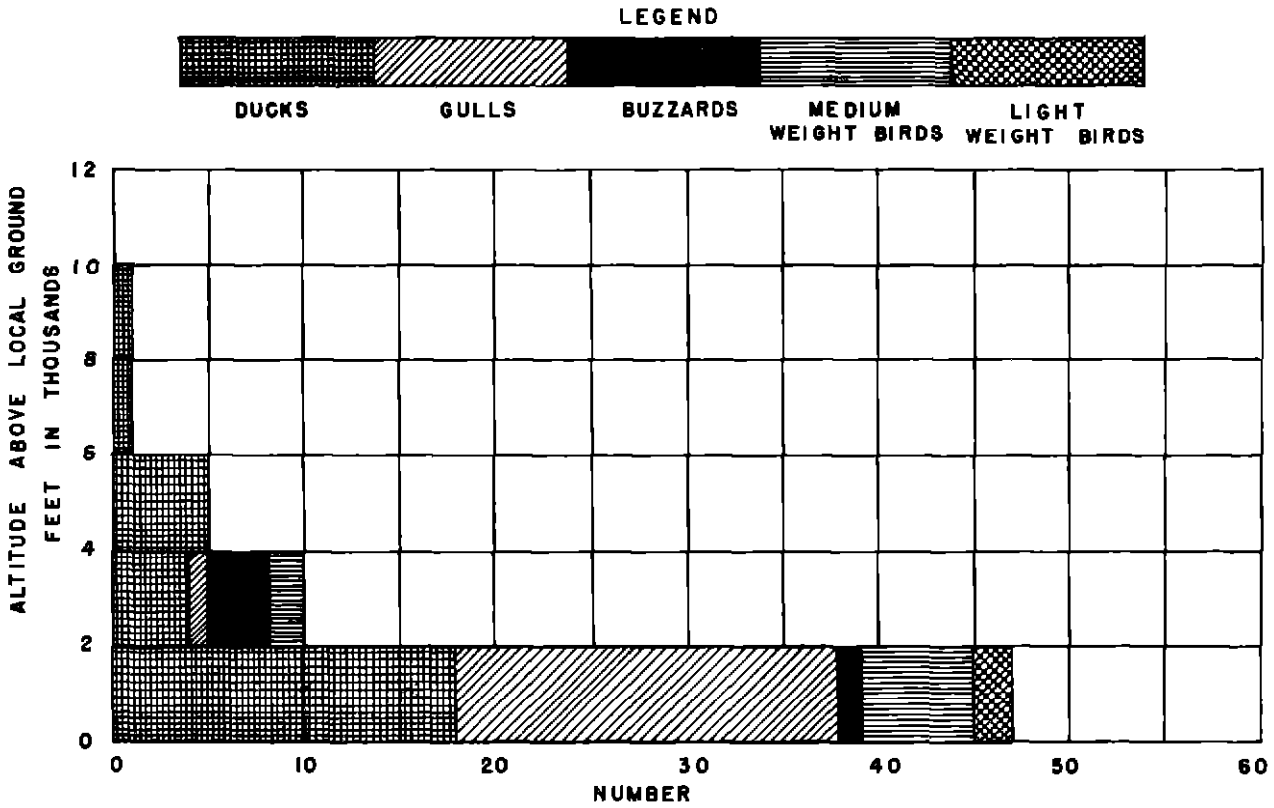

Fig 6 Identified Bird Types Struck at Various Altitudes Above Local Ground Level

separated from the general wing strikes, because of their particular interest

In Fig 7 also are shown the proportion of strikes at each general location which result in severe, moderate, or no damage

SEVERE DAMAGE is defined as considerable buckling or indentation, penetration, or failure of any portion of metallic structure, damage which affects the engine operating characteristics, or major cracking or penetration of glass Common examples are deep indentation of the leading edge of the wing with ribs buckled, rocker arm housings on the engine broken, jamming of engine airscoops, or major cracking or penetration of the windshield

MODERATE DAMAGE is defined as minor or moderate indentation of metal or minor cracking of glass Common examples of this condition are skin indentations which may be readily repaired, minor cracking of windshield glass, or moderate bending of engine cowling, air ducts, or ignition harness

The most obvious point of interest in the data given in Fig. 7 is that 28 per cent of all recorded strikes occur on the windshield, although the windshield represents much less than 28 per cent of the total forward area of the airplane Similarly, the landing lights which represent only a very small fraction of the forward area of the wing leading edge, and an even smaller fraction of the forward area of the entire airplane, received five per cent of all recorded strikes on the airplane and about 18 per cent of all recorded strikes on the entire wing.

The most obvious explanation of these data is that the windshield and landing lights are more readily damaged by collisions with birds than the metallic structure of the airplane, so that strikes by smaller birds at these locations are more effective and more easily recognized. Bird strikes can be directly observed on the windshield, and are commonly reported even though no damage is involved It is probable that many additional strikes involving small birds occur on the airplane structure generally but are not recognized or reported.

A second point of considerable interest in these particular data is the wide variation

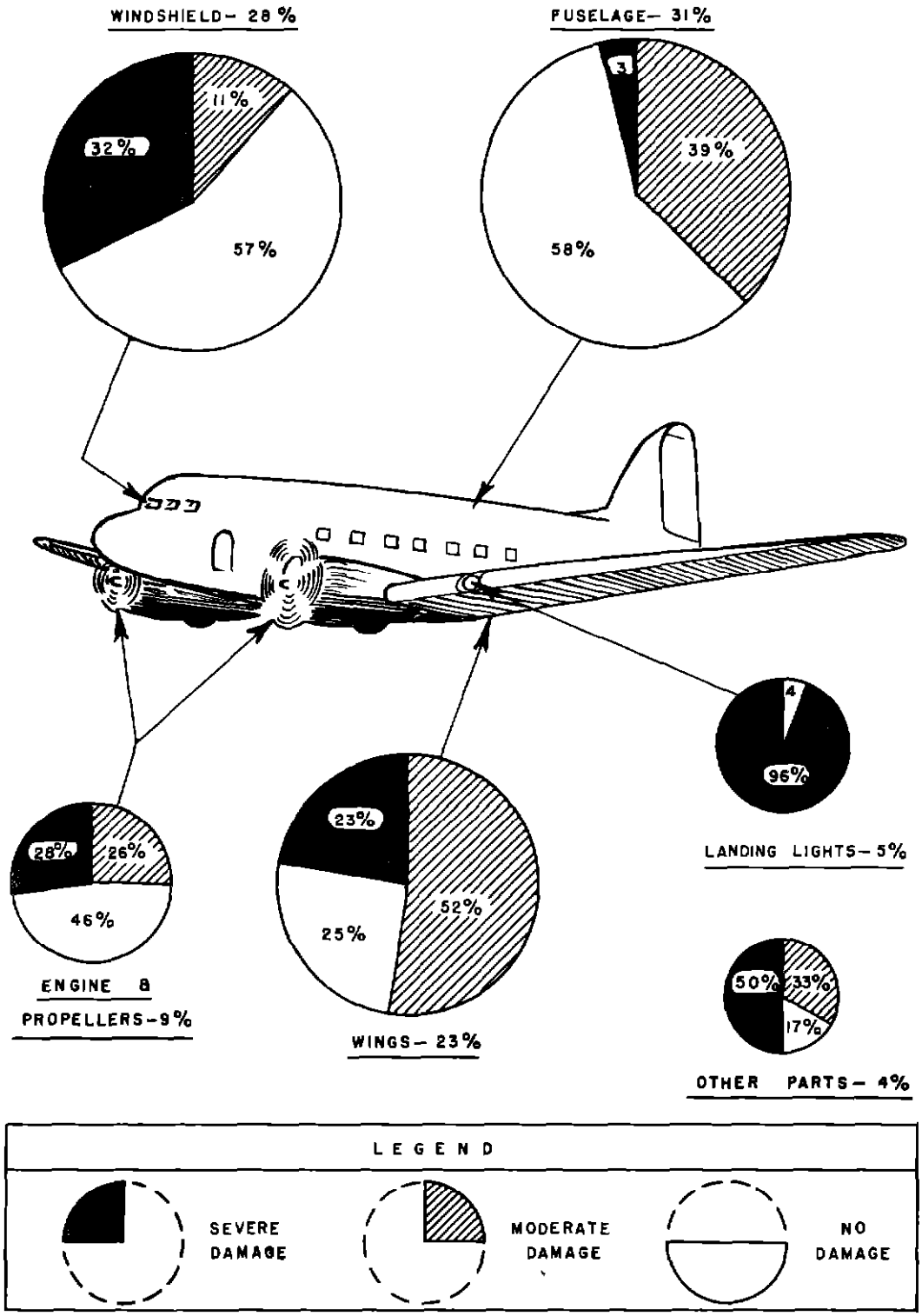

Fig 7 Location, Severity, and Relative Frequency of Bird Strikes on Airplanes

in the degree of damage sustained at the various general locations on the airplane

Of the 137 reported strikes on the windshield, 43 per cent caused some degree of damage and 32 per cent caused severe cracking or penetration, as noted in Table III A total of 14 strikes, or approximately 10 per cent, resulted in penetration of the windshield, causing the bird and broken glass particles to enter the cockpit In five cases involving penetration, the cockpit personnel were cut by flying glass and in a few cases were struck by the bird Damage rated as severe, but where no penetration occurred, generally resulted in glass splinters being thrown into the cockpit Approximately nine per cent of all recorded bird strikes on the airplane were on the windshield and caused severe damage, and three per cent of all recorded strikes on the airplane resulted in windshield penetration

In many instances where severe damage to the windshield occurred, the cockpit personnel were sufficiently injured to require hospitalization. No instance of fatal injury resulting from a bird strike in commercial airline operation is known However, several unexplained fatal crashes involving commercial aircraft have occurred in which this cause was suspected, and numerous records of fatalities and aircraft crashes resulting from bird collision exist in military aircraft operations.

In contrast to the severity of damage caused by bird strikes on the windshield, strikes on the fuselage, although practically equally numerous, usually caused no damage or only moderate damage Only three per cent of all recorded strikes on the fuselage caused damage rated as severe

Most of the bird strikes on the fuselage resulted in minor dents around the nose of the airplane. In certain cases deep dents were found in the nose, and in a few cases, penetration of the nose skin occurred A few instances of strikes along the side of the fuselage were recorded, and in one instance, a cabin window was reported as broken by a buzzard.

Recorded bird strikes on the airplane wing most commonly resulted in moderate damage, with 23 per cent causing severe damage and 25 per cent causing no damage The strikes causing severe damage involved major local buckling of the wing leading edge and ribs, and in several cases resulted in penetration of the leading edge structure with the carcass of the bird being found in the wing interior. In some such cases, interference with control cables resulted. Bird strikes of moderate intensity on the wing resulted in dents in the skin on the leading edge or tearing of the de-icer boot

Of the collisions involving the wing landing lights, 96 per cent are in the "severe" category and four per cent in the "no damage" category, with no strikes at this location classified as causing moderate damage. In most cases, the bird caused major cracking or penetration of the glass cover and seldom

TABLE III

DAMAGE TO WINDSHIELD AND INJURY TO PERSONNEL RESULTING FROM BIRD STRIKES ON WINDSHIELD

PERCENT OF ALL WINDSHIELD STRIKES				
NO DAMAGE	MODERATE DAMAGE	SEVERE DAMAGE		
		NO PENETRATION	PENETRATION	
			NO INJURY	INJURY
57	11	22	6	4

slid off without damaging the glass

Bird impact on the engine and propeller unit resulted in severe damage in 28 per cent of the strikes recorded for this location, and in moderate damage for 26 per cent

Normally, the damage sustained by the powerplant unit was not sufficient to cause shut-down of the engine However, in three instances the airscoop for the carburetor was jammed by a bird In one such case, an engine failed on take-off, and in another case, the engine could not be idled

No damage has been reported for any metal propeller, although birds frequently have hit propeller blades

Bird strikes on the nacelle have resulted in broken rocker arm housings, torn ignition harness, loosened cowling in the more severe cases, in dents in the cowling, in birds lodging between cylinders or in air intake ducts in less serious cases

Strikes on other miscellaneous portions of the aircraft structure represent four per cent of all recorded strikes of which one-half caused serious damage This category consisted mainly of radio antennae, rudder, vertical and horizontal stabilizers, landing wheels, ADF loop cases, and ice warning indicators The tail structure has been hit relatively few times, but one such strike by a large bird caused considerable damage to the vertical stabilizer, and partial loss of rudder control

In general, the data given in Fig 7 show that approximately 24 per cent of all recorded bird strikes on aircraft result in severe damage to some portion of the airplane structure About 37 per cent of the strikes involving severe damage to the aircraft are on the windshield. Approximately 31 per cent of all strikes result in moderate damage to some portion of the aircraft structure, of which about one-tenth are on the windshield Approximately 45 per cent of all recorded strikes on the airplane result in no damage

TYPE OF BIRD RELATED TO DEGREE OF DAMAGE

Data covering 211 bird strikes on aircraft, relating the type of bird involved in the collision and the degree of damage reported for the various portions of the airplane struck, are given in Fig 8 The differentiation between degrees of severity of damage is made according to the definitions previously given

An especially interesting fact shown by these data is that only two bird strikes involving buzzards, of which 44 were reported, occurred on the windshield No explanation of this unusual distribution is evident, although the size of the statistical sample is nearly the same as that for gulls where the distribution of strikes on the airplane appears more normal

The data given in Fig 8 is regrouped and condensed in Fig 9 to indicate the extent of damage caused by each of three principal weight groups There exists a reasonable correlation between the weight of bird and the severity of damage Forty per cent of the collisions with large birds result in severe damage to some portion of the airplane, whereas 27 per cent of the medium weight birds and 23 per cent of the light weight birds cause severe damage Conversely, 54 per cent of the collisions with light weight birds cause no damage, whereas 34 per cent of the medium weight birds and 22 per cent of the large weight birds cause no damage Collisions resulting in moderate damage occur at nearly the same rate as those resulting in severe damage

GEOGRAPHICAL DISTRIBUTION OF BIRD STRIKES

A study of the location of each recorded bird strike which has occurred in the continental United States, in relation to the types of bird hit and to the common migration routes of birds, is of importance in connection with the possible existence of geographical regions where abnormal probability of bird strikes may be found. In this connection data covering 321 reported collisions, for which the locations are known with reasonable accuracy, are shown in Fig 10.

Also plotted in Fig 10 are the principal bird migration routes across the United States [2] The migration paths indicated exist as actual bird routes at least 50 to 100 miles in width. Although it is not indicated in Fig

[2] Fish and Wildlife Service, U S Department of Interior

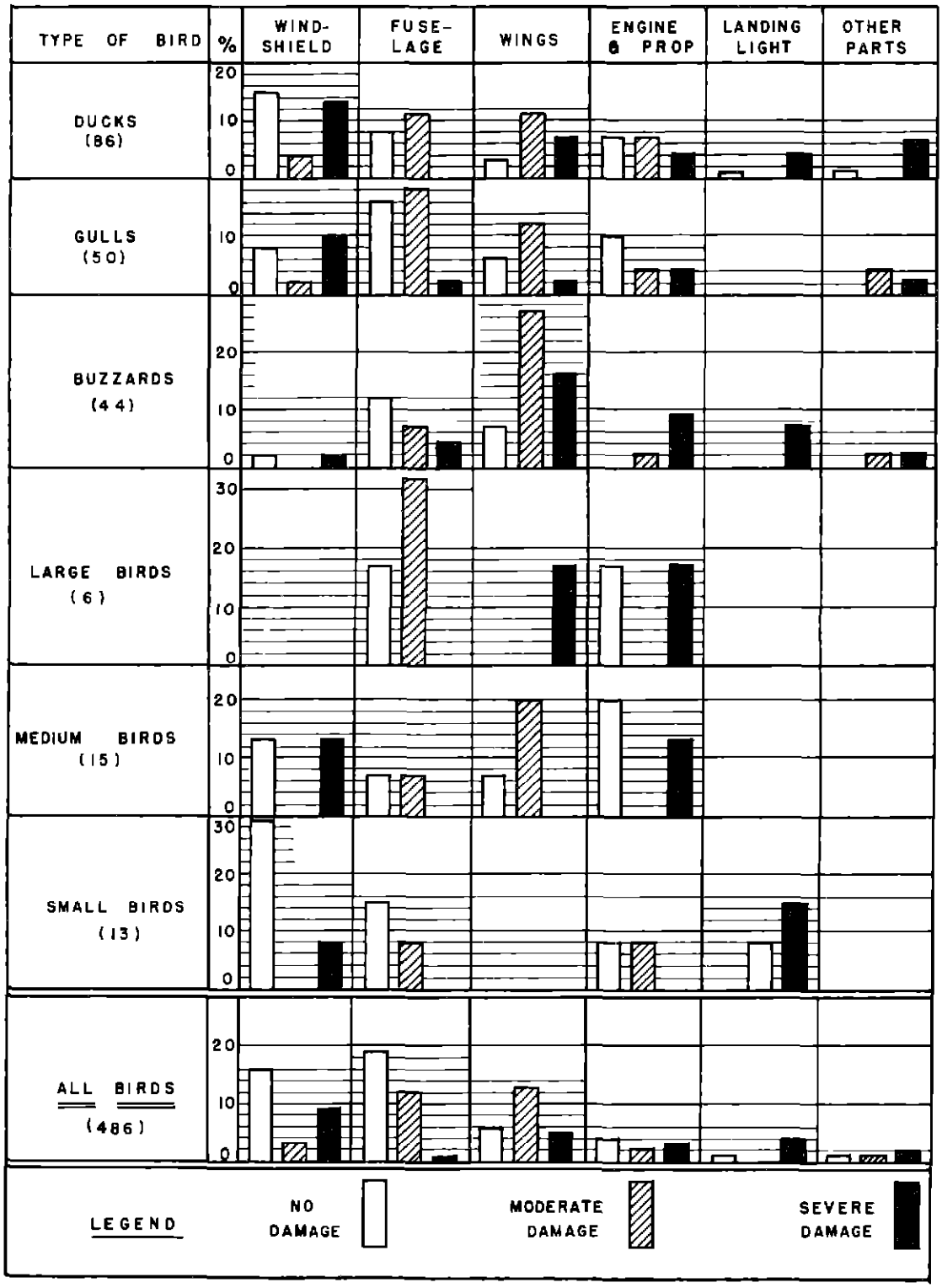

Fig. 8 Severity of Damage to Different Portions of the Aircraft Structure Caused by Various Types of Birds

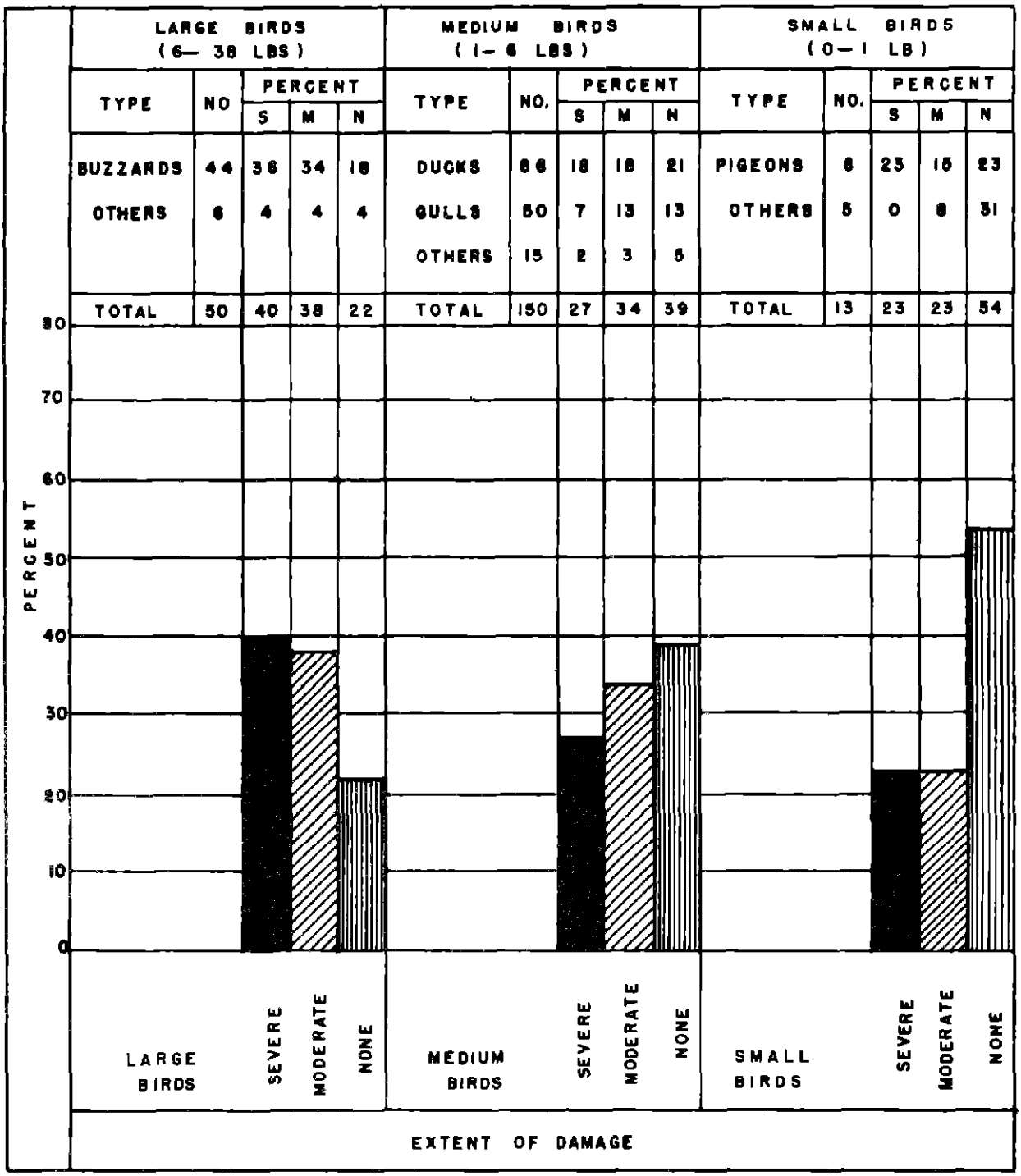

Fig 9 Severity of Damage to Aircraft Structures Caused by Birds of Various Weight Groups

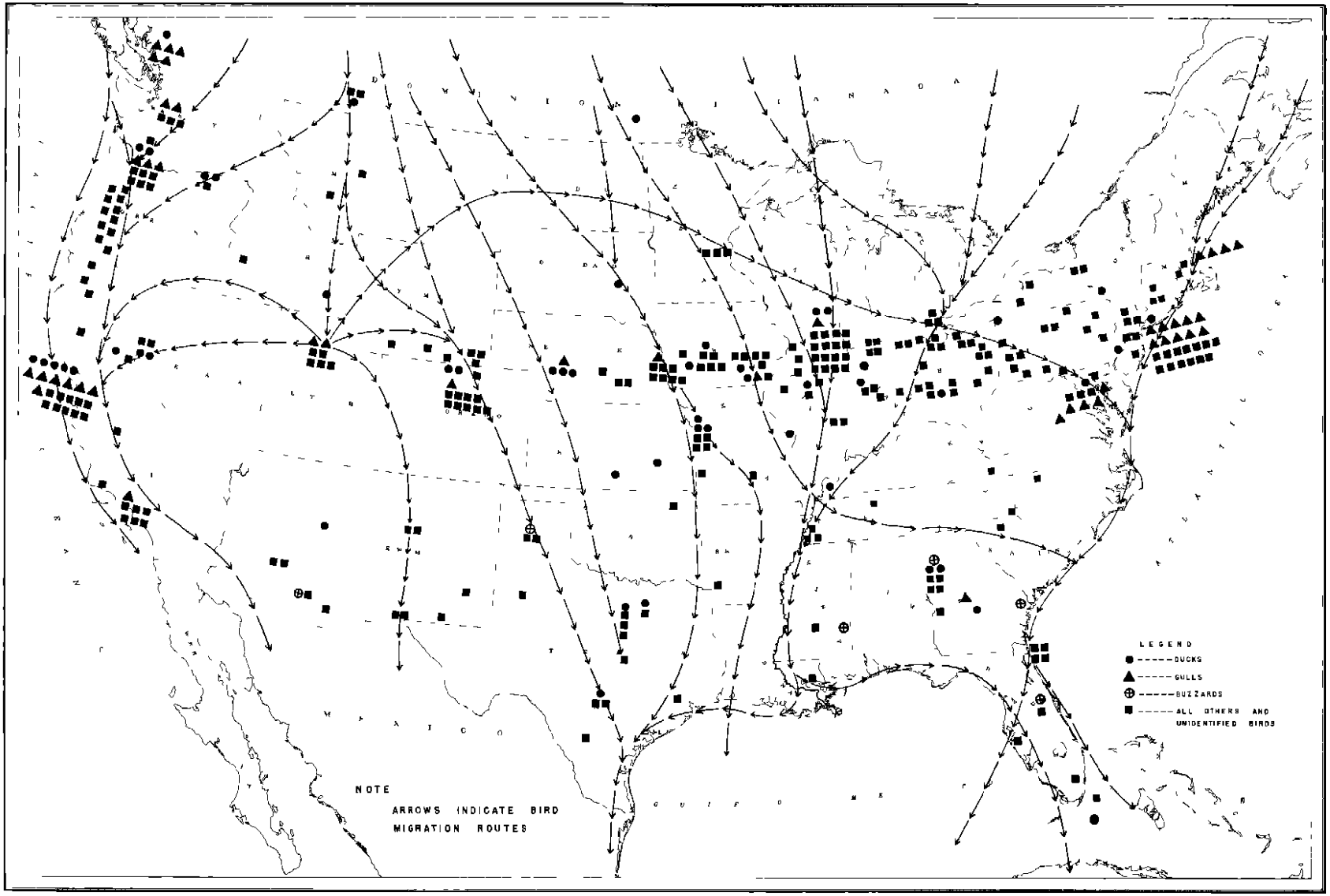

Fig 10 Geographic Distribution of Reported Bird Collision Accidents in the United States for Five Years (1942-1946)

10, many migration routes terminate at various points in the southern half of the United States and along the west coast where some varieties of northern birds remain during the winter season in large numbers

Examination of the migration pattern shows that the greatest concentration of moving migratory birds may be expected in the coastal regions, in the Great Lakes region, along the Mississippi and Missouri Rivers, across the northern states from Minnesota to Montana, and in the interior valleys of Oregon and California The bird wintering areas also are associated with concentrated local bird movements during the winter months

The location of recorded bird strikes are plotted in Fig 10 as closely as such locations are known In some instances only the route between two cities was reported for the strike location In such case the position of the strike is shown generally on the route indicated It also is probable that some strikes reported at one city and indicated in Fig 10 at the reported location actually occurred along an airway approaching the city, and only were confirmed and reported at that location.

A factor previously discussed concerning the completeness of reports submitted by one airline and the probable relative incompleteness of reports from other airlines should be particularly considered in connection with the data given in Fig 10 As one airline reported approximately 50 per cent of all recorded bird strikes shown, there is an artificial grouping of reported bird strikes along a central east-west line across the continent covered by operations of this company It is indicated that the relatively large number of bird strikes reported by this company is a result of more complete reporting, rather than an actual greater number of bird strikes occurring in this particular area of operation

An additional factor which should be considered in analyzing these data is the effect of variation in airway traffic density along different air routes It is to be expected that along routes of high traffic density, or around major cities where main traffic routes converge and where many landings and take-offs occur, a large number of bird strikes will be reported The existing probability of an individual airplane encountering a bird in this region may be no greater than at other portions of the country The present data have not been analyzed in this connection because of the relatively small number of data relating to certain geographical areas

The data given in Fig 10 show that the greatest number of reported bird strikes occur along the eastern coast from Washington, D C to Boston, Massachusetts, in a north-central band from Ohio through Iowa and Missouri, in the general Colorado and Utah area, and in the western portions of California, Oregon, and Washington A general scattering of strikes is found throughout the southern states with some concentration around principal air traffic centers. In the northwest border states few strikes have been reported

The geographical distribution of bird strikes shown in Fig 10 correlates reasonably well with the distribution of bird migration density, except for the small number of strikes found in the northwest border states and the southern Mississippi River area

Fig 10 also shows the geographical distribution of types of birds which were identified in collision reports Bird strikes involving ducks are not limited to any particular region of the country but occur in all areas However, as previously noted, the frequency of such strikes is apparently greater in localized regions of high bird-migration traffic

Bird strikes involving gulls occur almost solely in the northern half of the country, and there principally along the east and west coasts However, an appreciable number of collisions with gulls have been reported at interior portions of the country far from large bodies of water Only one gull strike has been recorded south of a line connecting Washington, D C and San Francisco, California

Most of the reported bird strikes in which buzzards were identified occur in Central and South America In the continental United States, the six bird strikes involving buzzards are limited to the extreme southern portion of the country The most northerly buzzard strike reported was in northern Texas

Three of the four reported strikes in the United States involving heavy birds, including geese, swans, and eagles, occurred in the western mountainous regions One such strike was reported on the lower

Mississippi River

Reports concerning other identified types of birds involved in airplane collisions, including hawks, mudhens, pheasants, and miscellaneous small birds, are too few in number to provide any significant conclusions regarding particular geographical areas where increased probability of such strikes might exist Strikes involving these miscellaneous birds are scattered fairly uniformly over the entire country

The general conclusions resulting from these data are that the probability of hitting all common types of birds is greatest in localized areas of high bird density during migration seasons, that ducks may be commonly struck at all sections of the country, that greater probability exists of hitting gulls in the northern half of the United States and particularly along the coastal areas, that strikes involving buzzards are limited to the extreme southern states and to Central and South America, and that bird strikes involving very large birds are more probable in the western mountainous sections of the country

DAY AND NIGHT DISTRIBUTION OF BIRD STRIKES

The data for bird strikes in which the type of bird was identified are shown in Fig 11, and are classified according to whether the strike occurred during hours of daylight or darkness

Eighty-one per cent of all identified ducks involved in aircraft collision were hit during hours of darkness, and 92 per cent of all identified buzzards were hit in daylight Gulls were struck more frequently during daylight hours in a proportion of three to two The average day and night distribution for all strikes reported is approximately equal for the two periods

A factor which should be considered in evaluating these data is the higher density of airplane traffic during daylight hours If the data given were weighted to include this factor, some increase in probability of night collisions would be shown

Although no breakdown of data has been made concerning the severity of accidents related to the daylight or darkness distribution, it appears that the most severe accidents have occurred at night. In particular, two-thirds of the collisions involving entire flocks of birds have occurred during hours of darkness Of twelve collisions with duck flocks, ten occurred at night, one at dawn, and one during daylight hours

The reasons for the distribution shown between collisions occurring during day and night undoubtedly are associated with the normal flying and migration habits of the various types of birds In the case of birds which commonly fly at night, the number of strikes may also be influenced by the reduced ability of the birds and the airplane to avoid collision during darkness Ducks normally fly at night during migration movements, and gulls most often are a day-flying bird.

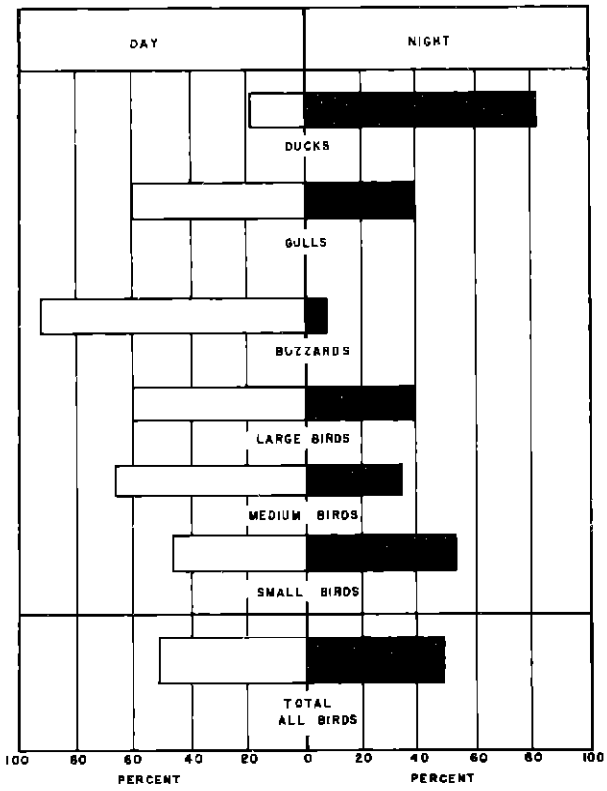

Fig 11 Distribution of Strikes Involving Identified Bird Types According to Occurrence During Daylight or Darkness

CONCLUSIONS

1 A total of 473 records of bird collisions with air carrier aircraft in scheduled operations, occurring from a period previous

to 1942 through 1946, have been obtained from reports furnished by airline operators.

2 The use of data obtained from one airline, which submitted a reasonably complete record of bird strikes occurring in its scheduled operations, indicates that all airlines together reported less than one-fourth of such strikes It is indicated further that the unreported strikes were of a slightly less serious nature with regard to damage incurred than the strikes which were reported

3 The data show that a bird may be expected to collide with some portion of the structure of an aircraft in scheduled air carrier operation each 759,000 miles of flight During 1946 this corresponded to one bird collision each 0 89 days

4 Approximately 28 per cent of all recorded bird strikes occur on the airplane windshield, and one-third of the windshield strikes result in severe cracking or penetration of the windshield panel

5 An additional 15 per cent of all recorded strikes on the airplane result in severe local damage to some portion of the aircraft structure other than the windshield Operational difficulties have resulted from such damage, including jammed carburetor airscoops, damaged control lines, and torn control surfaces

6 The greatest probability of encountering birds occurs during the spring and fall bird migratory seasons, and at elevations less than 2000 feet above local ground level

7 Ducks, with average weight of different species varying from one pound to approximately 5-1/2 lb, are most commonly hit Ducks are encountered at all portions of the country, at all normal flight altitudes of past air carrier operations, and principally during hours of darkness Collision with ducks on the airplane windshield usually causes severe damage

8 Gulls, with average weight of different species varying from approximately 2-1/2 to 4 lb, are the type of bird most commonly hit other than ducks Gulls are encountered principally in the northern half of the United States, and most commonly in coastal areas Gulls are struck most frequently at low altitude and during daylight hours Impact of gulls on the windshield usually results in severe damage

9 Buzzards, of average weight of 4-1/2 lb, are commonly hit by aircraft in South and Central America, and to some extent in southern portions of the United States Buzzards are struck at altitudes less than 4000 feet above local ground level and almost solely during daylight hours. Only two instances were recorded of buzzards striking the windshield, but severe damage was caused to wing and nacelle structures

10 A total of five collisions, or 1 1 per cent of all recorded strikes in the United States, was reported in which bird identification was established as a goose, swan or eagle Common varieties of these birds vary in average weight from 6 to 28 lb Although the number of reported collisions involving such birds is small, the probable severity of such collision is great

11 A total of 38 collisions, or eight per cent of all recorded strikes, involved an entire flock of birds, of which as many as six birds were struck simultaneously

12 No record exists of any fatality in air carrier operations in the United States caused by collision of aircraft with birds However, it has been suspected that several unexplained crashes were due to this cause, numerous fatalities occurred from bird collisions during military operations in the recent war, and bird strikes in commercial operations have resulted in serious damage to the airplane or injury to the pilot