AD-779 729

WINDSHIELD BIRD STRIKE STRUCTURE DESIGN CRITERIA

James H. Lawrence, Jr., et al

McDonnell Douglas Corporation

Prepared for:

Air Force Flight Dynamics Laboratory

October 1973

UNCLASSIFIED
Security Classification

AD779 729

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California	2a. REPORT SECURITY CLASSIFICATION: Unclassified; 2b. GROUP: N/A
3. REPORT TITLE: WINDSHIELD BIRD STRIKE STRUCTURE DESIGN CRITERIA	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates): Final Report (October 1, 1972 - October 20, 1973)	
5. AUTHOR(S) (First name, middle initial, last name): James H. Lawrence, Jr.; Murl J. Coker	
6. REPORT DATE: October 1973	7a. TOTAL NO. OF PAGES: ~~266~~ 260; 7b. NO. OF REFS: 72
8a. CONTRACT OR GRANT NO.: F33615-73-C-3030; b. PROJECT NO.: 4363; c. Item 0002-A001/A002; d.	9a. ORIGINATOR'S REPORT NUMBER(S): AFFDL-TR-73-103
	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report): None
10. DISTRIBUTION STATEMENT: Approved for public release, distribution unlimited	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY: Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

The purpose of this study contract was twofold. First, was to determine the inadequacies of existing bird impact design criteria for windshield/canopies and support structure. Second, was to establish recommended design criteria for future aircraft, particularly those involved in high speed-low level training missions. The methods used in this study were primarily that of collecting, examining, and selecting pertinent data from a multitude of sources on birds and their behaviour, aircraft/bird incidents, and aircraft design criteria. The large number of aircraft/bird collisions and their results; namely, loss of aircraft and flight crews graphically points out the inadequacy in current criteria applied to USAF aircraft. Extrapolation of data examined shows that the USAF can expect an average of 356 bird strikes annually with up to one-third of these on the crew enclosure. In sharp contrast is the performance of commercial aircraft certified to and operated within FAA requirements. Procedures are proposed for USAF aircraft designed to inadequate or no bird impact requirements. Of particular value are avoidance and alleviation techniques for reduction of the inviting bird environment surrounding airports, improved use of radar and other mechanical devices to predict/determine the presence of dangerous bird and/or flock sizes. Recommended design criteria for subsequent design of windshields/canopies and support structure are presented.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

260

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
BIRD AIRCRAFT STRIKES						
FLIGHT SAFETY						
RADAR DETECTION OF BIRDS						
ENVIRONICS						
PROBABILITY OF BIRD STRIKE						
AVOIDANCE						
BIRD POPULATION						
AIRPORT ECOLOGY						
AIRCRAFT DAMAGE						
WINDSHIELD/CANOPY						
DESIGN CONCEPTS						
FLIGHT PROCEDURE						
DESIGN CRITERIA						
BIRD IMPACT TEST						
STROBE LIGHTS						
BIRD STRIKE ALLEVIATION						

UNCLASSIFIED

Security Classification

☆U.S.Government Printing Office: 1974 — 758-434/547

WINDSHIELD BIRD STRIKE STRUCTURE DESIGN CRITERIA

James H. Lawrence, Jr.
Murl J. Coker

ib

FOREWORD

The research described in this report was performed by Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California, under the sponsorship and technical direction of the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base. The work was conducted under Contract F33615-73-C-3030, Project 4363.

This contract was part of the Air Force program to develop bird impact design criteria and to conduct the bird impact development testing program necessary for the safe operation of Air Force aircraft and for crew protection. This study was directed by Mr. C. Schmid, AFFDL/FBEB, with assistance from Mr. N. Loving and Mr. G. Muller as Project Engineers. The effort supports the overall Bird Impact Requirements program under the direction of Mr. R. W. Wittman and Capt. D. Chapin, AFFDL/PTW. This report covers work conducted between October 2, 1972 and August 1, 1973.

Mr. J. H. Lawrence was the Technical Manager for Douglas Aircraft Company. Principal investigators include Mr. M. J. Coker, Mr. F. P. Wang, Mr. J. C. Thomsen, and Mr. J. G. Potter - Structural Design and Mr. R. J. Caughey - Structural Analysis.

The authors are grateful to Mr. Max Kuhring, Mr. J. W. Noonan, Mr. W. J. Nemerever, Dr. V. F. Solman of Canada, Mr. N. New of Great Britain, Dr. J. Seubert of the U. S. Wildlife Services, Dr. B. Haines of the U. S. Navy Safety Center, Mr. C. McKinnon of the Flight Safety Foundation, Mr. J. T. Morris of the FAA, Mr. N. N. Shapter of the FAA - Air Frame Branch, and the Douglas Aircraft Company Librarians for supplying much of the pertinent data used in this program. Most of the USAF bird-aircraft incident data used in this study was obtained from the Directorate of Aerospace Safety, Norton AFB, California. Thanks are due to the directorate members, especially Col. P. P. Johnson, for their cooperation in making this data available.

This report was submitted by the authors on August 1, 1973.

This technical report has been reviewed and is approved.

Rodney A Bartholomew

R. A. BARTHOLOMEW, Major, USAF
Chief, Design Criteria Branch
Structures Division
Air Force Flight Dynamics Laboratory

TABLE OF CONTENTS

Pages iii and iv are Blank.

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

TABLES (Continued)

SECTION I

INTRODUCTION

Bird hazards to high speed aircraft have become one of the major flight safety problem areas of the jet age. The chances of hitting a bird while flying over the North American continent are great because of the vast populations and species of birds. Although breeding in the Arctic tundra or large areas of Alaska and Canada, and wintering in the more temperate climates of the United States, Central and South America, large numbers fly the intervening routes.

Birds generally migrate twice a year in a North-South direction and aircraft quite often fly East-West missions which cross bird migration pathways. Further, the airport perimeter is replete with sources of food and attractive lodging. Consequently, these situations supply almost limitless opportunities for aircraft/bird collisions to occur.

The purpose of this study program was to determine the adequacy of existing windshield bird-impact design criteria relative to existing and future low-level, high speed missions. Generally, it was concluded from the study that the existing criteria was found to be inadequate except for commercial aircraft certificated to FAA bird impact requirements and conservatively flown at reduced speeds below 10,000 feet.

The program was directed toward evaluating a significant segment of the copious worldwide information pertinent to cause and effect relationships of the bird hazard to aircraft.

Section II presents detailed information on the bird species involved in collisions with aircraft. Thirty-two birds were identified in various Air Force and commercial aircraft/bird incident reports occurring in CONUS, but in many cases only a generic identity was made, such as "duck". Thus, this study includes a detailed examination of 200 species. It was found that twenty billion birds, representing over six hundred species, frequent the United States.

Worldwide incident reports were collated, analyzed, and succinct studies of data obtained were conducted and developed in Section III. Included were descriptive statistical presentations establishing the relationship of the vulnerability of aircraft components to bird strikes, the frequency of strikes, phases of flight and critical altitudes at which strikes occur, bird weights, aircraft speeds, and the anticipated monthly impact rate.

Section IV includes predictable and probability studies to establish bird strike predictions per million flight hours, predictions for determining the frequency of strikes on windshields/canopies and support structure, normal distribution statistical studies to determine an acceptable bird weight required for design criteria, and the Poisson's statistical distribution to predict bird strikes by bird weight per altitude range for a five-year period.

Many aircraft in the current USAF inventory were not designed to meet bird impact requirements. These aircraft offer only marginal protection of the flight crew against bird impact and some are single-engine aircraft susceptible to engine bird ingestion. In Section V, four distinct procedures were developed, which, when implemented, would greatly reduce the bird strike frequencies for these aircraft.

In an endeavor to enhance the successful design of subsequent windshields/canopies and support structure, Section VI identifies recommendations for future design criteria. Inclusive in Section VI are critical parameters necessary for evaluating subsequent designs, verification testing, unique testing requirements and operational requirements. Since the forces associated with the impact of birds are of such great magnitude, precise failure mechanics methodology has been illusive. An initial attempt was made to show the relationship between the various weights of birds impacting the windshield/canopies and support structure at various speeds, and the resulting peak impact forces.

In Section VII a summarization is presented to show the effect of changes to airports that can reduce the attractiveness to birds. Since at least 50% of the aircraft/bird incidents occur during takoff/landing, these bird strike alleviation techniques could greatly reduce the frequency of these strikes.

Section VIII presents a summarization of programs that have been accomplished and directed toward bird collision avoidance techniques. Potentially, the development of these techniques could reduce the frequency of bird strikes up to 50% of the total strikes. Programs include strobe lights, microwave techniques, and the extensive use of radar systems.

The salient points of this study program were combined in Section IX to show how these broad relationships could be implemented in the design of future USAF aircraft. Pertinent discussions were presented on: the risk of not designing future crew compartments for bird impact; critical factors related to designing for bird impact; recommendations for the establishment of safe speeds for bird impact on production type windshields/windows; bird impact verification testing and associated costs; consideration for the installation of mechanical devices for bird avoidance; and the protection of components other than windshields which are vulnerable to bird impact.

Conclusions and recommendations based on this study are noted in Section X.

SECTION II

THE PHENOMENA OF SELECTED BIRDS IN THE CONTINENTAL UNITED STATES

The endeavor to define bird impact design criteria for windshield/canopy and support structure to a high degree of confidence must necessarily start with a study of the phenomena of birds.

It has been determined that there are over 600 species of birds that are resident or migratory in North America as observed north of the Mexican border. This estimated bird population of these 600 or more species is 20 billion as noted in Reference 6.

For this study the most recent annual F.A.A. and U.S.A.F. aircraft incident reports of aircraft/bird collisions were selected to determine the identification of those birds struck. A study of three years of aircraft incidents for the fleet of U.S.A.F. B-52 airplanes flying training missions within the continental United States were selected for comparative purposes to represent additional flight conditions.

From these aircraft incident reports, the birds that were identified and the frequency of collisions is noted in Table I.

In an effort to gain insight and an overview of associated bird problems, the works of ornithologists, biologists, wildlife research specialists, the Audubon Society. and others were extensively reviewed for pertinent information. Subsequent paragraphs present these findings in abstract format. Unless noted by other reference, the bird weights were obtained from the National Research Council of Canada Field Note No. 51 (Reference 5). The identification and migration of birds was determined from "Birds of North America" (Reference 6). The population densities were obtained from the works of Seaman (Reference 7), Bellrose (Reference 8), and the best estimate obtainable from the Wildlife Research Center.

The bird incident reports usually identified the bird involved by a general name such as "duck". In this study all of the species were studied to determine all of the peculiarities. As an example, under "ducks"

Preceding page blank

it was found that 34 species frequented the continental United States.

The species of birds studied are presented in the sequences noted in Table I and there was no attempt to categorize the species by their Orders.

TABLE I

IDENTIFIED BIRDS INVOLVED IN AIRCRAFT COLLISIONS

BIRDS' NAMES NOTED IN INCIDENT REPORTS	NUMBER OF BIRD STRIKES			
	FAA Commercial Aircraft '71-'72	USAF 1972	USAF B-52 Aircraft '65-'67	Totals
Gulls/Terns	57	25	9	91
Ducks	19	18	27	64
Buzzards/Vultures	8	13	9	30
Hawks/Falcons	13	11	7	31
Pigeons/Doves	23	5	0	28
Geese	9	2	11	22
Robins	3	-	8	11
Herons/Storks/ Egrets	1	4	3	8
Owls	4	3	1	8
Blackbirds	3	4	2	9
Starlings	5	2	2	9
Larks	2	4	-	6
Sparrows	3	1	-	4
Cranes	3	1	-	4
Pheasants	3	-	-	3
Crows	-	1	1	2
Pelicans	-	1	-	1
Eagles	1	-	-	1
Frigate Birds	-	1	-	1
Loons	1	-	-	1
Plovers	1	-	-	1
Curlews	-	1	-	1
Sandpipers	3	-	-	3
Puffins	1	-	-	1
Thrushes	1	-	-	1
Wilson Snipes	-	1	-	1
Veerys	-	1	-	1
Bats	1	9	-	10
Albatrosses	6	2	-	8
Totals	171	110	80	361
REFERENCES:	1, 2	3	4	

Gulls are sea birds of the Order Charadriiformes, Family Laridae, and are probably one of the most adaptable birds in existence.

There are 44 species of gulls throughout the world, (Reference 9), with as many as fifteen of the species that live and breed in the Continental United States. The species located in the United States range in size from the Great Black-backed Gull (Larus marinus), maximum weight four pounds, to the Mew Gull (Larus canus), minimum weight 2/3 pound.

It is believed that gulls have a potential life span of fifty years and upward (Reference 10).

Generally when gulls are in flight they take advantage of updrafts and eddy currents and often glide motionless in a thermal current when flying to their nightly roosting areas.

Most gulls have variable diets for which foods are conveniently available, including small fish, clams, oysters, dead fish, garbage, animals such as rabbits and rodents, worms and insects. The Black-backed Gulls are also predators and eat the eggs and young of other gulls, as well as the Shearwater and Puffin birds.

Generally gulls breed on prairies or marshes. They occasionally nest in trees and more recently have begun nesting on ledges of buildings.

An estimate of the total number of gulls that frequent the Coastal Regions and breed in the United States could easily reach one and one-half million at peak periods. This estimate is based on extrapolations of studies conducted by Cogswell in the San Francisco Bay area and by Drury and Nisbet in the New England area.

Cogswell (Reference 11), started a study of the 123-mile shoreline of South San Francisco Bay area and 200-mile North Bay area in July 1968 to determine the number of gulls frequenting the area. In the Bay Region are five major airports including Moffett Naval Air Station, Travis Air Force Base and the Alameda Naval Air Station. In this area there are 15 garbage disposal sites and 10 sites where rubbish only is handled. By actual counts there would be approximately 2000 gulls feeding at each garbage site and another 10,000-15,000 loafing or bathing in the nearby areas. It was estimated that a total of 145,000 gulls were in the area in mid-December and declined to approximately 3600 in June. There were seven gull species noted in the peak period of December including Herring, Glaucous, Glaucous-winged, California, Bonaparte's, Ring-billed and Western Gulls. After the migrations were completed in July, only the California, Western, and Ring-billed Gulls remained.

Drury and Nisbet (Reference 12), conducted a study in 1969 of the Herring Gulls along the New England, Atlantic and Gulf Coast areas and determined that the count was approximately 700,000 and doubles every 12 to 15 years. The doubling of Herring Gulls has taken place regularly since 1900 with no indication of this rate lessening.

Considering these two studies as a basis for an estimate, the total number of gulls during fall, winter, and spring months could easily reach one and one-half million for all fifteen species. It can be concluded also that Herring Gulls and Glaucous Gulls account for over a million in this estimate. A bird in these species may weigh approximately four pounds.

All gulls colonize, but when traveling, their flights are random and in small groups. The distributions of gulls throughout the United States are shown in Figures 1 through 7.

Western Gull (Larus occidentalis) - Weight maximum is 4 pounds; (Reference 13); wing span of 55 inches; a permanent resident along the coast.

Glaucous-winged Gull (Larus glaucescens) - Weight average is 2 pounds; winters along coast only.

Heermann's Gull (Larus heermanni) - A small gull that resides along the coast except in spring breeds on offshore islands.

Mew Gull (Larus canus) - The smallest gull, weighing an average of 2/3 pound and a maximum of one pound; in-flight the density is approximately 5/1000 cubic feet; winters along the coast only.

California Gull (Larus californicus) - Slightly smaller than the Herring Gull; resides along the coast except breeds inland in northeastern California, northern North Dakota, and Canada.

Black-legged Kittiwake (Rissa tridactyla) - A small gull that winters off the West Coast and New England Coast; generally follow ocean steamers.

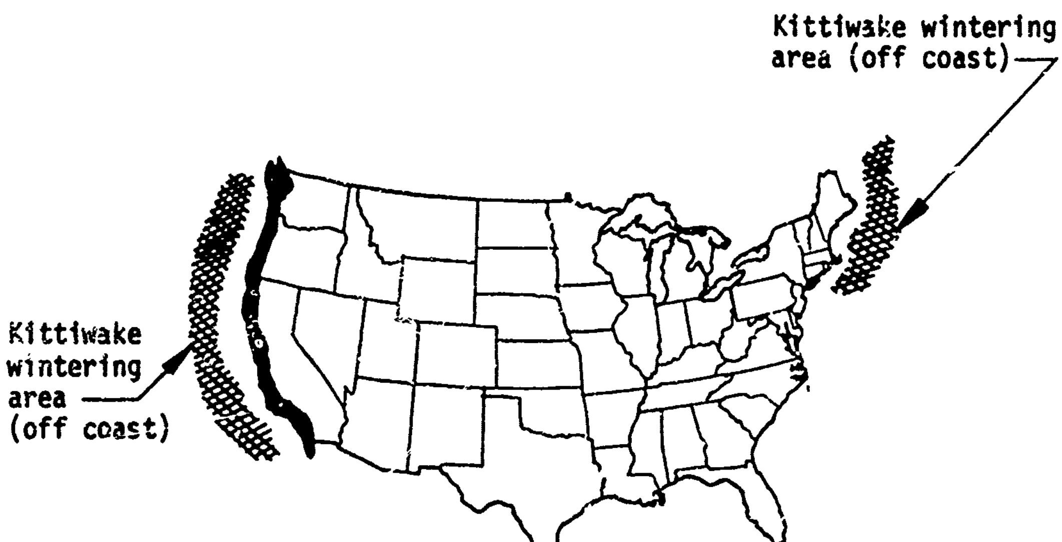


FIGURE 1

Gulls Frequenting the West Coast Only

Ring-billed Gull (Larus delawarensis) - Weight average is 1-1/2 pounds. Winters along both coasts and the Great Lakes; breeds in Oregon, Colorado, North Dakota, and Wisconsin.

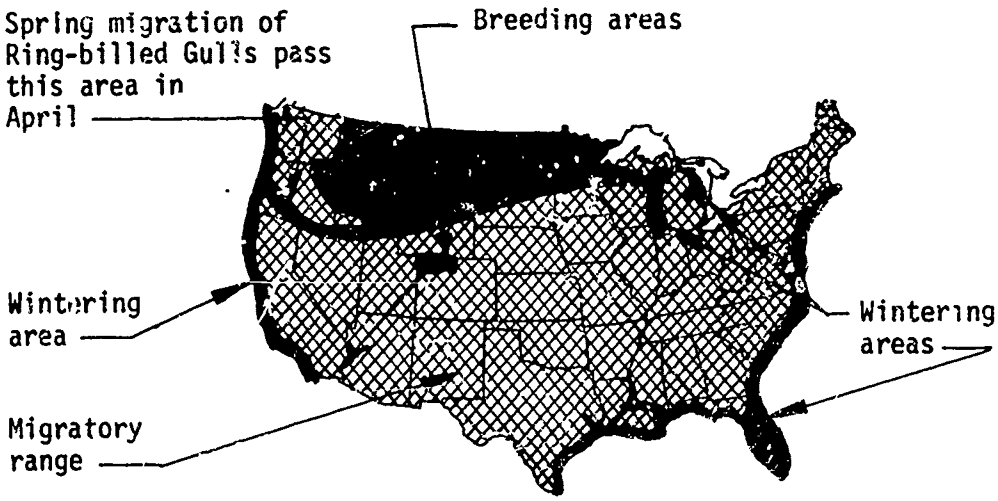


FIGURE 2

Distribution of Ring-billed Gull

Franklin's Gull (Larus pipixcan) - Commonly referred to as Gull of the Prairie; feeds on insects and fishes streams and lakes; winters from Gulf Coast of Texas and Louisiana into South America; breeds in South Dakota, Iowa, and Minnesota. The average weight is approximately the same as the Mew Gull which is 2/3 of a pound.

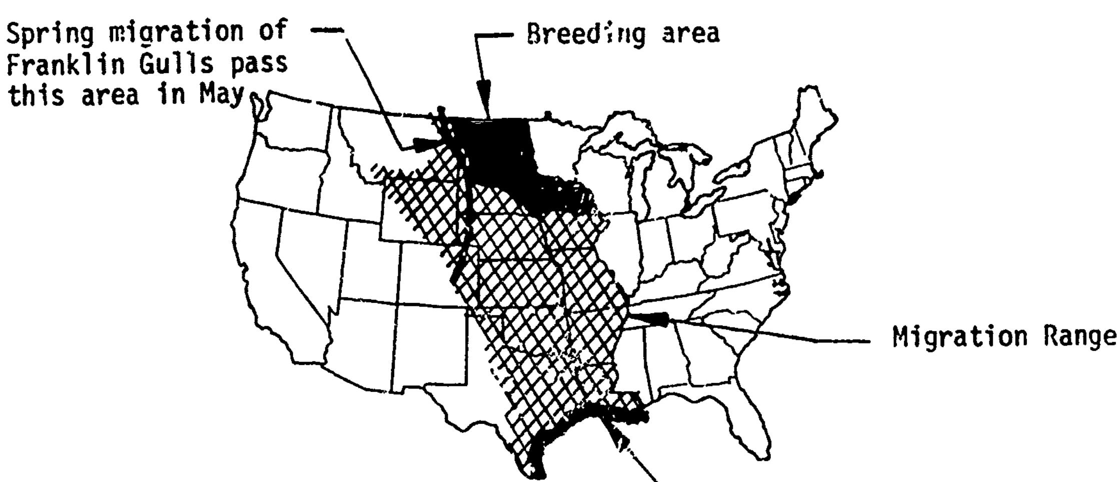


FIGURE 3

Distribution of Franklin's Gull

Herring Gull (Larus argentatus) - Minimum weight of 2-1/2 pounds to maximum weight of 4 pounds; in flight the density is 2/1000 cubic feet; is most common gull with upward of one million in the United States at peak periods; moults in fall; may nest in Maine and upper New York. During migration those that mate in Labrador do not arrive there until after May 1.

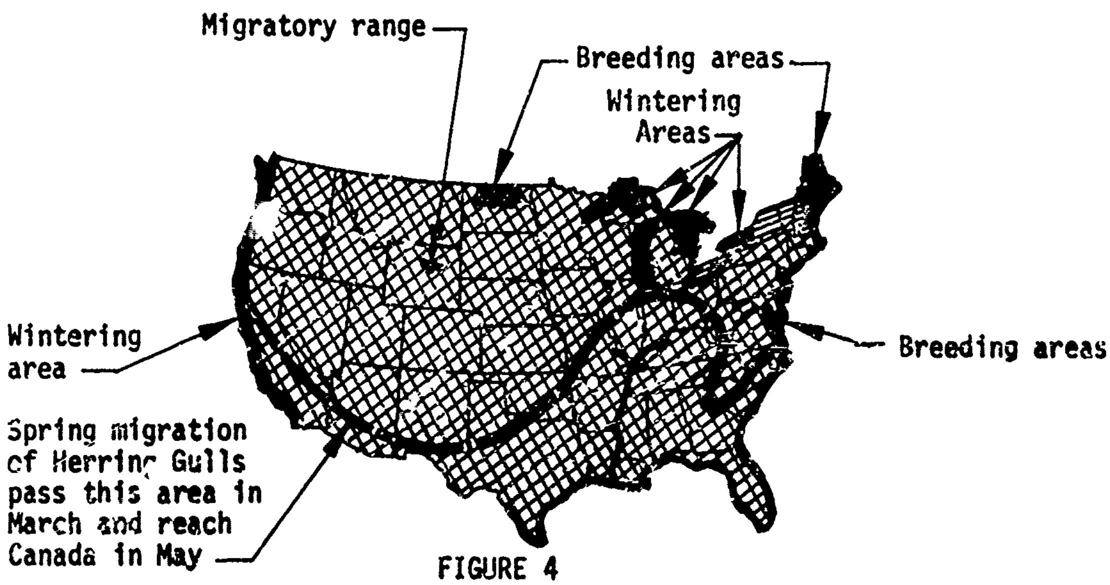


FIGURE 4

Distribution of Herring Gulls

Laughing Gulls (Larus atricilla) - A small gull, seldom found far from salt water; occasionally feeds on insects and worms. Common along Gulf Coast

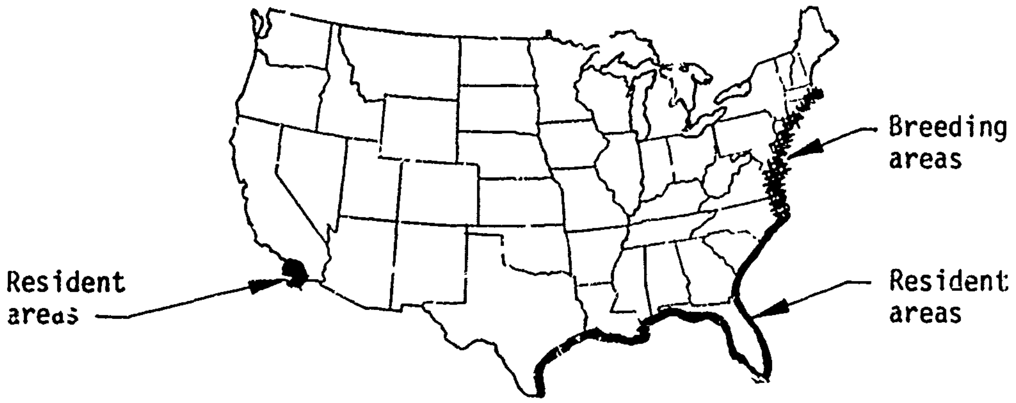


FIGURE 5

Distribution of Laughing Gulls

Boneparte's Gull (Larus philadelphia) - Is a small gull; breeds in Canada and Alaska; eats insects, earthworms, and crustaceans; winters from Maine to Florida and on the West Coast.

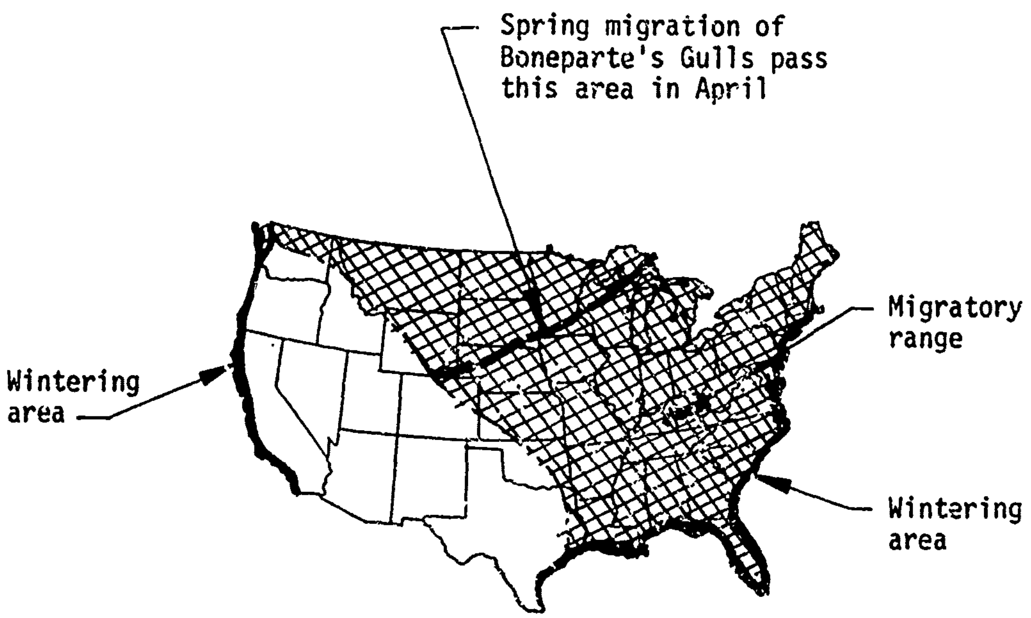


FIGURE 6

Distribution of Boneparte's Gull

Great Black-backed Gull (Larus marinus) - The largest gulls, has wing span of 65 inches; in addition to regular diet is also a predator of other gulls, birds and small animals; winters along East Coast and Great Lakes area: rapidly increasing in numbers; when traveling the density is approximately 2/1000 cubic feet.

Glaucous Gull (Larus hyderboreus) - Slightly larger wing span than the Herring Gull with 60 inches span; travels with Herring Gulls; winters in Great Lakes area, Long Island, New York and occasionally Monterey, California; nests on small islands in far north, occasionally follows ocean vessels.

Iceland Gull (Larus glaucoides) About the same weight as the Herring Gull (4 pounds); winters along the New England Coast; the number of birds is small.

FIGURE 7

Gulls Common to the East Coast

Ducks are waterfowl of the Order Anseriformes, Family Anatidae, and are divided into five subfamilies. It has been estimated that there are 90 million ducks that migrate through the United States in the fall.

Surface-feeding ducks are the first of the five duck subfamilies (Anatinae) that consists of thirteen species in the continental United States. They obtain their food from shallow rivers, lakes or marshes. As a general rule these ducks number 40 to 50 in a flock. Generally, they nest on the ground, usually under tall bushes, grass or marsh grasses hidden from view. Their eggs number four or five to a dozen or more. When these ducks take flight from the water it is almost straight up. The 13 species are the following:

Mallard (Anas platyrhynchos) - Average weight is 2.3 pounds; maximum weight is 4 pounds; wingspread is 36 inches; and when migrating the flock density is 17/1000 cubic feet. Historically, Mallards have been a source of countless tons of food for thousands of years to mankind. Mallards feed on grass, seeds, aquatic plants, grain, nuts, acorns, fruits, and wild rice. They also feed on crayfish, flies, grasshoppers, beetles, bugs, mollusks, earthworms and crustaceans.

Mallards are often found with Black Ducks and Pintails. Mallards are found throughout the United States during winter, and breed in Washington, Idaho, Montana, Wyoming, North Dakota, South Dakota, Wisconsin, Michigan, Ohio, New York, Indiana, Illinois, Pennsylvania, Vermont, New Hampshire, Massachusetts, Connecticut, and New Jersey. Mallards are the most abundant species found in the Mississippi Valley.

Mexican Duck (Anas diazi) - Rare and local resident in upper Rio Grande Valley into New Mexico. Weighs less than 3 pounds; resembles the female Mallard in coloring and marking; likes same surroundings as the Mallard.

Black Duck (Anas rubripes) - Average weight is 2.4 pounds; maximum weight is 3-1/2 pounds; wingspread is 36 inches. The most abundant surface feeding duck in the eastern half of the United States. Its habitat and food is the same as that of the Mallard. It breeds in the states surrounding the Great Lakes and in the New England States. These ducks feed at dawn, dusk and during the night.

Mottled Duck (Anas fulvigula) - Smaller and darker than the Mallard. Mottled Ducks use the same marshes as Mallards and Black Ducks along the coasts of Texas, Louisiana, Mississippi, and lower Florida where the Mottled Duck is a resident.

Pintail (Anas acuta) - Average weight is 1.8 pounds; maximum weight is 3.4 pounds; wingspread is 35 inches; during migration flocks are huge and the flock density is 5/1000 cubic feet. The most widely distributed duck in the continental United States during the winter. Its habitat and food is similar to the Mallard. It breeds in the Northwestern States from Minnesota and Iowa to the West Coast States of Washington, Oregon and Northern California on lakes, ponds, and bays.

Gadwall (Anas strepera) - Average weight is 1.2 pounds; maximum weight is 3.0 pounds; wingspread is 35 inches; rarely congregates in large flocks; the most cosmopolitan of all ducks. The Gadwall is uncommon and when found may be seen with Pintail and Widgeon Ducks. It is a resident along the coastal regions of California, Oregon and Washington; also breeds in Idaho, Wyoming, Montana, North Dakota, and Nebraska; winters in the Southern States from North Carolina, across the lower Gulf States to California.

American Widgeon (Mareca americana) - Average weight is 1-1/2 pounds; maximum weight is 2-1/2 pounds; wingspread is 34 inches; feeds on aquatic vegetation and occasionally eats shoots of grains and grasses on shore. American Widgeons are common and fly in tight flocks rather than long open V's notable of other ducks. Other than during breeding season, they congregate in large flocks. They breed in the Northwest quadrant of the United States; winter along Atlantic Coast from New Jersey to Florida, and the lower states, and along the West Coast; they start their northern migration in March.

European Widgeon (Mareca penelope) - Is slightly smaller than the American Widgeon. Regular fall visitor along Atlantic Coast, Mississippi River, and Pacific Coast. Usually occurs in small numbers.

Shoveler (Spatula clypeata) - Average weight is 1.3 pound; maximum weight is 2 pounds; wingspread is 31 inches; found mainly in ponds and flooded marshes. The species is common and abundant; winters in Florida, states along the Gulf Coast, Texas, New Mexico, Arizona, and the states along the Pacific Coast. Breeds in Northwestern States.

Blue-winged Teal (Anas discors) - Rather common; average weight is 0.8 pound; maximum weight is 1.3 pounds; wingspread is 24 inches; less able to endure cold than the Green-winged Teal; flies rapidly in small tight flocks. Winters along Gulf Coast in Florida, Alabama, Mississippi, Louisiana, and Texas. Breeds in all Northwestern States from Lake Huron, west, and has become a permanent resident in Louisiana. Likes shallow ponds, marshes, meadows, bogs and will frequent mudholes where it finds food.

Cinnamon Teal (Anas cyanoptera) - Common only in Southwestern and Pacific Coast States. Likes the same surroundings as the Blue-winged Teal. Tends to be a resident in the lower portions of California, Arizona, New Mexico, and the western portion of Texas. Birds that do migrate go farther into Mexico and Central America. Breed as far north as Washington, including states of Oregon, Idaho, Nevada, Montana, Wyoming, Utah and Colorado. At times they are more prevalent in Oregon than the Mallard and Pintail.

Green-winged Teal (Anas carolinensis) - The smallest surface-feeding duck; average weight is 3/4 pounds; maximum weight is 1.0 pound; wingspread is 24 inches; flies fast in tight flocks. In winter prefers fresh water to salt water. It winters from Virginia to Florida, throughout the Gulf States, New Mexico, Arizona, Colorado, lower California and Utah. It is a resident of Northern California, Oregon, Washington, Nevada, Idaho, and Utah. It breeds in summer in the Northern States westward of Lake Superior. Its foods are similar to those of the Blue-winged Teal, but also likes soaked rice, oats, berries, grapes, and nuts.

Wood Duck (Aix sponsa) - Is common in open woodland around lakes and along streams; average weight is 1-1/2 pounds; maximum weight is 2 pounds; builds nests in hollows of trees. The resident group of Northern California, Oregon and Washington do not migrate. The resident group along the Gulf Coast from Florida to Texas do migrate. Wood Ducks are found breeding in all states east of the Mississippi. They feed on plants, acorns, insects, and food from ponds and marshes. The Wood Duck is peculiarly a continental United States bird.

Tree ducks are the second subfamily (Dendrocygninae) of ducks and consists of two species. Feeding occurs at night. Their foods include corn, other seeds, acorns. Tree ducks do not dive. The two species are the following:

Fulvous Tree Duck (Dendrocygna bicolor) - Common in marshlands along the coasts of Mississippi, Louisiana, Texas, and lower California. It probably weighs upward to 3 pounds and has a wingspread of 36 inches. Seldom seen because of nocturnal feeding habits. Rarely perches in trees and never nests in trees.

Black-bellied Tree Duck (Dendrocygna autumnalis) - Common during breeding season to the lower end of Texas. It is found with the Fulvous, but usually in more wooded areas. Perches in trees and sometimes nests in hollows of trees or on branches. It probably weighs up to 3 pounds and has a wingspread of 37 inches.

Bay ducks are the third subfamily (Aythyinae) of ducks that winters along coastal bays, river mouths, and lakes. The bay ducks dive and swim under water, whereas the surface-feeding ducks do not. They also eat more animal food, mollusks, and are partial to roots and shoots of aquatic plants. There are eight species, as follows:

Redhead (Aythya americana) - Winters in tidewaters along coastal states of the Atlantic and Pacific Oceans and the Gulf of Mexico. It is common; average weight is 2.2 pounds; maximum weight is 3 pounds; has a wingspread of 33 inches. It breeds in North Dakota, South Dakota, Wyoming, Montana, Nebraska, Colorado, and Washington. It mixes with other bay ducks to form flocks of several hundred birds. As many as 22 eggs have been found in a nest. It includes in its diet small fish and other small marine life.

Canvasback (Aythya valisineria) - Is an abundant species; winters more in saltier water than the Redhead Duck; average weight is 2.6 pounds; maximum weight is 3-1/2 pounds; wingspread is 34 inches. It mixes less with other ducks, but often is found near them. Winters along the Atlantic and Pacific Coast and States along the Gulf of Mexico. It breeds in the Northwestern States and is one of the most hardy birds because it will not start its winter migration until the water freezes. It includes in its diet spicy wild celery.

Ring-necked Duck (Aythya collaris) - Common in woodland ponds; in winter more confined to fresh water than other bay ducks; average weight is 1.5 pound; maximum weight is 2.4 pounds; and wingspread is 28 inches. It does not travel in large flocks. Being an expert diver it captures minnows, crawfish, tadpoles, snails and frogs for food to supplement its diet of aquatic plants and seeds. It winters in Maryland, Virginia, North and South Carolina, Florida, Georgia, Alabama, Mississippi, Tennessee, Louisiana, Arkansas, Texas, New Mexico, California and Oregon. Breeds in Wisconsin, Minnesota, and Michigan.

Greater Scaup (Aythya marila) - Locally common in ponds, marshes, and lakes; average weight is 2.0 pounds; maximum weight is 3 pounds; wingspread is 31 inches; and during migration the flock density is 8/1000 cubic feet. Winters along the Atlantic, Pacific, and Gulf Coasts and in New York State.

Lesser Scaup (Aythya affinis) - Abundant; smaller than Greater Scaup; weight is probably upward to 2.5 pounds; and wingspread is 29 inches. Winters inland from Atlantic, Pacific and Gulf Coasts, up the Mississippi to Indiana, Southwest Texas, New Mexico, and Arizona. Breeds in Northwestern States from Lake Superior, west.

Common Goldeneye (Bucephala clangula) - Common in lakes and rivers in forested country; it nests in hollows of trees; average weight is 1.8 pounds; maximum weight is 3 pounds; wingspread is 31 inches; and when migrating the flock density is 8/1000 cubic feet. It winters in nearly all continental United States. It breeds in New England States above Massachusetts, Michigan, Wisconsin, and Minnesota.

Barrow's Goldeneye (Bucephala islandica) - Resembles the Common Goldeneye but generally has blacker sides; average weight is 1-1/2 pounds; maximum weight is 3 pounds; and wingspread is 31 inches. It is a common resident of Washington, Oregon, California, Montana, Wyoming, Idaho, and Utah. Winters on West Coast, and a group migrates down from Iceland and winters along coasts of New England States above New Jersey.

Bufflehead (Bucephala albeola) - Common in tidewaters; generally found in loose flocks; average weight is 0.7 pound; maximum weight is 1.3 pounds; and wingspread is 24 inches. It winters in all continental United States except the central Northern States. It is a resident of Washington, Oregon and California.

Sea ducks are also a subfamily (Aythyinae) similar to bay ducks except that they winter only along coasts and are rarely seen inland. In winter they usually appear in large flocks of mixed species. They mostly feed on mollusks. The seven species are the following:

Harlequin Duck (Histrionicus histrionicus) - Uncommon; winters along rocky coasts in heavy surf; probably weighs less than 2 pounds; and wingspread is 26 inches. Mussels are included in its diet. Winters along New England Coast and Pacific Coast. Breeds in mountainous areas of Washington, Oregon, Idaho, Montana, Wyoming and Utah.

Common Eider (Somateria mollissima) - The largest duck to frequent the continental United States; abundant but winters so locally (off Chatham, Mass., and rarely at other coastal locations) that the number should be considered negligible; average weight is 2-1/2 pounds; maximum weight is 4-1/2 pounds; wingspread is 41 inches; when migrating the flock density is 8/1000 cubic feet, but usually flies only a few feet off the water.

King Eider (Somateria spectabilis) - Rare in the continental United States; is similar to Common Eider except smaller; probably weighs less than 4.5 pounds; and wingspread is 37 inches. When seen in winter it is along upper New England coastal states and along the coasts of Washington and Oregon.

Oldsquaw (Clangula hyemalis) - Abundant within its range; average weight is 1-1/2 pounds; maximum weight is 2.3 pounds; wingspread is 30 inches; it migrates chiefly at night and the flock density is 10/1000 cubic feet. During winter it frequents the coasts along the Great Lakes, and along the Pacific down to California. Several thousand of these birds congregate during spring along the coasts of North Carolina. Their food consists mainly of shellfish and crustaceans.

Common Scoter (Oidemia nigra) - Abundant within its range, probably weighs less than 3 pounds since it is about the size of a Mallard; the wingspread is 33 inches. It winters along the Atlantic Coast down to North Carolina and along the Pacific Coast down to Mexico.

White-winged Scoter (Melanitta deglandi) - Often abundant; probably weighs less than 4 pounds; wingspread is 38 inches; and found in mixed flocks. On water rides in tight flocks, in loose flocks for flights of short distances, but during migration is in line and there may be as many as 100 in the line. It is a hardy bird and may not nest until early July. It winters along the Atlantic Coast down to North Carolina, along the Great Lakes and the Pacific Coast down to Mexico. It breeds in Montana and North Dakota.

Surf Scoter (Melanitta perspicillata) - Locally common; probably weighs less than 2.5 pounds; it has a wingspread of 33 inches. It winters along the Atlantic Coast down to South Carolina and along the Pacific Coast down to Mexico.

Stiff-tailed ducks are the fourth subfamily (Oxyurinae) that are small and stubby and when swimming their tail feathers point upwards. Consist only of the following two species:

Ruddy Duck (Oxyura jamaicensis) - Common in most of the continental United States particularly during migratory periods. Is a small duck probably weighing less than 2 pounds that has a wingspread of 23 inches. Winters along the Atlantic, Pacific and Gulf Coasts and the States bordering Mexico. Breeds in Minnesota, North and South Dakota, Nebraska, Montana, Wyoming, Colorado, Utah, Idaho, Washington, Oregon, Northern California and Nevada.

Masked Duck (Oxyura dominica) - Uncommon; small duck, probably weighing less than 2 pounds; has a wingspread of 20 inches. Nests in trees and is found only in Gulf States during the summer months.

Merganser ducks are the fifth subfamily (Merginae) that is comprised of 3 species. They have comparatively long narrow bills, whose saw-toothed edges enable the birds to devour fish of considerable size. The three species are the following:

Common Merganser (Mergus merganser) - Common, fresh water species; average weight is 2-1/2 pounds; maximum weight is 4 pounds; and during migration the flock density is 6/1000 cubic feet. Birds of this species nest in hollow trees and are so hardy they are seen in lakes that are nearly frozen over in areas that are difficult to freeze. They frequent most states except lower Texas and the Southern States. They are a resident of Washington, Oregon, California, Colorado, Indiana, Michigan, New York, Vermont, New Hampshire and Maine. They also breed in Wyoming, Montana and Idaho.

Red-breasted Merganser (Mergus serrator) - Common, probably weighs less than 3 pounds, and has a wingspread of 33 inches. A swift silent flyer and a fast diver. Winters along Atlantic, Pacific and Gulf Coasts, around the Great Lakes, and states bordering Mexico. May breed in upper Michigan.

Hooded Merganser (Lophodytes cucullatus) - Uncommon; average weight is 1 pound; maximum weight is 2.0 pounds; has a wingspread of 26 inches. Where found it will be seen on wooded fresh-water lakes and streams in states bordering the Atlantic from New Jersey to Florida; along the Gulf of Mexico to the edge of Texas and along the Pacific Coast to Mexico. It breeds in the Eastern States from the Mississippi, eastward except in Louisiana, Mississippi, Alabama, Georgia, Florida and South Carolina. It also breeds in the Northern States from the Mississippi River westward to Washington.

Of the five duck subfamilies 29 species migrate back and forth between the continental United States and Canada in four distinct flyways, and 5 species migrate between the continental United States and Mexico or South America.

As noted in Reference 8, the distribution of ducks in the four established migratory flyways and the breeding areas in the United States are as shown in Figure 8. The heaviest concentrations of ducks, as noted in Reference 8, occur in the areas shown in Figure 9. The four migratory routes are as follows:

Atlantic Flyway - At the peak of fall migration, about 9,000,000 ducks are found in the Eastern Seaboard States. Large concentrations of these birds occur on the Chesapeake Bay, Maryland, where 350,000 ducks spend the winter. Florida harbors some 600,000 ducks, mainly in the vicinity of Cape Kennedy, Apalachee Bay, and the interior lakes. South Carolina attracts some 450,000 ducks and North Carolina harbors 150,000 ducks. The bays of Long Island have concentrations of 160,000 ducks.

Mississippi Flyway - About 31,500,000 ducks migrate thru this flyway in the fall. They terminate on the Tennessee River in Alabama and Tennessee, and in southern Illinois, central Missouri, and coastal Louisiana. The largest concentration of waterfowl occurs along the Louisiana coasts with 5,800,000 ducks and geese. Arkansas has 1,100,000 birds, Illinois has 450,000 ducks. Missouri has 150,000 ducks and Tennessee has about 750,000 ducks.

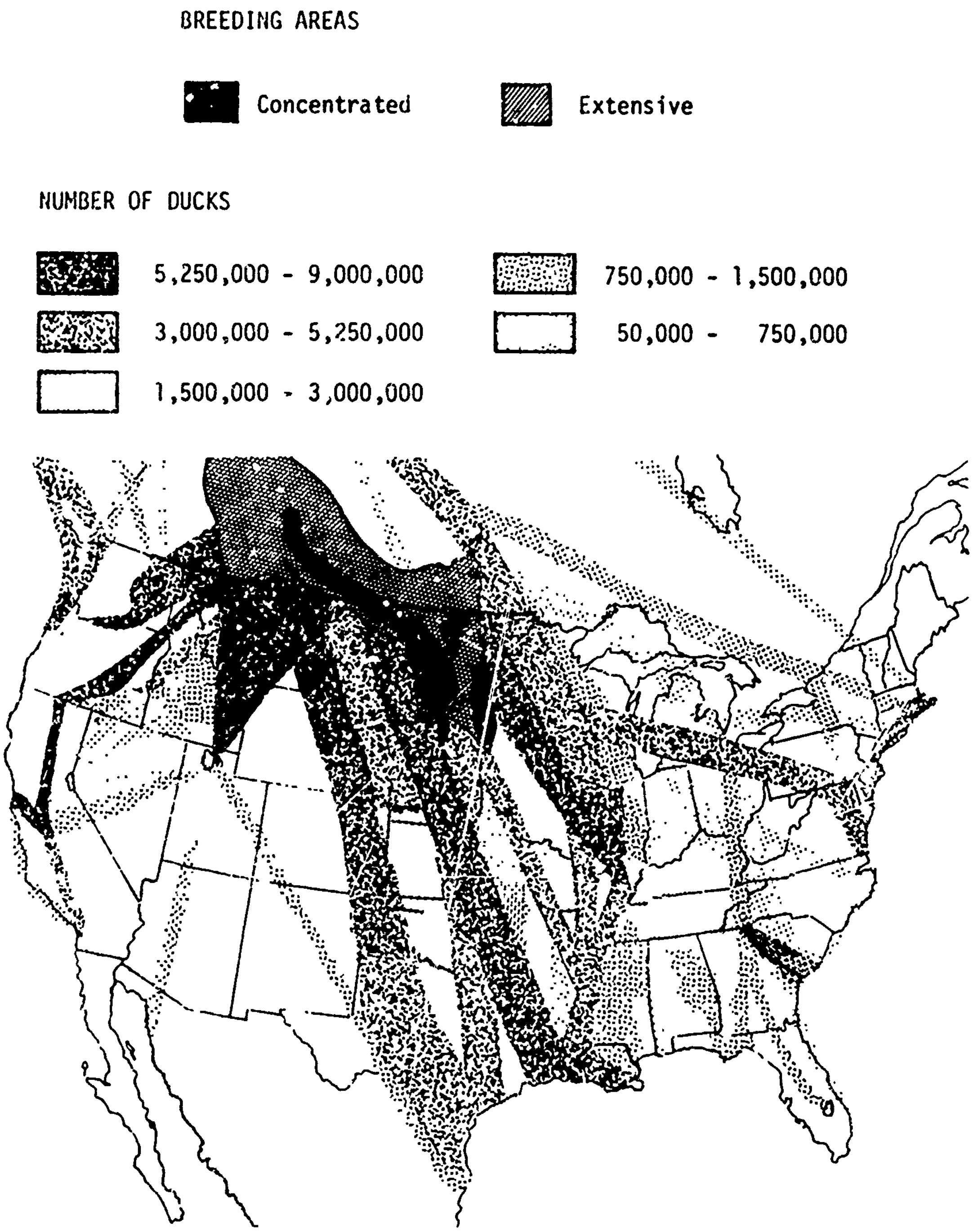


FIGURE 8

Migration Routes of Ducks

Central flyway - About 16,500,000 ducks migrate thru this flyway in the fall. The Mallard winters in all of the states in this region. Approximately 60,000 Mallards winter along the Yellowstone River and in Montana, 50,000 in Wyoming, and about 250,000 Mallards in southeast South Dakota. The Kansas reservoirs hosts some 470,000 Mallards in winter, Oklahoma hosts about 170,000 Mallards, and about 430,000 Mallards winter in western Nebraska and eastern Colorado. Some 900,000 ducks, other than Mallards, winter along the coasts of Texas, and some 400,000 spend the winter in the panhandle region of Texas.

Pacific Flyway - About 33,000,000 ducks migrate in this coastal flyway which embraces the Coastal States and the Rocky Mountains. Concentrations of 5,600,000 ducks and geese frequent the San Francisco Bay region, and Sacramento Valley; about 2,100,000 ducks and geese combined concentrate in the Klamath basin. The Great Salt Lake basin, Utah, hosts 1,300,000 ducks and the Columbia basin, Washington, hosts 1,100,000 ducks and geese in the winter.

The spring migrations commence as the isotherm temperatures generally exceed 35°F, noted in Reference 13, along the migratory paths to the various species' breeding grounds in the northern United States and Canada. Usually the spring migrations occur between March and May.

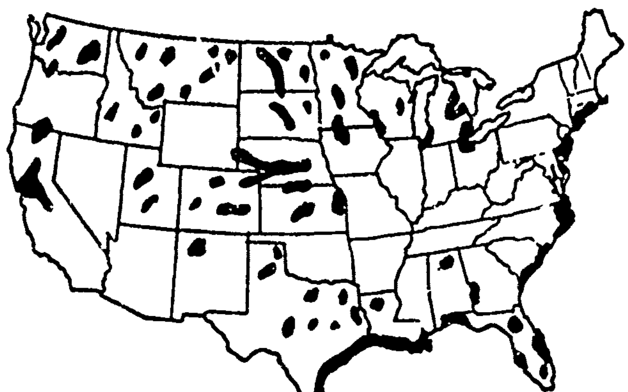


FIGURE 9
Concentrations of Wintering Ducks and Geese

Vultures are carrion eaters of the Order Falconiformes, Family Cathartidae. They are scavengers that live chiefly on decaying flesh and seldom attack living animals except for creatures that are dying from disease or injuries. Vultures or buzzards are interchangeable names for the two main species that are found in the continental United States. The three species, including California Condor, are the following:

Turkey Vulture (Cathartes aura) - Average weight is 3 pounds, maximum weight is 4 pounds; has wing span of 72 inches; travels in pairs, but may travel alone; soars for hours at great heights in thermals looking for dead animals; more abundant than the Black Vulture; a diurnal carrion eater, but also eats snakes, toads and probably mice, rats, and occasionally young birds; exceptional eyesight and can see great distances. Once a vulture has sighted a dead animal there will suddenly appear several other vultures to participate in the feeding.

Black Vulture (Coragyps atratus) - Average weight is 3 pounds, maximum weight is 4-1/2 pounds; is more stumpy than Turkey Vulture, has wing span of 54 inches; fewer in number than Turkey Vulture, otherwise similar to Turkey Vulture.

It has been estimated that there are 2 to 4 million Turkey and Black Vultures in the United States.

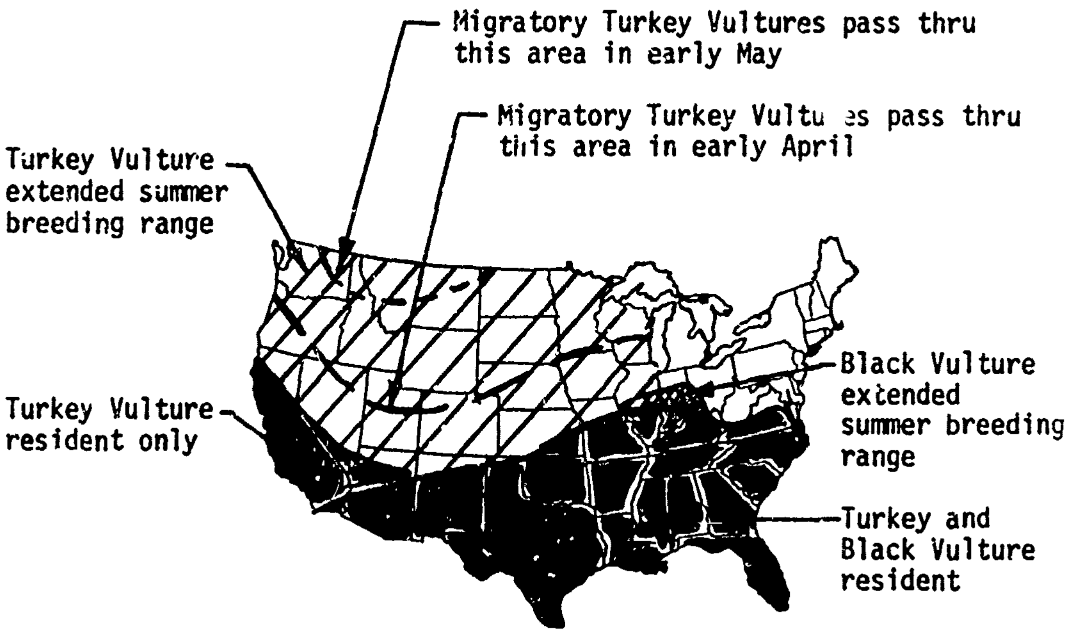


FIGURE 10

Distribution of Turkey and Black Vultures

California Condor (Gymnogyps calfornianus) - The largest of United States vultures; is almost extinct; has an average wing span of 10 feet; weight average is 21.5 pounds, weight maximum is 23 pounds; a diurnal carrion eater; confined to coastal mountainous regions of Southern California; less than two dozen in existence.

FIGURE 11

Distribution of California Condors

Hawks are raptorial birds of the Order Falconiformes, Family Accipitridae that kill their prey with their sharp claws and tear it to pieces with their bill. It has been estimated that there are 15 to 30 million hawks in the Continental United States.

There are eleven species of hawks that are either resident or migratory to the Continental United States. Some species are in large numbers while others are limited. Hawks are raptorial birds that generally feed on birds, rodents and small mammals. The eleven species are the following:

Goshawk (Accipiter gentilis) - Uncommon, is large enough to prey on grouse and squirrels; average weight is 2-1/2 pounds; maximum weight is 4-1/2 pounds; wingspread is 42 inches; and the flock density is 1/1000 cubic feet. In the United States the Goshawk breeds in New Hampshire, Washington, Oregon and California, and winters in most states except the Southern States.

Cooper's Hawk (Accipiter cooperii) - Uncommon, but more numerous than Goshawk; is most destructive species; wingspread is 28 inches; is a chicken hawk; also preys on grouse, rabbits, doves, chipmunks and squirrels; breeds in most states.

Sharp-shinned Hawk (Accipiter striatus) - Fairly common; wingspread is 21 inches; lives on small birds, up to the size of pigeons; breeds in most States except for parts of Texas and Florida.

Marsh Hawk (Circus cyaneus) - Is a slim common hawk of grasslands and marshes; wingspread is 42 inches; feeds on mice, rabbits, squirrels, lizards, snakes and frogs; breeds in the upper States and winters in lower States; and when migrating flies high, often soaring in groups of 50 birds.

Rough-legged Hawk (Buteo lagopus) - Uncommon open-country bird; is nearest of all hawks to being nocturnal; average weight is 2 pounds; wingspread is 52 inches; feeds on mice, thus saving many fruit orchards from destruction and searches for rabbits at night; breeds in Canada and winters in most States except Florida. During migration follows ridges and shorelines.

Ferruginous Hawk (Buteo regalis) - Common on the Great Plains; rarely seen east of Mississippi; wingspread is 54 inches; breeds in Washington, California, Utah, Colorado and Kansas; winters in western half of United States; and migrates similar to Rough-legged Hawk, but does not hover.

Red-tailed Hawk (Buteo jamaicensis) - Common throughout the United States; wingspread is 48 inches, body is heavier than other Buteos; principal food is rodents but will consume disabled and diseased poultry; at times is a carrion-eater; migrates into bordering States to Canada for nesting purposes; rarely hovers; and often perches on poles or treetops.

Red-shouldered Hawk (Buteo lineatus) - One of most common; average weight is 2-1/2 pounds; wingspread is 40 inches; hunts from a perch for rodents, insects, and small birds; found from the edge of the Great Plains to the Atlantic Coast; at times is referred to as the Red-shouldered Buzzard.

Swainson's Hawk (Buteo swainsoni) - Common west of the Mississippi during breeding season; wingspread is 49 inches; wintering range is Mexico and South American countries; perches near ground; feeds on mice, gophers, grasshoppers, and other insects; glides; migrates in flocks.

Broad-winged Hawk (Buteo platypterus) - Common woodland species; average weight is 1-1/2 pounds; maximum weight is 2-1/2 pounds; wingspread is 33 inches; is most silent hawk, and enjoys solitude for long periods; is a percher; feeds on mice, gophers, frogs, snakes, occasionally small birds, caterpillars, grasshoppers, crickets, chipmunks, shrews, squirrels, and occasionally rabbits and moles; breeds in the eastern half of the United States; winters in South America; migrates in large flocks. In Canada these hawks have been observed during September in large flocks (70,000 to 100,000). They have been observed on radar riding thermals across the approaches to Toronto, London, and Ontario airports at heights of 4,000 to 10,000 feet, as noted in Reference 14.

Harlan's Hawk (Buteo harlani) - Uncommon; most difficult to identify; wingspread is 50 inches; feeds on rabbits and chipmunks; winters in Texas, Oklahoma, Kansas, and Colorado; migratory range is through Colorado, Nebraska, Wyoming, South Dakota, and Montana to their breeding ranges in Canada.

Falcons are raptorial birds of the Order Falconiformes, Family Falconidae, and in some respects the most remarkable and most famous of the birds of prey. The true falcons have the bill sharply hooked, toothed and notched. All species fly remarkably swift and the birds movements on the wing are very quick and certain. They overtake and kill in flight the swiftest flying ducks, pigeons and grouse. They do not hesitate to attack birds much larger and stronger than themselves.

There are six species of falcons that are from rare to fairly common in the continental United States. The smallest falcon weighs 1/2 pound and the largest weighs 10 pounds. The six species are the following:

Gyrfalcon (Falco rusticolus) - An arctic bird that rarely wanders south of Canada, but in the past has casually visited Minnesota, Wisconsin, Michigan, New York, Vermont, Maine, New Hampshire; average weight is 5 pounds; maximum weight is 10 pounds; and has a wingspread of 48 inches.

Prairie Falcon (Falco mexicanus) - Found on plains, prairies, and sagebrush desert; nests on side of canyons on isolated buttes; wingspread is 40 inches; feeds on birds and small rodents, especially ground squirrels; and frequently soars.

The Prairie Falcon is a resident of Washington, Oregon, California, Arizona, New Mexico, Colorado; extends its breeding range to include all Western States; and winters into Texas as shown in Figure 12.

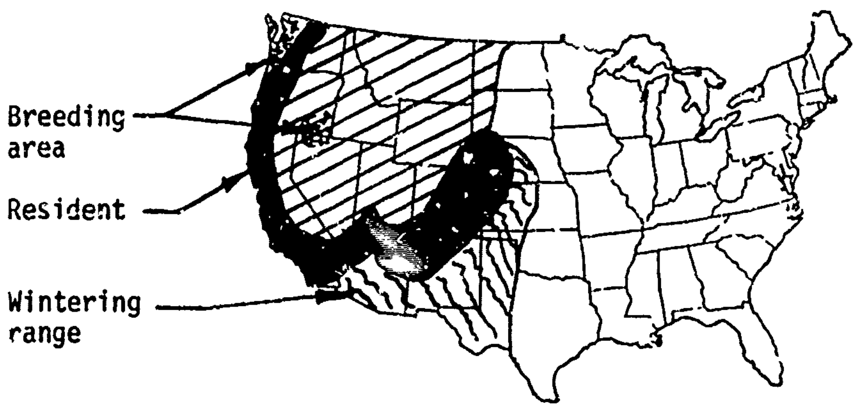


FIGURE 12
Distribution of Prairie Falcons

Peregrine Falcon (Falco peregrinus) - Rare local falcon of coasts, mountains, and woods; average weight is 1-1/2 pounds; maximum weight is 2-1/2 pounds; wingspread is 40 inches; it preys almost entirely on birds, and may kill more birds than required for food. It winters in most of the contiguous United States except the States along the Canada border. Breeds in upper Canada and Alaska.

Pigeon Hawk (Falco columbarius) - Widely distributed but nowhere common in the United States, except Washington, as noted in Figure 13; is a strong, well-built falcon with a wingspread of 23 inches; feeds on shorebirds, pigeons, mice and insects; and rarely soars.

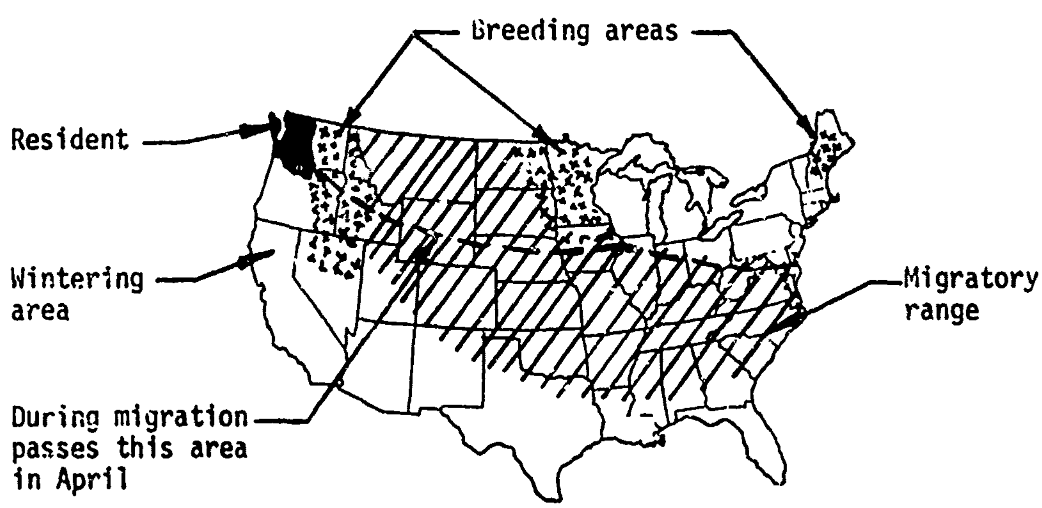


FIGURE 13

Distribution of Pigeon Hawk

Sparrow Hawk (Falco sparverius) - Most common falcon; lives in open and semi-open country; average weight is 1/2 pound; wingspread is 21 inches; during warm months its principal foods are grasshoppers, crickets and other insects; during other months mice is predominant food; during nesting season it may attack small birds for food when time is limited; it frequently hovers. The distribution of Sparrow Hawks is shown in Figure 14 .

Aplomado Falcon (Falco femoralis) - Rare along the Mexican border; longer and wider than most falcons; it has wingspread of 35 inches.

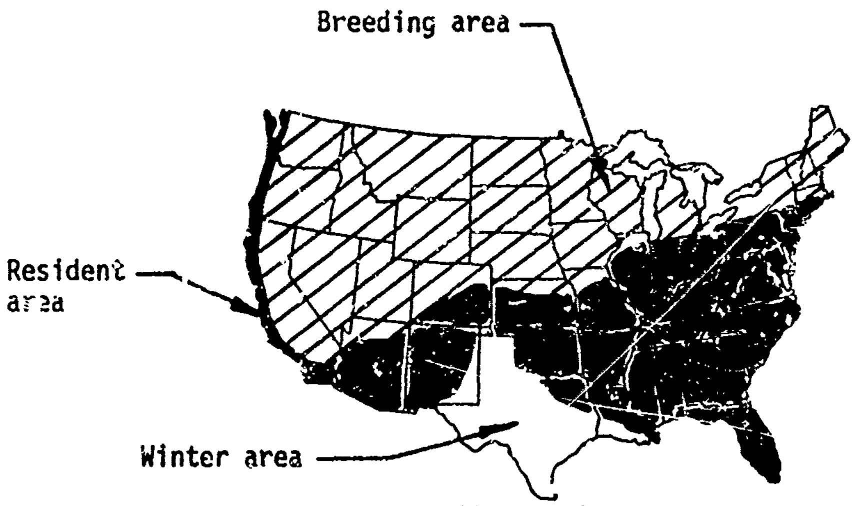


FIGURE 14

Distribution of Sparrow Hawks

Pigeons are of the Order Columbiformes, Family Columbidae. The names Pigeon and Dove are synonymous or interchangeable. Pigeons nest in trees, upon stumps, rocks, walls, clefts of cliffs, in buildings or on the ground in temperate climates. The food of pigeons consists of grains, seeds, fruit and salt.

There are over 500 species in the world, with eleven species frequenting the continental United States. It has been estimated that there are 20 to 40 million pigeons and doves in the United States excluding the Mourning Doves. The estimated number of Mourning Doves is between 240-280 million. The eleven species are the following:

Band-tailed Pigeon (Columba fasciata) - Common in western oak and pine woods especially in summer. Is the largest of the pigeons, and weighs less than one pound. Supplements its diet with acorns. It ranges up and down the West Coast, Arizona, New Mexico, West Texas and extends its breeding range into Utah and Colorado as noted in Figure 15.

Rock Dove (Columba livia) - Is the common domestic dove; found in all contiguous United States around farmyards and city parks; nests on buildings; average weight is 1/2 pound; maximum weight is 1 pound; a flock consists of 600 birds, and in flight the density is 126/1000 cubic feet.

Mourning Dove (Zenaidura macroura) - During all seasons is the most common native in suburbs and farmyards. Found in all of the contiguous United States. Maximum weight is 0.37 pounds.

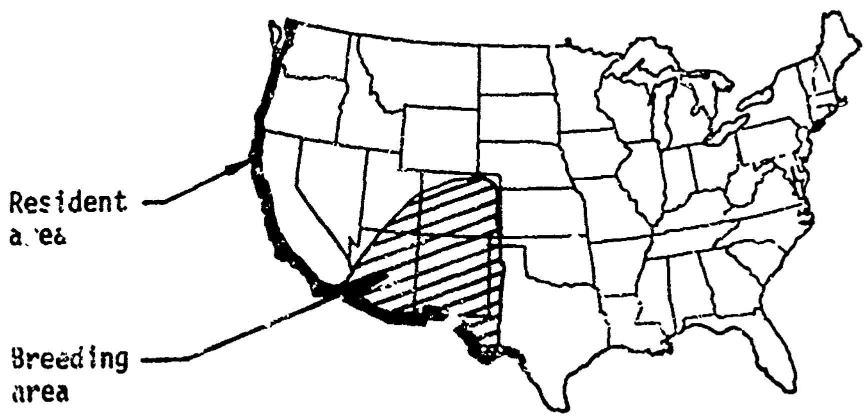


FIGURE 15

Distribution of Band-tailed Pigeons

White-winged Dove (Zenaida asiatica) - Locally abundant in lower California, Arizona, and lower Texas. Nests in colonies in citrus groves, mesquite, open woods, and maximum weight is 0.40 pounds.

White-crowned Pigeon (Columba leucocephala) - Commonly found only in the Florida Keys.

Red-billed Pigeon (Columba flavirostris) - Uncommon in summer, is occasionally found in the lower Rio Grande River in South Texas.

Spotted Dove (Streptopelia chinensis) - Common resident in Los Angeles County, California; occurs from Santa Barbara to San Diego.

Ringed Turtle Dove (Streptopelia risoria) - A common cage bird that has become resident in downtown Los Angeles, Tampa, and Miami.

Ground Dove (Columbigallina passerina) - Is the smallest of the American doves. Common along the Gulf Coast States and Arizona.

Inca Dove (Scardafella inca) - Resident in fields and pastures in the arid areas of lower Texas, Arizona, and California.

White-fronted Dove (Leptotila verreauxi) - Uncommon resident of the lower Rio Grande Valley, Texas.

Geese are waterfowl of the Order Anseriformes, Family Anatidae. The feeding habits of Geese often take them into fields far from water. Their food is almost wholly vegetable. In the water they eat seeds and roots of aquatic plants. On land, in the spring they feed on sprouting grain, and in the fall on corn, oats, wheat, and barley taken from the stubble fields. During fall migration there are approximately 5,000,000 geese, (Reference 8), consisting of eight species, as follows:

Canada Goose (Branta canadensis) - Most common, average weight is 8 pounds, maximum weight is 14 pounds, wingspread is 50-68 inches, and when migrating the flock density is 5/1000 cubic feet.

Brant (Branta bernicla) - Average weight is 2-1/2 pounds, maximum weight is 3-1/2 pounds, wingspread is 48 inches, and when migrating the flock density is 20/1000 cubic feet.

Black Brant (Branta nigricans) - Same as Brant except for black on breast and belly.

Barnacle Goose (Branta leucopsis) - Average weight is 4 pounds, wingspread is 56 inches, and when migrating the flock density is 4/1000 cubic feet.

White-fronted Goose (Anser albifrons) - Average weight is 4.9 pounds, and maximum weight is 7.3 pounds, wingspread is 60 inches, and when migrating the flock density is 3/1000 cubic feet.

Blue Goose (Chen caerulescens) - Similar to the White-fronted Goose except for coloring.

Snow Goose (Chen hyperborea) - Average weight is 6-1/2 pounds, maximum weight is 10-1/2 pounds, wingspread is 59 inches, and when migrating the flock density is 9/1000 cubic feet.

Ross' Goose (Chen rossii) - Average weight is 2.7 pounds, maximum weight is 5.5 pounds and wingspread is 51 inches.

The Canada Goose is the only goose to breed in the United States. It breeds in the states of Montana and Wyoming.

When migrating between breeding and wintering areas, geese follow migration corridors that are on a north-south axis as noted in Figure 16. The flocks fly in V-formations.

There are about 1,200,000 geese including the Canada Goose, the Brant, and Snow Goose that migrate in the Atlantic flyway.

There are about 1,260,000 geese including the Canada Goose, the Blue Goose, the Snow Goose, and White-fronted Goose that migrate in the Mississippi flyway.

There are about 1,000,000 geese including the Canada Goose, the White-fronted Goose, the Snow Goose and Blue Goose that migrate in the Central flyway.

There are about 1,500,000 geese including the Canada Goose, the White-fronted Goose, the Snow Goose, Black Brant, and Ross' Goose that migrate in the Pacific flyway.

As noted in Reference 8, the wintering grounds for geese are located in the following areas: Chesapeake Bay, Maryland; the Tennessee Valley, Alabama, and Tennessee, southern Illinois, central Missouri; coastal Louisiana and Texas; southeastern Colorado; and the central valley of California.

FIGURE 16

Migratory Paths of Geese

Perching birds are the largest group of related birds of the Order Passeriformes. There are 25 families of perching birds that represent at least 300 species. In this Order bird life reaches its highest development: the nervous system is acutely sensitive; the hearing and sight are keenly developed; the circulation and respiration are rapid; and the body temperature is the highest among animals. The adults moult in the fall. Most are insectivorous and some are fruit and seed eaters. Perching birds are generally highly migratory and are medium to small, weighing just a few ounces to a pound or more.

Of the birds involved in collisions noted in Table I, there are only eight perching birds that were identified in a total of 36 incidents. In this study only the eight will be considered.

Robin (Turdus migratorius) - of the Family Turdidae. The robin is well known and frequently seen on lawns in search of insects and earthworms. Its diet also includes grasshoppers, beetles, caterpillars, wild berries and wild fruit. Nests in orchard trees, shrubs, or on buildings. Migrate in flocks by day.

The robin is found in all of continental United States. It breeds in all States except in lower Florida, along the Gulf Coast and the arid areas of Texas, New Mexico and Arizona.

Blackbirds are perching birds of the Family Icteridae. The plumage varies from a uniform irridescent black, somber brown, or showy combinations of yellow, orange, scarlet and black. Occasionally the blackbird is mistaken for starlings. There are 12 species of blackbirds as follows:

Bobolink (Dolichonyx oryzivorus) - Found in hayfields; migrates in fall in large flocks near marshes. Migrates through Eastern portion of the United States and breeds in all of the Northern States. Resembles a sparrow in coloring.

Eastern Meadowlark (Sturnella magna) - Common in fields; have bright yellow breasts; residents of Eastern United States to the Great Plain States.

Western Meadowlark (Sturnella neglecta) - Common in fields; have bright yellow breasts and cheeks; found in the western half of the United States. Foods consist of harmful insects; noxious weeds, grass seeds and grain; beetles, spiders, grasshoppers, caterpillars, and in California has been accused of eating seeds of forage plants, especially clover, in an injurious way. It has also been accused in California of damaging the early crops of peas.

Yellow-headed Blackbird (Xanthocephalus xanthocephalus) - Locally abundant; has yellow head and black body; frequently associates with the Yellow-winged Blackbird and Cowbird; food consists of insects harmful to vegetation, beetles, grasshoppers and caterpillars; and in large flocks occasionally wrecks wheat and oat fields by eating the crops. Found in cattail and tule marshes in most states west of the Mississippi.

Red-winged Blackbird (Agelaius phoeniceus) - Abundant in marshes and fields in most States. Feeds, flies and roosts in large flocks.

Tricolored Blackbird (Agelaius tricolor) - Common in flocks; found in marshes, morasses, and bogs; generally found only on the West Coast; food consists of insects but more than 50 percent of its diet is seeds including seeds from ragweed, barn grass, and smartweed; and in California causes crop damage to corn, wheat and oats.

Rusty Blackbird (Euphagus carolinus) - Fairly common in swamps; is solid black, but not irridescent; it migrates to the United States in the fall after the first snow and leaves in the spring and migrates to its breeding grounds in Canada while there is still ice and frost on the ground; found along swampy borders of woodland lakes, swamps or streams. They feed on corn and other grains. It is found in the Great Plain States and all the eastern United States.

Brewer's Blackbird (Euphagus cyanocephalus) - Common around fields, farms and roadsides; has a glossy black coat that reflects a purplish tint around the head, and a greenish tint on body; and found west of the Mississippi and in Mississippi, Alabama and Georgia during the winter months. They feed on cankerworms, insects, worms, cherries, weed seed, and some grain.

Boat-tailed Grackle (Cassidix mexicanus) - Common along shores and coastal marshes, along inland lakes of Florida, in town, mesquite, and arid farmlands; probably the largest of the blackbird family; the average weight is 1-1/2 ounces; the male has a purplish head and steel-blue irridescent back; female is sepia-brown; in flight flock remains closely bunched during sustained flight, sharp turns, hoverings and sudden dives; and during breeding season the males remain in flocks and do not participate in the egg hatching or rearing the young. They feed on insects, caterpillars, but mainly prefer small crustaceans and occasionally is harmful to a corn crop. It is found along coastal areas from Virginia, through Florida, the Gulf States, Texas, New Mexico and Arizona along the Mexican border.

Common Grackle (Quiscalus quiscula) - Abundant on farmland; nests in evergreens if present; the coloring is irridescent on head and body may be green-blue or black; and inland Grackle is purple. They feed on insects, grubworms and frequently forage large amounts of grain. The Common Grackle is found in all States east of the Rocky Mountains.

Brown-headed Cowbird (Molothrus ater) - Common on farmland, often feeds and flocks with Red-wings, Brewer's, or Common Grackles; and is a frivolous bird that is parasitic, who lays its eggs in other bird species nests. They are found in all the contiguous United States. They feed on insects, worms, flies found around cows, weed seeds and grains.

Bronzed Cowbird (Tangavius aeneus) - Locally common on farms, where it flocks with other blackbirds. It is found at the lower end of Texas and long the Arizona border of Mexico.

Starling (Sturnus vulgaris) - Of the Family Sturnidae. The Starling is well known and distinguishable from Blackbirds by its shorter tail, and in flight by its browner wings. Spends the night in large groups. The Starling weighs approximately 1/4 pound and during flights the flock density is 310/1000 cubic feet. It is estimated that there are between 400 - 500 million in the continental United States.

Horned Lark (Eremophila alpestris) - Of the Family Alaudidae. The Horned Lark frequents the open country and never lives in forests. They feed along roads. weedy or freshly ploughed fields. The beaches and salt marshes of the coasts, the lake shores, muddy flats and swamps of the interior have an abundance of Horned Larks in fall and winter. In the West they live on the hot arid land, on level grassy prairies, and bare mountains. They molt usually in August. Their food consist of insects and weed seed. They are found in nearly 11 states except Florida as a resident bird, wintering, on or above ' . Great Lakes in extended breeding range.

Sparrows are perching birds of the Family Fringillidae which is the largest family of perching birds throughout the world except for Australia. There are over 30 species of sparrows within the continental United States. Sparrows are small plump birds and weigh only a few ounces. They build nests almost anywhere, - on buildings, in trees, bushes and brush. Their food is seeds, except during nesting when they also eat insects and worms. Generally, sparrows are brown-bodied with streaked backs. When sparrows are not nesting they are in large flocks. Some sparrow species breed twice a year.

Crows and Ravens are the largest of the perching birds recognized by their solid black coating, that are found in flocks. They fly in long lines to their roosting areas and when feeding post guards. Crows and ravens belong to the family Corridae, with five species found in the continental United States. The five species are the following:

Common Raven (Corvus corax) - This bird is the largest of the perching birds and probably weighs up to 2-1/2 pounds, and is sometimes mistaken for a hawk. It soars more than a crow and is found to form small separate groups of from 4 to 12 birds that are commonly found at the same places for a number of years. The Common Raven is a carrion eater that in the deserts eat dead rabbits and other flesh, either fresh or putrid. They forage in garbage dumps and cans around hotels in the National Parks for food. They have been known to rob the nests of gulls. The Common Raven is found in the United States only west of the Rocky Mountains.

White-necked Raven - (Corvus cryptoleucus) - Common in arid deserts near farmlands, probably weighs up to 1-1/2 pounds. It is a fairly tame bird that frequents areas where man throws particles of food such as lunch remains around school yards. He is a scavenger feeding principally on animal matter, including locusts. The White-necked Raven glides more in flight than the crow and is found in Colorado, Utah, Arizona, New Mexico, and West Texas.

Common Crow (Corvus brachyrhynchos) - Common; well known; seldom glides therefore should not be mistaken for a hawk; it is a clever bird and a thief who steals and hides any small object that is brightly colored; and is objectionable to the farmer since it will eat sprouting corn, destroys chickens and robs the nests of chickens and small birds. The Crow also includes in its diet frogs, toads, salamanders, some small snakes, turtles, crawfish, snails, mice, beetles, cutworms and wild species of fruit such as seeds of the dogwood, sour gum, and sumac. It is found as a resident in all of the Eastern States and locally in the West except arid regions, particularly when dense forests and conifer trees are found.

Northwestern Crow (Corvus caurinus) - Found only in Washington State in tidelands areas scavenging along shorelines.

Fish Crow (Corvus Ossifragus) - Scavenges on shore, but is found inland feeding with the Common Crow. It is slightly smaller than the Common Crow. It feeds on animal life that dies and floats ashore, flies above schools of fish and catches fish, and treads water for clams. He also eats grasshoppers and other insects, carrion, grain and berries. He is an egg-eater, and frequently robs Herons and Ibis rookeries. The Fish Crow is found on the Atlantic Seaboard States, Hudson Valley, Long Island Sound, all of Florida, the Gulf States from Florida to Texas, and along the Mississippi River up to Kansas.

Thrushes are perching birds of the Family Turdidae. The various members of the Thrushes present wide differences in general appearance, form, coloration and habits. Some live among trees, others on the ground, and some among rocks. They all eat worms, insects and fruit, and probably don't weigh more than 3 ounces. The typical Thrush migrates at night. The Thrushes covered for this group are six species, and does not include the Solitares, Bluebirds, or Robins that are covered above. The six species are the following:

Varied Thrush (Ixoreus naevius) - Is common in most coniferous woodlands of the mountain ranges along the Western Coastal States. It is driven from the mountains by heavy snow and extends its wintering range to the bottom of California. It is similar to the Robin in actions and habits. It includes apples in its diet.

Wood Thrush (Hylocichla mustelina) - Is common in the eastern half of the United States in deciduous forests and in residential areas. It is smaller than the Robin and has spots on its breast. It includes in its diet grasshoppers, crickets, cutworms, potato beetles, frost grapes, wild blackberries, wild cherries, seeds of the spice bush and the southern magnolia tree.

Hermit Thrush (Hylocichla guttata) - Common in northern woodlands during breeding season; is a resident of Washington, Oregon, California and Arizona; winters in the lower half of the United States. It seldom gets around man. Similar in coloring to the Wood Thrush. It eats insects, wild fruit and berries.

Swainson's Thrush (Hylocichla ustulata) - It breeds in the Northwestern States and migrates through the United States probably on its way to South America. Similar in ..kings of the Wood Thrush but its back is olive colored. Its food includes worms, snails, insects, beetles, ants, wasps, and wild fruits.

Grey-cheeked Thrush (Hylocichla minima) - Migrates through the United States enroute between Canada and Peru. Has grey cheeks, olive tail, and spotted breast.

Veery (Hylocichla fuscescens) - Common in deep woods. Similar in coloring to the Wood Thrush except spots on breast not as distinct. It breeds in the Northern States from the Rocky Mountains to the East Coast. It migrates through the Southern States in its migration to South America. It feeds on beetles, snails, insects, and wild fruit.

Herons and their allies are of the Order Ciconiiformes and Family Ardeidae. Under this order are grouped the long-legged wading birds generally found along shores or on muddy flats.

There are 13 species of herons including the egrets and bitterns that nest in colonies. Most feed on aquatic animal life in shallow water and marshes. These species are represented in all parts of contiguous United States except in areas of continuous cold or drought.

Including all the species there is probably a population of upward of one million by virtue of the fact there were 167,000 Great Blue Herons noted by Seaman in 1969 (Reference 7) and that many of the species are equally common. The thirteen species are the following:

Great White Heron (Ardea occidentalis) - Common in southern Florida and Florida Keys around salt water only; average weight is 9 pounds; maximum weight is 13 pounds; wingspread is 70 inches, but seldom soars or glides; is the largest of the white species; and does not flock.

Great Blue Heron (Ardea herodias) - Seaman in 1969 estimated that there were 167,000 of this species (Reference 7) and is common on fresh water as well as salt water; average weight is 9 pounds; maximum weight is 13 pounds; wingspread is 70 inches, but seldom soars or glides; is destructive to the spawn and young of game fish; and is the largest of the dark species. The species breeds in the entire contiguous United States except areas of the Rocky Mountains and Arizona. (See Figure 17).

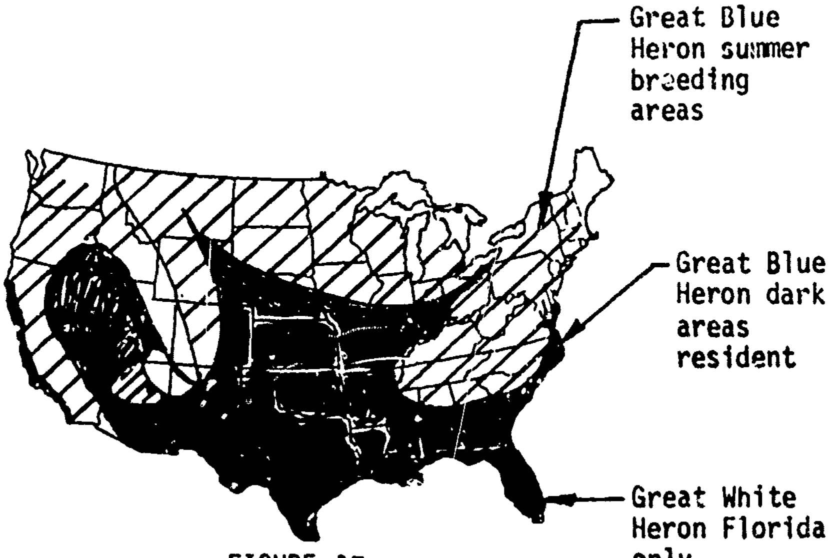


FIGURE 17

Distribution of Great White and Great Blue Herons

Common Egret (Casmerodius albus) - Common along streams, ponds, rice fields, salt and fresh water marshes and mudflats; is white but is slightly smaller than the Great White Heron; wingspread is 55 inches; and at one time was almost extinct due to the use of its plumage by the millinery trade. It is a permanent resident of North Carolina, South Carolina, Florida, Georgia, Alabama, Mississippi, Louisiana, Texas, California and Oregon; and the extended breeding range includes Arizona, New Mexico, States above the Gulf up to the Great Lakes, and States along the Atlantic as noted in Figure 18 .

FIGURE 18

Distribution of Common Egrets

Snowy Egret (Leucophoyx thula) - Common, mostly in fresh and salt water marshes, and has a wingspread of 38 inches. It is a permanent resident in lower Florida, parts of northern and lower California, and in the lower end of Texas. Its extended breeding ranges include Oregon, Nevada, the Gulf States, North and South Carolina and Virginia, as noted in Figure 19.

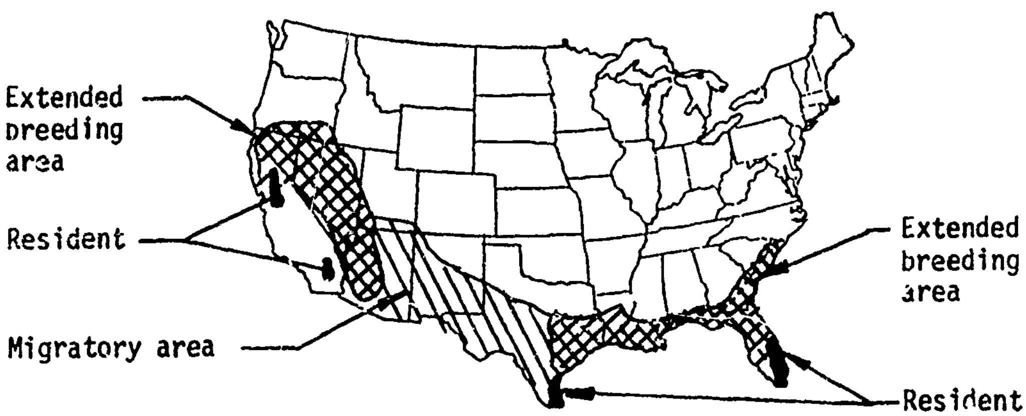


FIGURE 19

Distribution of Snowy Egret

Cattle Egret (Bubulcus ibis) - Common and spreading; seen in flocks in pastures feeding on insects; average weight is 3/4 pound; maximum weight is 1 pound; wingspread is 37 inches; and is white. Is a resident of Florida and along Gulf Coast to tip of Texas; and migrates inland through most of Southern States.

Reddish Egret (Dichromanassa rufescens) - Uncommon dark heron of salt-water flats and has a wingspread of 46 inches. It is a resident of the lower ends of Texas and Florida.

Yellow-crowned Night Heron (Nyctanassa violacea) - Less common; hunts at night but is found feeding during the day; is a solitary species and rarely more than three are found together; they usually feed on mussels, crawfish, and small crabs; and has a wingspread of 44 inches. It is a resident of Gulf Coast States and extends its breeding range inland the same as Reddish Egret, as noted in Figure 20.

FIGURE 20

Distribution of Cattle and Reddish Egret

Louisiana Heron (Hydranassa tricolor) - Common and abundant along salt-water shores, with a wingspread of 38 inches. It is a resident of the shores of North and South Carolina, Florida, Alabama, Mississippi, Louisiana, and Texas, and may extend the range along the Atlantic Coast upward to Connecticut.

Little Blue Heron (Florida caerulea) - Common along fresh and salt water, with a wingspread of 41 inches. It is a resident of the shores of North and South Carolina, Florida, Alabama, Mississippi, Louisiana and Texas and extends its range inland and along the Mississippi River to Wisconsin as noted in Figure 21.

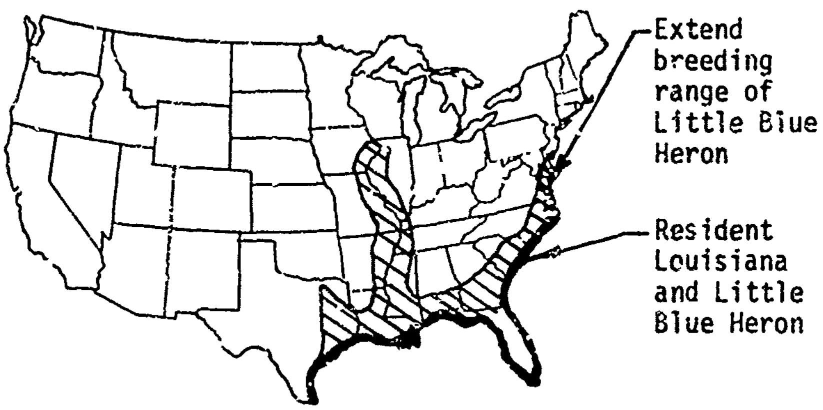


FIGURE 21

Distribution of Louisiana and Little Blue Heron

Green Heron (Butorides virescens) - Common, and abundant in both fresh and salt water; found more often than other herons in small ponds and wooded streams; is small with a wingspread of 25 inches. Is a common resident along coast of California, the tip of Texas and lower Florida; and breeds in Oregon, Washington, and all States from the Great Plains border to the Atlantic Coast as noted in Figure 22 .

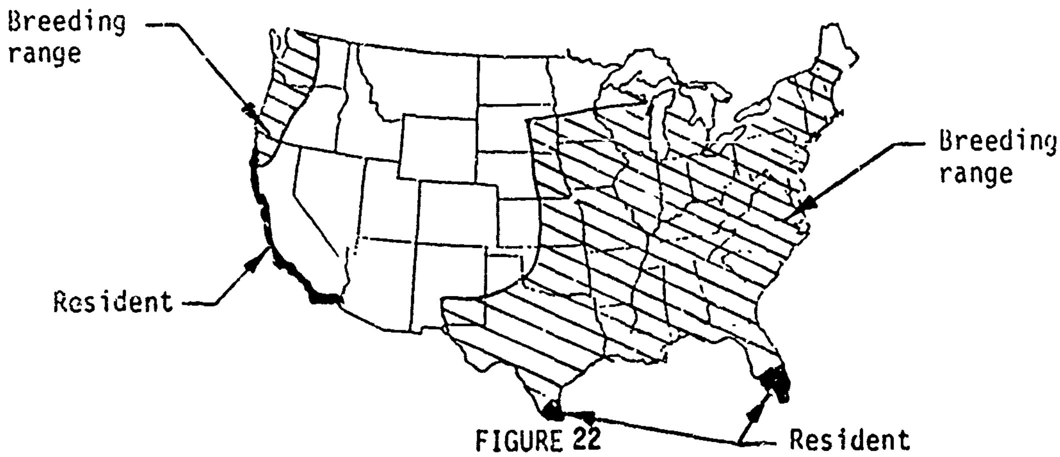


FIGURE 22

Distribution of Green Heron

Black-crowned Night Heron (Nycticorax nycticorax) - Common around fresh-water swamps, ponds, and tidal marshes; may raise two broods a year; has a heavy body and a wingspread of 44 inches. Fishes more at night and flies in loose flocks. Is a resident along the Atlantic Coast from New Jersey to the Florida Keys, along the Gulf Coast to Texas; in California, Oregon, Nevada; and up the Mississippi River. It extends its breeding range to the Central States and Washington, as noted in Figure 23.

American Bittern (Botaurus lentiginosus) - Common in fresh-water marshes, but is also seen in meadows hunting grasshoppers; is very elusive, most active at dusk and at night; wingspread is 45 inches; and does not flock. Breeds in all of the contiguous United States.

Least Bittern (Ixobrychus exilis) - Common, but very shy; remains hidden in tall fresh-water grasses and hedges; smallest heron, with a wingspread of 17 inches; rather run or climb than fly; seldom flies higher than 100 feet. Breeds in the eastern half of the contiguous United States.

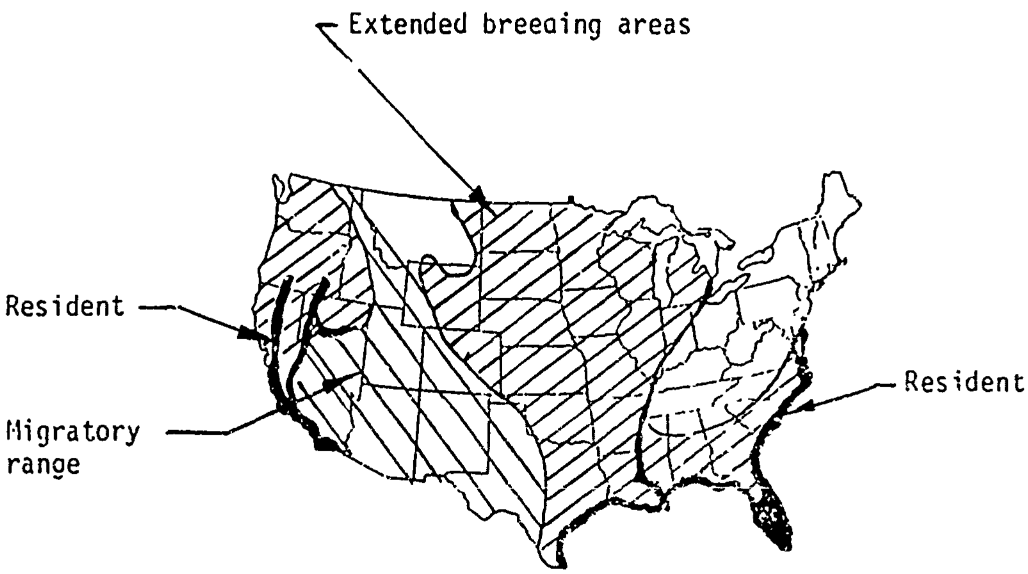


FIGURE 23

Distribution of Black-crowned Night Heron

Wood Ibis or Storks are of the Order Ciconiiformes and Family Ciconiidae. They are long-legged wading birds that are allies of the Heron.

The Wood Ibis, or Wood Stork (Mycteria americana), is the only American stork; weighs approximately 10 pounds; wingspread is 66 inches; breeding season is November through April in 14 successful breeding colonies located in the marshes of lower Florida; spends remainder of year in lower California, Texas, Louisiana, Mississippi, Arkansas, Alabama, Georgia, and South Carolina; (Figure 24).

The Wood Ibis is an expert glider, making use of the thermal air currents for transportation to feeding areas. They may rise 1000 to 2500 feet and soar as far as 20 miles at speeds to 35 miles per hour. (Reference 15).

The Wood Ibis dwindled from over 100,000 located in Florida to less than 8000 in 1957, but by 1964 had increased to over 20,000 (Reference 15).

FIGURE 24

Distribution of Wood Ibis (American Stork)

Owls are of the Order Strigiformes consisting of two Families; Tytonidae, the Barn Owls, and Strigidae, all other owls. Owls are mostly nocturnal raptorial birds of prey and like other raptorial birds capture their prey with their feet. All owls fly silently and swiftly hunting for rodents and small mammals. The number of owls in the continental United States is estimated to be 2 to 4 million.

There are 19 species of owls that are either local or are occasional migrators from Canada. The 19 species of owls are the following:

Great Horned Owl (Bubo virginianus) - Common, nocturnal, large-eared owl; average weight is 4 pounds; maximum weight is 6 pounds; wingspread is 55 inches; nests in caves, on ledges, or in a hollow tree; and is highly destructive. He feeds on game birds, song birds, rabbits, squirrels, partridge, and frequently skunks. He occasionally develops a craving for young turkeys and guinea fowl. His breeding habits are peculiar and he may nest and lay eggs as early as January, stolidly incubating under a thick blanket of snow. The Great Horned Owl is found in all the continental states.

Screech Owl (Otus asio) - Common small-eared owl of towns, orchards and small woodlots; average weight is 1/2 pound; and wingspread is 22 inches. The Screech Owls are scattered over the entire United States but are nonmigratory. It nests in cavities and feeds on insects, mice, crawfish, toads, scorpions, lizards, and fish. The insects include grasshoppers, crickets, beetles and cutworms.

Long-eared Owl (Asio otus) Locally common in deciduous or coniferous woods near open country in the States noted in Figure 25. Wingspread is 39 inches; is an industrious mouser and bothers comparatively few birds; and nests in trees.

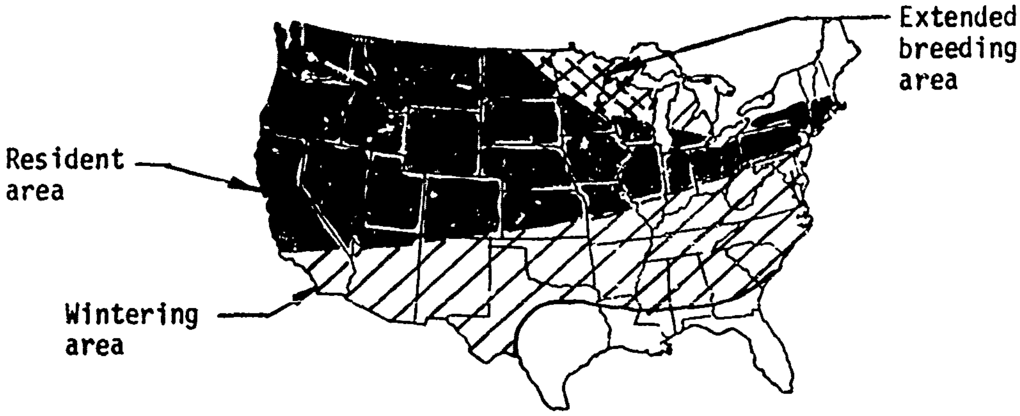


FIGURE 25

Distribution of Long-eared Owl

Short-eared Owl (Asio flammeus) - Common in open country over plains, bogs and marshes; wingspread is 41 inches; will gather in colonies or flocks of 100 or more; may hunt in foggy or cloudy days as well as at night; and feeds on mice, small ground squirrels, and sparrows. The Short-eared Owl breeds in the Northern States of Washington, Oregon, Idaho, Montana, Wyoming, North Dakota, South Dakota, Minnesota, Iowa, Wisconsin, Michigan, New York, and Massachusetts; and winters in remainder of the continental United States.

Barn Owl (Tyto alba) - Uncommon owl; average weight is 0.5 pound; maximum weight is 0.8 pound; wingspread is 44 inches; nests in church steeples, barns, abandoned buildings and tree cavities; feeds on mice and gophers and is strictly nocturnal. The Barn Owl is found in most States as shown in Figure 26.

Snowy Owl (Nyctea scandiaca) - A diurnal arctic owl that winters occasionally in States around the Great Lakes; average weight is 5 pounds; wingspread is 55 inches; feeds on lemmings, rodents and rabbits.

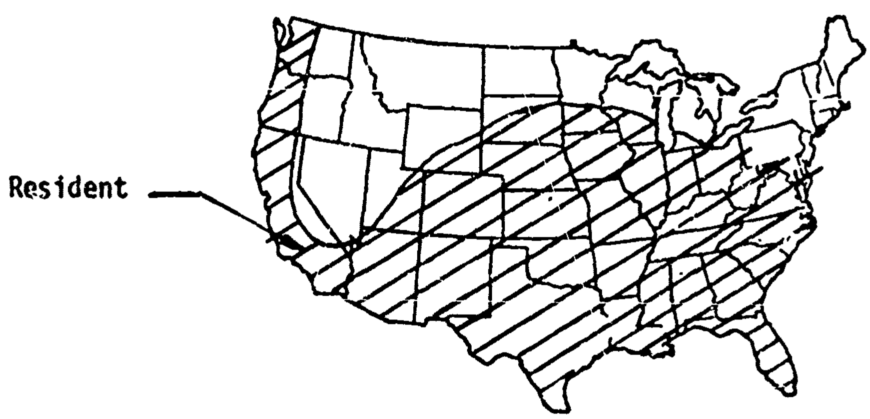


FIGURE 26

Distribution of Barn Owls

Barred Owl (Strix varia) - Common; found in swamps and river bottoms; average weight is 2 pounds; maximum weight is 3 pounds; wingspread is 44 inches; begin nesting in March or early April; and builds nest in the hollow of a tree or uses the deserted nests of crows or hawks. It feeds on mice, frogs, lizards, crawfish, spiders, other insects and occasionally will take small birds for food. It is a resident owl in the states shown in Figure 27.

Spotted Owl (Strix occidentalis) - Rare; is western counterpart of Barred Owl but much lighter, probably weighs up to 3 pounds, and wingspread is 42 inches. It is found in the mountains of Southern California, Oregon, Washington, Arizona, New Mexico, and southern Colorado, as noted in Figure 27.

Great Grey Owl (Strix nebulosa) - Rare; appears to be larger than the Great Horned Owl but weighs about the same as the Barred Owl; and wingspread is 60 inches. It is found in pine and spruce forests in the mountains of Northern California, Oregon, Washington, Idaho, Montana, North Dakota, and Minnesota. Its diet includes rabbits, mice, squirrels, and small birds. The Great Grey Owl hunts both by day and night.

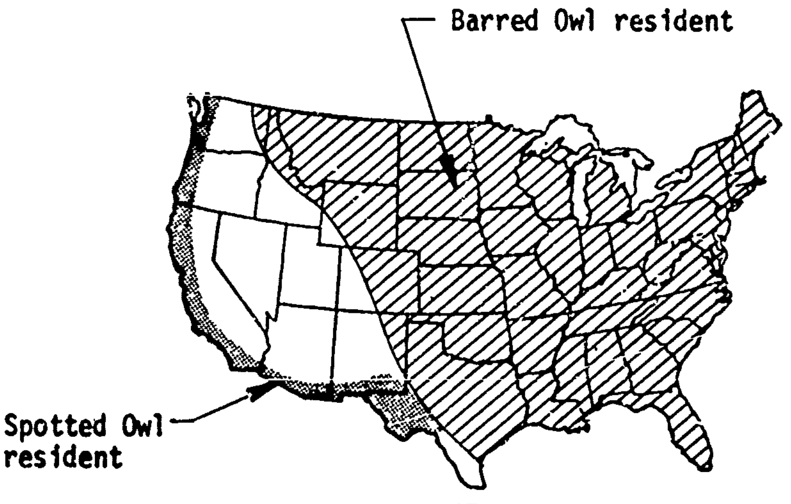


FIGURE 27

Distribution of Barred and Spotted Owl

Hawk Owl (Surnia ulula) - . to the United States; diurnal owl; because of long ta., resembles the falcon and hunts like a hawk; wingspread ' 33 inches; and when found in the United States it will b. long the Canadian border.

Burrowing Owl (Speotyto cunicularia) - Locally common; diurnal owl; nests in prairie dog holes, badger burrows or fox den deserted by prior owner; is a small owl that probably does not weigh more than 1/2 pound; wingspread is 22 inches; and includes in its diet squirrels, snakes, lizards, grasshoppers, small birds, and occasionally Rough-legged Hawks. In the lower portion of Florida is a permanent resident including inhabiting airports. It is found in all the Western States on the plains as a resident or extended breeding ranges. May winter in Texas.

Boreal Owl (Aegolius funereus) - Rare to the United States; nocturnal owl; probably weighs upward of one pound; wingspread is 24 inches; and is found only along the Canadian border.

Saw-whet Owl (Aegolius acadicus) - Common; nocturnal owl; a small owl probably weighs less than 1/2 pound; wingspread is 17 inches; is a sound sleeper by day and susceptible to attack from other predators including the Barred Owl; and it nests and roosts in evergreens and dense thickets. It is found in most states except the lower Southern States that border the Gulf of Mexico.

Whiskered Owl (Otus trichopsis) - Common in canyons of Arizona and lower California; similar to the Screech Owl; probably weighs 1/2 pound; and wingspread is 16 inches.

Flammulated Owl (Otus flammeolus) - Rare; found in pine woods of Western States; probably weighs less than 1/2 pound; and has wingspread of 14 inches.

Pygmy Owl (Glaucidium gnoma) - Common; small owl; probably weighs up to 1/2 pound; wingspread is 15 inches; roosts and nests in coniferous and deciduous woods; in flight its wings make a distinct whistling sound; partly diurnal; and its diet includes insects, small birds and rodents. It will attack squirrels, rodents, or birds much larger than itself. It is found in Montana, Wyoming, Colorado, New Mexico and states westward to the Pacific Coast. It is considered as a non-migratory bird.

Elf Owl (Micrathene whitneyi) - Common in the southwest deserts of Arizona, New Mexico and lower California and lower Texas where saguaro cactus are prevalent; a very small owl of the perching bird size; nests in the uppermost part of the cactii. Strictly a nocturnal owl that hunts insects throughout the night.

Ferruginous Owl (Glaucidium brasilianum) - Uncommon; is small; probably weighs less than 1/2 pound; wingspread is 15 inches; found in wooded river bottoms and saguaro deserts near Mexican border in states of Arizona, New Mexico, and Texas.

Cranes are of the Order Gruiformes and Family Gruidae. They are wading birds or marsh birds, consisting of two species as follows:

Sandhill Crane (Grus canadensis) - Has an average weight of 9 pounds and a maximum weight of 13 pounds. It has a wing span of approximately 6-1/2 feet.

The Sandhill Crane resides locally in open prairies and fields and eats roots, bulbs, grains, insects, small rodents and frogs.

It has been estimated by Seaman in 1969 (Reference 7) that there were 150,000 of these birds in the continental United States.

The Sandhill Crane permanently resides in Florida, winters in lower Texas and California, and breeds in the upper portions of the United States west of the Mississippi and in Canada (Figure 28). It is often seen in flocks except during the breeding season.

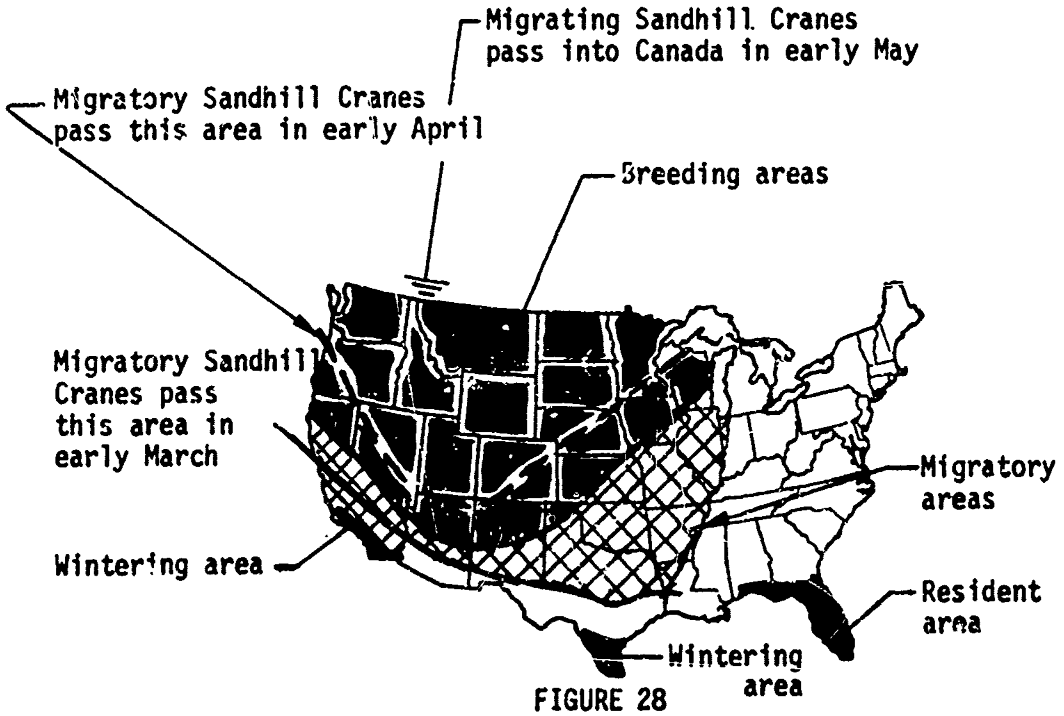


FIGURE 28

Distribution of Sandhill Cranes

Whooping Crane (Grus americana) - Was thought to be extinct until the early 1950's. The population of Whooping Cranes is estimated to total 50.

The Whooping Crane stands approximately five feet tall and has a wing span of 90 inches. The weight is not known but seems to be much greater than the Sandhill Crane's weight which is 13 pounds. He is almost pure white.

The Whoopers migrate 2500 miles between their nesting grounds in the Wood Buffalo National Park in Canada and their winter resort in Aransas National Park in Texas (Figure 29). The Whooping Crane travels approximately 200 miles per day may reach speeds of 45 miles pe. hour, and usually travel pairs.

The Whoopers arrive at their wintering grounds in mid-October and leave six months later for their nesting area in Canada. (Reference 16). Supposedly, the Whooping Crane flies at such great heights that the inhabitants below seldom see the birds migrate (Reference 16).

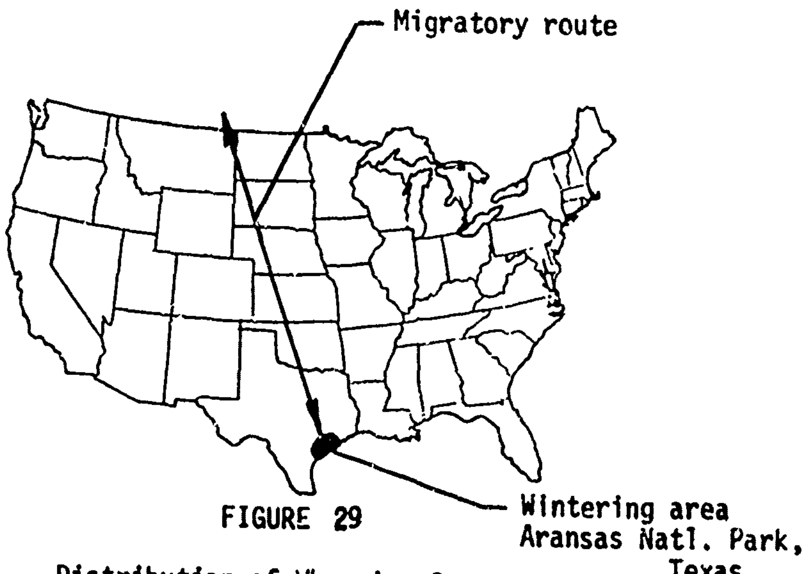


FIGURE 29

Distribution of Whooping Crane

Ring-necked Pheasant is a gallinaceous bird of the Order Galliformes, Family Phasianidae, species Phasianus colchicus that is strictly a ground dwelling bird.

The Ring-necked Pheasant is one of many gamebird species released in the United States and has succeeded in adapting sufficiently to become fairly common in States noted in Figure 30.

The average weight is 2.1 pounds; maximum weight is 4.1 pounds; wingspread is 32 inches; flies only short distances; commonly found in open woods, on farmlands in brush, hedgerows and cornfields. It roosts in trees and feeds on grains, seeds and berries.

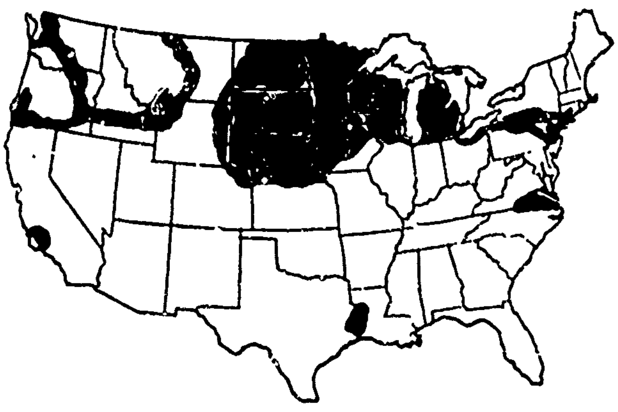


FIGURE 30

Distribution of Ring-necked Pheasant

Pelicans are of the Order Pelecaniformes, Family Pelecanidae and are extremely large birds. Seaman estimated that there are 67,000 Pelicans in the continental United States. There are two species of Pelicans as follows:

Brown Pelican (Pelecanus occidentalis) - Has an average weight of 8-1/2 pounds and wingspread of approximately 8-1/2 feet.

The Brown Pelican is nonmigratory and a colony nester that breeds along the Atlantic Coast south from South Carolina, the Gulf of Mexico, and the West Coast (Figure 31). When searching for fish, the Laughing Gulls follow the Brown Pelicans and steal their catches of fish.

Small flocks fly in long lines with a flock density of 2/1000 cubic feet.

Normally the Brown Pelicans nest in mangrove trees but will nest on the ground. The breeding season is from November to May (Reference 13).

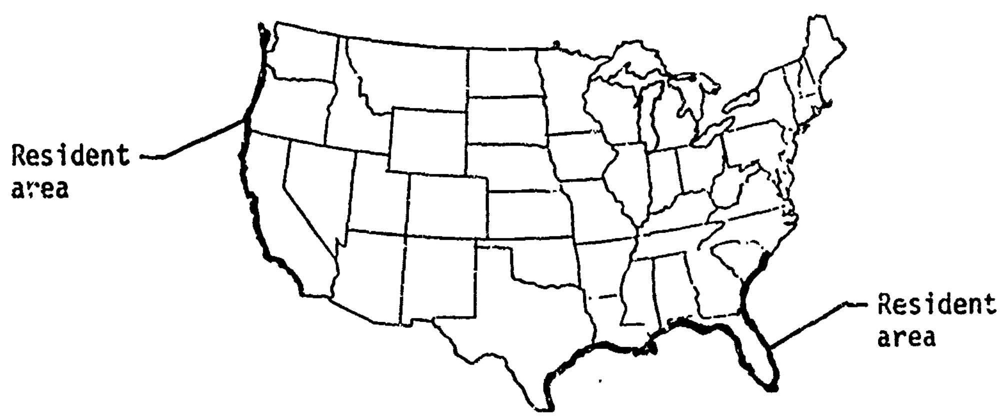


FIGURE 31

Distribution of Brown Pelicans

White Pelican (Pelecanus erythrorhynchos) - Has an average weight of 15 pounds and wingspread of approximately 9-1/2 feet.

The White Pelicans are locally common in breeding colonies in North Dakota, the West Coast and lakes in Northern California and Oregon with several hundred pairs in each colony. Their wintering areas are the lower coastal areas of California and in states along the Gulf of Mexico from Texas to Florida. (Figure 32).

The White Pelican migrates in long lines in V-formations and often soars at great heights. The flock density is approximately 3/1000 cubic feet.

The White Pelican season for breeding occurs between April and September (Reference 13).

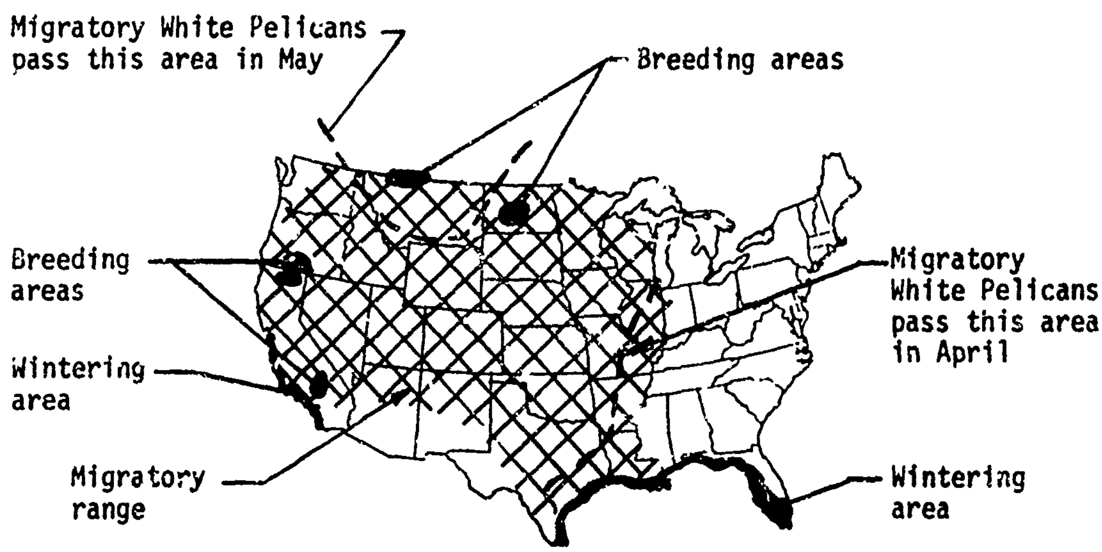


FIGURE 32

Distribution or White Pelicans

Frigatebirds are of the Order Pelecaniformes, Family Fregatidae. The Magnificent Frigatebird (Fregata magnificens), or "man-o'war" bird restricts its range to subtropical American waters, but in the summer is common to the Florida Keys. During storms may appear along West, Gulf and Southeast coasts. Average weight is 3-1/2 pounds; maximum weight is 4 pounds; its wingspread is 90 inches.

Since the frigatebird nests in temperate zones it may raise more than one brood a year. It is probably the most aerial of all sea birds and can soar for hours. When a flock of thousands soar it appears like an aerial invasion.

They feed on fish and act in a piratical manner chasing other birds, forcing them to drop their food that they catch in mid-air, like newly hatched turtles; and snatches Tern eggs and young.

Eagles are raptorial birds of the Order Falconiformes, Family Accipitridae that have strong talons used to kill their prey and a heavy sharp hooked bill used to rip their prey into pieces. The Eagles belong to the same family as the hawks but are generally much larger. There are two species of Eagles as follows:

Bald Eagle (Haliaeetus leucocephalus) or American Eagle has become a rare bird, and it is estimated that fewer than 500 pairs exist (Reference 17). Since 1940 it has been protected by law. Recent causes for the decrease in numbers is attributed to pesticides that have polluted the streams and fish inhabiting them. Generally, the Bald Eagle consumes salt or fresh water fish, and kills many rabbits, snakes, rodents and small waterfowl for his food. The Bald Eagle has a wingspread of 80 inches; is an average weight of 9.5 pounds and a maximum weight of 11.5 pounds.

Its favorite nesting areas seem to be Florida, the Great Lakes region, around Chesapeake Bay, the tidelands section of the Middle and South Atlantic States, along the Mississippi and occasionally other parts of the country. (See Figure 33) Normally, the Bald Eagle is a nonmigratory bird other than when the lakes are frozen or there is a local shortage of food.

The nesting sites are generally in tall trees or in crevices of cliffs.

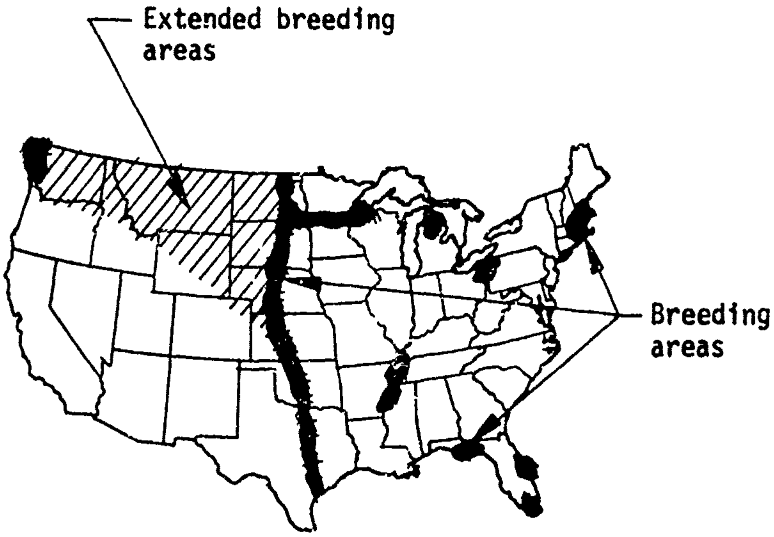


FIGURE 33

Distribution of Bald Eagles

Golden Eagle (Aquila chrysaetos) - Is becoming a rare bird, with less than 10,000 existing in the continental United States (Reference 18).

The Golden Eagle is a raptorial bird that has been protected since 1962 by Public Law 87-884. Generally consumes rabbits and rodents as a diet, but is a predator of snakes, other birds, squirrels, deer, and others.

The Golden Eagle has a wingspread of 78 inches, has an average weight of 11 pounds and a maximum weight of 14.8 pounds.

Its favorite nesting areas seem to be California, Idaho, Montana, Wyoming and South Dakota. It seems to favor New Mexico and West Texas as wintering range (Figure 34). It is rare east of the Mississippi. The nesting sites are generally in crevices of cliffs or in tall trees.

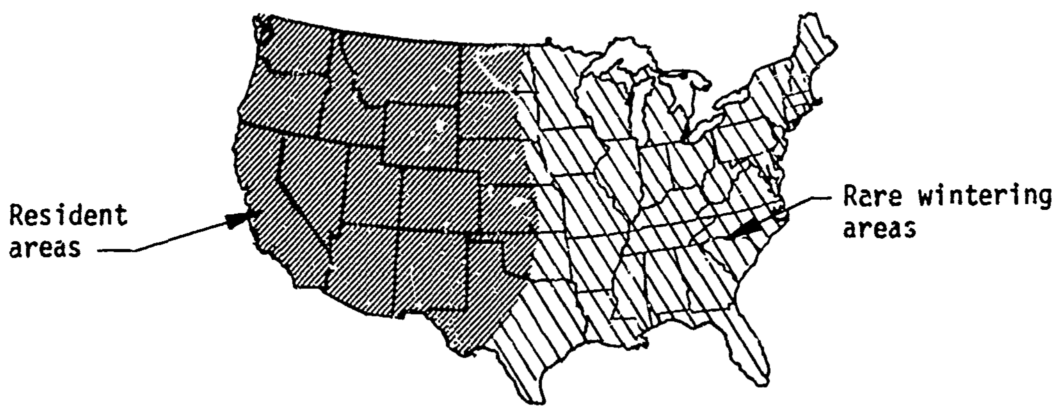


FIGURE 34

Distribution of Golden Eagles

Loons are of the Order Gaviiformes, Family Gaviidae, and are noted for their swiftness in swimming, diving and flying. In the breeding period they occur in the cooler regions north of the Arctic Circle. In winter they move into temperate regions, especially along seacoasts. There are five species of Loons but only three are found in the United States. The three species are the following:

Common Loon (Gavia immer) - Average weight is 3-1/2 pounds; maximum weight is 8 pounds; wingspread is 58 inches; and they generally migrate in small flocks. May breed in States bordering Canada as far south as the Great Lakes. It usually spends the nights on some off-shore island or sandbar and during the day stays off-shore on the water. Usually come ashore to breed and nest. Its wingbeats are fast even when gliding. It feeds on fish, crustaceans, some water plants. It winters along the Pacific, Atlantic, Gulf Coast, and Great Lakes.

Arctic Loon (Gavia arctica) - Is smaller than the Common Loon and probably weighs about the same as a heavy duck; wingspread is 47 inches; and its habits are similar to the Common Loon. In the United States it is found only along the West Coast from the Canadian border to Mexico.

Red-throated Loon (Gavia stellata) - Is the smallest loon frequenting the United States; probably weighs about the same as a Mallard Duck which is 3-1/2 pounds; has a wingspread of 44 inches; often migrate in flocks; and its habits are similar to the Common Loon. It is found during the winter along the Pacific Coast, the Atlantic Coast, and the shores of the Great Lakes. In the autumn it is seen in flocks migrating down the Atlantic Coast, but in spring it travels in the interior to its breeding grounds, generally in Canada. In the past it has bred in the Lake Ontario coastal regions.

Plovers are shore birds of the Order Charadriiformes of the Family Charadriidae. The Plovers are generally migratory and they may cover great distances in their journeys between their winter and summer homes. They are comparatively small birds, and feed from water surfaces and often feed on the dry uplands. Their food is insects and small marine life. Throughout the world there are 75 species of Plovers, but in the continental United States there are eight species as follows:

Mountain Plover (Eupoda montana) - Common in the Rocky Mountain States and adjacent prairies where water is abundant; it is a fast runner that seldom flies but when in flight it flies low; and probably weighs less than 4 ounces. It feeds on locusts and grasshoppers.

American Golden Plover (Pluvialis dominica) - Is one of the longest migrators traveling from their breeding grounds in the Arctic to Argentina. Usually, they pass off the Atlantic Coast in August and September and do not stop unless blown in by heavy winds. They return in April and May from South America going north along the Mississippi Valley. They weigh about 1/4 pound and their flock size is approximately 500 birds in number. Their diet includes seaweeds and grasshoppers.

Black-bellied Plover (Squatarola squatarola) - Is the largest of the Plovers, but does not migrate in large flocks. Breeds in the Arctic tundras and winters along the Atlantic, Pacific, and Gulf Coasts and into South America. It finds its food in the ocean and does not go inland for food except during migrations.

Piping Plover (Charadrius melodus) - Uncommon; when found it is on dry beaches along the Atlantic and Gulf Coasts in winter. Migrates up the Mississippi and may breed in North Dakota and Montana. They are seen singly or in small groups. Generally its food is marine life.

Snowy Plover (Charadrius alexandrinus) - Is a western bird that is found on sand flats and alkali ponds in California, Nevada, Utah, Colorado, Kansas, Texas, New Mexico, and Arizona during breeding season; and along the Gulf Coasts States in winter.

Semipalmated Plover (Charadrius semipalmatus) - Common; along Atlantic Seaboard is most common Plover, and found on beaches and mudflats; their breeding grounds are in the far north and they winter along Atlantic, Gulf States, and South America. The migration northward occurs North-South from their wintering areas. Its diet includes grasshoppers and mosquitoes.

Wilson's Plover (Charadrius wilsonia) - A local species found as residents of North Carolina, South Carolina, and Florida and has been found wintering in Texas and lower California.

Killdeer (Charadrius vociferus) - Common; found in fields and pastures; and found in nearly every State of the continental United States. It feeds on mosquitoes, fever tick, crane flies, weevils, billbugs, wire worms, click beetles, horse flies, crawfishes, and marine worms.

Sandpipers and Snipes are shorebird or wading birds of the Order Charadriiformes, Family Scolopacidae, that differ from Plovers in having longer bills with several species having curved bills. They migrate and pass the winter in flocks. They are seldom found far from shore and moist ground. Their foods consist of grasshoppers, army worms, cutworms, cabbage worms, cotton worms, boll weevils, rice weevils, Texas fever ticks, horseflies, and mosquitoes. There are approximately 100 species in the family but only 33 species, including Curlews, of Sandpipers and two species of Snipes. The weight ranges for these 35 species is probably one-quarter pound up to two-and-one-half pounds. Nine of the species breed in the continental United States. The most abundant seems to be the Common or Wilson's Snipe which has been known to have a population of 30 to 70 million. Maximum weight is 0.37 pounds.

Puffins are sea birds of the Order Charadriiformes, Family Alcidae, that come ashore only to breed. It is estimated that there are 100,000 Puffins that annually frequent the shores of the Atlantic and Pacific Coasts of the United States.

There are two species that are known to the continental United States as follows:

Common Puffin (Fratercula arctica) is the only puffin found along the Atlantic Coast. Breeds as far south as Maine, and occasionally winters in Massachusetts, and rarely in Delaware Bay. Average weight is one pound; and when migrating the flock density is 60/1000 cubic feet. Spends most of winter at sea.

Tufted Puffin (Lunda cirrhata) is found on the North Pacific Islands and as far south as the Santa Barbara Islands, California. Spends the winter at sea.

Even though this study has covered those birds identified with mid-air collisions in the noted years, there are other bird families that are potentially greater hazards. A few of these birds are presented in subsequent paragraphs.

Swans are waterfowl of the Order Anseriformes, Family Anatidae, subfamily Cygninae, that are the heaviest birds frequenting the continental United States. They are almost exclusively aquatic birds and are characterized by the length of their neck, which may be even longer than the body. Their plumage is generally pure white and, like the geese, the distribution of some swans is very wide. Their food consists mainly of the seeds and roots of waterplants, though they have been accused of destroying great quantities of fish-spawn. There are three species of Swans within the continental United States as follows:

Whistling Swan (Olor columbianus) - Species was an almost extinct species 70 years ago, but Federal laws were enacted to protect them. Since 1967 extensive studies have been conducted on the habits and migration patterns of the Whistling Swans. Specifics of these studies are contained in References 19, 20, and 21.

It is estimated there are over 100,000 Whistling Swans that breed in Canada and Alaska. Approximately two-thirds of the birds winter on the Atlantic Coast near the Chesapeake Bay of Maryland, and in small numbers in the bays and inlets of Currituck and Albermarle Sounds of Virginia and North Carolina. The remaining one-third of the birds winters in the West in Northern California.

The Whistling Swan has a wingspread of approximately 85 inches, is an average weight of 13.6 pounds and a maximum weight of 18.6 pounds.

The studies reveal that during migration there are upward of 40 birds in a flock that fly in V-formation with a density of 2/1000 cubic feet.

They leave the Atlantic Coast in late February and arrive in North Dakota in the middle of May. During spring migratory flights the flocks may fly 250 to 600 miles, before resting and feeding.

The flocks attain altitudes of 6000-8000 feet and speeds up to 60 mph.

Whistling Swan (Olor columbianus) travels by both day and night and generally flies with a tail wind. Temperatures recorded in Detroit during recent studies indicated temperatures as low as 18° during migrations to Canada.

FIGURE 35

Distribution of Whistling Swans

Mute Swan (Cygnus olor) is an Old World species introduced into eastern North America and is most commonly seen in parks. It breeds in the wild locally on Long Island and along the New Jersey coast (Figure 36). It has tendencies of extending its range southward.

Supposedly, no other swan breeds in the eastern United States.

The Mute Swan average weight is twenty-two pounds and maximum weight is 35 pounds.

When a flock of Mute Swans are in flight the density is approximately two per 1000 cubic feet.

FIGURE 36

Geographic Locations of Mute Swans

Trumpeter Swan (Olor buccinator) is the largest of swans and was close to extinction until a sanctuary was established in 1935 in the Red Rock Lakes in Montana.

In 1935 there were only 73 known Trumpeter Swans, with 46 in Red Rock Lakes and a few additional pairs in Yellowstone National Park and Idaho (Figure 37). The most recent account taken in 1966 indicated that there were 878 Trumpeter Swans in the continental United States, 84 in captivity and another 1000 or more in the Canadian Rockies and Alaska (Reference 22).

Once Trumpeter Swans in abundance and ranged from Alaska to Missouri, wintering in the Ohio and Mississippi valleys, the lower Columbia River valley and along the Gulf of Mexico.

Rarely do the Trumpeter Swans leave their present breeding areas, but with continued flock growths some pairs are now being moved to other sanctuaries for public viewing. It is believed by the refuge managers that the great migrations of the Trumpeter Swans will never take place again.

Trumpeter Swans, being wild birds have increased over ten-fold in the past thirty years and could potentially cause problems to aircraft in the event that North-South migrations are resumed.

The Trumpeter Swan is approximately five feet long with a wingspread in excess of seven feet, and weighs up to 38 pounds. Due to the birds' enormous size, a collision with an aircraft could cause catastrophic damage to the aircraft.

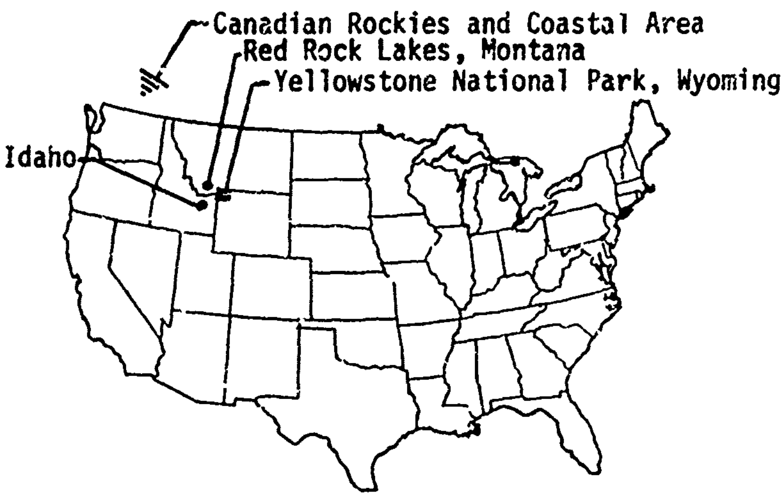


FIGURE 37

Geographical Locations of Trumpeter Swans

Cormorants are fish-eaters of the Order Pelecaniformes, Family Phalacrocoracidae that are chiefly maritime in their habits. They assemble in large colonies on ledges or rocky islands along the sea coasts. When migrating they fly at a considerable altitude but ordinarily they do not rise far above the water. They dive to great depths in pursuit of fish but do not dive from the air. Seamen estimate that there are 160,000 Cormorants frequenting the continental United States. There are five species of Cormorants that frequent the United States as follows:

Double Crested Cormorant (Phalacrocorax auritus) is the most common in the continental United States, Reference 7. It is found on lakes and rivers, but mainly on the coasts as noted in Figure 38. The average weight is 4-1/2 pounds and the wingspread is approximately 50 inches.

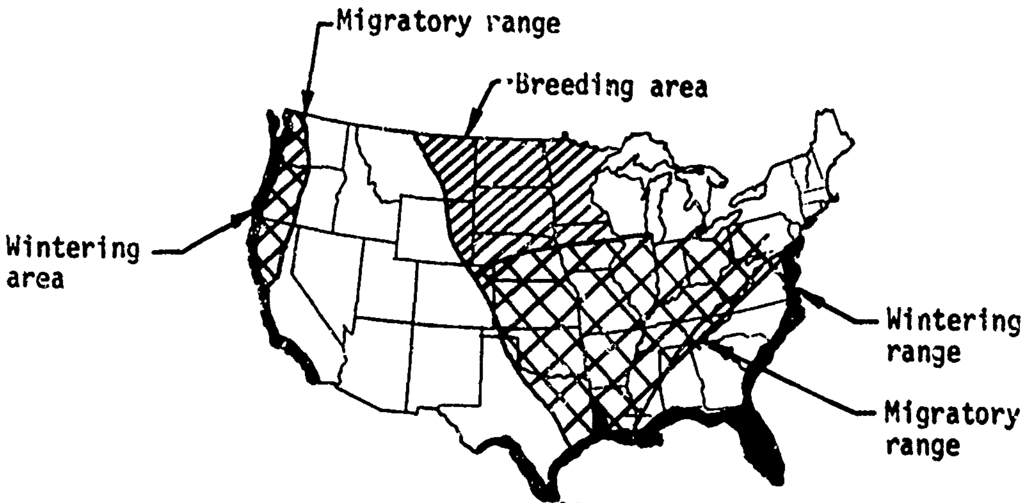


FIGURE 38

Distribution of Double Crested Cormorant

Great Cormorant (Phalacrocorax carbo) - Is the largest Cormorant; Average weight is 3-3/4 pounds; maximum weight is 9 pounds; wingspread is 60 inches; and feeds almost exclusively on fish. The Great Cormorant winters along the Atlantic shores in the upper New England States.

Brandt's Cormorant (Phalacrocorax penicillatus) - Is slightly smaller than the Great Cormorant; probably weighs an average of 3-3/4 pounds; wingspread is 50 inches; and feeds almost exclusively on fish. The Raven and Western Gull are predators of their eggs. Brandt's Cormorant winters on the Pacific Coast from Canada to Mexico.

Pelagic Cormorant (Phalacrocorax pelagicus) - Small Cormorant; wingspread is 40 inches; and winters on the Pacific Coast from Canada to Mexico.

Olivaceous Cormorant (Phalacrocorax olivaceus) - Small common Cormorant; wingspread is 40 inches; apparently breeds in South America; and is found only on the Gulf Coast of Texas and Louisiana.

Conclusions and Pertinent Findings

The term "migratory", as used within the context of bird relocation, is misleading. Literature studied and experts contacted assign the term "migratory" to only that portion of bird movement involved in semi-annual migrations for survival and breeding. Any bird movement is of interest and concern; e.g., from roost to and from feeding areas, to and from winter/summer homes, soaring in search of food, and escape from hunters' firearms. Lexicographers define migratory as moving from one area to another, and while it is felt that the latter definition is far more appropriate for use in the examination of bird behavior, the standard ornithological meaning of the word has been applied throughout this report.

The birds studied in this section were those listed in Table I, identified as having been involved in collisions with aircraft. They belong to specific bird orders and have many similar characteristics. Table II categorizes the birds studied in this section by bird orders and includes other pertinent information such as the number of species, weights, and population.

TABLE II

PERTINENT DATA OF IDENTIFIED BIRDS INVOLVED IN REPORTED BIRDSTRIKES

ORDER Type and/or Characteristic	Common Name	No. of Species in U.S.	Avg.Wt. of Smallest Species	Avg.Wt. of Largest Species	Max.Wt. of Largest Species	Population Density in the U.S. (All Species)	Source of Ref.
Charadriformes		109					
(Wading or Swimming Birds)	Gulls	15	.66#	2.5#	4.0#	1,000,000-1,500,000	11,12,9
•Highly migratory	Plovers	8	.25#				
•Shore birds except for	Sandpipers	33	.25#		2.5#		
Puffins which are pelagic	Snipes	2	.25#		.37#	30,000,000-70,000,000	27
	Puffins	2		1.0#		100,000	27
Anseriformes		46					
(Waterfowl)	Swans	3	13.6#	22.6#	38.0#	100,000	8,19,20, 21
•Aquatic							
•Migratory	Geese	8	2.5#	8.0#	14.0#	5,000,000	8
•Fly in Flocks	Ducks	35	.75#	2.7#	4.0#	90,000,000	8
Falconiformes		29					
•Rapacious	Buzzards/	2	3.0#		4.5#	2,000,000-4,000,000	27
•Birds of Prey	Vultures						
•Vultures and California	California	1		21.5#	23.0#	24	
Condors are carrion feeders	Condors						
	Hawks	11	2.0#	2.5#	4.5#	15,000,000-30,000,000	
	Eagles	2	9.5#	11.0#	14.8#	10,000	17
	Falcons	6	.5#	5.0#	10.0#		
Columbiformes		11					
•Vegetarians	Pigeons/	10	.5#		1.0#	20,000,000-40,000,000	
	Doves						
	Mourning	1	.3#		.37#	240,000,000-280,000,000	
	Doves						
Passeriformes		300					
(Perching Birds)	Robins	1					
•Includes most all song birds	Thrushes	6	.2#				
•Senses keenly developed	Veerys	1					
•Most species are insecti-	Sparrows	30					
vorous	Blackbirds	12	.1#			400,000,000-500,000,000	
•Some are fruit & seed eaters	Starlings	1	.25#				
•Some species are migratory	Larks		.2#				
	Crows/Ravens	5			2.5#		
Ciconiiformes		19					
(Wading Birds)	Herons/						
•Aquatic animal life feeders	Egrets/	13	0.75#	9.0#	13.0#	1,000,000	
•Some species fly at night	Bitterns						
	Storks	1			10.0#	20,000	
	(Wood Ibis)						
Strigiformes		19					
•Most species are nocturnal	Owls	19	.5#	4.0#	6.0#	2,000,000-4,000,000	
•Birds of prey							
•Raptorial							
Gruiformes		12					
(Wading Birds)	Cranes	2		9.0#	13.0#	150,000	7
•Long-legged marsh dwellers							
Peiecaniformes		15					
•Large aquatic birds	Pelicans	2	8.5#	15.0#		67,000	
•Fish-eating	Frigatebirds	1		3.5#	4.0#		
•Frigatebirds often rob gulls	Cormorants	5		3.75#	9.0#	160,000	
and Terns for food							
•Cormorants are divers							
Galliformes		21					
(Chicken-like)	Pheasants,						
•Ground dwellers	Ring-necked	1		2.1#	4.1#		
•Small head and heavy body							
Gaviiformes		3					
(Diving Birds)	Loons	3		3.5#	8.0#		
•Skilled swimmers							
•Eat fish, crustaceans and aquatic plants							

SECTION III

A QUANTITATIVE REVIEW OF REPORTED BIRD/AIRCRAFT MID-AID COLLISIONS

In Section II a study was made of the various species of birds that have been repeatedly involved in aircraft collisions. The great number of birds and the frequencies that aircraft are airborne points up that there may not be sufficient air space for both at all times.

In this section the worldwide data that was collected pertaining to bird/aircraft mid-air collisions was compiled, sorted, and a quantitative review was made to establish the cause and effect relationships of bird hazards to aircraft.

As shown in Table III, it was believed that a sufficient data base was established from which different kinds of studies were conducted. Although the data compiled represented 18,097 aircraft/bird incidents, some of the data were more complete and accurate, and it was found that the methods of summarizing and depicting the data in the reports were many and varied. When detailed data were available, the individual reports frequently had missing details such as the altitudes, speeds, bird identifications, time of day and other items. Therefore, as the program progressed it was found that the same data were not usable for every study.

From the data collected pertinent details were selected for study in the following categories:

- Phase-of-flight collisions occur
- Altitude collisions occur
- Frequency of strikes per aircraft component
- Aircraft component damage
- Severity of damage/cost of collisions
- Severity of injury to personnel
- Type and weight of birds struck
- Frequency of collisions by month

Preceding page blank

- Time of day
- Geographic location of bird collisions in CONUS
- Bird types struck at randomly selected airfields

TABLE III

DATA BASE: WORLDWIDE REPORTED AIRCRAFT/BIRD COLLISION INCIDENTS

Reporting Agency	Years Included	Total Incidents Reported	Reference Number
FAA	1942-1946	473	23
FAA	1963-1965	1075	24
FAA	1971 & 1972	532	1 & 2
ICAO (Civil-Worldwide)	1965-1969	5021	25
KLM Airline	1963-1967	775	26
Air Canada Airline	1964 & 1965	287	27
U.S. Navy	Fy'60-Fy'72	2889	28
USAF	1965-1972	3333	3
USAF B-52	1965-1967	372	4
German Air-force	1966-1968	593	29
USSR	1963-1968	584	30
RAF	1964-1968	2063	31
Total	18,097		

Phase of Flight Collisions Occur

Categorically, the phase of flight in which bird/aircraft collisions occur dictates the starting point in order to develop meaningful conclusions.

As noted in Reference 25, the ICAO has concluded from internationally reported bird strikes for the years 1967, '68 and '69 that 75% of confirmed bird strikes occur below 1000 feet during takeoff or landing, 20% between 1000 and 5000 feet, and the remaining 5% occurs above 5000 feet altitudes.

Since the ICAO data included data from twenty-five nations including Canada, it is believed the ICAO conclusions would be representative of the expected occurrences of bird collisions involving commercial airlines. The inclusion of the Canadian data assures that birds struck are representative of birds that could be expected to be involved in strikes in the CONUS.

Military aircraft fly different mission profiles and it would be expected that the number of bird strikes per phase of flight could be different. The U.S. Navy in 1972 reported 405 incidents involving birds, of which approximately 54% occurred during takeoff and landing, approximately 42% enroute or during training missions and the remainder unknown.

Selected data were compiled as shown in Table IV that represents five years of operations by KLM Airlines which flies to many parts of the world, two years of operations reported to the FAA by United States commercial carriers operating in the contiguous United States, and eight years of operations by the USAF.

TABLE IV

IDENTIFIED BIRD STRIKES DURING PHASE OF FLIGHT

	% BIRD STRIKES/PHASE OF FLIGHT		
Phase of Flight	KLM Fleet 1963-1967	FAA US Carriers 1971-1972	USAF 1965-1972
Takeoff	22.32%		5.55%
Takeoff &/or Initial Climb	1.55%	33.08%	8.82%
Taxi	.77%		5.28%
Roll			3.72%
Aborted			.15%
Sub-Total	24.64%	33.08%	23.52%
Landing	29.42%		5.52%
Approach	7.74%		4.02%
Approach/Landing		43.06%	
Traffic Pattern (or Go Round)			13.71%
Flare			1.32%
Roll			.99%
Sub-Total	37.26%	43.06%	25.56%
Enroute			2.22%
Prolonged Climb			.12%
Normal Flight			11.28%
Cruise/Enroute		13.91%	
Low Level Flight			21.45%
Ordnance Delivery			1.05%
Descent	1.42%		.21%
Sub-Total	1.42%	13.91%	36.33%
Unknown	36.77%	9.95%	14.59%
Total	100.0%	100.0%	100.0%
Total Number of Bird Strikes	775	532	3333
REFERENCES:	26	1 & 2	3

The data shown in Table IV shows that approximately 62% of the KLM strikes occurred during landing and takeoff and approximately 37% were unknown. It can be assumed that some of these unknown incidents were in the takeoff/landing phase and would raise that percentage to approximately 75%.

The FAA data shows approximately 76% of the strikes occurred during the takeoff/landing phase, which is a close correlation to the ICAO worldwide data. The USAF data reveals that approximately 50% occur during takeoff/landing, correlating closely with the U.S. Navy data of 54%. The USAF data does, however, reveal another key point; that 22% of their strikes occur during low-level training missions and ordnance deliveries. A consideration of these data reveals that with appropriate ecological changes to the airports, and possible use of ground radar, upward of 75% of the worldwide bird strikes involving commercial carriers and approximately 50% of the U.S. military bird strikes could be eliminated.

Altitude Collisions Occur

Much of the data collected did not indicate the phase-of-flight in which aircraft/bird incidents occurred but did report altitudes. Altitude is one of the most important considerations that must be assessed in the determination of aircraft speeds for the selection of appropriate design criteria for windshields/canopies and support structure.

Table V is a compilation of bird strike incidents denoting the frequency of occurrence at various altitudes and Table VI relates these strikes in terms of cumulative frequency percentages. From these tables it becomes apparent that the selection of a relatively safe altitude for determining design criteria is 8000 feet above ground level. In each of the eight sets of data, at least 95% of all strikes occur below 8000 feet. It is believed that some of the incident reports used for this study may have indicated altitudes as mean sea level rather than above ground level. It is believed that a USAF aircraft flying a low-level training mission (below 8000 feet) would fly at faster speeds than would be expected during cruise flights above 8000 feet.

TABLE V

REPORTED BIRD STRIKES AT KNOWN ALTITUDES

Altitude Range AGL (Feet)	KLM Fleet '63-'67	U.S. Navy '60-'71	U.S. Navy '72	FAA-U.S. Carriers '71-'72	FAA-U.S. Transport Aircraft '63-'66	USAF 1972	German Air Force '66-'68
0-100	136	2	126	161	—	42	123
101-500	30	20	91	59	—	41	61
501-1000	12	12	50	31	—	45	279
1001-2000	10	15	45	42	—	37	45
0-2000	—	—	—	—	109	—	—
2001-3000	7	3	20	28	—	9	14
Over 3000	—	—	18	—	—	—	—
3001-4000	3	1	—	23	—	6	—
2001-4000	—	—	—	—	38	—	—
4001-5000	1	2	—	15	—	4	—
5001-6000	2	1	—	9	—	1	—
4001-6000	—	—	—	—	25	—	—
6001-7000	1	—	—	8	—	1	—
7001-8000	2	—	—	7	—	—	—
6001-8000	—	—	—	—	8	—	—
Over 8000	—	—	—	16	18	3	—
Total Incidents at Known Alt.	204	56	350	399	198	189	522
Total Incidents at Unknown Alt.	571	2311	55	133	764	162	71
Total Incidents	775	2367	405	532	962	351	593
REFERENCES:	26	37, 28		1 & 2	24	3	29

TABLE VI

PERCENT CUMULATIVE FREQUENCY OF BIRD STRIKES AT KNOWN ALTITUDES

Known Altitudes AGL (Feet)	PER CENT CUMULATIVE BIRD STRIKES								
	KLM Fleet '63-'67	U.S. Navy '60-'71	U.S. Navy 1972	FAA U.S. Carriers '71-'72	FAA-U.S. Transport Aircraft '63-'66	German Air Force '66-'68	ICAO Com'l Aircraft '67-'69	USAF '65-'71	USAF 1972
Below 100	66.0%		36.0%	38.40%		23.56%		26.7%	22.22%
Below 500	81.3%	39.28%	62.0%	52.12%		35.25%			43.91%
Below 1000	87.2%	60.71%	76.28%	59.85%		88.70%	75.0%	65.4%	66.66%
Below 1500		80.34%				91.57%			81.47%
Below 2000	92.1%	87.48%	89.14%	72.82%	55.05%	97.31%			86.23%
Below 2500		91.05%				100.0%			88.88%
Below 3000	95.6%	92.84%	94.84%	79.80%				93.4%	91.00%
Above 3000			5.14%					6.7%	
Below 3500									93.12%
Below 4000		94.62%		85.54%	74.24%				94.18%
Below 4500		96.42%							
Below 5000	97.0%	97.21%		89.28%			95.0%		97.30%
Above 5000							5.0%		
Below 5500									
Below 6000	97.5%	100.0%		91.77%	86.87%				97.83%
Below 6500									
Below 7000	98.5%			94.01%					98.36%
Below 7500									
Below 8000	100.0%			95.76%	91.91%				
Below 8500									
Below 9000									98.89%
Below 9500									
Below 10,000					95.45%				99.42%
Below 12,000					98.48%				
Below 14,000				100.00%	100.0%				100.0%
REFERENCES:	26	28		1 & 2	24	29	25	3	3

Selected data for additional study is shown in Figures 39, 40 and 41 which were developed to show the percentage of strikes occurring at different altitudes.

It became apparent from reviewing Table VI and Figures 39, 40, and 41 that certain general conclusions could be adopted as follows:

1. At least 22% of all bird strikes occur below 100 feet (AGL).
2. Approximately 60% of all bird strikes occur below 1000 feet (AGL).
3. Approximately 80% of commercial aircraft and approximately 90% of USAF aircraft bird strikes occur below 3000 feet (AGL).
4. Approximately 90% of commercial aircraft and approximately 95% of USAF aircraft bird strikes occur below 5000 feet (AGL).
5. That less than 5% of all bird strikes occur above 8000 feet (AGL).

It is believed that the altitude data noted for the FAA (1963-1966) have indicated mean sea level altitudes rather than altitudes above ground level.

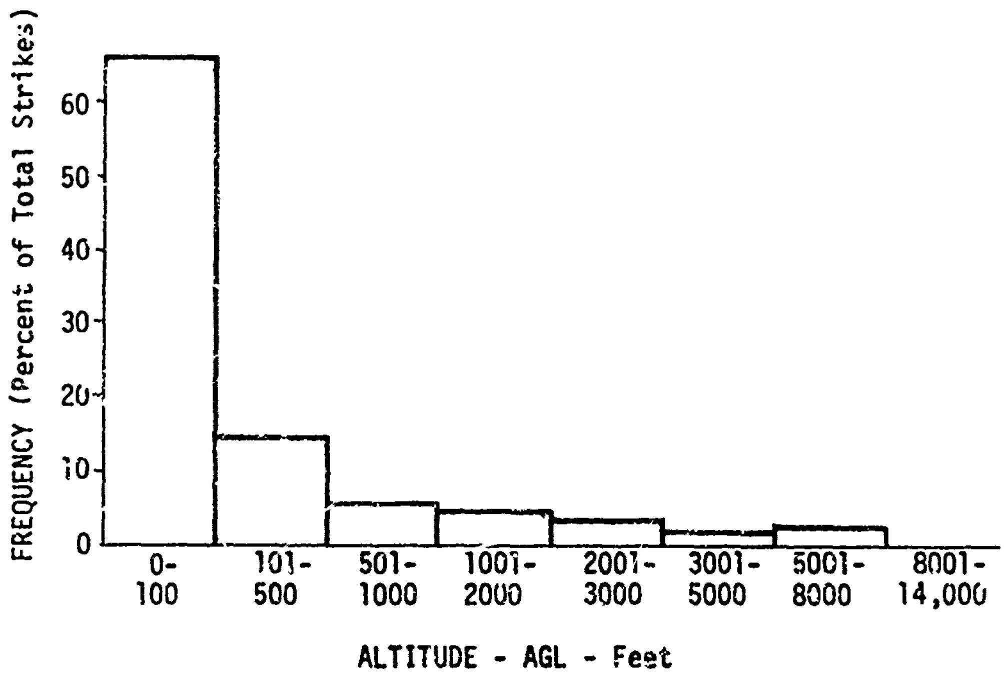


FIGURE 39

KLM 1963-1967 - 204 Bird Strikes

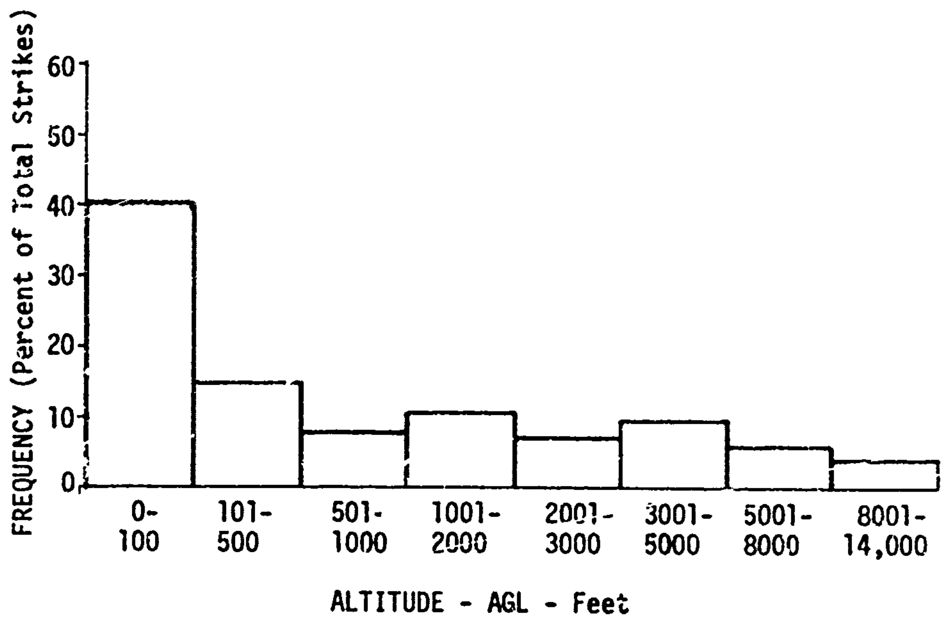


FIGURE 40

FAA 1971-1972 - 399 Bird Strikes

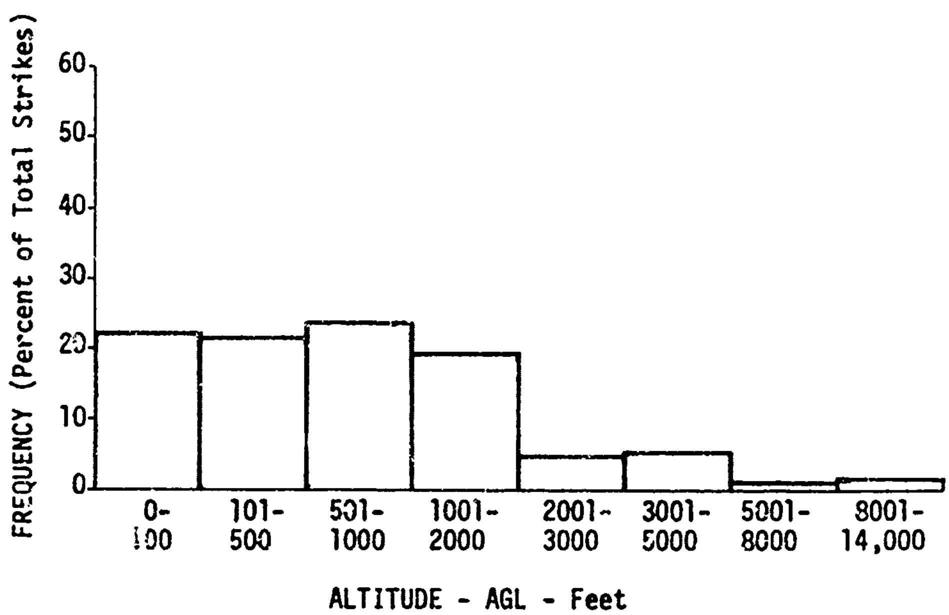


FIGURE 41

USAF 1972 - 189 Bird Strikes

Aircraft Component Damage

The data presented in Table VII represents the operations of many aircraft users and is representative of every mode of operation, type of aircraft, type of flight condition, and over terrain worldwide. This data includes over 8100 strikes studied to evaluate the vulnerability of various aircraft components to bird strikes. The percent frequency of bird strikes on windshield/canopies is below 18%. The noted worst condition of 18% is that of the Air Canada operations of DC-8 aircraft. Although the frequency of bird strikes on windscreens may be low, the interactions resulting from bird strikes can easily be classed as the most drastic other than, perhaps, a total loss of engines from bird ingestions. Some results of a windscreen bird strike include:

1. Pilot fatality with ultimate loss of aircraft.
2. Pilot incapacitation which prevents mission completion.
3. Pressurization losses that would prevent mission completion.
4. Structural damage to escape system that would prevent emergency escape for crew.
5. Aerodynamic noises resulting from loss of windscreen portions that could cause radio equipment and communications with crew to be ineffective.
6. Damage to instruments and systems components that would prevent mission completion.

Comparatively, the U.S. Navy reported in Reference 28, for fiscal year 1972, an even greater percentage of 21% for windscreen incidents including bird penetrations that caused at least one injury.

The USSR noted in Reference 32, that commercial aircraft experienced 12.6%, and military aircraft experienced 9.6% of the reported bird strikes on windshields/canopies. The USSR report also revealed that over 40% of all bird strikes occurred on engines.

TABLE VII

AIRCRAFT IDENTIFIED COMPONENTS STRUCK BY BIRDS

Location of Bird Strike on Aircraft	% BIRD STRIKES/LOCATION					
	ICAO Com'l Aircraft '67-'69	KLM Fleet '63-'67	B-52 Fleet '65-'67	Air Canada DC-8 Fleet '64-'65	FAA US Carriers '71-'72	USAF '65-'72
Radome	3%	2.16%	—	—	17.20%	11.23%
Nose Section (Aft of Radome)	15%	15.9 %	—	—	—	—
Windshields, Canopy	13%	9.97%	5.38%	18%	16.10%	11.56%
Fuselage & Radomes	—	—	12.63%	—	—	—
Fuselage including Cockpit	—	13.61%	—	27%	9.81%	6.14%
Engines, Nacelles, & Wings	60%	.27%	—	—	—	—
Engines, Cowls, Pods	—	—	29.03%	—	—	—
Engines	—	21.97%	—	40%	29.43%	31.40%
Heat Exchanger	—	1.21%	—	—	—	—
Nacelle/Pylon	—	1.48%	—	—	—	—
Oil Cooler	—	4.04%	—	—	—	—
Wings	—	9.57%	—	14%	21.55%	25.11%
Wings & Flaps	—	—	45.97%	—	—	—
Trailing Edge Flaps	2%	—	—	—	—	2.83%
L.E. Flaps/Slats	—	—	—	—	—	1.11%
Landing Gear & Lights	6%	2.96%	.54%	—	3.70%	2.11%
Wheel Well/Doors	—	.67%	—	—	—	—
Prop/Rotor Blades	—	—	—	—	—	.66%
External Tanks	—	—	1.88%	—	—	1.84%
Empennage	1.5%	.27%	3.76%	1%	1.29%	2.74%
Area Unknown	—	16.04%	.81%	—	—	3.28%
Total Number of Bird Strikes	3028	742	372	89	622	3333
REFERENCES:	25	26	4	27	1, 2	3

Severity of Damage/Costs of Collisions

The severity of component damage and associated costs is difficult to ascertain for a multitude of reasons, but some pertinent facts are available. The complete loss of either a commercial or military aircraft could easily exceed $10,000,000. Repair costs reported by KLM in Reference 26 for five years was in excess of $330,375. This includes 32 engine changes, and does not include fuel dumped, loss of revenue, loss of prestige with their customers because of flight delays, or passenger claims for injuries.

Solman in Reference 33 cites that Air Canada's cost for repairs per year average to be:

1958 - 1962	$ 239,000
1963 - 1968	$ 125,000
1969	less than $ 50,000

The reductions in repair costs noted for Air Canada seems impressive but is even more impressive when considerations are given to the increase in aircraft movements as noted in Reference 35 from 275,000 in 1963 to 400,000 in 1968. This factual information clearly shows that the control procedures around the Canadian airports to reduce the attractiveness to birds are showing some successful results.

In addition, Reference 33 estimates that catastrophic damage to an engine would cost at least $200,000 and possibly up to $1,000,000 for replacement. One air line reported changing 75 engines over a 2-1/2 year period. The ICAO reports for 1967 through 1969 indicates that 5% of the bird strikes cause significant or major damage to the aircraft. In six years Canada lost ten CF-104s through bird strikes, which may suggest the vulnerability of a single-engine aircraft to bird ingestion and the resultant loss of the aircraft.

It has been estimated by the USAF as noted in Reference 34, that the direct repair costs for USAF aircraft was $20,000,000 due to bird strikes for the years 1966 through 1972. This estimate does not include associated costs for jettisoned fuel, lost operational time, aborted missions, or lost aircraft. The known USAF aircraft lost due to bird strikes since 1964 include seven high performance jet trainers and fighter-type aircraft.

Severity of Injury to Personnel

The cost of a human life and injuries is difficult at best to price. After the 1960 crash at Boston in which over 60 lives were lost, the courts awarded $100,000 per human life to the heirs. Realistically, that could be considered to be a very low figure when some of the passengers and crew might have had productive years that earnings could have easily gone over $500,000, and can never account for intangible costs to their loved ones. In the USAF since 1965 there have been seven fatalities that represented a large investment to the Air Force in pilot training, education and experience that is not easily replaceable, plus the loss of productive earning power to each of the respective families. In addition to the seven fatalities, there were five major injuries and 26 reported minor injuries to flight crews aboard USAF aircraft during the same period. Again the costs attributed to the five major injuries could be exorbitant when one considers that the resultant effect could be permanent incapacitation of the recipients.

Type and Weight of Birds Struck

Generally, it is believed that there are over 7000 bird species scattered throughout the world with over 600 species in the continental United States. To evaluate the birds involved with aircraft collisions, several different sets of data were examined in an effort to determine the similarities of the bird strikes involved.

As shown in Table VIII the FAA reported bird strikes involving commercial air lines for two years operating in the continental United States, Hawaii, and Midway Islands. These data were considered first to establish a pattern.

TABLE VIII

IDENTIFIED BIRDS STRUCK DURING 1971 AND 1972 BY COMMERCIAL AIRCRAFT

BIRD SPECIES			NUMBER OF BIRD STRIKES	
Type	Maximum Weight (Lbs)	Average Weight (Lbs)	Enroute	Takeoff/ Landing
Gull	4	2-1/2	1	56
Plover		1/4		1
Sandpiper		1/8		3
Puffin		1		1
Pigeon/Dove	1	1/2		23
Vulture	4-1/2	3		8
Eagle	14-3/4	10	1	
Hawk/Falcon	4-1/2	2-1/2		12
Nighthawk		1/5		1
Robin		1/4		3
Thrush		1/4		1
Blackbird		1/5		3
Starlings		1/4		5
Lark		1/5		2
Sparrow		1/8		3
Swallow		1/32		1
Killdeer				1
Duck	4	2-1/2	2	17
Goose	14	8	1	7
Owl	6	4		4
Crane	13	9		3
Heron	13	9	1	
Loon	8	3-1/2	1	
Snow Bunting				1
Pheasant	4	2-1/2		3
Albatross	8	6		6
Bats		1/5		1
Total			7	166
REFERENCES:	5		1 & 2	

The bird strike incidents reported by the USAF during 1972 worldwide operations were then compared as noted in Table IX. The data revealed that there were two strikes in Turkey involving storks at high altitudes, a pelican, an egret, a frigate bird, as well as additional species of perching birds occurring in CONUS.

TABLE IX

IDENTIFIED BIRDS STRUCK DURING 1972 BY USAF AIRCRAFT

Bird Species	Maximum Weight(Lbs)	Average Weight(Lbs)	Enroute	Takeoff/ Landings
Gulls	4.0	2.5	8	12
Franklin Gull		.5	2	3
Curlew		1.5		1
Wilson Snipe		.2	1	
Vultures	4.5	3.0	6	7
Hawk	4.5	2.5	4	7
Pigeon/Dove		.5		5
Small Birds		.3	5	10
Blackbird		.3	1	3
Lark		.2		4
Veery		.2	1	
Sparrow		.13		1
Starling		.25	1	1
Crow		1.0		1
Ducks	4.0	2.5	7	11
Canada Goose	14.0	8.0	1	1
Great Horned Owl	6.0	4.0		1
Screech Owl		.5		2
Pelican		10.0		1
Frigate Bird		3.5		1
Stork	10.0	5.0	2	1
Egret		1.0		1
Sandhill Crane	13.0	9.0	1	
Prairie Chicken		1.0		1
Albatross	8.0	6.0	1	1
Bat		.2	2	7
Total			43	83
REFERENCES:	5		3	

Three years of USAF B-52 training mission incidents were compared to the 1972 USAF operations. This comparison was made because the oil-burner missions of the B-52 included routes along the Canadian border and in states not commonly frequented by commercial and USAF flights. There were no differences in the bird species. However, there was a noted increase in the frequency of strikes involving ducks, as noted in Table X.

TABLE X

IDENTIFIED BIRDS STRUCK DURING 1965-1967 ON USAF B-52 AIRCRAFT

BIRD SPECIES			NUMBER BIRD STRIKES			
Types	Maximum Weight(Lb)	Average Weight(Lb)	1965	1966	1967	Total
Gulls	4	2-1/2	4	-	5	9
Vulture	4-1/2	3	1	2	6	9
Hawk	4-1/2	2	1	6	-	7
Blackbird	-	1/5	-	2	-	2
Starling	-	1/4	2	-	-	2
Crow	-	1	-	-	1	1
Robin	-	1/4	1	-	7	8
Ducks	4	2-1/2	14	7	6	27
Canada Goose	14	8	1	1	9	11
Screech Owl	-	1/2	1	-	-	1
Egret	-	1	-	-	3	3
REFERENCES:	5		4			

KLM Airlines bird strike incident reports as noted in Table XI were used since KLM's worldwide operations revealed only two new species of birds were involved. These were the partridge, which is common in the continental United States, and the Wagtail Plover that is rare to the CONUS.

TABLE XI

IDENTIFIED BIRDS STRUCK DURING 1963-1967 BY KLM AIRLINE FLEET

BIRD SPECIES			NUMBER OF BIRD STRIKES	
Type	Maximum Weight (Lbs)	Average Weight (Lbs)	Number of Strikes (Total) Worldwide	Number of Strikes at Schipcl Airpt (only)
Gull	4	2-1/2	97	70
Lapwing/Plover	1/2	1/4	16	8
Vulture	4-1/2	3	9	-
Pigeons	1	1/2	17	4
Swallow	-	1/32	17	3
Sparrow	-	1/8	12	3
Blackbird	-	1/4	2	-
Crow	-	1	3	-
Lark	-	1/8	1	-
Wagtail	-	1/2	1	1
Duck	4	2-1/2	4	3
Goose	14	8	1	-
Pheasant	4	2-1/2	4	-
Partridges	1	3/4	7	4
Heron	13	9	2	1
REFERENCES:	5		26	

Since the USAF flies into various air bases in Europe, two sets of data are presented in Tables XII and XIII to confirm the similarities of birds struck in the continental United States. Table XII shows the bird strike incidents that occurred in the British RAF and Table XIII shows the bird strike incidents that occurred in the German Air Force. The only identified birds that were not also common in the United States were the Black-headed Gull, Plover and Rook.

TABLE XII

IDENTIFIED BIRDS STRUCK DURING 1964-1968 BY THE UNITED KINGDOM RAF

BIRD SPECIES			NUMBER BIRD STRIKES				
Type	Maximum Weight (Lbs)	Average Weight (Lbs)	1964	1965	1966	1967	1968
Gull	4	2-1/2	46	58	53	51	66
Herring Gull	4	2-1/2	-	-	-	-	6
Black-headed Gull	2/3	1/2	-	-	-	-	5
Common Gull	1	2/3	-	-	-	-	4
Oyster Catcher	-	2	1	1	2	1	3
Lapwing/Plover	1/2	1/4	7	11	8	13	20
Pigeon	1	1/2	10	15	3	13	18
Starling	-	1/4	4	4	16	15	15
Swallow/Swift	-	1/16	7	6	5	14	9
Rook	-	1	13	6	2	11	11
REFERENCES:	5		31				

TABLE XIII

IDENTIFIED BIRDS STRUCK DURING 1966 - 1968 BY THE GERMAN AIRFORCE

BIRD SPECIES			NUMBER OF BIRD STRIKES	
Type	Maximum Weight (Lbs)	Average Weight (Lbs)	In Flight	Takeoff/ Landing
Gull	4	2-1/2	43	26
Plovers	1/2	1/4	4	10
Vultures/Falcon	4-1/2	3	30	2
Pigeon	1	1/2	13	1
Small Birds	-	1/8	7	1
Starling	-	1/4	6	2
Swallow	-	1/32	5	1
Crow	-	1	5	1
Thrushes	-	1/4	2	-
Magpie	-	1/2	1	-
Ducks	4	2-1/2	2	1
Owl	1-1/2	1/2	1	-
Pheasant	4	2-1/2	-	1
Partridge	1	3/4	-	2
REFERENCES:	5		29	

The most commonly struck bird as determined from Tables VIII through XIII is the gull, followed closely by the perching bird group (including robins, sparrows, starlings, blackbirds, swallows, crows, etc.). Nearly all of these birds in these tables are small with the exception of the Herring and Black-backed Gull. The principal danger from the small bird group lies in engine ingestion because of the relatively large numbers involved in a single incident.

One interpretation of these tables is that man probably provided most of these birds with their normal requirements for shelter and food around airports, - such items as shrubs, trees and buildings for roosting sites; and such items as grass, seed-bearing plants, jackrabbits, rodents, and garbage dumps, as well as drainage ditches.

Airports attract some of the 300 or more species of perching birds, gulls, pigeons, plovers, sandpipers, snipes, and pelicans. Airports also attract birds such as vultures, eagles, hawks, falcons, and owls, and others because of the usual availability of rodents and jackrabbits.

Unquestionably, over 50% of the bird strikes could be prevented if all airport/air base managements would eliminate the attractions around the airports that are necessary for the survival of these birds.

Waterfowl, including ducks, geese, and swans, currently present problems to aircraft because of their migratory habits and abilities to fly at high altitudes. Generally, they become involved with aircraft when the aircraft are enroute, on descents, or low altitude long climbouts. These waterfowl in the future could pose even greater problems since each species is in some manner protected by national laws and wildlife reserves are making every effort to increase the population of each species. A Canadian Broadcasting Company Winnipeg Production pertaining to the Canada Goose, titled "NIS'KU", was presented 8 July 1973 on KTLA Television Station by the Southern California Gas Company.

It was interesting to note that there were upward of 15,000 of these big birds spending the winter on the grounds of the Mayo Clinic in Rochester, Minnesota. There were additional refuges covered in North Dakota, Missouri and Illinois. In each locale, the birds were somewhat cosmopolitan since many man-inhabited buildings were close by, and many were hand-fed by man. The proximity of these refuges and future refuges to airports or training routes could pose serious problems to USAF aircraft.

Bird weight is a prime factor in the development of design criteria for windshields/canopy and support structure. Table XIV was developed to depict the frequency by percentage of bird strike occurrences by weight ranges. The reported operations by the RAF and German Air Forces operating in Europe unquestionably shows that 100% of the strikes involved birds weighing less than four pounds. The data representing continental United States and worldwide operations such as the ICAO commercial airlines, all FAA commercial airlines, and the USAF 1972 data indicated that over 90% of the strikes involved birds weighing less than four pounds. This same data also includes bird strike involvements by both the USAF and commercial airlines with Albatrosses (Gooney birds) at Midway Islands. The KLM data, as expected, shows that over 95% of the strikes involved birds weighing less than four pounds since KLM does not fly into Midway Island and has few of their total flights into North America. Also, to be expected, the B-52 data reveals that approximately 14% of the strikes involved Canadian Geese during their oil-burner training missions. More recently, however, it has been reported that the B-52 training missions are pre-programmed and at all times take advantage of the Canadian reports on migratory movements of the Great Canada Goose as well as other waterfowl. As a result, bird strike incidents with Canadian Geese have almost been eliminated.

TABLE XIV

SUMMARY OF IDENTIFIED BIRD STRIKES BY WEIGHT RANGES

Average Bird Weight Range (Pounds)	PERCENT OF TOTAL							
	ICAO Com'l Aircraft '67-'69	KLM Fleet '63-'67	German Air Force '66-'68	RAF '64-'68	FAA-U.S. Transport Aircraft '63-'66	FAA U.S. Carriers '71-'72	USAF B-52 '65-'67	USAF '72
0 - 1	---	39.38%	37.72%	46.25%	50.53%	34.10%	20.25%	41.27%
1 - 2	---	2.07%	1.80%	1.40%	---	18.57%	54.43%	23.81%
2 - 3	---	56.99%	60.48%	48.87%	---	34.10%	---	26.19%
3 - 4	---	1.04%	---	---	---	4.00	---	1.59%
4 - 5	---	---	---	---	---	.58%	11.39%	---
0 - 4	94.5%	---	---	---	---	---	---	---
1 - 6	---	---	---	---	4[illegible].79%	---	---	---
4 - 8	4%	---	---	---	---	---	---	---
8 - 9	---	.52%	---	---	---	4.62%	13.92%	---
5 - 8	---	---	---	---	---	3.47%	---	5.56%
6 - 38	---	---	---	---	8.68%	---	---	---
8 & Over	1.5%	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	.79%
10	---	---	---	---	.58%	---	---	.79%
Total Identified Bird Strikes	3028	193	167	553	760	173	80	126
REFERENCES:	25	26	29	31	24	1, & 2	4	3

Frequency of Collisions by Month

Anyone undertaking the study of birds relative to their nesting and breeding habits is confronted with many variables. Some birds are resident the year around, unless forced to move due to food and water shortages, and yet, others like the Arctic Tern migrate 22,000 miles round trip between their winter and summer homes. Some birds do not mate until after the second or third year and do not migrate from their winter homes. Some birds breed and nest in the continental United States in the summers and winter in South America. Some birds spend the winter in the Southern United States and breed in the Northern United States, Canada or the Arctic.

Only a few birds migrate when isothermal temperatures are below 35°F, but most birds will start their migration long after the 35°F temperatures are assured. Consequently, the migration period is between late February and early May, depending on the temperature conditions and the species of bird. Considering other peculiarities of birds in general the number of birds per species will be at the lowest during spring migrations; thus, taking into account the high mortality occurring during winter caused by normal attrition, starvation, freezing to death; poisonous foods due to man's chemical pollution of the environment; land fills on coasts to fill marshes; man's elimination of woods and forests that force the birds into congested areas where disease can wipe out whole artificially-enlarged colonies; hunters and other causes. June and July are the peak months that newly hatched birds must be attended, keeping the parents busy providing foods, and some birds will moult at least three weeks during the summer, at which time they cannot fly. After the new birds are able to fly, migrations back to their winter homes start in late August and will continue into late November.

Changes in the local environment while the various birds were at their nesting grounds pose a problem upon their return to their wintering grounds. They seem to be in a state of flux trying to establish specific new domains for roosting and feeding.

Considering all of these variables, Table XV was prepared to determine the effects of these variables on the frequency of strikes on a monthly basis.

From this table it becomes obvious that these variables do have an affect on the frequency of strikes on a monthly basis. It appears that during the months of December, January and February, birds are not as active because of the cold temperatures; that during June, birds are caring for their young and do not venture far from their nesting grounds; and that August, September, October, and November are the peak months for bird strikes reflecting the population growths and other associated problems of new flocks.

TABLE XV

TOTAL MONTHLY REPORTED BIRD STRIKES BY EUROPEAN & NORTH AMERICAN CIVIL & MILITARY AIRCRAFT OPERATORS

Month	USSR Civil '68	German AF '66-'68	KLM Fleet '63-'67	Air Canada '61-'64	FAA U.S. Transprt Aircraft '63-'65	FAA U.S. Carriers '71-'72	USAF B-52 '65-'67	USAF '67-'72	USAF Low Level Cruise CONUS '65-'71	Total
January	17	5	39	9	36	23	18	130	10	287
February	20	14	28	13	24	19	18	144	23	303
March	33	58	40	19	57	44	12	159	37	459
April	46	36	48	51	78	53	38	193	33	576
May	39	51	42	54	92	42	40	211	56	627
June	64	56	[illegible]	32	20	22	4	123	26	402
July	89	89	93	22	13	40	11	130	35	522
August	83	85	107	104	66	45	26	151	45	712
September	96	75	96	111	131	67	54	275	87	992
October	71	98	109	80	180	68	87	322	89	1104
November	19	22	80	29	76	46	51	219	42	584
December	7	4	38	18	26	24	13	117	20	267
Totals	584	593	775	542	799	493	372	2174	503	6835
REFERENCES:	30	29	26	27	24	1, & 2	4	3	36	

Time of Day Collisions Occur

A factor which must be considered in evaluating bird habits and bird strike incidents is the day and night distribution of collisions.

It has been noted in Reference 27 that two-thirds of collisions involving entire flocks have occurred during hours of darkness. Considering twelve incidents with duck flocks, ten occurred at night, one at dawn, and one during daylight hours.

Many peculiar habits of birds have been determined by ornithologists, biologists, and others. Gulls during damp, wet or cold weather search for food during the early morning hours in the winter months. When the weather is warm, gulls are lazy and search for food later in the day. Vultures and raptorial birds are not found soaring until mid-morning because they soar only when thermals are available, at the earliest about 9:30 a.m. Many diurnal birds such as the perching birds and ducks will migrate at night in the spring and fall between their winter and summer homes. Ornithologists have found that diurnal birds will migrate at night at high altitude, particularly when they travel long distances; thus, assuring themselves that food and water will be available when they end their flights in the early morning hours. Birds generally fly at lower altitudes between roosting and feeding areas.

Table XVI shows the number of strikes at various times of the day on a worldwide basis. Table XVII shows the frequency of strikes during a three-year period for mission training flights for USAF B-52 aircraft operational in CONUS. As noted in Reference 36, the USAF incident reports for 1965-1971 were analyzed for low-level cruise flights and it indicates that of 505 incidents studied, 111 strikes (22 percent) occurred at night.

Studies conducted by the Air Force Weapons Laboratory - Environics (AFWL) indicate the number of bird strikes at night to be 28.9% for all USAF airplanes.

TABLE XVI

BIRD STRIKES PER TIME OF DAY

Time of Day	NUMBER STRIKES PER TIME OF DAY		
	KLM Fleet '63-'67	German Air Force '66-'68	USSR Civil Aviation 1968
0 - 0200	8	—	2
0200 - 0400	2	—	
0400 - 0600	11	—	28
0600 - 0800	70	23	
0800 - 1000	112	83	141
1000 - 1200	100	119	
1200 - 1400	61	86	108
1400 - 1600	76	86	
1600 - 1800	72	27	22
1800 - 2000	57	10	
2000 - 2200	58	12	33
2200 - 2400	27	6	

TABLE XVII

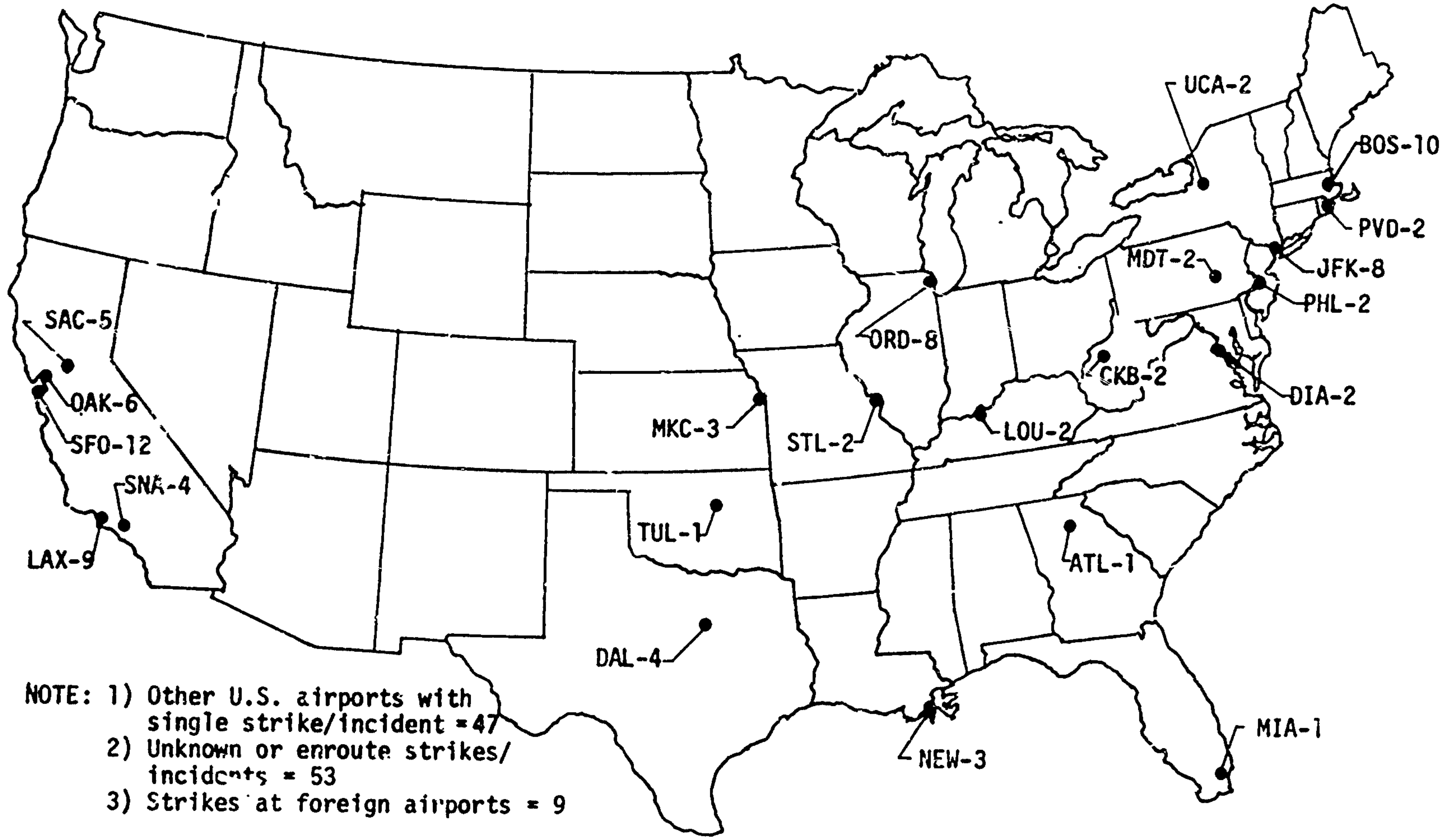
BIRD STRIKES PER PERIOD OF DAY FOR USAF B-52 AIRCRAFT - 1965-1967

PERIOD OF DAY	NUMBER OF BIRD STRIKES
Night	137
Day	106
Dawn	2
Dusk	29
Unknown	61

Geographic Locations of Bird Collisions in CONUS

Bird movements and locally established bird concentrations have been well documented as noted from Section II of this report. The frequency of bird strikes locally should theoretically match these heavy concentration areas. For instance, based on the studies mentioned earlier by Cogswell and Drury it is easily hypothesized that the number of strikes in the San Francisco and Boston areas would easily involve some types of sea gulls.

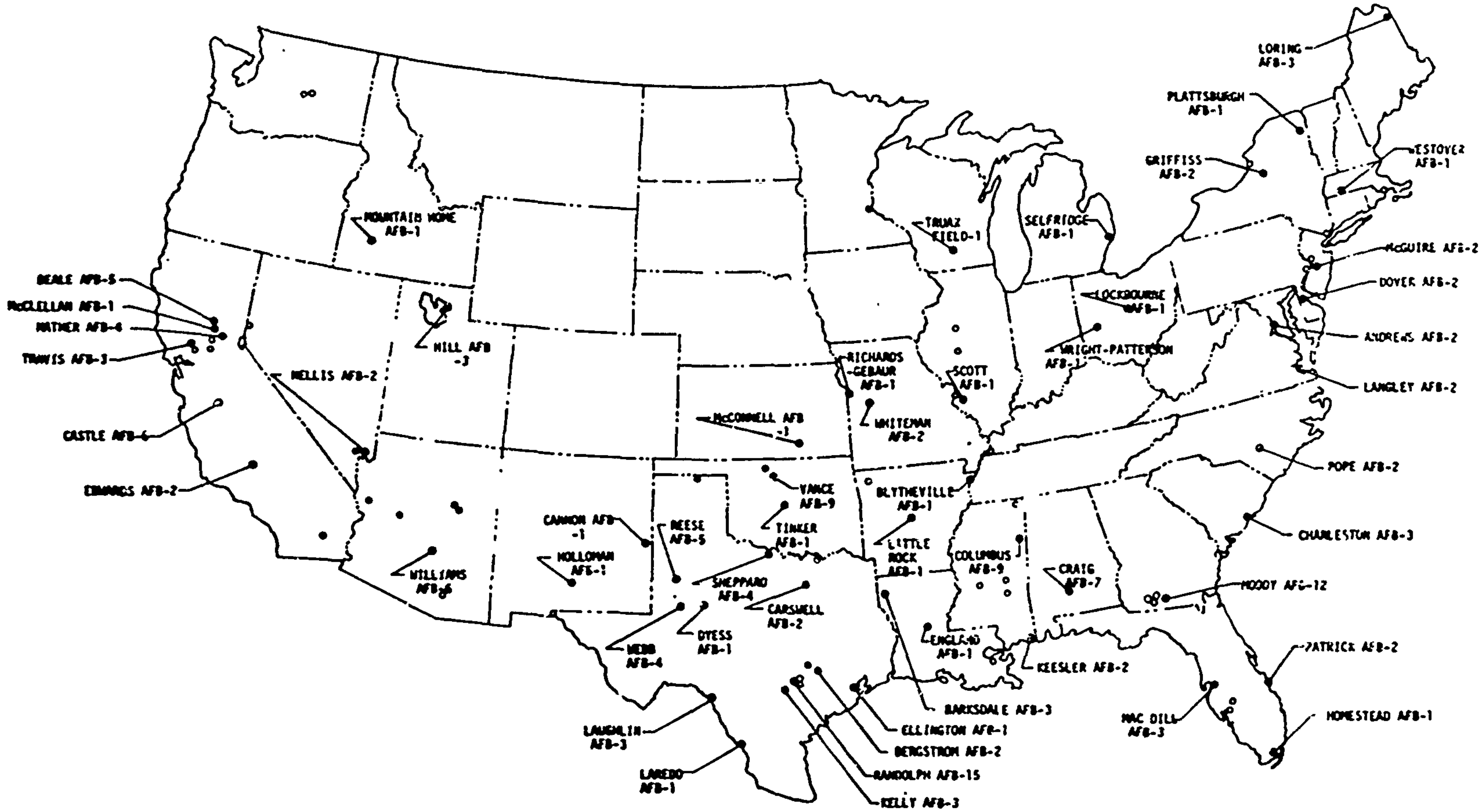
Figure 42 was developed to show the frequency of bird strikes at various airports in the continental United States, as reported to the FAA by U.S. commercial air lines during 1972 and Figure 43 was developed to show the frequency of bird strikes on or around various USAF facilities during 1972. In general, it was interesting to note that the Air Force strikes tend to correlate with some of the migration paths and concentrations of ducks and geese noted in Section II, Figure 9.



NOTE: 1) Other U.S. airports with single strike/incident = 47
2) Unknown or enroute strikes/incidents = 53
3) Strikes at foreign airports = 9

FIGURE 42

Distribution of Bird Strikes Reported to FAA for 1972
by United States Commercial Airlines



NOTE: • Denotes additional single bird strike to USAF aircraft

FIGURE 43

Distribution of Reported USAF Bird Strikes for 1972 In or Around Air Force Facilities

Bird Types Struck at Randomly Selected Airfields

Table XVIII shows a random selection of airports in CONUS where U.S. commercial air lines experienced strikes during 1972. It is believed from reviewing this data that the unidentified birds were probably small birds of the perching bird variety, pigeons, or gulls that frequent all of the airports noted. Several incidents of reported strikes where waterfowls were involved includes a noted incident in Boston that involved a goose; and two other geese and five duck strikes. This again points up a need to track such birds with ground radar and notify the aircraft flying in the areas. Since upward of 33 million waterfowl frequent and/or winter in California, it was surprising to note that there were no strikes involving commercial aircraft and ducks or geese in California. Other than gulls, all bird strikes identified at the commercial airports were small birds and could be eliminated in the future with appropriate changes to the airports ecological balance and runway operations.

TABLE XVIII

BIRD STRIKES OCCURRING AT RANDOMLY SELECTED AIRPORTS IN CONUS (1972)

MOST COMMON BIRDS STRUCK	AIRPORTS							
	SFO (CA)	OAK (CA)	SAC (CA)	SNA (CA)	LAX (CA)	BOS (MA)	JFK (NY)	ORD (IL)
Gull/Tern	-	2	1	-	-	3	-	-
Plover	-	-	-	-	-	-	-	-
Sandpipers/Curlews	2	-	-	-	-	-	-	-
Puffin	-	-	-	-	-	-	-	-
Pigeon/Doves	1	-	-	-	2	-	-	-
Vulture/Buzzard	-	-	-	-	-	-	-	-
Eagle	-	-	-	-	-	-	-	-
Hawk/Falcon	-	-	-	-	-	-	-	-
Nighthawk	-	-	-	-	-	-	-	-
Robin	-	-	-	-	-	-	-	-
Blackbird	-	-	-	-	-	-	-	1
Starlings	-	-	-	-	-	-	-	1
Larks	1	-	-	-	1	-	-	-
Sparrows	-	-	-	-	-	-	-	-
Swallow	-	-	-	-	-	-	-	-
Killdeer	-	-	-	-	-	-	-	-
Duck	-	-	-	-	-	-	-	-
Goose	-	-	-	-	-	1	-	-
Owl	-	-	-	-	-	-	-	-
Crane	-	-	-	-	-	-	-	-
Heron/Egrets	-	-	-	-	-	-	-	-
Loon	-	-	-	-	-	-	-	-
Snow Bunting	-	-	-	-	1	-	-	-
Pheasant	-	-	-	-	-	-	-	-
Albatross	-	-	-	-	-	-	-	-
Bats	-	-	-	-	-	-	-	-
Not Identified	8	4	4	4	6	5	8	6
Max.Flt.Speed (IAS) Knots	250	250	100	130	180	250	230	210
Max.Alt. AGL -(Feet)	11000	98	985	394	4000	1067	1219	1524
REFERENCES:	2							

Table XIX shows the number of bird strike occurrences around USAF bases and facilities located in CONUS. The criteria for the selection of specific bases was that five or more strikes were reported or that there were two or more bases in an area with a total of more than five strikes reported. The bases located in the Sacramento Valley of California reported duck strikes and a goose strike. These strikes could be anticipated since upward of 33 million ducks and geese frequent or winter in this valley.

In the Southern States, two incidents were reported of impacts with vultures and a single incident reported of an impact with an egret. Both vultures and egrets are common to the area. Those birds that were not identified were probably small birds of the perching bird variety, pigeons or gulls that are common throughout the CONUS. Bats were only reported at air bases in San Antonio, Texas.

Other than waterfowl it is believed that strikes would not have occurred if adequate base management changes had been made to eliminate the attractions for birds.

Repeatedly the "U.S. Bird Strike Summaries" published annually by the Air Force Safety Center at Norton AFB, California have outlined bird control procedures around airports and operational procedures. They also have emphasized that the Air Force Weapons Laboratory (AFWL) has trained personnel that can assist air base managers in identifying and correcting the bird problems. Directives should be issued to the various Air Force Commands to force compliance with the recommendations established by AFWL (BASH).

TABLE XIX

BIRD STRIKES OCCURRING AT RANDOMLY SELECTED USAF AIR BASES & FACILITIES IN CONUS (1972)

	Castle AFB (CA)	Beale AFB (CA)	Mather McClellan Travis (CA)	Williams AFB (AZ)	Reese AFB (TX)	Randolph Kelly Brooks Lackland AFB (TX)	Vance AFB (OK)	Columbus AFB (MS)	Moody AFB (GA)	Craig AFB (AL)	Dover Andrews McGuire AFB (DE,MD, VA)
Gull/Tern			1				3				2
Pigeon/ Doves				1		1					
Vulture/ Buzzard									2		
Hawk/Falcon						1	1				
Blackbird								1	1		1
Starlings									1		
Larks					3		1				
Duck	5	1	2								
Goose			1								
Heron/ Egrets									1		
Bats						8					
Not Identi-fied	2	4	8	4	2	8	4	8	10	7	8
Max.Flt Speed (IAS)Kts	180	159	250	300	195	300	240	280	280	300	360
Max.Alt. AGL-Feet	3000	300	1900	7500	200	4500	5000	1000	5000	300	4000
REFERENCES:	3										

Conclusions and Pertinent Findings

1. Approximately 50% of USAF aircraft/bird collisions occur during takeoff/landings, 22% occur during low-level missions, approximately 14% occur during normal flight conditions, and 14% of the collisions occurred at unknown geographic locations.

2. Specific altitudes (AGL) were established for USAF aircraft/bird collisions as being significant. (These altitudes and aircraft/bird collisions were established as 22% up to 100 feet, 60% up to 1000 feet, 90% up to 3000 feet, 95% up to 5000 feet, and less than 5% of the aircraft/bird collisions occur above 5000 feet, with less than 2% occurring above 8000 feet.)

3. Windshield/canopy bird strikes for USAF aircraft averaged 11.56% of the total identified bird strikes.

4. The repair costs for USAF aircraft was at least $20,000,000 due to bird strikes for the years 1966 through 1972.

5. At least seven USAF aircraft have been lost as a result of bird strikes.

6. Canada has clearly shown that the reduction of attractions for birds around airdromes has greatly reduced the frequency of bird collisions and the costs of repairs to both military and civil aircraft.

7. The most commonly struck birds are gulls, perching birds (300 species), ducks and vultures.

8. The greatest number of bird strikes occur during October in CONUS.

9. Between 22% and 28.9% of USAF aircraft/bird strikes occur at night.

10. Bird strikes occur at geographical locations that have been determined by the U.S. Wildlife Services as having heavy concentrations of waterfowl and gulls.

11. It is recommended that the USAF Office of Operational Analysis and the Defense Mapping Agency Aerospace Center develop the training routes based on:

a) Critical altitudes to minimize the chances for bird strikes;

b) Additional studies by the USAF to determine the relationship of flights per day/night versus the number of strikes;

c) Training flights for October-November being kept to an absolute minimum (i.e.; the use of ground-based trainers could be maximized for this period);

d) AFWL be enabled to implement a radar tracking system.

SECTION IV

BIRD STRIKE PREDICTION METHODOLOGIES

Pertinent details were selected from the data noted in Section III, and analytically combined in this section with additional factual data to develop statistical predictions of bird hazards to aircraft.

Statistical studies were conducted and shown in this section to confidently show justification for the selection of design criteria and other recommendations developed in subsequent sections. The statistical studies described in this section are the following:

- Probability Predictions: Historic Data Averaging
- Vulnerability of Component Frontal Areas to Bird Strikes and Model Probability Prediction
- Trend Analysis of Frontal Area vs Bird Strikes
- Validity Test of Trend Analysis: Component Frontal Area vs Bird Strikes
- Bird Weight Statistical Analyses: Curve Fitting Data
- Bird Weight Analyses: Descriptive Statistical Methodologies
- Bird Weight Analyses: Theoretical Distributions - Probability Predictions
- Bird Weight vs Altitude - Poisson's Statistical Analysis

Probability Predictions: Historic Data Averaging

Certain portions of the data compiled was readily adaptable to the calculations of probabilities when flight hours were known. Based on these calculations it became apparent that some aircraft operators have more bird strikes than others which seems to be traceable to the airports from which they operate and to the methods of reporting the bird strike incidents. Most incident reports indicated that damage had occurred as a result of the incident but in some cases the data also included incidents that did not cause damage.

ICAO data were used to establish initial probabilities because of the worldwide operations of commercial air lines. As noted in Table XX data for 1967 through 1969 shows that the probability of a bird impact on aircraft is upward of 342 per million flying hours. It is believed, however, that the ICAO initial report covers only those air lines that reported bird strikes and does not include air lines in which no strikes occurred. Thus, the explanation for the low number of flight hours.

TABLE XX

NUMBER OF HOURS FLOWN, BIRD STRIKES, STRIKES/1,000,000 FLIGHT HOURS, COMPILED BY THE INTERNATIONAL CIVIL AVIATION ORGANIZATION FROM INTERNATIONAL DATA SUBMITTED BY COMMERCIAL AIR LINES

Year	Number Countries Reporting	Hours Reported Total	Bird Strikes	Strikes/ 1,000,000 Flt Hrs
1967	14	2,080,090	591	284.0
1968	25	9,575,044	1513	158.0
1969	17	2,705,513	924	342.0
Avg.		4,786,882	1009	210.85
REFERENCES:		25		

KLM was selected as a specific air line that operates out of Europe and flies into many countries. The purpose for selecting KLM and specifically the DC8 was that the data seemed to be more detailed and flight hours were available for analytical studies. KLM noted all strikes regardless of the minute amount of damage and were interested in determining the bird strike hazards at their own base airport - Amsterdam. Further, the KLM data should theoretically be included in the ICAO data noted for 1967. Shown in Table XXI, the probability for bird strike occurrences for KLM was 1251 strikes per million flight hours for 1967. The rate experienced by KLM for the year 1967 was 3.66 times as great as the average for all operators reported in the ICAO data. Since the ICAO and KLM strike rates per million flight hours were found to be radically different, it must be assumed that either KLM data was not included in the ICAO data, or when combined with the ICAO data the differences are the result of averaging large amounts of data, and/or the data submitted to ICAO from the airlines did not have the depth or detail noted by KLM.

Of significance in the KLM data for 1967 is the number of strikes occurring at Amsterdam. Approximately 28% of the strikes occurred at the KLM base airport of Amsterdam indicating:

1) The need for an intensive effort in Europe to reduce bird hazards around airports;
2) The incentive behind the development of a potentially efficient system which combines ground radar networks for tracking migrating birds throughout Europe, and mapping the migrations similar to the method used to present weather conditions.

TABLE XXI

NUMBER OF HOURS FLOWN ON DC8 AIRCRAFT, BIRD STRIKES, STRIKES/MILLION FLIGHT HOURS REPORTED BY KLM ROYAL DUTCH AIR LINES DURING 1963 THRU 1967

Year	Hours Flown on DC8 Aircraft	Bird Strikes	Strikes Per 1,000,000 Flt Hours
1963	49,231	53 (28)	1076.0
1964	56,020	89 (35)	1589.0
1965	72,654	96 (33)	1321.0
1966	39,402	107 (34)	2716.0
1967	70,325	88 (25)	1251.0

REFERENCES: 26

NOTE: Bird strikes shown in parenthesis are the number from the total that occurred near Amsterdam.

Shown in Table XXII is a summarization of USAF bird strike activities for the period 1966 through 1972. The raw data from which this table was developed were considered to be more accurate and more complete than any other data used in the studies for this program. The reason for this accuracy is that the USAF Flight Safety Center at Norton AFB, Ca., provided complete computer printouts of all the incident reports in a sanitized format for the period noted. Assuming that the Air Force continues to operate under similar flight conditions in the future, averages were computed from these data. Extrapolations of these averages result in the predictions for subsequent years of 356 strikes per year on aircraft and specifically 29 of these strikes will occur on the windshield/canopy. Stated in terms of predicted probabilities, the expected strikes on aircraft is 52.6 per million flight hours and specifically 4.3 strikes on windshields/canopies per million flight hours. Compared to the worldwide data developed by ICAO the probability of USAF strikes per million flight hours on the average is approximately 25% as great as those reported for commercial activities determined from the computation:

$$\frac{\text{Avg. USAF Strikes/Million Flt. Hours}}{\text{Avg. ICAO Strikes/Million Flt. Hours}} = \frac{52.6}{210.85} \times 100\% = 24.95\%$$

Analyzing the data in Table XXII it becomes apparent that the predicted frequency of strikes on windshields/canopies would be at least 8-1/4% of the total number of strikes expected per year for Air Force airplanes determined from the computation:

$$\frac{\text{Avg. Windshield Strikes}}{\text{Avg. Aircraft Strikes}} = \frac{29.4}{356} \times 100\% = 8\text{-}1/4\%$$

The 8-1/4% is a much lower number than the numbers reported in Section III, Table VII, because the USAF 1965 data were not included in these calculations. 1965 was not shown because it included strikes in which no damage occurred on the aircraft and subsequent years did not include such incidents.

TABLE XXII

NUMBER OF HOURS FLOWN, BIRD STRIKES, STRIKES/MILLION FLIGHT HOURS, STRIKES ON W/S, STRIKES/MILLION FLIGHT HOURS ON W/S REPORTED BY USAF AIRCRAFT DURING 1966 THRU 1972

Year	USAF Hours Flown World Total	Bird Strikes	Strikes per Million Flt. Hrs.	Strikes on W/S	Strikes per Million Flt. Hrs. on W/S
1966	7,030,015	320	45.5	28	4.0
1967	7,311,121	379	51.8	30	4.1
1968	7,983,688	363	45.5	26	3.2
1969	7,388,976	338	45.7	30	4.1
1970	6,597,248	360	54.6	34	5.2
1971	5,754,376	383	66.6	31	5.4
1972	5,356,984	351	65.5	27	5.0
AVG.	6,774,629	356	52.6	29.4	4.3
REFERENCES:		3			

Comparatively, the U.S. Navy has reported their bird strike activities for the last 13 fiscal years. These data are summarized in Table XXIII. The average expected bird strikes was found to be 65.3 per million flight hours, which is approximately 24% higher than the Air Force.

Data analyzed, points out that Naval flight operations may always result in more bird impacts than that experienced by the Air Force. Naval flight operations take place over or near large bodies of water because Naval Bases are situated near the water. Thus, Naval aircraft are continually exposed to birds following surface vessels, migrating off-shore birds, birds that are in abundance on numerous off-shore islands, in addition to the locally cosmopolitan birds that frequent air bases for food and roosting.

TABLE XXIII

U.S. NAVY REPORTED BIRD STRIKES, AIRCRAFT DAMAGED, STRIKES/MILLION FLIGHT HOURS REPORTED FOR FISCAL YEARS 1960 THRU 1972

Fiscal Year	Major Damage		Bird Strikes	Strikes per Million Flt. Hours
	Losses	Other		
1960	2	10	361	107.0
1961	0	8	275	78.0
1962	0	7	390	105.0
1963	0	4	354	100.0
1964	1	4	306	83.0
1965	0	3	183	50.0
1966	0	0	116	31.0
1967	0	0	106	28.0
1968	0	1	113	31.0
1969	2	0	102	27.0
1970	1	0	92	29.0
1971	1	0	86	30.0
1972	0	0	405	150.0
Total	7	37	2,889	
Avg/Yr	.54	2.85	222.23	65.3

Vulnerability of Component Frontal Areas to Bird Strikes and Model Probability Predictions

It is believed that the probability of striking any component on the aircraft may be by chance and that it may be equally likely that the bird strikes could occur anywhere on the aircraft.

A preliminary study of bird strike occurrences on frontal areas of three McDonnell-Douglas designed aircraft, was accomplished for the DC9/C9A, DC8 and F-4 aircraft.

The C9A was introduced into the Air Force inventory in 1968 and for all practicable purposes is identical to the commercial DC9 versions.

The frontal areas and the locations of the bird strikes on the aircraft were determined from available data for the C9A for the period 1968 thru 1972. It was closely observed from these data that the frequencies and strike locations would vary from one year to the next, but when several years of data are summed and averaged the effect results in depressing some of the strike percentages. Thus, to select one year of bird strike data for detailed studies would be misleading and emphasis could be placed on strike locations and percent frequencies; that is the 1972 data which indicated that the vulnerability of windshields to bird strikes is 0, while the frequency of bird strikes on engines was 65%. The five years are shown in Figure 44 to indicate the effect of averaging over long periods of times, and 1972 was extracted from the total data and shown for comparisons.

The following probability predicting calculations tend to verify the effect of averaging:

$$\text{C9A Aircraft Bird Strike Frequency (1968-1972)} = \frac{\text{Total Bird Strikes}}{\text{Total Flight Hours}} \times \text{One Million}$$

$$= \frac{18}{84{,}509} \times 1{,}000{,}000$$

$$= 213 \text{ strikes/per million flight hours}$$

$$\text{(1972 only)} = \frac{3}{27{,}559} \times 1{,}000{,}000$$

$$= 109 \text{ strikes per million flight hours}$$

$$\text{C9A Windshield Bird Strike Frequency (1968-1972)} = \frac{\text{Total W.S. Bird Strikes}}{\text{Total Flight Hours}} \times \text{One Million}$$

$$= \frac{5}{84{,}509} \times 1{,}000{,}000$$

= 59 strikes per million flight hours

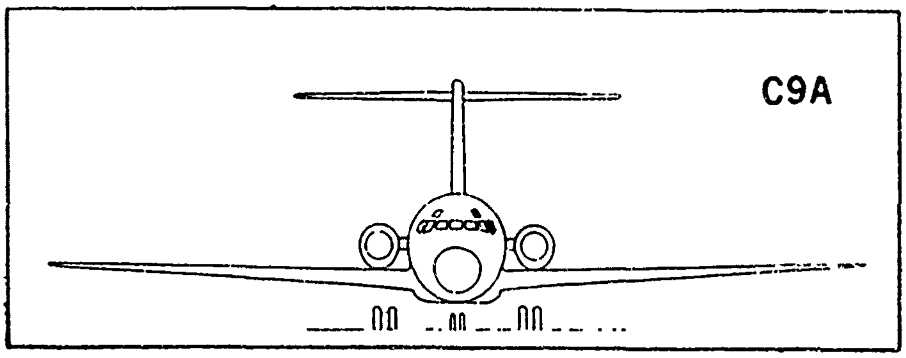
(1972 only) = 0 strikes per million flight hours

Comparing the frequency of strikes on the wing and engines noted in the 1972 C9A data to the five-year C9A operation data and the data in Section III, Table VII, indicates that the increase in strikes for 1972 on these components was as a result of chance. Particularly, since there didn't seem to be any changes in the operation of the aircraft for 1972.

The rate for the occurrence per million flight hours, shows that the average C9A can expect four times as many strikes as the average Air Force aircraft as noted in Table XXII, determined from the following calculations:

$$\frac{\text{Avg. C9A strikes per million flight hours (1968-1972)}}{\text{Avg. USAF strikes per year per million flight hours (1966-1972)}} = \frac{213}{52.6} = 4.05$$

In this study a bird strike incident might include several strikes; therefore, the total strikes might not agree with the total incidents.



	COMPONENT'S FRONTAL AREA (SQ. INCHES)	% OF TOTAL FRONTAL AREA OF AIR CRAFT	NUMBER OF BIRD STRIKES ON COMPONENT		% OF TOTAL BIRD STRIKES ON AIRCRAFT	
			'68-'72	'72	'68-'72	'72
WINGS	14,300	34.0%	3	1	16.67%	33%
TAIL	6,650	15.8%	0	0	0.0	0
ENGINES	5,460	13.0%	3	2	16.67%	66%
NOSE/RADOME	2,830	6.7%	2	0	11.10%	0
FUSELAGE	11,100	26.3%	5	0	27.78%	0
WINDSHIELDS	1,761	4.2%	5	0	27.78%	0
TOTALS	42,101	100.0%	18	3	100.00%	100%

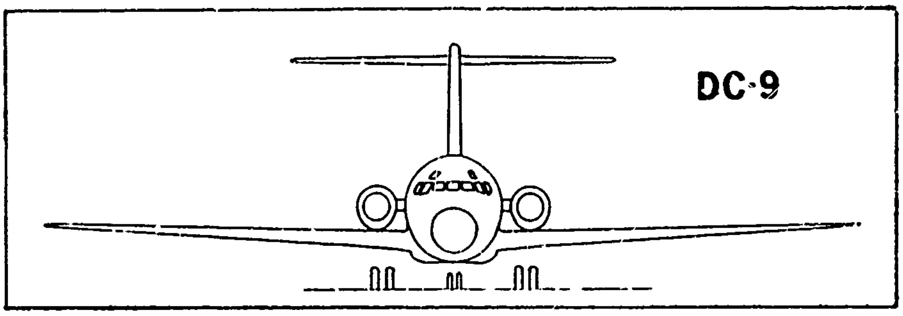
FIGURE 44

Comparisons of Frontal Area to Number of Birdstrikes for USAF C9A Aircraft Operational during 1968 through 1972

FAA data for 1972 combined with known flight hours for the DC9 commercial version, operational in the contiguous United States, are shown in Figure 45. In these data it becomes obvious that the total flight hours logged by a greater number of operational aircraft also has a depressing effect on averaging. Thus, the USAF C9A for 1972 had an expected 213 strikes per million flight hours, which was approximately eight times greater than the commercial DC9 version which had only an expected 27.1 strikes per million flight hours. It is realized that the C9A and DC9 may operate entirely different from most Air Force airplanes because the primary mission is to transport hospital patients. Hypothetical differences in the operational procedures for the airplanes might include:

- Commercial aircraft queue to await control tower approval for takeoff, reducing the probability of more than one aircraft being involved with bird strikes on takeoff.
- Most commercial aircraft are queued in stacks awaiting approvals for approaches and landing.
- The great number of commercial aircraft queued for landing/takeoff reduces the probabilities for bird strikes on any one aircraft.
- Most commercial aircraft fly per local noise abatement requirements and use less runway for takeoff.
- Commercial aircraft may climb faster within safe limits, but not exceeding 250 knots up to cruise altitudes beyond 10,000 feet.
- The DC9 may take-off and fly to altitude at greater pitch attitudes than the C9A.
- Because of the nature of the passengers carried, the C9A may not rotate and climb as fast as commercial DC9s.
- Many military airplanes fly in formation but not the C9A.
- The C9As may take-off/land at air bases during the hours that birds frequent the areas.

- The C9A flight schedules, because of the nature of passengers, may be entirely different from normal TAC/SAC operational flight schedules.



AIRCRAFT BIRDSTRIKE FREQUENCY (1972) $= \frac{\text{Total bird strikes}}{\text{Total flight hours}} \times 1{,}000{,}000$

$= \frac{25}{922{,}436} \times 1{,}000{,}000$

= 27.1 strikes per million flight hours

WINDSHIELD BIRD STRIKE FREQUENCY $= \frac{4}{922{,}436} \times 1{,}000{,}000$

= 4.3 strikes per million flight hours

Air Lines Reporting Bird Strikes: Allegheny, Continental, Hawaiian, Southern, Texas International and Trans-World.

	COMPONENT'S FRONTAL AREA (SQ. INCHES)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRD STRIKES ON COMPONENT	% OF TOTAL BIRD STRIKES ON AIRCRAFT
WINGS	14,300	34.0%	8	32%
TAIL	6,650	15.8%	0	0%
ENG INTAKES	5,460	13.0%	3	12%
NOSE/RADOME	2,830	6.7%	9	36%
FUSELAGE	11,100	26.3%	1	4%
WINDSHIELDS	1,761	4.2%	4	16%
TOTALS	42,101	100.0%	25	100%

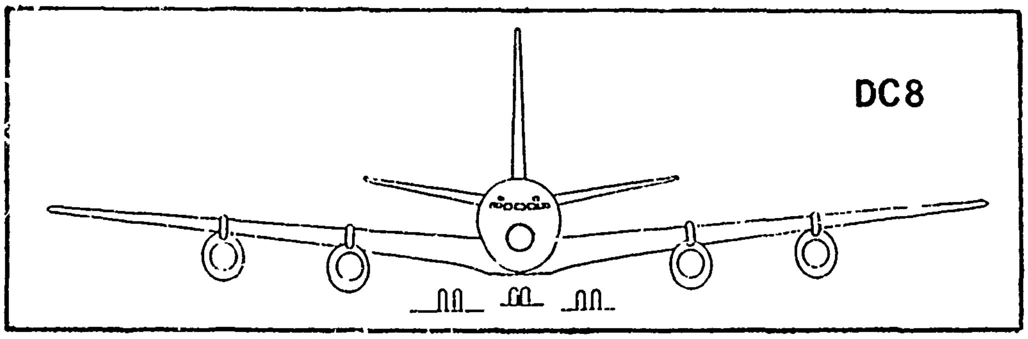
FIGURE 45

Comparisons of Frontal Area vs No. Bird Strikes for Commercial DC9 Aircraft Operated by U.S. Air Lines in 1972

The frontal areas for the DC8 aircraft were determined, and two different sets of bird strike data were used for the evaluation. The Air Canada usage of DC8 was selected because they operate from several airports located in Canada. The Canadian airports unquestionably have more migratory flocks of birds frequenting the immediate areas than anywhere else in the world. The DC8 compared to the C9A/DC9 has four engines mounted from the wing and generally the flights are of longer durations - upward of 12 hours for a single flight. Shown in Figure 46 is the Air Canada Airlines operations for 1964-1965 and the comparisons of DC8 frontal area versus bird strikes. The data shown indicated a very high rate of 958 bird strikes per million flight hours with 172 bird strikes per million flight hours for the windshields.

Second, the DC8 data were analyzed for the 1972 operations for many U.S. air lines operating in the CONUS, as shown in Figure 47. In comparison the U.S. operators reported only three strikes for the year on two aircraft and logged more than nine times as many hours as shown for Air Canada. The results showed that the expected frequency of bird strikes was two per million flight hours with none reported for the windshields. The mode of operations for the U.S. air lines may have been entirely different from that of Air Canada's including longer flights and possible compliance with noise abatement procedures. The latter requires short takeoff roll, steep climb angle and rapid rate of climb.

It is also possible the frequency of bird strikes for the Air Canada DC8 would be entirely different for recent years, but such data were not available. In recent years there have been many changes to airport ecology in Canada, and the Air Canada Pilots are constantly made aware of bird strike potentials.



$$\text{AIRCRAFT BIRDSTRIKE FREQUENCY} = \frac{\text{Total bird strikes}}{\text{Total flight hours}} \times 1{,}000{,}000$$

$$= \frac{89}{92{,}882} \times 1{,}000{,}000$$

= 958 strikes per million flight hours

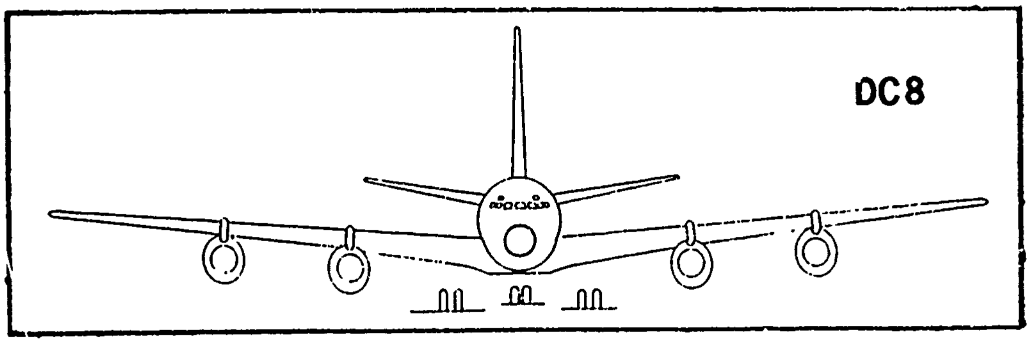
$$\text{WINDSHIELD BIRD STRIKE FREQUENCY} = \frac{16}{92{,}882} \times 1{,}000{,}000$$

= 172 strikes per million flight hours

	COMPONENT'S FRONTAL AREA (SQ. INCHES)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRD STRIKES ON COMPONENT	% OF TOTAL BIRD STRIKES ON AIRCRAFT
WINGS	40,800	48.9%	12	13.4%
TAIL	8,580	10.3%	1	1.1%
ENGINES	15,400	18.5%	36	40.5%
NOSE/RADOME	3,850	4.6%		
FUSELAGE	12,989	15.6%	24	27.0%
WINDSHIELDS	1,761	2.1%	16	18.0%
TOTALS	83,480	100.0%	89	100.0%

FIGURE 46

Comparisons of Frontal Areas vs No. Bird Strikes for Commercial DC8 Aircraft Operated by Air Canada Air Lines During 1964 & 1965



$$\text{AIRCRAFT BIRDSTRIKE FREQUENCY} = \frac{\text{Total Incidents}}{\text{Total flight hours}} \times 1{,}000{,}000$$

$$= \frac{2}{823{,}104} \times 1{,}000{,}000$$

= 2.4 incidents per million flight hours

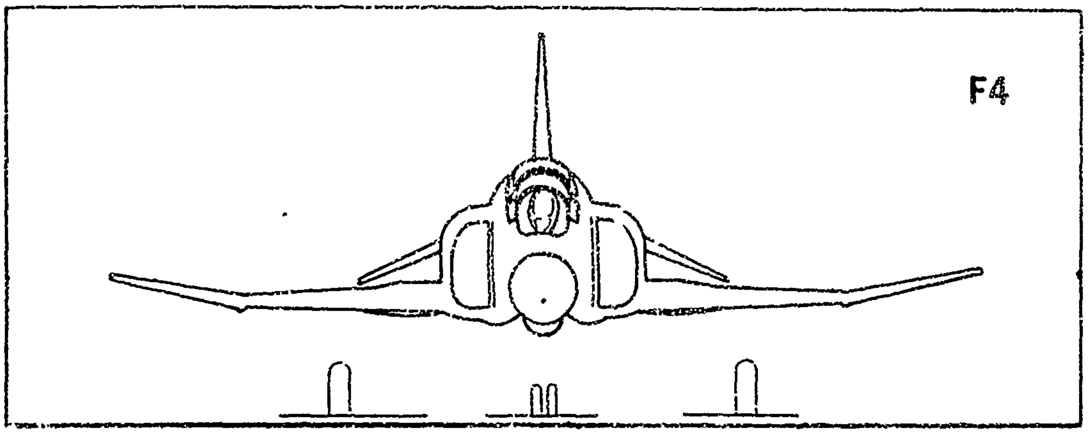
	COMPONENT'S FRONTAL AREA (SQ. INCHES)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRD STRIKES ON COMPONENT	% OF TOTAL BIRD STRIKES ON AIRCRAFT
WINGS	40,800	48.9%	1	33.3%
TAIL	8,580	10.3%	-	-
ENGINES	15,400	18.5%	1	33.3%
NOSE/RADOME	3,850	4.6%	1	33.3%
FUSELAGE	12,989	15.6%	-	-
WINDSHIELDS	1,761	2.1%	-	-
TOTALS	83,480	100.0%	3	100.0%

FIGURE 47

Comparisons of Frontal Areas vs No. Bird Strikes for Commercial DC8 Aircraft Operated by U.S. Air Lines During 1972

The F-4 is probably the only single aircraft model in the U.S. Air Force inventory that is subjected to such a broad operational spectrum, including normal flights, low level training missions, formation flights, single flights, and precision team acrobatics. It is likely that the F-4 flights would include short and long flights, flights above and below 8000 feet, at various times of the day, in areas where birds are prevalent, and at various speeds.

The data for the F-4 shown in Figure 48 shows that the frequency of expected bird strikes is 56 strikes per million flight hours, which is approximately 6% higher than the expected USAF average noted in Table XXII. The expected frequency of bird strikes on windshields/canopies is shown as 9.3 strikes per million flight hours which is over twice the expected average noted for the USAF windshields noted in Table XXII. The operation during 1972 by the U.S. Navy noted in Reference 28 shows the Navy expected F-4 bird strike frequency as 101 strikes per million flight hours which is almost twice as high as the expected average obtained for the USAF operation of the F-4 aircraft.



$$\text{AIRCRAFT BIRDSTRIKE FREQUENCY} = \frac{\text{Total bird strikes}}{\text{Total flight hours}} \times 1,000,000$$

$$= \frac{163}{2,914,385} \times 1,000,000$$

= 56 strikes per million flight hours

$$\text{WINDSHIELD/CANOPY BIRDSTRIKE FREQUENCY} = \frac{27}{2,914,385} \times 1,000,000$$

= 9.3 strikes per million flight hours

	COMPONENT'S FRONTAL AREA (SQ. INCHES)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRD STRIKES ON COMPONENT	% OF TOTAL BIRD STRIKES ON AIRCRAFT
WINGS	2,349	24.7%	32	19.6%
TAIL	445	4.7%	2	1.2%
ENGINES	1,964	20.7%	55	33.7%
NOSE/RADOME	1,529	16.1%	18	11.0%
FUSELAGE	2,229	23.5%	29	17.8%
WINDSHIELDS	975	10.3%	27	16.6%
TOTALS	9,492	100.0%	163	99.9%

FIGURE 48

Comparisons of Frontal Areas vs No. Bird Strikes for the USAF F-4 Aircraft Operational During Years 1965 thru 1972

Trend Analysis of Component Frontal Area vs Bird Strikes

The data obtained from the studies of the C9A/DC9, DC8, and F-4 aircraft were used for further analysis to determine potential trends for component frontal area versus bird strikes. It was believed that the data represented ample numbers of operational conditions, and that the three aircraft were sufficiently representative of types and models of aircraft for preliminary studies. The smaller of the three, the F-4, had a total frontal area of 9492 square inches with two engines and inlets mounted forward on the fuselage. The medium-sized C9A/DC9 had a total frontal area of 42,101 square inches with two engines mounted off the aft fuselage, and the larger DC8 had a frontal area of 83,400 square inches with four engines suspended below the wings.

Computations for this study were made using the method of linear regression analysis. The trend line equation used was of the form:

$$Y = a + bX$$

where: Y = % of bird strikes

X = % of aircraft frontal area component

a = intersect on Y axis

b = slope of trend line

Solving two simultaneous equations:

$$\Sigma Y = Na + b\Sigma X \text{ and } \Sigma XY = a\Sigma X + b\Sigma X^2$$

where:

N = no. conditions

= 3 aircraft x 6 conditions each

= 18

The trend for the data was found to be:

$$Y = 12.559 + .246X$$

The original assumptions were that the probability for a bird strike on any component of the aircraft was equally likely.

To determine how well the data used were correlated the following calculations were made:

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[(N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

where:

r = coefficient of correlation

The value determined was:

$r = .249$

For a perfect correlation r should be +1 or -1. In this case r = .249 indicating that some component frontal areas seem to be more vulnerable to bird strikes than others and that the hypothesis with respect to the probability of bird strikes on any component being equally likely may not be valid. Other factors to be considered are:

1) Size of data base
2) Reporting factors with respect to:
   a) Awareness of strike
   b) Psychological aspect of windshield or engine strikes

The regression line gives only a "best estimate" of the data used and to take into account the scatter of conditions two standard errors of estimates were used to establish a 95% confidence level to compensate for the scatters. The formula used was:

$$2S_Y = \pm 2\sqrt{\frac{\Sigma(Y - Yc)^2}{N}}$$

where:

S_Y = standard error of estimate in Y direction

Yc = calculated values of Y from trend line.

The value determined was:

$2S_Y = \pm 18.438$

A mathematical model depicting the functional relationship of the percentage of aircraft component frontal area as a function of the expected percentage of aircraft bird strikes is shown in Figure 49.

A review was made of all the windshield/canopy bird strike data available. Since the windshield and canopy represented 10.3% of the F-4 total area, and is probably a maximum for most aircraft; from Figure 49 it is shown that in any given period of time, on any aircraft, the predicted percent of bird strikes for windshield/canopies ranges from 0 to 33% with an average of 15%. From the multitude of available bird strike incident reports, no other data exceeded the 33% for windshields, which tends to indicate a good expectation range for bird strikes on windshields. This model shows a clear delineation that bird strikes can be expected on windshields and canopies; therefore, subsequent aircraft must be designed for bird impact requirements.

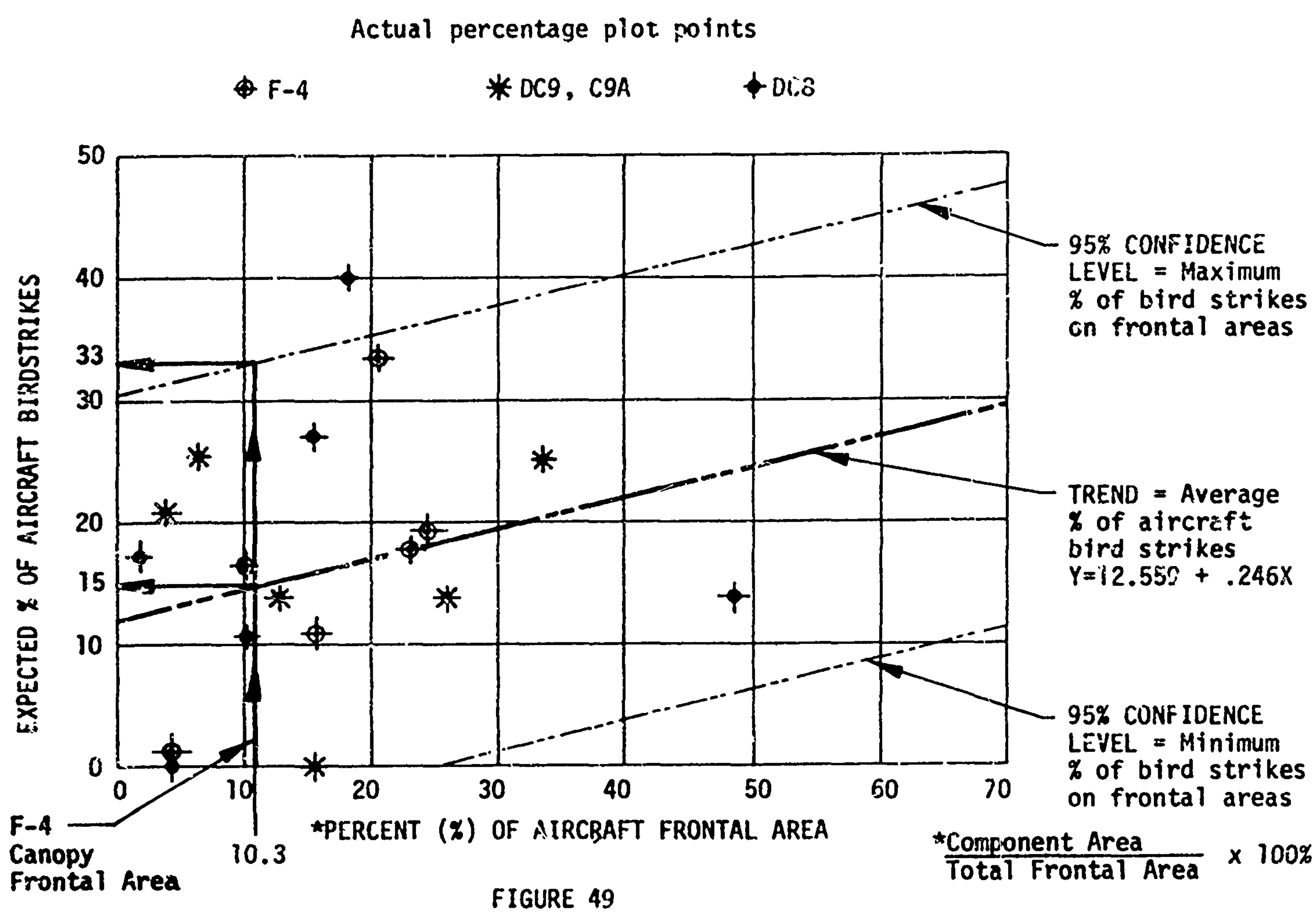


FIGURE 49

MODEL: % Aircraft Frontal Area vs % Expected Birdstrikes

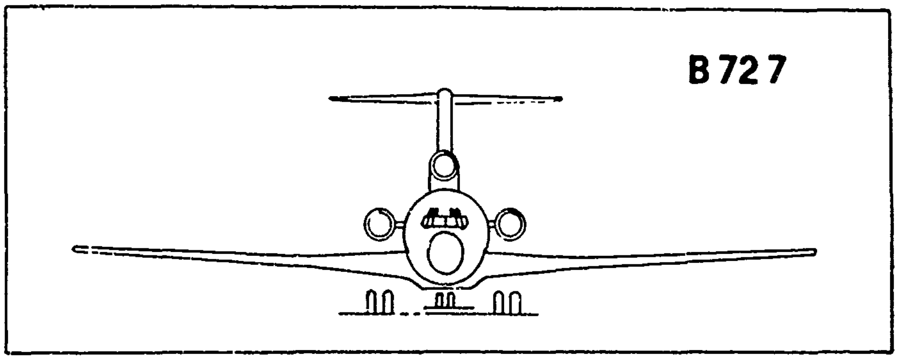
Validity Test of Trend Analysis: Component Frontal Area vs Bird Strikes

To test the validity of the trend analysis theory that was developed around the three McDonnell-Douglas aircraft, the following three aircraft were studied for comparison: the Boeing B727 aircraft operated by U.S. domestic air lines; the Ling-Temco-Vought A7 aircraft operated by the USAF; and the Douglas A4 aircraft operated by the U.S. Navy. The 1972 FAA data showed 47 bird strikes for the B727 aircraft. Figure 50 was developed for the B727 Component Frontal Areas vs percentage of bird strikes and when each of the findings for the B727 frontal areas were compared to the Trend Analysis shown in Figure 49, the actual percentage of bird strikes per component did fall within the established ranges.

A review of the DC9 and B727 data for 1972 also shows other similarities that are significant. The B727 flew approximately 1.7 times as many hours and had twice as many bird strikes as the DC9.

The bird strike probability predictions were similar between the two aircraft, revealing 27.1 strikes per million flight hours for the DC9 and 29.52 strikes per million flight hours for the B727. It was virtually impossible to obtain all of the flight hours logged by all U.S. commercial air lines for all different types of operational aircraft; however, an approximate 29 strikes per million flight hours might be an expected average for commercial aircraft operating in CONUS.

Figure 51 was developed for the A7 Component Frontal Area vs percentage of bird strikes and when each of the findings for the A7 frontal areas were compared to the Trend Analysis shown in Figure 49, the actual percentage of bird strikes per component did fall within the established ranges.



$$\text{AIRCRAFT BIRDSTRIKE FREQUENCY} = \frac{\text{Total bird strikes}}{\text{Total flight hours}} \times 1{,}000{,}000$$

$$= \frac{47}{1{,}591{,}751} \times 1{,}000{,}000$$

= 29.52 per million flight hours

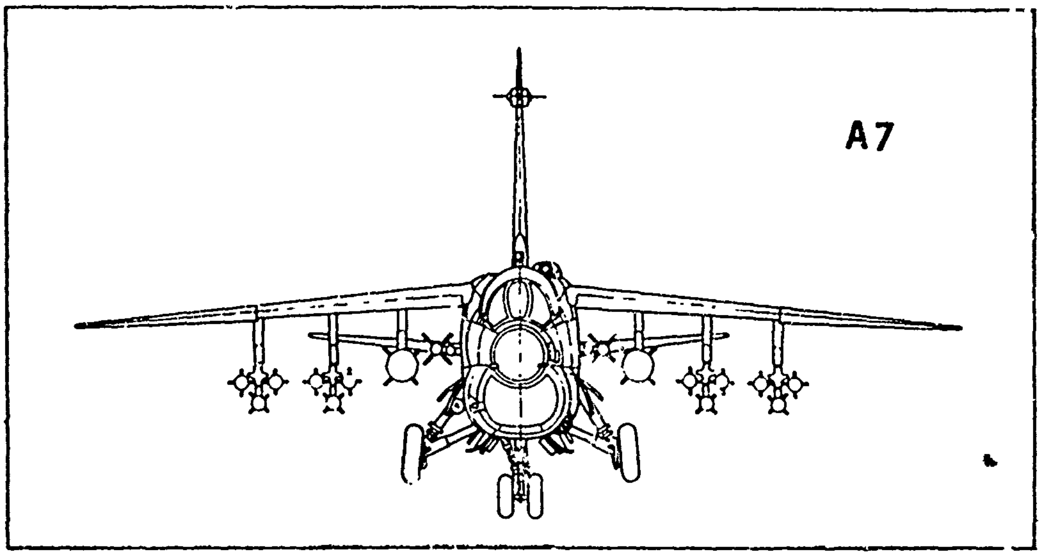
$$\text{WINDSHIELD BIRDSTRIKE FREQUENCY} = \frac{10}{1{,}591{,}751} \times 1{,}000{,}000$$

= 6.28 per million flight hours

	COMPONENT'S FRONTAL AREA (APPROX SQ IN)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRD STRIKES ON COMPONENT	% OF TOTAL BIRD STRIKES ON AIRCRAFT
WINGS	22,500	41.35%	12	25.53%
TAIL	6,044	11.11%	2	4.25%
ENGINES	6,000	11.03%	1	2.13%
NOSE/RADOME	3,215	5.91%	13	27.66%
FUSELAGE	14,700	27.02%	9	19.15%
WINDSHIELDS	1,950	3.58%	10	21.28%
TOTALS	54,409	100.00%	47	100.00%

FIGURE 50

Comparison of Frontal Areas vs Number of Bird Strikes for Commercial B727 Aircraft Operated by U.S. Air Lines During 1972



AIRCRAFT BIRDSTRIKE FREQUENCY $= \frac{\text{Total Birdstrikes}}{\text{Total flight hours}} \times 1{,}000{,}000$

$= \frac{9}{127{,}779} \times 1{,}000{,}000$

$=$ 70.43 per million flight hours

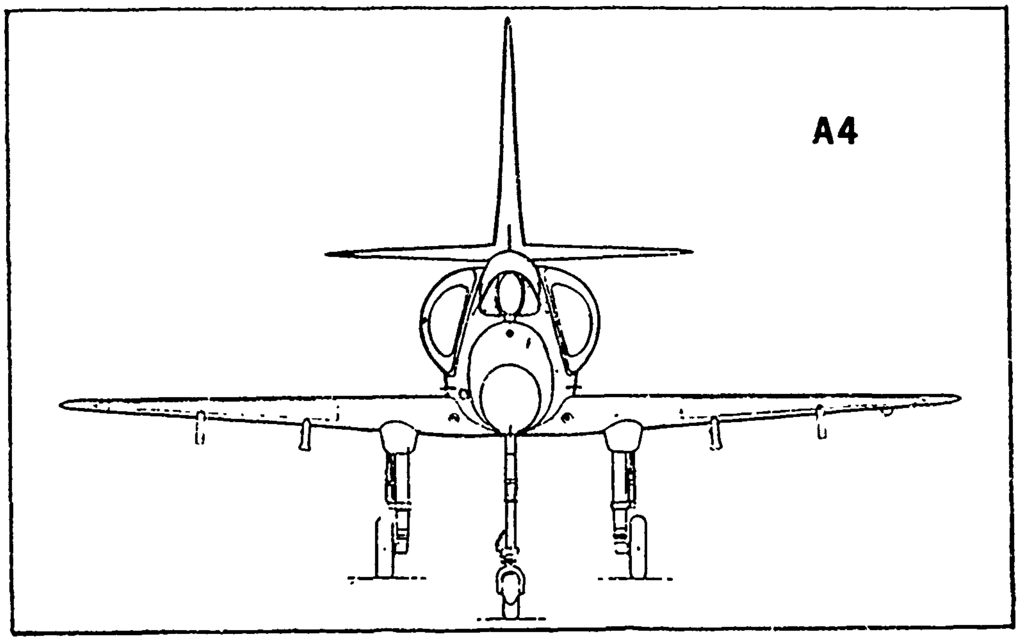
	COMPONENT'S FRONTAL AREA (APPROX SQ IN)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRDSTRIKES ON COMPONENT	% OF TOTAL BIRDSTRIKES ON AIRCRAFT
WINGS	2397	29.47	2	22.22
TAIL	1175	14.45	0	0
ENGINES	1659	20.40	3	33.33
NOSE/RADOME	573	7.04	1	11.11
FUSELAGE	1457	17.91	2	22.22
WINDSHIELDS	873	10.73	1	11.11
TOTALS	8134	100.00	9	99.99

FIGURE 51

Comparison of Frontal Areas vs Number of Birdstrikes for A7 Aircraft Operated by USAF 1968 through 1972

When comparing the C9A, F4 and A7 to the data noted in Table XXII, the C9A shows 109 strikes/million flight hours which is 2.07 times the USAF average of 52.6 strikes/million flight hours; the F4 shows 56 strikes/million flight hours which is very close to the USAF average of 52.6 strikes/million flight hours; and the A7 data shows 70.43 strikes/million flight hours which is 1.34 times the USAF average. It is probable that these differences are the result of numbers of aircraft involved, bases from which the aircraft are operational, the flight durations at altitudes, the frequency of low-level training missions, the difference in normal operations between the F4 and A7, or other unknown reasons.

Figure 52 was developed for the A4 Component Frontal Area vs percentage of bird strikes and when the canopy and engine frontal areas were compared to the Trend Analysis shown in Figure 49, the actual percentages of bird strikes per component did fall within the established range. The A4 was the smallest airplane studied and is operated from U.S. Navy carriers as well as coastal Navy bases, but actual flight hours were not available.



	COMPONENT'S FRONTAL AREA (APPROX SQ IN)	% OF TOTAL FRONTAL AREA OF AIRCRAFT	NUMBER OF BIRDSTRIKES ON COMPONENT	% OF TOTAL BRIDSTRIKES ON AIRCRAFT
ENGINE	952	15.30	12	21.43
WINDSHIELD	413	6.64	5	8.93
WINGS	2491	40.04		
FUSELAGE	1137	18.27	39	69 64
TAIL	848	13.63		
NOSE/RADOME	381	6.12		
TOTALS	6222	100.00	56	100.00

FIGURE 52

Comparison of Frontal Areas vs Number of Birdstrikes for A4 Aircraft Operated by U.S. Navy for FY 1972

Bird Weight Statistical Analyses: Curve Fitting Data

The most controversial factor in the selection of design criteria for windshield/canopy and support structure is unquestionably the selection of bird weight or weights. Considering the 20 billion birds that frequent the CONUS, most are lightweight and of the perching bird variety. There seems to be some differences of opinion regarding the selection of exact weights for some of the heavier birds; i.e., the albatross may weigh, depending on the data, either a nominal weight range of 4-8 pounds, or up to 18 pounds.

Of the many thousand of birds in each species only a few hundred are ever weighed, which is a questionable sampling plan. Also, in the identified weight data there is a marked difference in weight between the male and the females of the species. Another factor that could greatly influence the actual weights of species is the time of year and whether or not the species were weighed before or after migrations to or from their breeding grounds. For this series of studies the average weights were selected from the available data.

Birds involved in actual collisions were not easily studied statistically and at best the ensuing studies have many compromises in an attempt to provide some meaningful selection of bird weights.

The ICAO data for 1967-1969, Reference 25, indicated that 94.5% of the birds struck worldwide weighed less than 4 pounds, 4% of the birds weighed between 4 and 8 pounds, and 1.5% or 45 incidents, indicated the birds weighed more than 8 pounds.

It was of interest to note that the RAF and German Air Force did not have any strikes above three pounds, as noted in Section III, Table XII and XIII respectively.

This tends to indicate that the Europeans are not involved with heavy-weight birds. Yet, 0.52% of the KLM bird strikes weighed between

8 and 9 pounds. This can possibly be explained as occurrences outside of Europe.

The sanitized computer printout data, supplied by the Air Force Safety Center at Norton AFB, covering the period 1965-1972 was analyzed and it was determined that 619 incidents identified the birds struck.

Incident reports noted in Reference 1 and 2, obtained from the FAA pertaining to commercial air lines operating in the CONUS identified 173 of the birds struck during 1971 and 1972.

These two sets of data were analyzed initially by sorting the data individually in weight ranges, and calculating cumulative frequencies (percents) as noted in Table XXIV.

TABLE XXIV

FREQUENCY DISTRIBUTIONS OF IDENTIFIED BIRD WEIGHTS FOR USAF 1965-1972 AND FAA 1971-1972 DATA

Bird Wt. Range	USAF		FAA	
	Frequency Distribution	Cumulative Percent Frequency	Frequency Distribution Number	Cumulative Percent Frequency
0 - 1	235	37.96	59	3[illegible].10
1 - 2	38	44.10	32	52.60
2 - 3	237	82.39	59	86.70
3 - 4	62	92.41	7	90.75
4 - 5	11	94.19	1	91.28
5 - 6	4	94.84	6	94.80
6 - 7	7	95.96	0	94.80
7 - 8	0	95.96	0	94.80
8 - 9	13	98.06	8	99.42
9 - 10	4	98.71	0	99.42
10 - 11	8	99.99	1	99.99
Total	619	100.00%	173	100.00%

Linear regression analysis was performed on each set of data using the polynomial formulations to develop averages. In the analysis the bird weights were considered as the independent variable and the cumulative frequencies (percent) were considered as the dependent variable.

The data was input into a computer that had the capabilities for specifying the largest degree of polynomial to provide the best fit or averages for each set of data.

The equations computed were:

$$Y = a + bX + cX^2 + dX^3 + eX^4$$

FAA: $$Y = 9.978 + 47.08X - 9.70X^2 + 0.874X^3 - 0.0285X^4$$

USAF: $$Y = 16.72 + 34.27X - 4.91X^2 + 0.26X^3 - 0.0033X^4$$

where:

X = Bird Weights

Y = Cumulative Frequency (Percent)

Shown in Figure 53 the actual cumulative frequencies were plotted as well as the polynomial curves. Reviewing the curves indicated that approximately 92% of the birds struck weighed less than four pounds. The remaining 8% included all of the birds above four pounds. It was interesting to note the close similarity of the curves to previous studies accomplished by the FAA (formerly CAA) noted in Reference 23 and National Research Council of Canada, noted in Reference 27.

Cumulative Frequency of Bird Strikes as a Function of Bird Weight

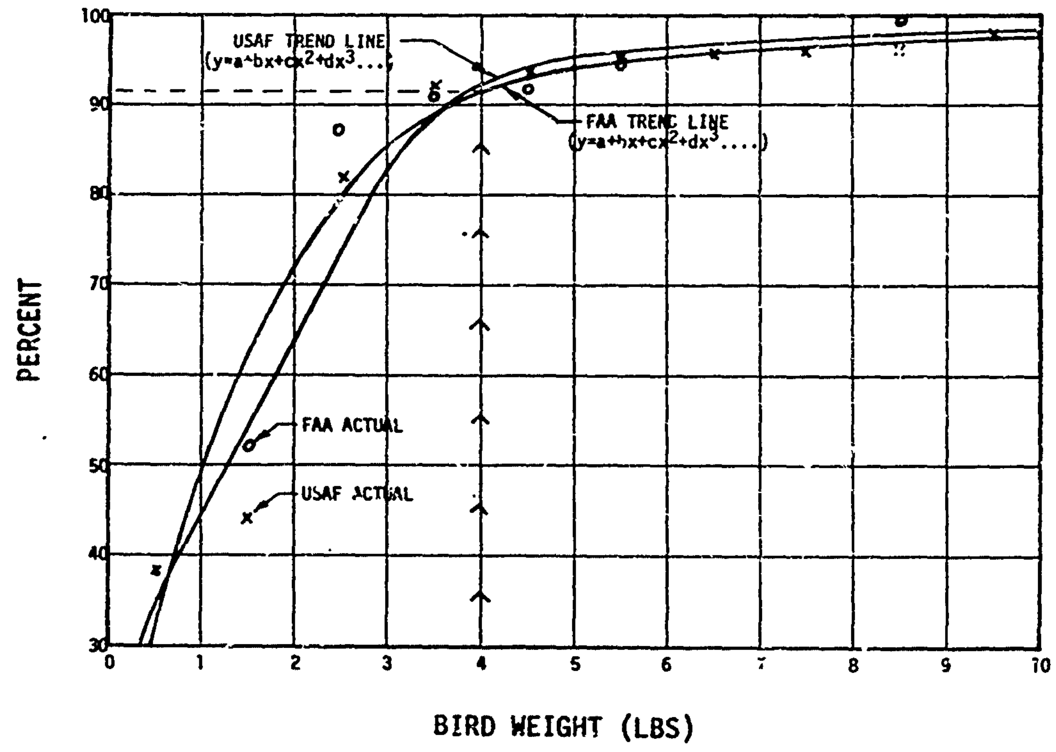


FIGURE 53

Cumulative Frequency (Percent) Bird Strikes vs Bird Weight

Bird Weight Analyses: Descriptive Statistical Methodologies

Using descriptive statistical methodologies described by Wolf (Reference 71), the data shown in Table XXIV were further analyzed to determine confidence limits for the selection of bird weights for use as recommended design criteria.

As shown in Figures 54 and 55 histograms were plotted to show the frequency distributions for each set of data.

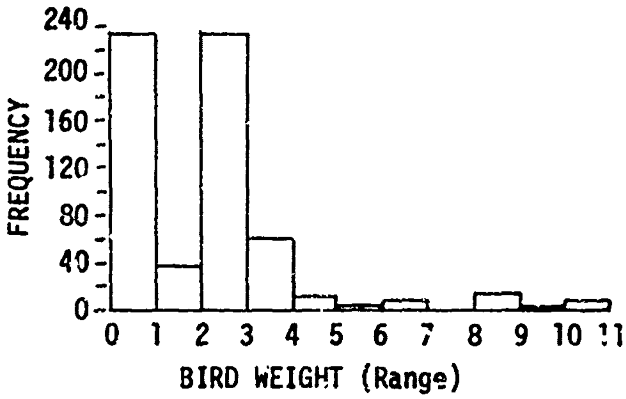


FIGURE 54

Frequency Distribution of USAF Identified Birdstrikes in CONUS 1965-1972

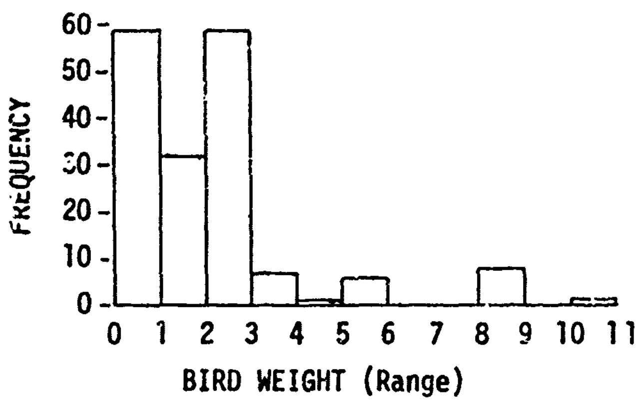


FIGURE 55

Frequency Distribution of Commercial Airlines (FAA) Identified Birdstrikes in CONUS 1971-1972

The calculations required to develop the statistical analysis for subsequent paragraphs are shown in Tables XXV through XXVIII.

TABLE XXV

COMPUTATIONS DERIVED FROM THE USAF
IDENTIFIED BIRDSTRIKES DATA IN CONUS 1965-1972

X_i	f_i	$X_i f_i$	$(\bar{X}-X_i)$	$(\bar{X}-X_i)^2$	$(\bar{X}-X_i)^2 f_i$
0.5	235	117.5	1.654	2.736	642.960
1.5	38	57.0	0.654	.428	16.264
2.5	237	592.5	-0.346	.120	28.440
3.5	62	217.0	-1.346	1.812	112.344
4.5	11	49.5	-2.346	5.504	60.544
5.5	4	22.0	-3.346	11.196	44.784
6.5	7	45.5	-4.346	18.888	132.216
7.5	0	0	-5.346	28.580	0
8.5	13	110.5	-6.346	40.272	523.536
9.5	4	38.0	-7.346	53.964	215.856
10.5	8	84.0	-8.346	69.656	557.248
Total	619	1333.5		233.160	2334.192

TABLE XXVI

COMPUTATIONS DERIVED FROM THE USAF
IDENTIFIED BIRDSTRIKES DATA IN CONUS 1965-1972

X_i	f_i	$X_i f_i$	$(\bar{X}'-X_i)$	$(\bar{X}'-X_i)^2$	$(\bar{X}'-X_i)^2 f_i$
2.5	200.5	501.25	-0.346	.120	24.060
3.5	62	217.0	-1.346	1.812	112.344
4.5	11	49.5	-2.346	5.504	60.544
5.5	4	22.0	-3.346	11.196	44.784
6.5	7	45.5	-4.346	18.888	132.216
7.5	0	0	-5.346	28.580	0
8.5	13	110.5	-6.346	40.272	523.536
9.5	4	38.0	-7.346	53.964	215.856
10.5	8	84.0	-8.346	69.656	557.248
Total	309.5	1067.75		229.996	1670.59

TABLE XXVII

COMPUTATIONS DERIVED FROM THE COMMERCIAL AIRLINES (FAA) IDENTIFIED BIRDSTRIKE DATA IN CONUS 1971-1972

X_i	f_i	$X_i f_i$	$(\bar{X}-X_i)$	$(\bar{X}-X_i)^2$	$(\bar{X}-X_i)^2 f_i$	$(\bar{X}_L-X_i)$	$(\bar{X}_L-X_i)^2$	$(\bar{X}_L-X_i)^2 f_i$	$(\bar{X}_u-X_i)$	$(\bar{X}_u-X_i)^2$	$(\bar{X}_u-X_i)^2 f_i$
0.5	59	29.5	1.613	2.602	153.518	1.17	1.369	80.771	2.06	4.244	250.396
1.5	32	48.0	0.613	0.376	12.032	0.17	0.029	0.928	1.06	1.124	35.968
2.5	59	147.5	0.387	0.150	8.85	-0.83	0.689	40.651	0.06	0.003	0.177
3.5	7	24.5	-1.387	1.924	13.468	-1.83	3.349	23.443	-0.94	0.884	6.188
4.5	1	4.5	-2.387	5.698	5.698	-2.83	8.009	8.009	-1.94	3.764	3.764
5.5	6	33.0	-3.387	11.472	68.832	-3.83	14.669	88.014	-2.94	8.644	51.864
6.5	0	0	-4.387	19.246	0.	-4.83	23.329	0.	-3.94	15.524	0.
7.5	0	0.	-5.387	29.020	0.	-5.83	33.989	0.	-4.94	24.404	0.
8.5	8	68.0	-6.387	40.794	326.352	-6.83	46.649	373.192	-5.94	35.284	282.272
9.5	0	0.	-7.387	54.568	0.	-7.83	61.309	0.	-6.94	48.164	0.
10.5	1	10.5	-8.387	70.342	70.342	-8.83	77.969	77.969	-7.94	63.044	63.044
Total	173	365.5		236.192	659.092			692.98			693.673

TABLE XXVIII

COMPUTATIONS DERIVED FROM THE COMMERCIAL AIRLINES (FAA)
IDENTIFIED BIRDSTRIKE DATA IN CONUS 1971 - 1972

X_i	f_i	$X_i f_i$	$(\overline{X}' - X_i)$	$(\overline{X}' - X_i)^2$	$(\overline{X}' - X_i)^2 f_i$	$(\overline{X}_u' - X_i)$	$(\overline{X}_u' - X_i)^2$	$(\overline{X}_u' - X_i)^2 f_i$
1.5	4.5	6.75	0.359	0.129	0.581	1.184	1.402	6.308
2.5	59.0	147.5	-0.641	0.411	24.249	.184	.034	2.000
3.5	7.0	24.5	-1.641	2.693	18.851	- .816	.666	4.661
4.5	1.0	4.5	-2.641	6.975	6.975	-1.816	3.299	3.299
5.5	6.0	33.0	-3.641	13.257	79.542	-2.816	7.930	47.580
6.5	0.	0.	-4.641	21.539	0.	-3.816	14.562	0.
7.5	0.	0.	-5.641	31.821	0.	-4.816	23.194	0.
8.5	8.0	68.0	-6.641	44.103	352.824	-5.816	33.826	270.607
9.5	0.	0.	-7.641	58.385	0.	-6.816	46.458	0.
10.5	1.0	10.5	-8.641	74.667	74.667	-7.816	61.090	61.090
Total	86.5	294.75		253.980	557.689			395.545

The means or arithmetic means for the frequency distributions were determined as follows:

$$\bar{X} = \frac{\Sigma X_i f_i}{N}$$

where:

$\bar{X}$ = arithmetic mean

X_i = midpoint of individual intervals

f_i = frequency of individual intervals

N = total number of occurrences

then:

$$\text{USAF: } \bar{X} = \frac{1333.5}{619} = 2.154$$

$$\text{FAA : } \bar{X} = \frac{365.5}{173} = 2.113$$

These arithmetic means indicated the average weights of birds struck. The assumption was made that these will also represent the average weights of birds expected to be struck in the future.

Actually, it was intended that these two sets of data were samples taken from an unknown universe. The USAF sample data with a total of 619 identified bird strikes were considered to be very large and the FAA sample data of 173 identified bird strikes were considered to be a large sample.

Estimating means from sample data could produce built-in errors. The standard error of the estimated means was calculated from the formula:

$$S_{\bar{X}} = \pm\sqrt{\frac{\Sigma(\bar{X} - X_i)^2 f_i}{N(N - 1)}}$$

where:

$\pm S_{\overline{X}}$ = one standard error of the estimated mean to a 68.26% confidence level

$\pm 3\ S_{\overline{X}}$ = three standard errors of the estimated mean to a 99.74% confidence level

then:

USAF:

$$S_{\overline{X}} = \pm\sqrt{\frac{2334.192}{(619)(618)}}$$

$$S_{\overline{X}} = \pm .078$$

$$3\ S_{\overline{X}} = \pm .234$$

FAA:

$$S_{\overline{X}} = \pm\sqrt{\frac{659.092}{(173)(172)}}$$

$$S_{\overline{X}} = \pm .149$$

$$3\ S_{\overline{X}} = \pm .447$$

Using these two sets of data as a method of predicting, it was established to a 99.74% confidence level that the average bird weight (arithmetic mean) of bird strike data that may be compiled in the future for either commercial airlines or the USAF operating in the CONUS would occur in intervals determined as follows:

$$\overline{X}_u = \overline{X} + 3S_{\overline{X}}$$

$$\overline{X}_L = \overline{X} - 3S_{\overline{X}}$$

where:

$\overline{X}_u$ = the upper limit of the range of arithmetic mean

$\overline{X}_L$ = the lower limit of the range of the arithmetic mean

then:

FAA:

$$\overline{X}_u = 2.113 + .447$$
$$= 2.56$$
$$\overline{X}_L = 2.113 - .447$$
$$= 1.67$$

USAF:

$$\overline{X}_u = 2.154 + .234$$
$$= 2.39$$
$$\overline{X}_L = 2.154 - .234$$
$$= 1.92$$

As noted the average bird weight obtained for the USAF data of $\overline{X} = 2.156$ did fall within the limits. Further, the USAF sample size being much larger than the FAA sample size, the distribution about $\overline{X}$ is not as great when establishing the error of the mean.

The medians were calculated for these frequency distributions as follows:

$$\overline{X}' = b_L + \frac{\frac{N}{2} - F_{m-1}}{f_m} \times C$$

where:

$\overline{X}'$ = median

N = number of occurrences

$\frac{N}{2}$ = establishes the number of occurrences that must lie on each side of the median to be established

b_L = lower boundary of the median

F_{m-1} = number of occurrences in the m-1 intervals preceding the median interval

f_m = number of observations in the median class

C = class interval

then:

USAF:

$$\overline{X}' = 2 + \frac{\frac{619}{2} - (235+38)}{237} \times 1$$

$$= 2 + \frac{309.5 - 273}{237} \times 1$$

$$= 2.154$$

FAA:

$$\overline{X}' = 1 + \frac{\frac{173}{2} - (59)}{32} \times 1$$

$$= 1 + \frac{86.5 - 59}{32} \times 1$$

$$= 1.859$$

Both sets of data included bird weights starting from 0 weight to establish frequency distributions; therefore, it must be concluded that 50% of the bird strikes must occur between 0 and the medians. Tables XXVI and XXVIII were compiled to show the standard error of the medians. It was assumed that estimating medians from sample data could produce built-in errors. The standard error of the medians was calculated from the formula:

$$S_{\overline{X}'} = \pm \sqrt{\frac{\Sigma(\overline{X}' - X_i)^2 f_i}{N(N-1)}}$$

where:

$\pm S_{\overline{X}'}$ = one standard error of the median to a 68.26% confidence level

$\pm 3S_{\overline{X}'}$ = three standard errors of the median to a 99.74% confidence level

then:

USAF:

$$S_{\overline{X}}' = \pm \sqrt{\frac{1670.59}{309.5\ (308.5)}}$$

$$S_{\overline{X}}' = \pm\ 0.132$$

$$3S_{\overline{X}}' = \pm\ 0.396$$

FAA:

$$S_{\overline{X}}' = \pm \sqrt{\frac{557.689}{86.5\ (85.5)}}$$

$$S_{\overline{X}}' = \pm\ 0.275$$

$$3S_{\overline{X}}' = \pm\ 0.825$$

then:

USAF:

$$\overline{X}'_u = 2.154 + .396$$

$$= 2.550$$

$$\overline{X}'_L = 2.154 - .397$$

$$= 1.757$$

FAA:

$$\overline{X}'_u = 1.859 + .825$$

$$= 2.684$$

$$\overline{X}'_L = 1.859 - .825$$

$$= 1.034$$

These means and medians are shown in Figure 56 as points on a line to illustrate the variations.

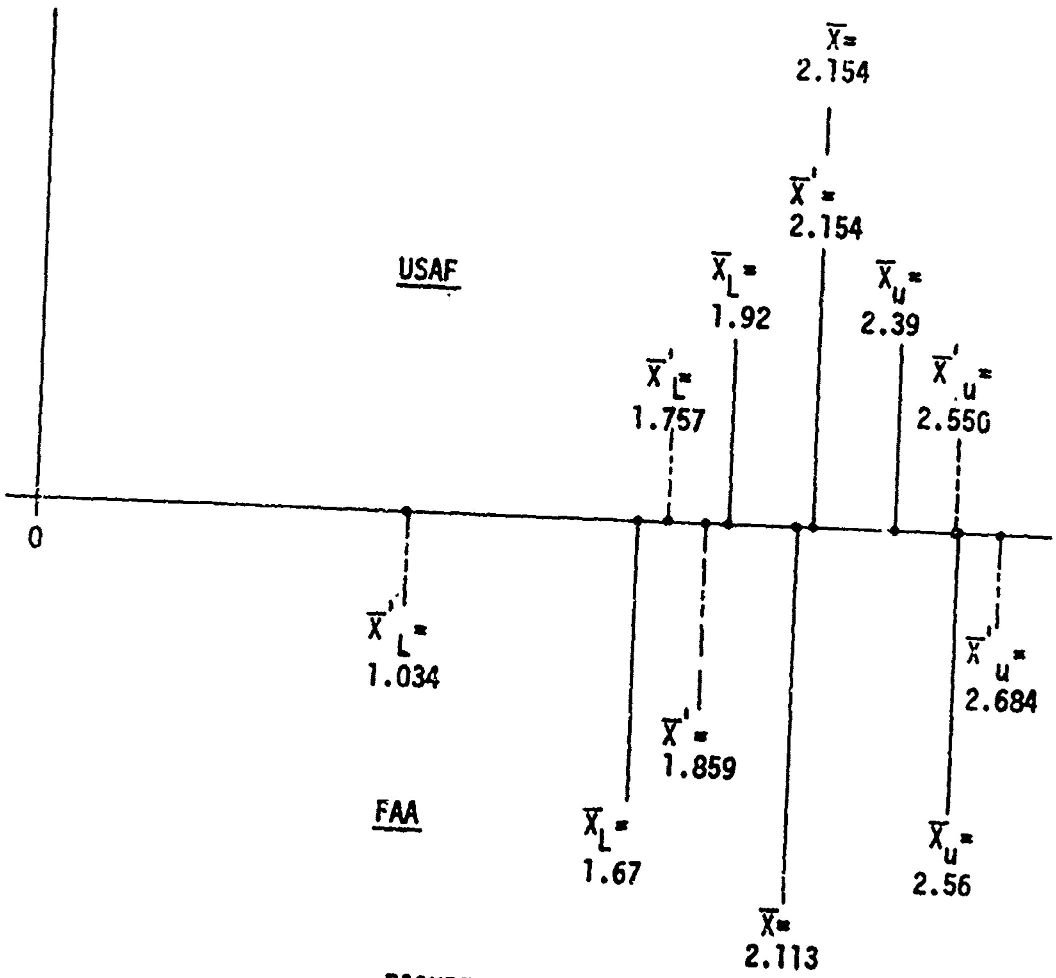


FIGURE 56

ILLUSTRATION OF MEANS AND MEDIANS

A measure of dispersion for establishing a distribution or spread from these averages is statistically defined as a standard deviation. The equation for the standard deviation is as follows:

$$SD = \sqrt{\frac{\Sigma(\overline{X} - X_i)^2 f_i}{(N - 1)}} \quad \text{and} \quad \sqrt{\frac{\Sigma(\overline{X}' - X_i)^2 f_i}{(N - 1)}}$$

As noted in Figure 56 averages may be greatly dispersed, particularly when the error of estimated mean or median is also considered.

In an endeavor to establish bird weights for design criteria, only those averages that represent the upper 50% were used to determine standard deviations.

Computations were made to determine various standard deviations from the averages as follows:

SD_1 = Standard deviation for USAF data taken to right side of $\overline{X}$

SD_2 = Standard deviation for FAA data taken to right side of $\overline{X}$

SD_3 = Standard deviation for USAF data taken to the right side of $\overline{X}'$

SD_4 = Standard deviation for FAA data taken to the right side of $\overline{X}'$

SD_5 = Standard deviation for FAA data taken to the right side of $\overline{X}_u'$.

The computations used are shown in Tables XXV through XXVIII and the standard deviations computed are as follows:

$$SD_1 = \sqrt{\frac{2334.192}{618}} = 1.94$$

$$SD_2 = \sqrt{\frac{659.092}{172}} = 1.96$$

$$SD_3 = \sqrt{\frac{1670.59}{308.5}} = 2.327$$

$$SD_4 = \sqrt{\frac{557.689}{85.5}} = 2.554$$

$$SD_5 = \sqrt{\frac{395.545}{85.5}} = 2.151$$

In order to establish confidence levels certain assumptions must be accepted. Since birds will always have some weight greater than zero, it must be accepted that 50% of the birds previously struck and predictions for future strikes must occur in the weight range between zero and the central point or averages selected. This is obvious from the frequency distribution noted in Figures 54 and 55 and assuming that normal distribution theory can be applied to the right side taken about these averages (means and medians).

Using this approach, the left side of each average selected would represent 50% of the totals, and the averages would automatically represent a 50% confidence level. Applying the normal distribution theory to obtain confidence levels on the right side of the averages; one, two, and three standard deviations would respectively represent 34.13%, 47.72% and 49.87% of the predicted distributions as determined from tables of normal curves. These percentages would be additive to the 50%. The summary of these calculations are shown in Table XXIX.

TABLE XXIX

CONFIDENCE LEVELS PREDICTIONS OF BIRD WEIGHTS
FOR FUTURE USAF AND COMMERCIAL AIRLINES (FAA)

	USAF BIRD WEIGHT (LBS)	FAA BIRD WEIGHT (LBS)	ASSUMED CONFIDENCE LEVELS
$\overline{X}$	2.154	2.113	50%
$\overline{X}_L$	1.92	1.67	50%
$\overline{X}_u$	2.39	2.56	50%
$\overline{X}'$	2.154	1.859	50%
$\overline{X}'_L$	1.757	1.034	50%
$\overline{X}'_u$	2.550	2.684	50%
SD_1	1.940		
$SD_1 + \overline{X}$	4.094		84.13%
$2SD_1 + \overline{X}$	6.034		97.72%
$3SD_1 + \overline{X}$	7.974		99.87%
SD_2		1.96	
$SD_2 + \overline{X}$		4.073	84.13%
$2SD_2 + \overline{X}$		6.033	97.72%
$3SD_2 + \overline{X}$		7.993	99.87%
SD_3	2.327		
$SD_3 + \overline{X}'$	4.481		84.13%
$2SD_3 + \overline{X}'$	6.808		97.72%
$3SD_3 + \overline{X}'$	9.135		99.87%
SD_4		2.554	
$SD_4 + \overline{X}'$		4.413	84.13%
$2SD_4 + \overline{X}'$		6.967	97.72%
$3SD_4 + \overline{X}'$		9.521	99.87%
SD_5		2.151	
$SD_5 + \overline{X}'_u$		4.835	84.13%
$2SD_5 + \overline{X}'_u$		6.986	97.72%
$3SD_5 + \overline{X}'_u$		9.137	99.87%

It can be concluded and reasonably assumed that compiled data pertinent to future bird strikes of USAF and commercial airlines operating in CONUS would result in similar results as noted in this study.

Historically, the design criteria for commercial aircraft has included a requirement for a four-pound bird impact design and test verification for windshields/windows and support structure. Therefore, many companies in the airframe industry located in CONUS, Canada, and England, as well as the recent implementation of test equipment by the USAF are designed and calibrated for verification testing with a four-pound bird.

Thus, the data from this study was further analyzed to establish more precise approximations for the confidence levels for four, six and eight-pound birds.

Tables of cumulative areas of a normal curve taken about the mean and median (averages) to the indicated deviation from the averages were used to determine the following calculations:

$$\frac{X^1}{SD} = SD^1$$

where:

$X^1 = X - \overline{X}$

$\overline{X}$ = selected average

X = selected bird weight (4, 6, or 8 pound)

SD = selected standard deviation

from these calculations of SD^1 the confidence levels (areas) were determined by using the table.

Then:

USAF data taken from $\overline{X}$

$\overline{X}$ = 2.154 pounds or 50% confidence level or area under curve between 0 and $\overline{X}$

SD_1 = 1.94

Four Pound: $\frac{4-2.154}{1.94} = .95154$

From table $\frac{X^1}{SD} = .95154$ the confidence level or area was determined as 82.929% (.82929 area)

Six Pound: $\frac{6-2.154}{1.94} = 1.9825$

From table the confidence level or area was determined as 97.625% (.97625 area)

Eight Pound: $\frac{8-2.154}{1.94} = 3.013$

From table the confidence level or area was determined as 99.87% (.9987 area).

FAA data taken from $\overline{X}$:

$\overline{X} = 2.113$

$SD_2 = 1.96$

Four Pound: $\frac{4-2.113}{1.96} = .96275$

From table the confidence level or area was determined as 83.22% (.8322 area).

Six Pound: $\frac{6-2.113}{1.96} = 1.9831$

From table the confidence level or area was determined as 97.63% (.9763 area).

Eight Pound: $\frac{8-2.113}{1.96} = 3.0035$

From table the confidence level or area was determined as 99.87% (.9987 area).

USAF data taken from $\overline{X}'$

$\overline{X}' = 2.154$

$SD_3 = 2.327$

Four Pound: $\frac{4-2.154}{2.327} = .7933$

From table the confidence level or area was determined as 78.55% (.7855 area).

Six Pound: $\frac{6-2.154}{2.327} = 1.653$

From table the confidence level or area was determined as 95.06% (.9506 area).

Eight Pound: $\frac{8-2.154}{2.327} = 2.512$

From table the confidence level or area was determined as 99.41% (.9941 area).

FAA data taken from $\overline{X}'$:

$\overline{X}' = 1.859$

$SD_4 = 2.554$

Four Pound: $\frac{4-1.859}{2.554} = .8383$

From table the confidence level or area was determined as 79.9% (.799 area).

Six Pound: $\frac{6-1.859}{2.554} = 1.621$

From table the confidence level or area was determined as 94.75% (.9475 area).

Eight Pound: $\frac{8-1.859}{2.554} = 2.404$

From table the confidence level or area was determined as 99.19% (.9919 area).

FAA data taken from $\overline{X}'_u$:

$\overline{X}'_u = 2.684$

$SD_5 = 2.151$

Four Pound: $\frac{4-2.684}{2.151} = .6118$

From table the confidence level or area was determined as 72.97% (.7297 area).

Six Pound: $\frac{6-2.684}{2.151} = 1.5416$

From table the confidence level or area was determined as 93.85% (.9385 area).

Eight Pound: $\frac{8-2.684}{2.151} = 2.4714$

From table the confidence level or area was determined as 99.32% (.9932 area).

It is believed that with absolute conservatism the confidence level for the selection of a four-pound bird weight for design criteria would be between 72.97% and 83.22% with an acceptable normal confidence level of 78.55% taken from the USAF median.

The confidence level for a six-pound bird weight would be in the range 93.85% and 97.63%.

The confidence level for an eight-pound bird weight would be in the range 99.32% and 99.87%.

Bird Weight Analyses: Theoretical Distributions - Probability Predictions

Treating the data noted in Table XXIV as sample data and applying descriptive statistical methodologies, the confidence levels established for the expectations of a bird strike being less than four pounds proved to be radically different than the actual reported data. Consistently, reported data shows that over 90% of the birds struck weigh less than four pounds, while the greatest confidence level obtainable using sampling plan theory was 83.22%.

The data from Table XXIV was further analyzed using one-dimensional distributions theories developed by Hald (Reference 73) to develop probabilities for the upper 50% of the data. The median bird weights was selected as the central limit.

Cumulative frequency distributions for the USAF and FAA data are shown plotted in Figure 57 and 58 respectively.

It was virtually impossible to develop curve fitting equations for the data to account for both sides of the median. Since it was accepted that 50% of the bird strikes would occur on each side of the median only the area of the upper 50% of the cumulative frequency distributions were selected for curve fitting.

The points representing the upper 50% of the data were input into an IBM 2250 Computer Graphics machine. The purpose for using this equipment was to obtain assistance in developing curves and their equations. The smooth curves are shown in Figures 59 and 60.

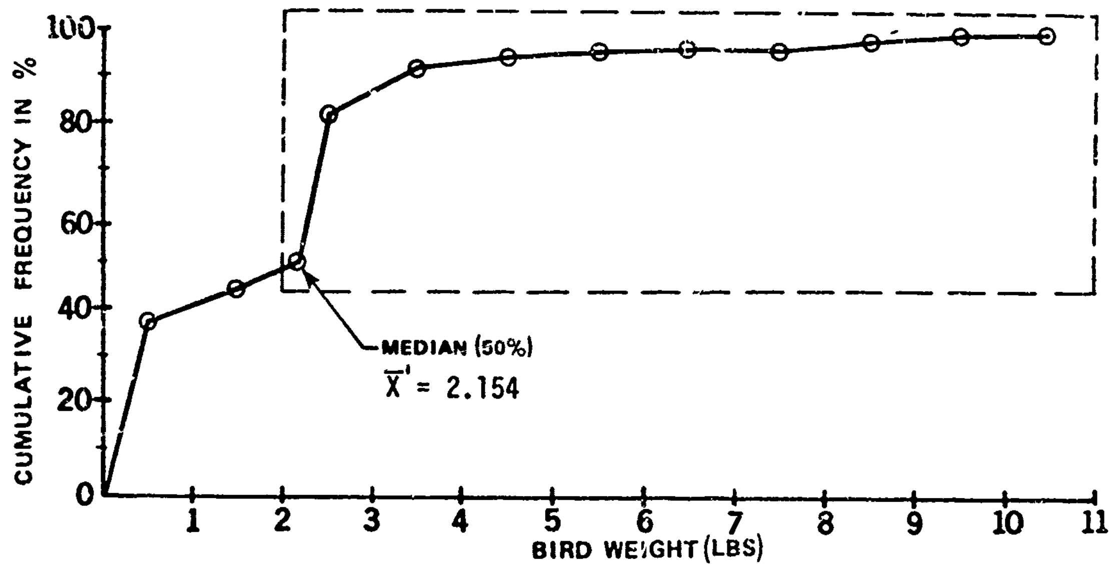


FIGURE 57

Cumulative Frequency Distribution for USAF Data (1965-1972)

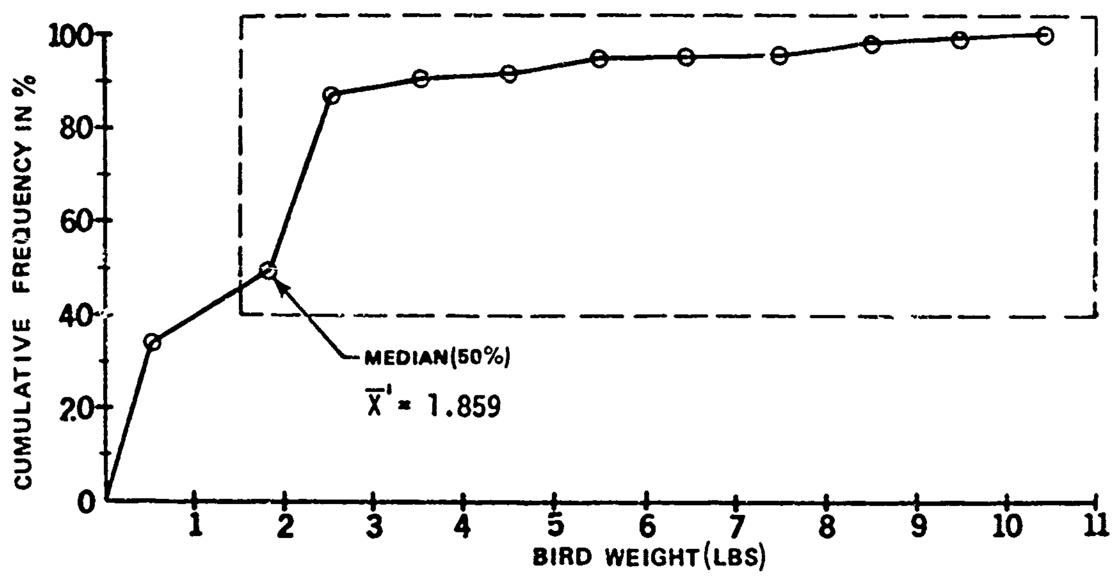


FIGURE 58

Cumulative Frequency Distribution for FAA Data (1971-1972)

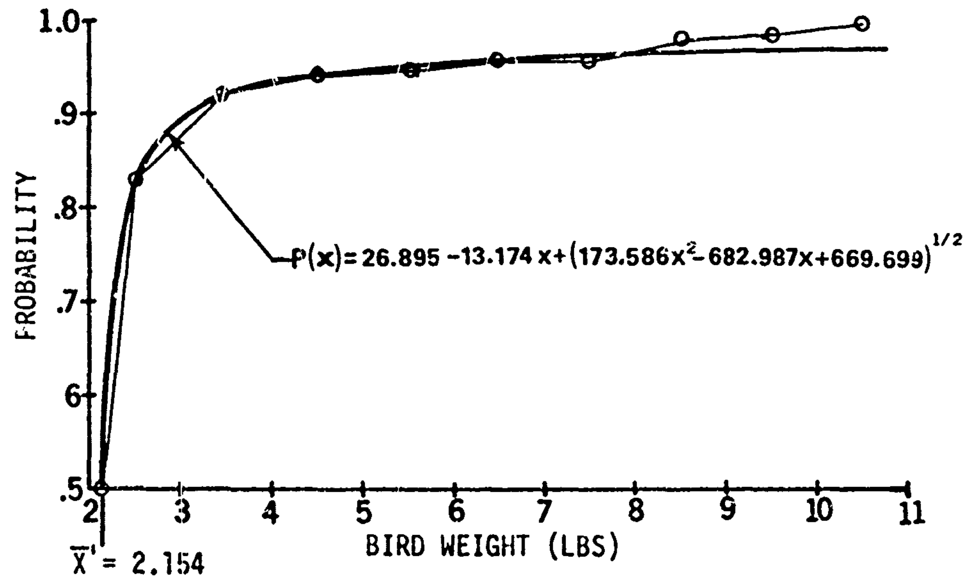


FIGURE 59

Curve Fit for Upper 50% of USAF Data

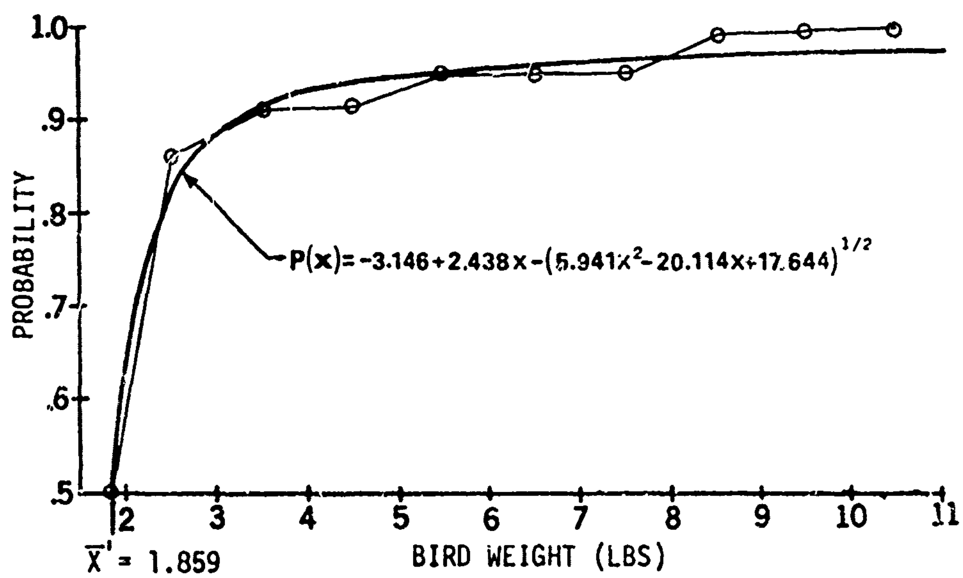


FIGURE 60

Curve Fit for Upper 50% of FAA Data

The equations of the curves represent the cumulative distribution function noted by:

$$P\left\{X\right\}$$

Taking the derivative

$$\frac{dP\left\{X\right\}}{dX} = p\left\{X\right\}$$

gives the density function of X; which, when multiplied by the frequency of bird strikes (N), is the frequency distribution. These equations and curves with corresponding histograms are shown in Figures 61 and 62.

To determine the probability that a bird weight falls within an interval on the right side (upper 50%) of the median, accepting that 50% or $p_0 = .500$ occurs between 0 and the median and that the cumulative probabilities equal one. Then:

$$p_0 + p_1 + p_2 + \ldots. = 1$$

These probabilities were then determined by finding the area under the curves noted in Figure 61 and 62.

Then:

$$p_0 + \int_{\overline{X}'}^{\text{bird wt. desired}} p\left\{X\right\} = .500 + p\left\{X\right\}\Big]_{\overline{X}'}^{\text{bird wt. desired}}$$

The probabilities derived are as follows:

Bird Wt. Interval	Probability	
	USAF	FAA
0 - 4	.941	.928
0 - 6	.963	.954
0 - 8	.972	.965

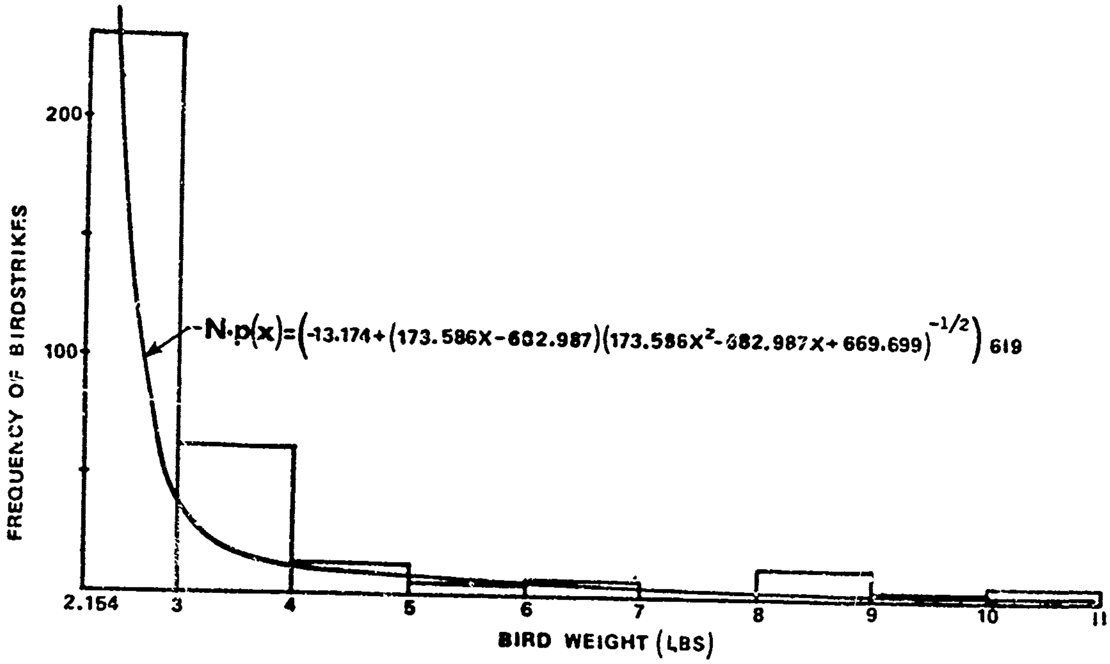


FIGURE 61

Frequency Distribution Curve for USAF Data

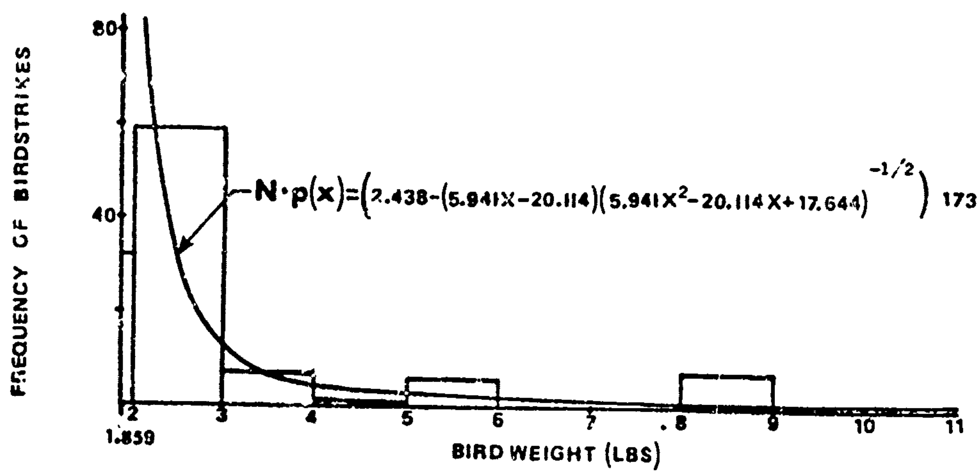


FIGURE 62

Frequency Distribution Curve for FAA Data

Bird Weight vs Altitude - Poisson's Statistical Analysis

The Poisson statistical distribution was chosen as the most appropriate method to depict the probability of having a given number of bird strikes by a bird exceeding a selected weight within a specific altitude range. The data for this study was taken from the USAF bird-aircraft incidents for the years 1965 thru 1972. The number of incidents where the bird weight and altitude was known, was 619. The average number of bird strikes per year on the windscreen/canopy for the years 1966 thru 1972 was 29.41. If the 619 bird strikes on various components of the airplanes were all assumed to strike the windscreen/canopy, the 619 strikes would, theoretically, represent 21 years of strikes on windshields/canopies, calculated as follows:

$$\frac{619 \text{ strikes}}{29.4 \text{ strikes/year}} = 21 \text{ years}$$

The equation for the Poisson distribution used was of the form:

$$P_{(S)} = e^{-X}\sum_{S=0}^{\infty}\frac{X^S}{S!} \quad \text{where } S = 0, 1, 2, 3 \ldots \qquad (1)$$

where:

$P_{(S)}$ = Probability of not having more than S no. of strikes

X = Expected no. of strikes by birds over a specific weight in a selected altitude range

S = No. of strikes in a series from 0 to ∞

! = Factorial

In the scale of probabilities, zero means there is no chance of a strike, while 1.0 means it is absolutely certain to occur.

For this study, five years was chosen and the value of X was factored as follows:

$$X = \frac{(n)(a)(5 \text{ years})}{619 \text{ strikes}}$$

where:

n = Expected number of strikes

a = Average strikes per year on windscreen (29.4)

for example:

n = 1, for a bird over 8 pounds in the altitude range of 0-100 feet.

$$x = \frac{(1)(2\text{[illegible] strikes})(5\text{ years})}{619\text{ strikes}} = .238$$

A series of curves were developed using the Poisson's distribution, as shown in Figure 63 for several bird weights at selected altitude ranges to define the probability values for having more than an expected number of strikes with birds weighing more than the weights specified.

These curves may be used by selecting an expected number of strikes occurring over a five-year period and then reading directly the probability of occurrence. Example: the probability of hitting more than 9 birds over two pounds in the altitude range of 0-100 feet is 0.10 or a 10% probability.

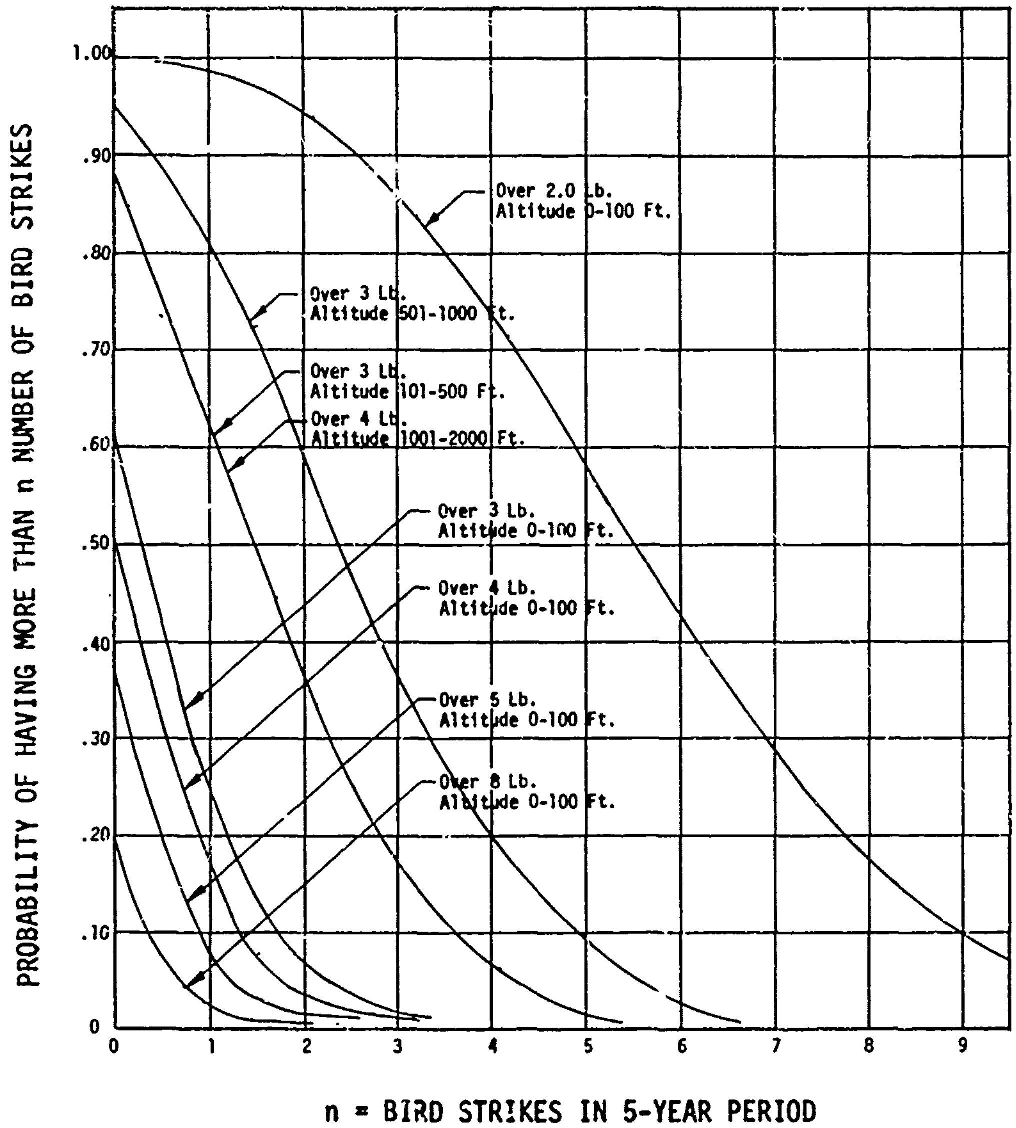


FIGURE 63

Poisson's Distribution

Conclusions and Pertinent Findings

1. Section IV presented the statistical methods used to justify recommended bird impact design criteria for windshields/canopies and support structure for future USAF aircraft.

2. The average number of bird strikes occurring on USAF aircraft during the past seven years (1966-1972) was determined as 356 strikes per year. It must be assumed that as long as flight frequencies and mission profiles are unchanged this trend will continue in the USAF unless air base attractions for birds are eliminated; unless bird tracking radar systems are implemented; and/or unless low-level training missions are planned to avoid bird migrations.

3. Table VI (Section III) showed that over 91% of the USAF bird strikes occurred below 3,000 feet for the eight-year period (1965-1972). In terms of the 356 strikes per year, the number of bird strikes per week would be approximately seven. Comparatively, the data compiled for commercial airlines (1942-1946) operating in CONUS (Reference 23) showed predictions of as many as nine bird strikes per week for nonpressurized, propeller-driven aircraft that generally did not fly at altitudes above 10,000 feet. The significance of these analogies is that continued operation of aircraft at low altitudes increases the likelihood of bird strikes. With the advent of pressurized jet aircraft, most commercial flights are flown at high altitudes, thus reducing the exposure to birds. The FAA data for 1971-1972 shows that bird strikes on commercial aircraft in CONUS were less than two bird strikes per week.

4. The U.S. Navy, over a thirteen-year period (1960-1972), averaged 65.3 bird strikes per million flight hours which is a 25% higher rate than the USAF. Since Naval aircraft are continually exposed to birds following surface vessels, migrating off-shore birds, birds abundant on numerous off-shore islands, in addition to the locally cosmopolitan birds that frequent land bases for food and roosting, it is reasonable to expect a greater frequency rate of bird strikes on Naval aircraft.

5. Regardless of the reporting periods, the five birds struck most frequently were ducks, gulls, vultures, hawks, and pigeons. As noted in Section II, the habits and migratory patterns of these birds are well known. Changes to air base ecological balances would drive many of these birds from the bases.

6. It was assumed that the probability of a bird striking any component on the aircraft was by chance. To validate this hypothesis, the C9A/DC9, DC8 and F4 aircraft were selected to assess the frequency of bird strikes versus component frontal area. It was concluded from the study that an aircraft was struck by chance, but some components seem to be more susceptible to bird strikes than others.

7. A model was developed from the data of the three selected aircraft (C9A, DC8, and F4) to depict to a 95% confidence level for the percentage of component frontal area versus the percentage of bird strikes. Three additional aircraft (B727, A7, and A4) were selected for comparison that tended to validate the model.

8. During the design of future aircraft, the model can be used as a useful tool to predict the percentages of bird strikes that could occur on the various component frontal areas.

9. The C9A had a bird strike rate 4.05 times greater per million flight hours than the USAF average, and was 7.86 times greater than the equivalent DC9 operated by commercial airlines. This anomaly was attributed to differences in C9A operational procedures, mission profiles, and operating base locations.

10. Air Canada operations of the DC8 aircraft reported a rate of 172 strikes per million flight hours (1964-1965), while the U.S. carriers reported for the DC8 aircraft, 2.4 incidents per million flight hours (1971-1972). It was expected that Air Canada would have a much higher bird strike rate since the reporting period occurred prior to the implementation of ecological changes to the Canadian airports.

11. The data for the six aircraft studied revealed that the bird strikes on the windshields, fuselage, nose/radome and engines were consistently greater than the expected averages for those specific frontal areas.

12. The data for the six aircraft studied revealed that the likelihood of bird strikes on the tail was consistently lower than the expected average for the tail. The placement of the engines on the aircraft seemed to have an effect on the frequency of strikes on the tail. The C9A/DC9 with the engines located aft on the fuselage did not have any bird strikes on the tail; the DC8 with the engines located on the wings had only one strike on the tail; the B727 with three engines located aft on the fuselage had two strikes on the tail, compared with five predicted tail strikes; the F4 with the engines located forward and on the fuselage had two strikes, which compared with eight predicted strikes; and the A7 with the engine located on the fuselage nose had no strikes on the tail.

13. The USAF data (1965-1972) and the FAA data (1971-1972) were plotted and curve fitting equations developed comparing bird weights versus cumulative bird strike frequencies. It was found that approximately 92% of the birds weighed less than four pounds, compared with the 94.5% developed by ICAO, and data noted in Reference 23 and 27.

14. The USAF data (1965-1972) and the FAA data (1971-1972) were treated as data samples and analyzed using descriptive statistical methodologies. From the mean and median bird weights and standard estimated errors, it was concluded that the average bird weight taken from any future sample data would be between 1.034 and 2.684 pounds. Large sample sizes greater than 600 should show an average bird weight of 2.154 pounds. It was assumed that the medians derived from the data would more closely represent the average bird weights so that normal distribution theory could be applied more accurately. This assumes that between 0 and each median the weights represent 50% of all birds struck and the median was established as the 50% confidence level. Standard deviations were calculated from the two

medians and upper limit of the FAA estimated median, and subsequently, calculations were made to establish confidence levels for four, six and eight-pound birds. The range of confidence levels for these bird weights were respectively 72.97% to 83.22%, 93.85% to 97.63%, and 99.32% to 99.87%.

15. The results of the normal distribution theory study indicated a significant difference to the actual weights. Even with the larger USAF sample size used from the median as the central limit, the confidence level for birds struck weighing less than four pounds was determined as 78.55%, which is much lower than the 92% determined from the actuals.

16. A mathematical study was also conducted from the two sets of data in terms of the cumulative distribution function. The previously determined medians were accepted as the mid-points of the data and curves developed for the upper 50% of the data. By integration techniques, the probabilities were determined from the area under the curves. The probabilities of birds struck weighing less than four pounds for the USAF and FAA respectively, were determined as .941 and .928, which is in close agreement with the ICAO data.

17. A statistical analysis was performed on the USAF 619 bird strikes using Poisson's distribution theory and curves developed for the probabilities of hitting specific weight birds in altitude ranges over a five-year period. For example, the probability of hitting more than nine birds weighing over two pounds in the altitude range of 0 - 100 feet during a five-year period is 0.10 or 10% probability.

18. Future USAF aircraft should be designed and verification tested for bird impact requirements.

19. There have been no catastrophic failures due to bird strikes on windshields/canopies and support structures that were designed to the FAA requirements for impact of a four-pound bird at V_C speeds at sea level.

20. There were only two renowned bird strikes that caused catastrophic damage to commercial aircraft in the past 23 years. The first incident occurred in Boston during 1960 when a Lockheed Electra ingested starlings in the engine causing the aircraft to crash on takeoff, killing 62 persons. The second occurrence resulted in the loss of a Viscount Airline plane with 17 persons killed, when at 6,000 feet over Maryland in 1962 the aircraft lost its vertical tail after impact of a whistling swan.

21. It is concluded and recommended that the windshields/windows and support structure be designed to withstand the impact of a four-pound bird at maximum obtainable velocities to 8,000 feet altitude (AGL) plus 60 knots, allowed for bird speeds, and verification tested to environmental temperatures including the effects of aero-dynamic heating as required.

22. During the bird migration periods, particularly August through November, aircraft designed for a four-pound bird impact shall be restricted to speeds that would allow for the impact of an eight-pound bird -- particularly when flying in areas such as the Sacramento Valley in California and the Chesapeake Bay area on the East Coast of the United States.

SECTION V

PROPOSED INTERIM AND UNIQUE CRITERIA FOR USAF AIRCRAFT IN INVENTORY

Many different models of aircraft in the current USAF inventory were not designed to any bird impact requirements.

The costs required to redesign and retrofit the windshields/canopies and support structure, and to verify the redesign for these aircraft would be prohibitive.

Cost effective programs could easily be implemented that would greatly reduce the bird strike frequencies for these aircraft. Programs for development and implementation could include the following:

- Air base interim procedures
- Windshield/canopy ratings
- Base operations procedures
- Flight procedures

Air Base Interim Procedures

Until procedures developed by the AFWL Environics Section and Air Force Base personnel eliminate those specific items around air bases that attract birds, certain interim actions should be taken to minimize the local bird population during takeoff/landing operations. Since the expected number of strikes per year during the takeoff/landing phases is 178, or 50% of the expected Air Force strikes, it is recommended that the following procedure, or an equivalent procedure that the AFWL may have developed, be adopted:

> Establish an air base runway patrol group for purposes of frightening birds from the vicinity of runways and taxiways. Pyrotechnic scare devices may be used, such as shotgun shells firing a small explosive projectile. Specific details for such devices, or alternate approaches to bird dispersion are available from the AFWL Environics Section. Patrols should thoroughly tour the

runway and adjacent areas at least 30 minutes in the early morning and again 15 minutes prior to the scheduled first flight. Additional patrols should be timed to match the daily flight schedule to scare birds away before takeoffs and when landings are anticipated. Flight operations should schedule sequentially as many flights as possible to preclude the possibility of more than one aircraft being damaged due to bird strikes.

Helicopters should fly regular search patterns to locate dead animals within five miles of the base perimeter. Cognizant authorities should remove the carcasses to particularly reduce the traffic from the heavier birds such as vultures, hawks, eagles, and owls.

Bird strikes and bird movements occur constantly, but the greatest potential hazard exists for major damage to aircraft during the migrations of waterfowl - ducks and geese. The fall migrations pose the gravest hazard because of the flock size, and may occur at any time between late August and late November. The spring migrations pose an uncertain lesser hazard and occur between late March and early May.

Flight Safety and Flight Operations Officers should treat waterfowl migrations with the same respect as they now treat thunderstorms, and every effort should be made to schedule flights to avoid areas where flocks of birds may be expected during the migration seasons. To ascertain the occurrence of movements of these flocks, pilots should report observations of flocks to the control towers. Base Operations Officers may obtain such information from the local U.S. Fish and Wildlife Services, local Audubon societies, local resident ornithologists, and from the Canadian Wildlife Services.

Windshield/Canopy Ratings

The greatest potential hazards to the safety of aircraft and crew are bird strikes on windshields/canopies. Some Air Force airplanes have been designed and tested to FAA bird impact requirements and others have been tested by Air Force contract; yet, other Air Force aircraft were neither bird impact tested nor have a design requirement for bird impact.

It is recommended that the Air Force review all aircraft models in the inventory, and quantitatively evaluate the windshield/canopy and structural support with regard to bird impact resistance. The Air Force should require that this evaluation be an integral part of planning all flight operations. Categorically, each aircraft windshield/window could be rated as follows:

- Tested
- Acceptable by analysis
- Acceptable by comparison
- Marginal by comparison
- Unacceptable by comparison
- Comparisons are not available

At the completion of the review of existing aircraft the findings should be documented in a similar manner as shown in Table XXX. The Douglas C9A, Northrop T-38, and Rockwell International T-39 aircraft are shown as an illustrative example in this table to indicate the conditions tested to the FAA requirements. When comparisons are made between aircraft not tested to aircraft tested, certain precautions are warranted with regard to such items as corner structural joints, section properties of structural members, and latching mechanisms for openable windows and hatches.

TABLE XXX

PROPOSED TABULAR METHOD FOR RATING USAF AIRCRAFT WINDSCREENS

Aircraft Model	Rating	Bird Wt. (Min)	Speed Vc (Max) (1)	Temps. of Component	Component	Material (Mil Spec)	Operat'l Reqmts	Debris Flying at Impact	Expected Injury to Crew	Component Visibility Affected On Impact
C9A	Tested	4	350K	+110°F	Center Windshlds	MIL-G-25871	Anti-Ice Sys. On.	Minute Glass Particles	None	Yes
C9A	Tested	4	260K	-65°F	Center Windshlds	MIL-G-25871	Anti-Ice Sys. Off	Minute Glass Particles	None	Yes
C9A	Analysis	4	235K		Center Windshlds	MIL-G-25871	Anti-Ice Off-Cracked Glass		None	Yes
C9A	Tested	4	350k	+110°F	Side Windshld	MIL-G-25871	Anti-Ice Sys. On	Minute Glass Particles	None	Yes
C9A	Tested	4	285K	-65°F	Side Windshld	MIL-G-25871	Anti-Ice Sys. Off	Minute Glass Particles	None	Yes
C9A	Tested	4	350K	-65° to 110°	Clearview Window	MIL-P-25690 & 25374	Defog on Optional	None	None	No
C9A	Tested	4	350K	-65° to 110°F	Eyebrow Window	MIL-P-25690 & 25374	Defog on Optional	None	None	No
C9A	Tested	4	350K	-65° to 110°F	Struct. Between Windows	Alum.	Normal	None	None	No
T-38	Tested	4	320		W/S	Mono-Str. Acrylic .60	---	None	None	Yes
T-39	Tested	4	350	111°F	W/S	MIL-G-25871	Anti-Ice On	None	None	Yes
T-39	Tested	4	350	75°F	Eyebrow	Str Acrylic	Defog on	Small Amount	None	Yes
T-39	Tested	4	350	75°F	C/V	Str Acrylic	Heat on	None	None	Yes
T-39	Tested	4	350	75°F	Fixed Co-Pilot	Str Acrylic	Heat on	None	None	Yes

NOTE: (1) Max speed is restricted below 10,000 feet only

Base Operations Procedures

Each Base Operations Office and each assigned operational unit should adopt stringent policies regarding the safety of aircraft entrusted to their control. Since 50% of all bird strikes happen on or near the airport, the responsibility for safeguarding these aircraft from potential bird hazards rests with their command. The following is a minimum procedure that should be adopted:

> Establish schedules for runway patrols to frighten birds from the vicinity of runways before takeoffs are allowed. Flight Operations should be responsible for determining that patrol schedules have been carried out and become knowledgeable of bird patterns in the airdrome area.
>
> Since control towers are arranged so that 360° observations are possible, adopt a schedule for regular observations of the entire area to determine the presence of any birds. The frequency of observations must be based upon local conditions but should be at least once each hour during routine aircraft traffic. High-powered field glasses may be required to spot smaller birds. When birds are observed notify the patrol group so that detailed investigation may be made. When birds are seen in the vicinity repeatedly, notify the Flight Safety and/or Base Operations Officers so that appropriate action is taken for removing the attractions to these birds. A soaring vulture rarely will be seen when he is not looking for food. When a vulture is seen soaring, send the patrol or a helicopter to the area and remove any dead animals found.
>
> Base Operations Offices should establish contacts with local Refuge Centers, Audubon Societies, and local ornithologists to develop a listing of birds that are known to frequent the areas, the birds' migratory habits, and the effect of hunters on bird movement habits. Since most of the noted bird followers will also be aware of the occurrences of migrations, this type of information should be

obtained on a regular basis so that flight schedules may be adjusted. Lakes, streams, and water holes where waterfowl may concentrate should be considered when flight plans are developed so that the flights may be made in a direction to avoid heavy concentrations of birds.

Radar operators should never tune out snow on their radar sets without first investigating the possibility of birds being the cause. Thus, the presence of bird movement in the area should be justification for bird alert procedures the same as cyclones and thunderstorms, and similar avoidance procedures should be instituted. Ultimately, it is believed that the efforts of the AFWL in the development of radar systems for tracking migratory birds will result in the development of a complete system for bird tracking.

Flight Procedures

Many changes can be made to minimize the potential hazards of bird impact and to limit potential damage to aircraft components. It is suggested that Base Operations Officers, Flight Safety Officers, Operational Unit Commanders, and individual Flight Crews adopt procedures that will minimize these dangers.

Some beneficial procedures include the following:

- The USAF should develop training films with sound featuring bird tests that have been conducted on test vehicles by the industry. The films should show the results of successful and unsuccessful tests. These films should convince all Flight Crews that the hazard of bird collision is severe in any aircraft.

- Flight Safety Centers should complete the listing of aircraft evaluations for windshields and establish speed restrictions below 8000 feet for the respective aircraft.

- It should be mandatory that aircraft equipped with strobe-lights have the lights on at all times below 8000 feet (AGL) altitude.

- It should be mandatory to have the landing lights on when flying below 8000 feet (AGL).

- Unique criteria should be established for each aircraft to ensure the most rapid penetration of bird-sensitive altitudes. This should include minimum take-off rolls and maximum climb angles to at least 3000 feet altitude.

- Establish cruise altitude above 8000 feet minimum.

- For low-level training missions, the flight should be at 3000 feet (AGL) minimum. This will reduce the chance of bird impact by at least 90%.

- For other low-level training missions, particularly during migratory season or flying in areas where vultures and eagles are prevalent, the flight should be a minimum of 1000 feet (AGL). This will reduce the chance of bird impact by at least 60%

- During landing approach maintain 1000 feet (AGL) as long as possible. This will reduce chances of bird impact by at least 60%.

- Maintain contact with control towers to coordinate bird activities in the areas in which the flight is being made.

- It is highly recommended that mission planning for all training missions and particularly for oil burner routes, include complete coordination with the AFWL Environics group and others regarding their predictions for migratory bird movements anticipated during the period planned.

- Consideration should be given to grounding aircraft that are below marginal evaluation for windshield bird impact resistance during heavy concentrations of medium to heavy birds.

- Consideration should be given to grounding single-engine aircraft during heavy concentrations of birds around the base, reducing the likelihood of aircraft losses due to engine ingestion. Flocks of small songbirds are just as dangerous as large birds, when engine ingestion is involved.

- It is recommended that any and all successful procedures implemented at the local level be passed on through appropriate Safety Office channels so that other Air Force units may benefit from these procedures.

Conclusions and Pertinent Findings

1. It was shown in Section III that 50% of bird strikes on USAF Aircraft will occur during the takeoff/landing phases of flight.

2. Of the 178 expected bird strikes per year during the takeoff/landing phases this number potentially could be greatly reduced by the implementation of bird dispersion techniques around the vicinity of runways and taxiways.

3. Since 1965 there have been seven fatalities, five major injuries and 25 minor injuries to flight crew members as a results of bird strikes. Many of these injuries could have been prevented had the aircraft windshields/windows and support structure been designed for bird impact and the aircraft placarded for safe flight speeds.

4. A comparative analysis should be made of the windshields/windows installed in the current inventory of USAF aircraft to determine ratings for safe flight speeds below 8000 feet (AGL) based on comparisons to known bird impact tested windshields.

5. Flight Safety and Flight Operations Offices should treat waterfowl migrations with the same respect as thunderstorms, and every effort should be made to schedule flights to avoid areas where flocks may be expected during migration seasons.

6. Radar operators could be trained to recognize bird movements on their radar sets and bird alert procedures instituted the same as weather reporting.

7. It should be mandatory for USAF flight of current aircraft in inventory that strobe - lights and/or landing lights be on at all times when the phase of flight is below 8000 feet (AGL).

8. For all flights and low-level training missions, unique criteria for current USAF aircraft should include minimum take-off rolls and maximum climb angles to 3000 feet altitude (AGL), and maintain flights above 3000 feet altitude to reduce the chance of bird impact by upward of 90%.

9. Consideration should be given to grounding aircraft that are below a marginal evaluation for windshields and single engine aircraft during heavy concentrations of medium to heavy birds, thus, reducing the chance for aircraft losses.

10. During all flights, it is recommended that the flight crews maintain contact with control towers to coordinate bird activity in areas in which the flight is made.

11. Mission planning for all training missions and particularly oil burner routes should include complete coordination with the AFWL Environics group and others regarding predictions for migratory bird movements.

SECTION VI

RECOMMENDED DESIGN, VERIFICATION & UNIQUE CRITERIA FOR WINDSHIELDS/CANOPIES AND SUPPORT STRUCTURE

Section II established that CONUS will always have an abundance of birds. Section III established that the USAF could expect 356 aircraft/bird collisions per year. Section IV established that up to 33% of birds striking an aircraft would strike the crew compartment enclosure. In this section criteria were developed and are recommended for the design of windshields/canopies and support structure to protect the flight crews and to assure completion of the intended mission of the aircraft.

The successful design of windshields/canopies and support structure requires that the following details be covered:

- Critical Parameters
- Adequacy of Existing Design Criteria
- Recommended Design Criteria
- Verification Testing
- Unique Testing Requirements
- Definition of Operational Procedures

Critical Parameters

Consideration of critical parameters requires that:

1. The crew compartment enclosure of all heavier than air aircraft (including helicopters and rotor craft) shall be designed for bird impact resistance.
2. In the event that an electrical system or a pneumatic system is required for anti-icing or de-icing the windshields/windows, the maximum obtainable temperature for the selected system under normal operations shall be selected as a temperature testing requirement.

Preceding page blank

3. 8000 feet (AGL) altitude is critical for the determination of maximum true airspeeds (closing speeds) of the craft.

4. There are many conditions of flight where the airspeed indicator does not truly reflect the actual velocity of the craft through the air mass. The selection of airspeed should be the maximum true airspeed (closing speed) of the aircraft up to an altitude of 8000 feet as required to meet the most critical mission requirement. The speed selected shall consider any and all variables tending to indicate an airspeed less than the actual velocity of the aircraft through its air mass. In summary, the intention is to establish a conservative velocity value for design and testing.

   Certain specifications shall be considered in the selection of the maximum true speeds such as the following:

   Air Force Systems Command Design Handbook DH 2-2, Chapter 3.

   Basic Aerodynamics - NAVWEPS 00-80T-80

   Military Specifications:
   MIL-A-38137
   MIL-A-38138
   MIL-I-27851
   MIL-I-27197
   MIL-I-27279

   The maximum true air speed of the aircraft should be increased by 60 knots to allow for the speed of some species of birds.

5. The selected design weight of bird shall be four pounds.

6. The crew compartment pressure differential of the aircraft shall be considered to be that required to provide for mission completion.

7. The selection of temperature requirements for design purposes shall include the maximum hot temperature extremes specified by MIL-STD-210. When applicable, the additive effects of aerodynamic heating shall also be considered. The minimum temperature shall be that associated with cold soaking at altitude and low ambient temperatures, as offset by the fact that some birds will migrate and fly at 8000 feet altitude when the temperatures for a standard day is -15°F. It may be infrequent but the Canada Goose has been observed to start migrations at ground temperatures of 18°F which corresponds to -15°F at 8000 feet for a standard day.

Adequacy of Existing Design Criteria

Various governmental agencies have bird impact design requirements that are not totally acceptable for the design of future USAF aircraft, particularly those with high speed, low-level mission requirements.

A study was made of these known requirements and the comments that follow indicate the main inadequacies.

- The FAA regulation FAR 25, paragraph 25.775, is adequate only for transport-type aircraft that have been designed at a Vc speed above 250 knots sea level and flown at the conservative speeds imposed by the FAA on commercial aircraft flying below 10,000 feet at 250 knots. Further, the FAA requirements do not include any criteria for hatches and latching mechanisms.

- The British Civil Airworthiness Requirements Document, Section D, Chapter D4-2, "Requirements for Commercial Aircraft", seems to be the most representative of what might be expected for Air Force flight conditions.

- FAA requirements of an eight-pound bird impact on empennage structure is excessively severe. Section III, Table VII shows that the frequency of empennage strikes is less than 3% of all strikes.

- The Air Force Systems mand Design Handbook DH2-1, Chapter 3, on 3A1 (9), dated 1 April 1973, specifies that windshields can be made bird resistant by (1) adding vinyl interlayers and (2) heating the assembly to reduce its brittleness.

- The requirements specified by USAF MIL-A-008865 are considered to cover requirements only very briefly and should be expanded.

- U.S. Navy MIL-W-81752 (AS), paragraph 3.6.6.1, states that the windshield shall be designed to withstand inflight collision with a four-pound bird at 1.75 times the stall velocity in cruise configuration. It also states that for aircraft which will be operated extensively at low altitude, and transport-type aircraft, impact velocity shall be the normal operating speed of the aircraft. Since this is a U.S. Navy specification, it is suggested that it be revised as follows: The windshield shall be designed to withstand without penetration the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane flight path) is equal to the maximum operational true airspeed in knots which can be achieved below 8000 feet.

- The FAA requirements (AC 33-1B) for Turbine Engine Certification Procedures although not applicable to the design of crew compartments should be considered for designs of engines.

Recommended Design Criteria

To ensure mission success the following design criteria for all future USAF aircraft (including helicopters and rotor craft) is recommended.

The windshields, windows, canopy and all supporting structure ahead of and protecting the pilot and crew shall be designed to withstand, without penetration, the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane flight path) is equal to the maximum operational true airspeed in knots, plus 60 knots, which can be achieved at altitudes up to 8000 feet with the most adverse temperatures selected after considering the maximum hot temperatures (including aerodynamic heating), anti-icing system maximum temperature, and the coldest temperature expected on the windshields/windows at 8000 feet.

Verification Tests

Unless it can be shown by analysis, or comparative analysis of similar designs, tests shall be conducted to verify the following:

1. Each transparency located in the front view of the airplane or those transparencies located where critical fragmentation would injure the pilot and crew shall be tested at the location of maximum deflection that will occur on impact at temperature conditions. Each test results shall show that the critical fragmentation is of such low order, not to cause injury to the flight crew, the loss of vision area shall be limited to 50%, and the structural damage shall not prevent the mission completion.

2. Each transparency shall be tested at locations of maximum stiffness under temperature conditions likely to occur for the most extreme cold temperature selected. Each test results shall show that the critical fragmentation is of sufficiently low order not to cause injury to the flight crew, and that structural damage shall be a minimum to allow pressurization to 15,000 feet or mission completion altitude, whichever is greatest.

3. Each transparency vertical support member adjacent to a transparency shall be tested at its center and its intersection with horizontal members. The resultant damage shall not be cause for aborting the mission.

4. Each transparency horizontal support member adjacent to the transparency shall be tested at its center and its intersection with verti- ` members. The allowed damage shall not be cause for aborting the mission.

5. When openable hatches or openable canopies are used and any edge is ahead of the flight crew, all tests shall substantiate that deflections or failures will not allow solid portions of the bird to enter the compartment and cause injury to the flight crew or prevent the pilot and crew from performing their normal duties. The allowed damage shall not be cause for aborting the mission.

6. All tests shall substantiate that the openable hatches or openable canopy latching mechanism will not be damaged to the extent that crew escape is restricted.

7. The bird weight shall be a minimum of 4.0 pounds and the package weight shall be additive to the bird weight.

8. Acceptable critical fragmentation shall be defined as spalling of the transparencies that will not penetrate the skin or eyes of the flight crew unless the pilot and crew are required to wear visors.

9. In cases where the windshield is heated in order to meet the bird impact requirements, the Flight Manual shall contain any instructions for the necessary safe operation of the heating system.

10. Bombers and fighters will not be allowed speed restrictions as a result of testing.

11. All other aircraft may be allowed speed restrictions as a result of testing. The Flight Manual shall contain any instructions necessary for these speed restrictions. In the event speed restrictions are required, the maximum true air speed (knots) that is permissible shall be stated in speeds that are readily identified by the pilot when looking at instruments within the aircraft.

The pilot and crew for a bomber, attack, or fighter aircraft is defined as the member(s) of the crew whose functions are mandatory to the successful completion of a mission.

The flight crew for a trainer or transport aircraft is defined as the member of the crew whose functions are mandatory for returning the aircraft to an air base.

The tests outlined above will result in success or failure of a given design within conditions noted. To minimize future failures, one alternative method for consideration as a future analytical tool is discussed

Metcalf, Reference 39, verified the relationship between the bird weight and the bird "effective diameter" by testing and recommended the following equation for a conservative prediction for birds weighing up to 19.5 pounds.

$$D = 3.18\ W^{1/3}$$

where D is the effective bird dimension in inches

The peak impact force exerted by a bird striking normal to a structure, assuming no structural deformation, is given by the equation:

$$F = \frac{2\pi W V^2}{3gD}$$

$$F = \frac{2\pi W\ V^2}{(3)(32.2)(3.18\ W^{1/3})}$$

$$F = .245\ W^{2/3}\ V^2$$

where V is in feet per second

or

$$F = .705\ W^{2/3}\ V^2$$

where V is in knots.

Mitchell, Reference 40, idealized this situation by characterizing birds in order to arrive at a realistic estimate of the peak forces associated with a bird impact. By the assumptions Mitchell made in his report, the following equations are derived in three modes:

Mode 1, Bird stationary

$$F_1 = KW^{2/3} V_2^2$$

Mode 2, Bird flying away from aircraft

$$F_2 = KW^{2/3} (V_2 - V_1)^2$$

Mode 3, Bird flying toward aircraft

$$F_3 = KW^{2/3} (V_2 + V_1)^2$$

where:

W is bird weight in (lbs)

K is a dimensional constant, $K = 0.705$

V_2 is aircraft TAS (KTS)

V_1 is bird TAS (KTS)

F_1, F_2 and F_3 are the peak impact forces in (lbs)

Computation of selected bird weights and aircraft true airspeeds at impact are given in Table XXXI. It is obvious that by doubling the impact speed the peak impact force would be quadrupled. However, in order to establish this quadrupled impact force relative to bird weight, it is necessary to increase bird weight by a factor of 8. A one-pound stationary bird tested at 400 knots would be theoretically equivalent to an eight-pound stationary bird tested at 200 knots if the relationship between the bird weight and the bird effective diameter is not considered. (See Figure 64 and Reference 38-40)

The response of an aircraft windshield/canopy to bird impact is a very complicated problem. The peak impact force as established by Mitchell provides the force for static analysis of bird impact. A study incorporating the elastic and inelastic effects of the impacting bodies to the wave propagation and the natural response of windshields subjected to bird impact can be beneficial to the establishment of design criteria.

TABLE XXXI

PEAK IMPACT FORCE ASSUMING SINUSOIDAL VARIATION (1000 POUNDS)

BIRD WEIGHT (LBS)	TRUE AIRSPEED OF IMPACTING AIRPLANE (KNOTS)							
	MODE	100	200	300	400	500	600	700
0.25	1	2.80	11.19	25.18	44.76	69.94	100.72	137.09
0.25	2	0.45	5.48	16.12	32.34	54.17	81.58	114.60
0.25	3	7.16	18.91	36.26	59.20	87.74	121.87	161.60
0.50	1	4.44	17.76	39.97	71.06	111.03	159.88	217.62
0.50	2	0.71	8.70	25.58	51.34	85.98	129.51	191.91
0.50	3	11.37	30.02	57.56	93.98	139.28	193.46	256.52
0.75	1	5.82	23.28	52.38	93.11	145.49	209.51	285.16
0.75	2	0.93	11.41	33.52	67.28	112.67	169.70	238.37
0.75	3	14.90	39.34	75.42	123.14	182.50	253.50	336.14
1.00	1	7.05	28.20	63.45	112.80	176.25	253.80	345.45
1.00	2	1.13	13.82	40.61	81.50	136.49	205.58	288.77
1.00	3	18.05	47.66	91.37	149.18	221.09	307.10	407.21
1.50	1	9.24	36.95	83.14	147.81	230.95	332.57	452.67
1.50	2	1.48	18.11	53.21	106.79	178.85	269.38	378.39
1.50	3	23.65	62.45	119.73	195.48	289.71	402.41	533.59
2.00	1	11.19	44.76	100.72	179.06	279.78	402.88	548.37
2.00	2	1.78	21.93	64.46	129.37	216.66	326.33	458.39
2.00	3	28.65	75.65	145.04	236.81	350.96	487.49	646.40
2.50	1	12.99	51.94	116.88	207.78	324.66	467.60	636.32
2.50	2	2.08	25.45	74.80	150.12	251.41	378.68	531.92
2.50	3	33.24	87.79	168.30	274.79	407.25	565.68	750.08
3.00	1	14.66	58.66	131.98	234.63	366.61	527.93	718.56
3.00	2	2.35	28.74	84.47	169.52	283.91	427.62	600.66
3.00	3	37.54	99.13	190.05	310.30	459.88	638.79	847.03
3.50	1	16.25	65.01	146.27	260.03	406.29	585.06	796.34
3.50	2	2.60	31.85	93.61	187.87	314.63	473.90	665.67
3.50	3	41.60	109.86	210.62	343.89	509.66	707.93	938.70
4.00	1	17.76	71.06	159.88	284.24	444.12	639.54	870.48
4.00	2	2.84	34.82	102.33	205.36	343.93	518.02	727.65
4.00	3	45.48	120.09	230.23	375.91	557.11	773.84	1026.10
5.00	1	20.61	82.46	185.53	329.83	515.36	742.12	1010.10
5.00	2	3.30	40.40	118.74	238.30	399.09	601.11	844.36
5.00	3	52.77	139.35	267.16	436.20	646.47	897.96	1190.68
6.00	1	23.26	93.11	209.51	372.46	581.96	838.03	1140.65
6.00	2	3.72	45.63	134.08	269.10	450.67	678.80	953.49
6.00	3	59.59	157.36	301.69	492.57	730.02	1014.02	1344.57
7.00	1	25.80	103.19	232.18	412.77	644.95	928.73	1264.11
7.00	2	4.13	50.56	148.60	298.23	499.45	752.27	1056.69
7.00	3	66.04	174.40	334.34	545.89	809.03	1123.77	1490.10
8.00	1	28.20	112.80	253.80	451.20	705.00	1015.20	1381.80
8.00	2	4.51	55.27	162.43	325.99	545.95	822.31	1155.07
8.00	3	72.19	190.63	366.47	596.71	884.35	1228.39	1628.83

MODE 1: BIRD STATIONARY
MODE 2: BIRD FLYING AWAY FROM AIRCRAFT AT 60 KNOTS TAS
MODE 3: BIRD FLYING TOWARDS AIRCRAFT AT 60 KNOTS TAS.

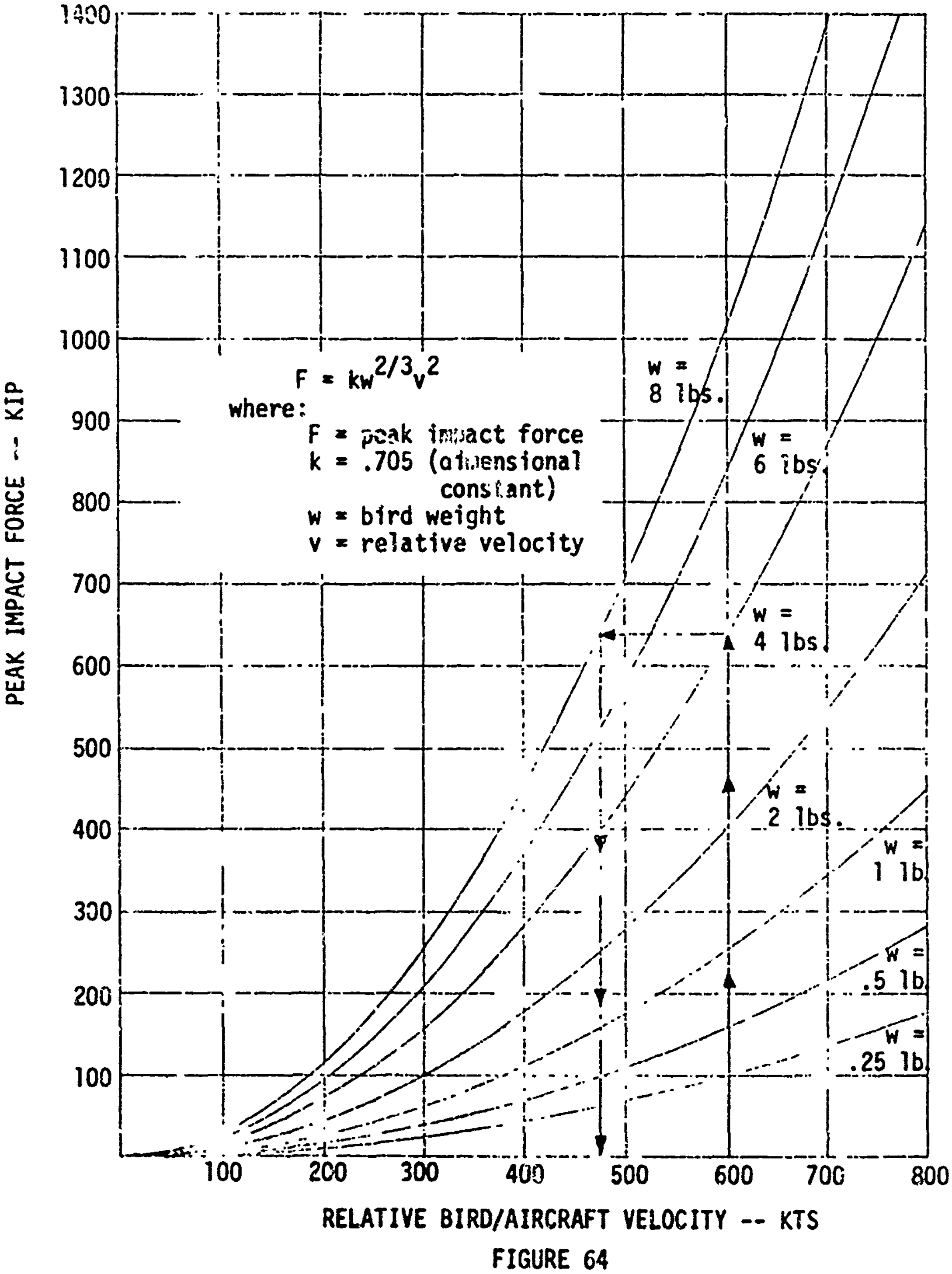


FIGURE 64

Impact Force vs Relative Velocity of Aircraft to Bird for Various Bird Weights

Unique Testing Requirements

Many times it will be virtually impossible to avoid scheduling training missions into areas free of bird migrations. To insure the success of these missions with 99% confidence, unique testing is recommended for the following:

1. It must be shown that the windshields, windows, canopies and all supporting structure ahead of and protecting the pilot and crew will withstand the impact of an eight-pound bird at a maximum operational true airspeed in knots, less 60 knots, which can be achieved at altitudes up to 8000 feet, under temperature conditions noted for the design and testing of a four-pound bird to these altitudes within the range of climatic conditions selected for which the aircraft is to be designed that will allow the completion of the intended mission.
2. At the selected speed, the damage shall not exceed the damage listed in the verification tests for a four-pound bird unless authorized by the Air Force during testing.
3. The selected speed shall become an operational limitation on the aircraft.

The development costs associated with launching equipment and test samples may be so prohibitive that eight-pound bird verification testing is impractical. Two alternative approaches were examined based upon an energy equivalence assumption. Verification testing of a qualified design has demonstrated the capability of that design to absorb the kinetic energy of a four-pound bird at some specific relative velocity. This kinetic energy is expressed by:

$$KE = \frac{w}{2}\frac{v^2}{g}$$

when

w = bird weight in pounds

v = velocity of aircraft in feet per second

g = acceleration due to gravity

If it is assumed that the specific kinetic energy level remains constant, the equation provides a convenient means of defining the reduction of velocity required with an increase in bird weight.

In order to keep the total kinetic energy of an impact to a constant, an alternative by testing a four-pound bird in lieu of an eight-pound bird may be expressed as follows:

$$KE = KE_8 = KE_4$$

where:

$$KE_4 = \frac{1}{2} m_4 V_4^2$$

then:

$$\frac{1}{2} m_8 V_8^2 = \frac{1}{2} m_4 V_4^2$$

and:

$$\frac{1}{2} \left(\frac{W_8}{g} \right) V_8^2 = \frac{1}{2} \left(\frac{W_4}{g} \right) V_4^2$$

Solving:

$$V_8 = \frac{V_4}{1.414}$$

Thus, an eight-pound bird, for instance, requires that the impact velocity be reduced by a factor of 1.414. This assumption is depicted in graphical form in Figure 65.

Conservatively, two approaches may be taken to verify the requirements for an eight-pound bird.

Approach 1: After completion of tests for a four-pound bird, rather than test with an eight-pound bird, additional testing may be made with four-pound birds at the increased speed equivalence of 1.414 times the velocity selected for a four-pound bird.

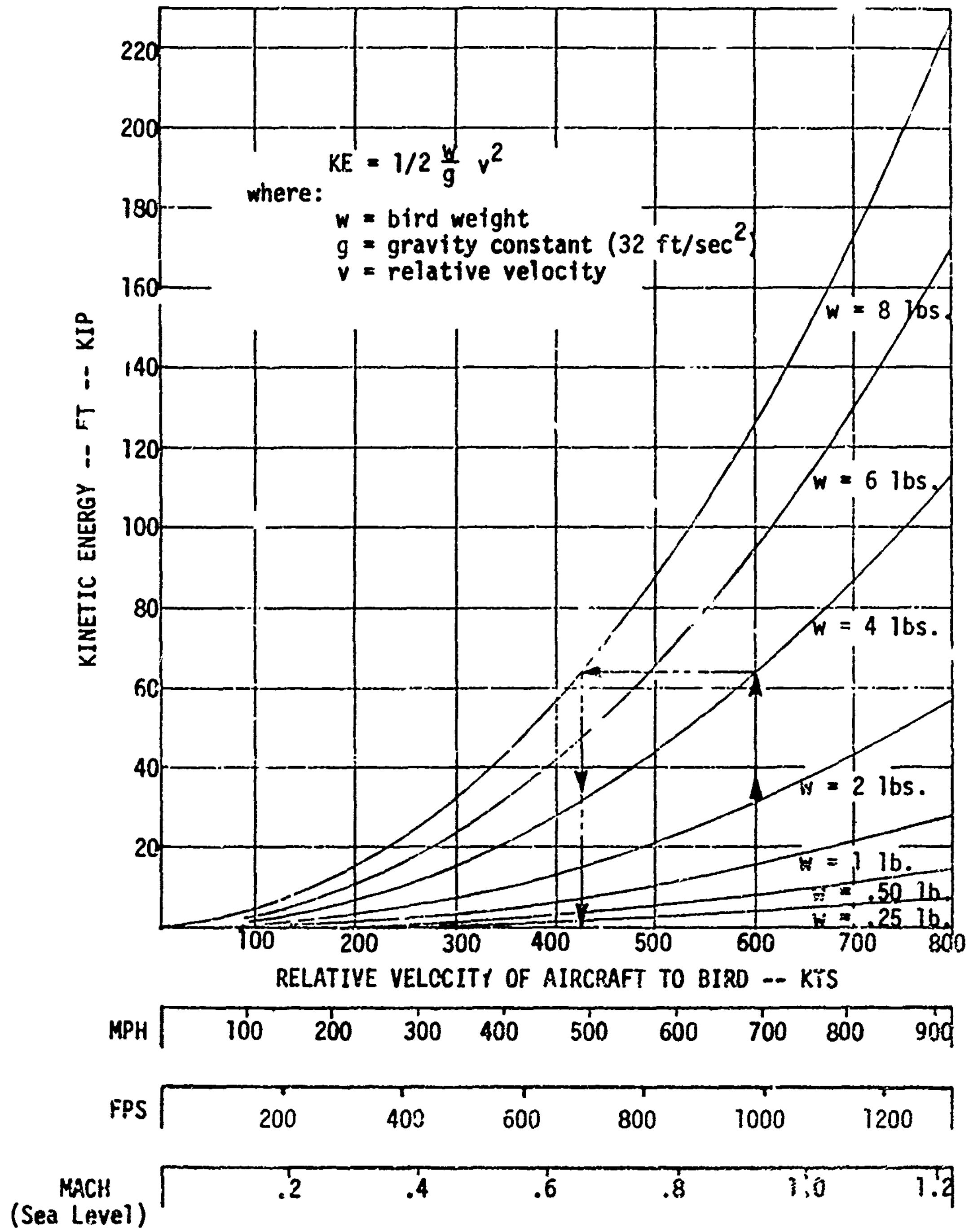


FIGURE 65

Kinetic Energy vs Relative Velocity of Aircraft to Bird for Various Bird Weights is recommended, because of the severity of such an increase in the forces associated with the increased velocities, that the test results should verify that the resultant damage will not be injurious to the pilot and crew, will not damage the windshield/canopy and support structure, and will allow the flight crew to complete the intended mission under lesser flight requirements. Modified flight requirements acceptable to both USAF and contractor, should be established at the conclusion of testing, and should include such items as reduced pressurization and increased noise levels.

Approach 2: A more realistic and conservative approach would be the acceptance of the test results for a four-pound bird and placard the aircraft at a reduced speed to meet the intended requirements for the impact of an eight-pound bird by:

letting

$$V_8 = \frac{V_4}{1.414}$$

As illustrated in Figure 56, assuming that the accepted aircraft to be 540 knots + 60 knots = 600 knots, then following the directional lines it is determined that the equivalent kinetic energy for an eight-pound bird, the speed is 424 knots, less 60 knots is equal to 364 knots, or the maximum placarded speed of the aircraft when flying during migration seasons below 8000 feet altitude.

Definition of Operational Procedures

Production type aircraft are expected to be in the USAF inventory for many years. Oftentimes the background information pertaining to the design and tests are difficult to obtain. It is therefore recommended that the entire test results be included in the appropriate Flight Manual or Crew Operating Manuals. A simplified table similar to that noted in Section V, Table XXX should be included in the appropriate manual.

The test results for an eight-pound bird should be justification for placarding the aircraft for reduced speeds when flying at altitudes of 8000 feet (AGL) or less during the bird migratory seasons of the year.

Conclusions and Pertinent Findings

1. Based on the findings of this study it was determined that future heavier-than-air aircraft designs include bird impact resistance design requirements for the windshields/canopies and support structure.

2. When heat is an anti-icing requirement for any transparency in the crew compartment the maximum obtainable temperature shall be selected as a test verification requirement and the Flight Manual shall indicate all operational requirements when heating is required.

3. The selected design bird weight shall be four pounds with consideration given to placarding the aircraft for speed restrictions commensurate with requirements for a six and eight-pound bird impact during verification testing.

4. The selection of a design airspeed should be a maximum true airspeed (closing speed) of the aircraft up to an altitude of 8000 feet (AGL) as required to meet the most critical mission requirement. This maximum true airspeed should also be increased by 60 knots to allow for the flying speed of some species of birds.

5. Since many airspeed indicators do not truly reflect the actual velocity of the craft through the air mass, the true airspeed selected shall consider any and all variables tending to indicate an airspeed less than the actual operational velocity of the craft.

6. The adequacy of existing U.S. governmental specifications for bird impact requirements are not totally acceptable for use in the design of future USAF aircraft with high speed, low-level mission requirements.

7. Transport type aircraft in USAF inventory that were designed and tested to FAA - FAR 25 for bird imp : requirements are generally considered to be acceptable.

8. Since less than 3% of all bird strikes occur on the empennage, the FAA requirement for an eight-pound bird is excessive, but design consideration should be given toward the design requirement of a four-pound bird for fail-safe requirements for those controls that are necessary for flight safety.

9. The FAA requirements (AC 33-1B) might be worthwhile for consideration for the designs of future engines and engine inlet ducts.

10. Each transparency located in the front view of the airplane or where located that critical fragmentation would injure the pilot and crew shall be tested to show that fragmentation is of such low order, not to cause injury to the crew and the loss of total vision area shall be limited to 50% and structural damage shall not prevent the mission completion.

11. Test results shall show the transparency and structural damage to be a minimum to allow pressurization to 15,000 feet or mission completion altitude whichever is greater.

12. Bombers and fighters should not be allowed speed restrictions as a result of testing to a four-pound bird requirement.

13. All other aircraft may be allowed speed restrictions as a result of testing to a four-pound bird requirement, and consequently, the Flight Manual shall contain flight speed restrictions that are readily identified by the Pilot when looking at instruments within the aircraft.

14. During any series of bird impact tests, sufficient data should be collected for subsequent study that could lead to the establishment of design criteria for bird impact requirements that could ultimately eliminate the need for extensive bird impact verification testing.

15. Subsequent studies should incorporate the elastic and inelastic effects of the impacting bodies to the wave propagation and the natural response of windshields subjected to bird impact for the establishment of design criteria.

16. It is reccommended that the verification test data collected for any aircraft to be summarized and incorporated into the appropriate Flight Manuals for use by the using commands to schedule training missions and flight speed restrictions when required.

SECTION VII

BIRD STRIKE ALLEVIATION TECHNIQUES

Bird migratory habits and survival needs have been well documented worldwide by ornithologists and others.

In Section II a study was made of the various species of birds that have been repeatedly involved in aircraft/bird incidents in CONUS.

In this section the data describing various methods of diverting birds from airports were analyzed and pertinent studies conducted in the following categories:

- Airport/airfield ecological management
- Bird dispersal methods

Airport/Airfield Ecological Management

Birds habitate the airfield area for a variety of reasons, and it is very important to determine what they are. If the reasons for habitation can be eliminated, the airfield will be unattractive to birds and a large part of the bird hazard will disappear. Some of the reasons are:

(a) To obtain food,
(b) To obtain shelter,
(c) For safety,
(d) An established migration route across the airfield,
(e) To obtain nest sites,
(f) Resting or loafing.

If edible garbage is deposited or left in an accessible place on or near airfields, it forms an obvious attraction for birds. Sometimes a municipal garbage dump is situated near the airfield; or the food is made available by only discarded portions of lunches. Garbage attracts such birds as gulls, starlings, crows, ravens, and sparrows. (References 41, 42, 43, and 44)

Preceding page blank

Earthworms also form attractive food for various kinds of birds, at night, early morning, and after heavy rain has caused them to leave their burrows and crawl over the surface of the ground and runway. Birds that are attracted by earthworms include gulls, American robins, American woodcock, plovers, starlings, crows, and most perching birds. (References 41, 42, 43, and 44)

Small bodies of water are apt to provide a variety of bird foods, including small fish, tadpoles, frogs, insect larvae, other invertebrates, pondweeds, and other water plants. Consequently, they are centers of attraction, not only for ducks, coots, and various marsh birds, but also for kingfishers, sandpipers, plovers, blackbirds, and American robins, (References 41, 42, 43, and 44)

Insects occur on every airfield, and are an attractive food for many birds. Starlings, American robins, meadowlarks, bobolinks, and plovers are birds that feed commonly on insects that frequent the low vegetation. Swallows, swifts, sparrow hawks, small owls, terns, and some gulls feed on insects that fly above such an area.

Seeds are common bird food, much sought after by various small birds and upland game birds. Not only the seeds, but grass itself - leaves, stems and roots - is eaten by some birds. (References 47 and 48)

Predatory birds chiefly short-eared owls, snowy owls, and hawks, are attracted to airfields where such mammals as rats, gophers, chipmunks, and rabbits are usually numerous.

Birds often seek shelter on airfields in hangars and in nooks around other buildings. Some find sufficient shelter by roosting or resting in trees or shrubbery on the aifield. (Reference 49)

Birds such as starlings, house sparrows, and swallows nest in numbers in or around buildings on an airfield. Pheasants are attracted to nest in dense growths of weeds, grass or legumes. Scattered nests of other birds are sometimes built in vegetation, shrubs, and trees on airfields.

Safety is often associated with shelter. An example of birds seeking safety without shelter is the roosing of a flock of gulls on a runway. There they feel comparatively safe, because they have a clear view of their surroundings.

It has been observed that birds sometimes appear on an airfield chiefly at the time of migration and that they cross it with little or no stopping. Apparently the airfield happens to have been placed on an established migration route for these birds.

Environmental management offers the best methods of eliminating the attractions outlined. Environmental management is the modification of the airfield with the aim of removing or cancelling the features that attract birds. Before undertaking an actual program of environmental management, it is highly important to have an ecological survey of the area made by a trained biologist with experience in such matters. He will submit those recommendations that in his opinion are feasible and meet the needs of the individual situation.

In examining the recommendations, care should be taken to decide priorities with the biologist. For example, in one area, cleaning a clogged drainage ditch might be more important than cutting down trees, while in another area the reverse would be true because of the species of bird in the area.

Garbage is a never-ending problem. The quantity discarded is increasing and acceptable areas for dumping are becoming scarcer. It is strongly recommended that dumps should be at least four (4) miles from an airfield. It would be well to consult a biologist before locating the dump. If a dump must be present, it and any body of water should be on the same side of the airfield.

Earthworms are particularly hardy and are not easily poisoned by material that can safely be used on large areas. Where earthworms are present, they come to the surface at certain times, travel along the grassed areas and reach the paved runways. Some tests in which "worm traps" are placed along the sides of the paved runways to prevent the worms from reaching the pavement have been reported. How effective these traps have been is not known. (References 41, 42, and 43)

Surface water should be as little in evidence as possible. Drainage ditches tend to clog with vegetation or eroded soil, the flow of water is impeded, and insect aquatic life flourishes. The ditches should be cleared at regular intervals and so graded that the water will run off as rapidly as possible. Where practicable, the situation can be greatly improved by replacing the ditches with buried drain pipes.

Insects such as grasshoppers, beetles, caterpillars, and other larvae should be killed by spraying at suitable intervals. Advice should be obtained from the USDA or other agricultural specialists on spray material, dosage, and safety precautions.

Seeds, wild or cultivated, should be eliminated. Farm crops often attract birds to an airfield. Large areas of the airfield are sometimes rented to farmers. From the view of controlling birds, it is desirable that crop leases not be permitted. If such leases are permitted, every effort should be made to specify the crops which are acceptable. Crops such as cereal grains and corn (maize) attract birds. Regardless of the crop selected, it should be remembered that cultivation of the soil exposes worms and insects which attract birds. The seeds of some weeds, such as ragweed, pigweed, and chickweed are very attractive to birds. The biologist will advise as to the weeds that cannot be tolerated. (References 41, 47, and 48)

Mammals, as such, do not necessarily present a hazard to aircraft. However, such mammals as mice, rabbits, ground squirrels, etc., are frequently found on airfields, and are eagerly sought by predators. The only safe procedure is to remove the attractions that encourage the presence of the mammals.

Trees provide food, protection, and nesting sites for birds and serve as lookout perches for predatory birds. Trees should be cut back from the runways or taxiways to a distance of at least 600 feet.

It is very difficult to deflect birds from a traditional migration route that has been in use for centuries. If the hazard of such a route is sufficient to justify its modification, the attempt can be made by a shotgun patrol to frighten the birds into adopting a new flightline.

Ground cover on and around airfields is very important. Grass requires fertile soil and worms thrive in fertile soil. There are many airfields where the soil is of poor quality and the use of ordinary grasses is not satisfactory. There is a need for plants to bind the soil, withstand vehicle traffic and discourage the presence of birds. If grass is used, it should be cut to a height just sufficient to inconvenience the birds. The most desirable height is probably 4 to 7 inches. (References 41, 50, and 51)

Building design on and near airfields should be given consideration. Architects and construction personnel are often not familiar with the habits of birds and as a result, frequently provide ideal nesting places in new construction. Buildings should be designed with a minimum number of holes and recesses.

Orange lights for runway lighting attract approximately 92% less insects and spiders than white lights of equal visibility to humans. The International Civil Aviation Organization has a requirement that white lighting must be used, but the rationale for this requirement could be re-examined. (Reference 54)

Bird Dispersal Methods

In attempting to disperse birds, it should be remembered that birds have chosen an area because it meets their needs. The removal of basic attractions, such as food, and nesting sites has already been discussed, but there are still other attractions, such as loafing places, that cannot easily be removed. It is therefore necessary to use some method of dispersal which will drive away the remaining birds. The following dispersal methods have been used with varying degrees of success:

a. Falconry was first practised at Royal Naval Air Station, Lossiemouth, in Scotland. (References 45 and 46) This air base, located in a bird rich area, was recording some two bird strikes every month when three falcons were acquired and trained by falconers to form an anti-bird flight.

   This medieval method of achieving supersonic safety soon proved quite promising, although certain limitations became apparent. Falcons are not true all-weather fighters; they do not operate at night, and only with great difficulty in fog conditions and winds of more than 30 knots. Furthermore, their performance degrades during the moulting period.

   The presence of a falcon is sufficient to drive away many bird species even though the falcon does not directly attack the birds. Peregrine Falcons (Falco peregrinus), Gyfalcons (Falco rusticolus), and Goshawks (Accipiter gentilis) have been trained and used with some success. The falconer must be supplied with a radio-equipped vehicle to provide mobility and maintain control tower communications.

   The falcon may soon be a rare bird. The American Peregrine Falcon (Falco peregrinus anatum), now considered extinct, has been decimated by widespread applications of DDT. This, and other reasons discourage the use of this bird-scaring technique. (Reference 7)

b. Distress calls is the term commonly used to describe the sounds emitted by a bird under different conditions of stress. They have also been called among others, warning calls, and agony calls. In the simplest form, the bird is persuaded to give a distress call. The call is recorded on magnetic tape, and played back through a loudspeaker to drive away birds of that species. If the call is correct and is played back over suitable equipment, good results can be obtained in dispersing birds by this method. The best means of playback is to install the speaker/speakers on the roof of a vehicle and bring the vehicle to the habitated area before broadcasting the distress call. The speakers should have a power of about 50 watts and a frequency response up to at least 20,000 hertz (C.P.S.) without undue distortion. (References 41, 45, and 49)

c. Pyrotechnic devices are defined as fast burning or explosive devices used to scare the birds. They are found in many forms such as firecrackers, flares, rockets, and shell-crackers. Some airports utilize a shotgun (or special firearm) firing special ammunition such as shell-crackers. Shell-crackers have a superficial resemblance to ordinary shotgun shells, but each cartridge contains a small explosive charge which explodes loudly at a predetermined distance.

Automatic acetylene exploders are machines that ignite acetylene gas to produce loud explosions at regular intervals. Acetylene is generated by dripping water on calcium carbide or supplied from a tank of compressed acetylene gas. These exploders work well with certain species of birds.

Two kinds of flares have been found effective - those which are fired from a Verey pistol and those which have been developed for personnel use. The latter are usually fired from a pen-type gun carried in a pocket. The range of these flares is usually less than that of shell-crackers. (References 41 and 49)

Live ammunition may be used to remove resident birds such as pheasants and partridge, however, the hazards involved in the use of live ammunition are obvious. (Reference 41)

d. Trapping of many birds, such as pigeons, owls, hawks, and crows, can be accomplished more readily than they can be dispersed. (Reference 41)

The costs of environmental management may appear to be excessive. At Boston, a commercial aircraft accident in 1960 was caused by bird injestion, and resulted in the loss of 60 human lives. In the first test cases, court awards have exceeded $100,000 for each lost life. With the exception of engine bird injestion, take-off and landing strikes of civil aircraft may not be hazardous to human life, but they do result in a variety of expenses to the airlines. One airline reported 75 engine changes due to bird strikes in 2-1/2 years of flying. (Reference 33) Some modern jet engines cost approximately one million dollars.

Each year the United States Air Force spends millions of dollars to repair or replace aircraft that have collided with birds. (Reference 54) The U.S.A.F. Office of Scientific Research estimated the annual cost to repair, and replace aircraft parts damaged by bird strikes at 10 million dollars. (Reference 7) However, dollar-costs and man-hours do not accurately reflect the magnitude of this problem. They fail to take into account the delays, jettisoned fuel, emergency landings with its attendant hazards and time the aircraft is out-of-service. (Reference 53)

The U.S.A.F. has a group of bird experts working on a program called Bird-Aircraft Strike Hazard, or, appropriately, BASH. Experienced Biologists, Zoologists, and Ornithologists operate out of the Ecosystems Technology Section of the Air Force Weapons Laboratory (AFWL) at Kirtland AFB, New Mexico. This Section is working on methods of reporting and forecasting bird movements, equipment for diverting birds away from aircraft, and procedures for keeping birds away from airfields. (Reference 52) Their efforts should be closely monitored and their recommendations followed to reduce the bird population around airfields.

Modern techniques of design and management can place Civilian and Military aircraft in the same skies as millions of birds and reduce the probability of an aircraft/bird impact. Many ecological and mechanical methods of bird control can be implemented with less financial impact than that involved in the repair of high performance aircraft.

Conclusions and Pertinent Findings

1. Ecological management offers the best methods to reduce the bird population on and around airfields.

2. As noted in Section III, approximately 75% of the worldwide bird strikes involving commercial carriers and approximately 50% of the bird strikes on U.S. military aircraft occur or or near the airport.

3. Airports/airfields should be made as unattractive to birds as possible by eliminating attractions such as food, shelter, nesting sites, water, etc.

4. Bird dispersal methods such as distress calls, pyrotechnic devices, falconry, etc., should be utilized to drive birds from airfields.

5. The Ecosystems Technology Section of the AFWL at Kirtland AFB, New Mexico, should be consulted for recommendations and methods to reduce the bird population on and around airfields.

6. Proper design can make airfield structures unusable by birds.

SECTION VIII

BIRD STRIKE AVOIDANCE TECHNIQUES

It was shown in Section II that over 20 billion birds representing 600 species were regulary found in CONUS.

In Section III it was shown that 11.56% of the USAF aircraft/bird incidents between 1965 and 1972 were on the windshields/canopies and over 30% of the strikes were on the engines. Bird strikes at either location could result in the loss of both flight crew and aircraft. Further it was shown that the USAF had lost seven aircraft since 1964.

In Section IV it was determined that the USAF could expect 356 bird strikes per year. Of these strikes at least 29.4 strikes can be expected on the windshields/canopies and support structure.

The greatest hazards to aircraft are the swans, geese, and ducks during migatory seasons; vultures soaring in search of food; and flocks of birds that can cause engine failures due to ingestion.

There are several systems that, if implemented, would reduce the frequency of all bird strikes. Thus the frequency of bird/aircraft collisions involving the most dangerous birds would also be reduced.

This section summarizes the data collected that pertained to the reduction of bird hazards to aircraft through the use of avoidance systems and procedures.

Pertinent details were selected for study in the following categories:

- Radar studies of bird migrations and bird movements in North America.
- Aircraft lighting systems for bird hazard reduction.
- Microwave radiation systems.

Preceding page blank

Radar Studies of Bird Migrations and Bird Movements In North America

Ornithologists, the Audubon Society and others have used various radar units as tools to study bird migrations since the introduction of radar systems. During the past two decades many studies have been undertaken to determine the exact migratory routes, weather conditions for migration and other pertinent factors concerning various species of birds. Such studies serve a multitude of purposes including the establishment of allotments of birds by areas for hunters and the development of aircraft/bird hazard warning systems.

Subsequent paragraphs will briefly describe some of these studies pertaining to the North American continent, the results of the studies and the radar systems used. Reference 14, Kuhring initiated radar studies of bird movements in 1953. The significant item that led him to commence these studies originated with the belief that the radar phenommenon known as "angels" had been, in large part, echos from a single bird or flocks of birds. In Canada it was believed that "birds fly the pressure patterns during migration. For instance, in the northern hemisphere, winds tend to move clockwise around a high pressure area. Birds migrating southward in the autumn usually do so with a north wind, flowing down the east side of a high pressure area. They are very seldom found moving south against the south wind on the west side of a high pressure area. The reverse holds true for the spring migration when the birds are moving north." Kuhring set out to prove these theories by setting up a radar console in 1963 at the Toronto airport and used time lapse movies to make the flow and direction of bird movement more evident. Photographs covering 300 hours were taken during October 1963 mostly at night. The results indicated that radar, time lapse movies and the weather map could be combined to provide prediction methods for movements of local and migrating birds. In 1964 the program was expanded to cover the entire 2-1/2 month autumn migrations with camera set-ups at eleven radar stations, seven military and four civilian. The program was expanded again in 1965 to include eighteen radar stations located between Quebec and Vancouver to cover the spring migrations of birds returning from the United States. For these programs the cameras were operated 22-1/2 hours per day, each camera using 200 feet of 16 mm. film. Kuhring pointed out that the intended use of movies was to provide a record from which ornithologists could undertake studies of the movements and identification of the bird species. A 24-hour film can be shown in six minutes. The delay in the development of special film makes it unavailable for immediate operational use. However, the Scan Conversion radar presentation had a long decay period for echoes, and bird movement could be detected without the use of a camera.

Kuhring concluded from these studies that the work done could be of considerable value to Air Traffic Control. Some important findings of his studies were:

1. During September large flocks (70,000 to 100,000) of broad winged hawks have been observed on radar riding the thermals across the approaches to Toronto and London, Ontario, airports at heights of 4,000 to 10,000 feet.
2. Major flights of geese have been followed from one radar region to the next.
3. In the western foothills several major flight routes are becoming evident, including one where birds fly through the mountain passes, as well as over the mountains on their way to the Pacific.
4. Bird strikes reported by pilots can usually be detected on radar film if a strike occurs within radar range. Two examples of this occurred in the same region on the same day in October. One, a T33, had collided with a Canada Goose. The other, a DC-8, collided with a duck. Both incidents were shown clearly on the radar film giving an indication of the type of echo for these bird species.

Blokpoel and Desfosses described their findings as part of this initial program in Reference 55. They describe the films made from the Plan Position Indicator (PPI) scope attached to a 23-cm. Air Traffic Control radar at Calgary International Airport. The films taken showed air traffic, bird movements, ground traffic (vehicles on the highway to Edmonton), "weather" and sometimes ground clutter. They found that bird movements could be classed as migratory and local. Migration was usually a long-range movement often covering a large area of the scope. Local movements were of short duration and of limited range covering only a small part of the scope. Local movements varied in intensity, shape and behavior. Those to or from a roost area were classed as "roost movements". The local birds identified were starlings that seemed to roost about 5.5 to 6.5 n. mi. south of the radar site. The early morning dispersals began about 30 minutes before sunrise and lasted approximately 30 minutes. The morning dispersal showed on the radar screen as one or more expanding, concentric, ring-shaped echoes or as one or a series of arc-like echoes. The maximum distance traveled was approximately 24 n. mi. The return flights were observed generally from one to two hours before sunset, to one hour after sunset and were less distinctive consisting of echoes converging toward and disappearing at one spot on the radar screen. The birds disappeared on October 23. During the spring of 1965, dispersal movements were harder to detect than during the previous fall. No return movements were observed.

Blokpoel discusses, in Reference 56, the aim of Operation Bird Track for the development of a system for forecasting the intensity of bird nocturnal fall bird migration over the area around the Canadian Forces Base Cold Lake, Alberta (54° 24' N latitude, 110° 17' W longitude) using the local weather forecasts as a basis.

Detailed weather data were obtained from the Base Meteorological Office including predicted wind direction at ground level, 3,000 feet and 5,000 feet, pressure tendency, sky cover and precipitation. These data were used to make daily bird intensity forecasts for the period 1900 - 0500 hours MST. from 16 September through 16 October 1968. The same method was used to make "post predictions" using the actual weather conditions rather than the forecast weather. The migration data were obtained by taking time lapse movies of the PPI scope (range 85 miles) of a 23 cm. surveillance radar located two miles NE of CFB Cold Lake. The intensity of an event was established on an overall intensity scale of 0 to 8 for this experiment even though the RCAF was interested only in intensities greather than five. He based his forecasts of the overall intensity of nocturnal movements considering the weather factors noted in Table XXXII.

TABLE XXXII
WEATHER FACTORS USED TO FORECAST THE INTENSITY OF NOCTURNAL FALL MIGRATION AROUND COLD LAKE, ALBERTA - 1968

	FAVORABLE	NEUTRAL	UNFAVORABLE
Direction of ground wind	W-N or calm (0-3 m.p.h.)	N-E and S-W	E-S
Direction of wind at 3,000 ft.	W-N	N-E and S-W	E-S
Direction of wind at 5,000 ft.	W-N	N-E and S-W	E-S
Pressure tendency	rising	no clear tendency	falling
Cloud cover	scattered clouds	clear sky	thick, extensive layer(s) of over-cast or fog
Precipitation	no precipi-tation	scattered, light showers	extensive, heavy precipitation

He used the following guidelines:

1. If all weather factors are neutral the migration will be of average intensity. If most weather factors are favorable (or unfavorable), the intensity of migration will be above (or below) average.

maximum (or minimum) intensity occurring when all weather factors are favorable (or unfavorable). If some weather factors are favorable and others unfavorable, they may "neutralize" each other in which case migration will be of average intensity.

2. When all or most weather factors have been unfavorable for three consecutive nights, their influence decreases; in other words the birds start to fly under unfavorable conditions in numbers greater than usual.

3. In October, when all or most weather factors have been favorable for two or three nights, the number of migrating birds decreases on successive nights even though the favorable weather conditions continue.

On an hourly basis, the accuracies of the post predictions for the periods 16 September - 1 October and 1-17 October (77 and 92 percent) were higher than those forecast for the same periods (63 and 76 percent).

Blokpoel discusses (Reference 57) the progress of Operation Bird Track for the years 1964 through 1969. The initial objective of Operation Bird Track was to investigate the volume and pattern of bird migrations across Canada. Radar surveillance was considered the best method because large areas could be covered effectively and ontinuously for little cost.

The scale that was adopted for the density of bird echoes was arbitrarily established as:

Echo Density	Migration Density
0	None or almost none
1	Very light
2	Light
3	Light - medium
4	Medium

Continued

Echo Density	Migration Density
5	Medium - heavy
6	Heavy
7	Very heavy
8	Extremely heavy

A series of nine pictures were used to determine the echo density for individual observances on the radar scopes.

The data obtained at Cold Lake yielded no results regarding the size of the flocks or the heights of the migrations. However,the altitudes were successfully studied during 1968 and 1969 with an M33C Tracking Radar at the Primrose Lake Evaluation Range, about 30 miles north of CFB Cold Lake. Whereas the migration predictions were made by three different people during 1969 at Cold Lake (and usually in a hurry), the post predictions were made more leisurely. Thus, the post predictions had a high accuracy (88% of 512 hours, 87% of all 52 nights and 82% of the 22 nights). These accuracy levels that, given the right working conditions, a migration prediction forecast procedure could be accurate enough for operational use. The M33C track radar used at Primrose Lake detected birds flying only above 1200 feet (AGL). It was determined that 50% were, on the average, below 3500 feet, 90% below 5000, and 99% below 10,000 feet. The highest bird echoes were recorded at 14,200 to 14,400 feet (AGL). There were indications that cloud cover and upper wind influenced the height distribution on nights with heavy migrations.

Blokpoel discusses in Reference 58, the spring migration of Lesser Snow and Blue Geese through Southern Manitoba during early May 1970. It was estimated that 300,000 of these geese stage in the area in North Dakota north of Devil's Lake. Blokpoel's findings were: "The biological information gathered during a project to monitor and warn of the spring 1970 migration of Lesser Snow and Blue Geese (snow geese) in the vicinity of Winnipeg International Airport. Visual observations from the ground and the air supplemented observations were made with the Airport's AASR-1 surveillance radar and Precision Approach Radar. In early May the snow geese were staging in southern Manitoba along the international border from Whitewater Lake east to Dominion City.

Both radar and visual observations showed that the great majority (the main wave) of the snow geese flew between the afternoon of May 15 and mid-morning of May 17. Small scattered numbers of birds flew earlier with a distinct minor movement on the morning of May 6 (radar observations only). The snow geese migrated in a broad front, at least 100 nautical miles wide.

There is little proof but considerable circumstantial evidence that at least the majority of the daytime 'goose echoes' during the main wave were caused by flocks of migrating snow geese. The main wave started after a 10-day period of poor weather (northerly and easterly winds, rain, heavy overcast); the vanguard flew against headwinds, a good proportion with sidewinds and the main part with tailwinds. Some 650,000 to 1,000,000 snow geese were flying during the main wave, with major peaks during the nights May 15-16 and 16-17 and a minor one on the morning of May 16.

The radar data suggests that different populations flew at different times in different directions. Throughout the night May 15-16 the geese flew ENE (notwithstanding a change in wind direction), on May 16 NE, and on May 16-17 NNE.

During the evenings of May 15 and 16, the Precision Approach Radar showed that most geese were flying at about 1200 to 1400 feet above ground level. Individual ground speeds varied from 17 to 73 kts, and mean hourly ground speeds from 24 to 62 kts. Mean air speeds, calculated from the mean ground speeds for five one-hour periods, varied from 26.6 to 33.3 kts.

It is hypothesized that snow geese migrate with constant air speed, regardless of the wind condition. During a minor movement of 'goose echoes' on the morning of May 6 very strong tail winds resulted in a very high mean ground speed (69 kts)."

Richardson discusses in Reference 59, the variations obtainable in the use of surveillance radars at over 30 different Air Traffic Control and military sites used to study migrations in Canada. His work describes the radar adjustments and changes in flight behavior that have been found to effect the bird detection capabilities of several radars and evaluates the severity of these effects and suggests approaches to overcome them. The ASR-5 radar was tested and a systematic series of adjustments made and studied at Halifax International Airport, Nova Scotia, Canada (44°53'N, 63°30'W) during October 1969. The ASR-5 radar is a relatively low-powered (400 kw), 10 cm. radar designed for short and medium range (0-60 n. mi.) air traffic control. Its short pulse duration (0.833 microsec) has a relatively high resolution for a surveillance radar. It uses a parametric amplifier, multiple modes of Moving Target Indicator (MTI) and Sensitivity Time Control (STC) circuitry, a video integrator, and pulse staggering.

The AASR-1 radar was tested and a systematic series of adjustments were made and studied at Moncton, New Brunswick, Canada (46°05'N, 64°40'W) on the nights of 13, 14, 15 and 16 May 1970. The AASR-1 radar is medium powered (550 Kw), 23 cm., used for long range air traffic control in many areas of Canada. Many birds were observed at ranges of 2-25 n.mi., and large flocks were observed at ranges of 50 n.mi., or more. It has moderate resolution and is less complex than the ASR-5. There is a single MTI canceller without feedback, only one STC mode, and no pulse staggering capability. The ASR-7 radar was tested and a systematic series of adjustments were made and studied at NASA/Wallops Station, Virginia (37°57'N, 75°27'W), in seven days in the period 19 October - 1 November 1971. The ASR-7 is a very modern but low powered (450 Kw), 10.8 cm. Its use is similar to the ASR-5 in purpose, parameters, and capabilities. The ASR-7 differs from most surveillance radars in that it has digital rather than analogue MTI and video integration. It has a logarithmetic as well as a linear receiver. Only a few large flocks are visible beyond 10 n. mi. range.

Richardson adjusted every variable item on each radar system evaluated during the tests. He cited pertinent facts about digitized radar data. In the SAGE/BUIC system of the North American Air Defense Command (NORAD) the original analogue data are converted to digital form by a computer at each site and then transmitted to various control centers. One of the purposes of digitization is to provide further means for surpressing echoes from the ground, weather and birds. Weak echoes from passerines generally were surpressed, but on most occasions at most radar sites intense echoes probably from flocks were still visible on the digitized PPI displays. These larger targets were frequently easier to track on the digitized PPI display than on analogue displays. At a NORAD control center it is possible to observe digitized data from many radar sites simultaneously. Thus, it is possible to observe the progressive changes in the distributions of flight directions of bird flocks at various sites as pressure systems and weather fronts move across a wide area. The data are definitely biased in favor or large flocks which would be ideal for the study of waterfowl migrations. The FAA is at present converting to a nationwide digitized radar system that will ultimately reduce the bird level observed on the PPI's to those used by NORAD. It can be concluded from Richardson's studies that there are many adjustments that can be made and are made to the radar units. In general, he indicates that surveillance radars are not precisely calibrated precision instruments. At least these radars can provide excellent qualitative information about migrations but even with careful use can provide only moderately accurate quantitative data.

Bellrose discussed in Reference 60, the waterfowl migration corridors east of the Rocky Mountains and the various techniques used in his studies. Pertinent studies were accomplished by using radar surveillance in determining direction and magnitude of movement particularly at night, through clouds not laden with water droplets. He and Dr. Graber used an APS-42A radar at Havana and Champaign, Illinois, and a mobile unit in Illinois, Indiana, Iowa and Missouri during waterfowl migrations i.. the years 1960 - 1964. In addition he had the cooperation during 1963 - 1965 of the U.S. Weather Bureau WSR-57 radar surveillance of waterfowl migrations at 27 stations. These WSR-7 radars furnished data for waterfowl in a range of 40-100 miles. It appears that Bellrose had excellent coverage of the migrations during 1963 - 1965 starting at the first U.S. Weather Station in Amarillo, Texas to the Atlantic and Gulf Coasts.

Flock and Bellrose discussed in Reference 61, a radar study of spring bird migrations in the central United States that took place on March 21 and 22, 1969, using the radar facilities of FAA centers. They showed that maximum coverage could be obtained during bird migration periods for specific areas through the use of the FAA Air Route Traffic Control Centers (ARTCC) located at Denver, Kansas City and Chicago. Fourteen units at these three centers were monitored and radar echoes caused by birds recorded.

From the Denver (Longmont), Colorado center radar displays were photographed for the Trinidad, Colorado; Lusk, Wyoming; and Grand Junction, Colorado radar units. At the Kansas City (Olathe), Kansas; Garden City, Kansas; Hutchison, Kansas; Olathe, Kansas; and St. Louis, Missouri radar displays were photographed. At Chicago (Aurora), Illinois center the West Branch, Iowa; Horican, Wisconsin; McCook (Chicago), Illinois; and LaGrange, Indiana the radar displays were monitored.

Continuous photographic coverage was already being monitored for the North Platte, Nebraska and Denver, Colorado radars. Except for the Denver radars, all are long-range either Air Route Surveillance Radars (ARSR) or Air Force radars, which transmit their signals to ARTC centers. This study demonstrated the feasibility of using existing radar displays at Traffic Control Centers throughout the United States to gain better understanding of bird migration and to provide the feasibility of allowing improved prediction methods and real time warnings of heavy migrations.

Jackson and Fiedler discussed in Reference 62, a radar study of crow movements around the Toledo Express Airport, Ohio. The study covered the period between October 18, 1964 and March 23, 1965. The radar type was an ASR-4 with a peak power output of 450 Kw, frequency of 2700-2900 megacycles and a pulse width of 1.5 degrees. It was determined that the crows fly around the airport at an altitude of 50-500 feet (AGL), that their activities around the roost took place approximately one hour before sunrise, and that they returned to roosting as late as 15 minutes after sunset. The maximum populations were estimated to be 20,000 birds and at times it was observed that as many as 14,000 crows would move from one roosting area to another. The distance travelled during the daylight hours by the crows was estimated to be upward of 30 miles.

Williams, et al. discussed in Reference 63 tracking radar studies of birds in or near cloud layers. The radar used in this study was the Spander radar at Wallops Stations, Virginia. Spander is a 10 cm (2700-2900 MHz) with a 5 megawatts peak power, a 60 foot parabolic dish antenna producing a 0.39° beam width. During the fall of 1969, they were able to track birds on three nights with totally overcast skies. Some birds were tracked at an altitude of 7000-8000 feet (AGL) and on occasions they were able to detect that the birds were confronted with cross-winds.

Flock discussed in Reference 64, the use of a GEC-AEI Number 654 radar which was evaluated at Gunbarrel Hill and Valmont Reservoir, near Boulder, Colorado from March 16 to December 19, 1971. Morning and evening flights of Mallards and Canada Geese provided good test radar targets. Some doppler radar signature data were also taken with a CW radar at Ballar Lake in 1971. The 654 radar is a compact, largely solid state radar consisting of motor-generator, transceiver, PPI, and antenna drive subunits. It had a power output of 20 Kw, a frequency of 94°45'MHz, a horizontal beamwidth of 0.7°, and was operable with 0.5 microsec pulses on the 3/4 to 1 1/2 n. mi. range, with 0.25 microsec pulses on the 3 to 6 n. mi. ranges, and with 1 microsec pulses on the ranges up to 48 n. mi. Flock showed in his tests that the 654 radar was good but improvements were desirable to better detect birds at a greater distance on runways.

Aircraft Lighting Systems for Bird Hazard Reduction

Considerable interest was created about the use of flashing light as a means of preventing bird/aircraft collisions when Major-General Caldera noted that commercial airlines with Atkins anti-collision lights installed had not experienced bird strikes during a four-year period. (Reference 65)

Golden (Reference 66) made a comparative study of the American Airlines fleet of over 200 aircraft, most of which were equipped with anti-collision lights, and the Mohawk Airlines fleet of aircraft which were not equipped with anti-collision lights. It was indicated that of American's 28 BAC 1-11 aircraft, one birdstrike in 1968 resulted in repair costs of $1,695.00. Mohawk's annual average repair costs of $50,000 due to birdstrikes reached $176,000.00 in 1969. Further, for the entire American Airlines fleet, it was estimated that less than $20,000 was spent in 1968 for aircraft/bird collision repairs. Included in the American Fleet were 57 B-727's.

It has been estimated that aircraft equipped with anti-collision lights are visible for seven miles. This visibility should provide most birds with sufficient warning for collision avoidance maneuvers.

The latest generation of commercial aircraft, Boeing 747, Lockheed 1011, and Douglas DC-10, were all designed to the FAA requirement, FAR 25, Paragraph 25.1401, for the installation and certification of an anti-collision lighting system. For instance, the DC-10 aircraft are delivered with a 3200 candlepower intensity strobe light on each wing tip. The success of these lights as a deterrent to bird strikes is dubious since their use is optional to the airline pilots.

Consequently, as noted in Reference 2, during 1972 there were 14 birdstrikes reported to the FAA by commercial airlines for the B747, and 3 for the DC-10. The number of strikes might have been less if strobe light usage were mandatory.

While the installation of strobe lights on aircraft for aircraft/bird collision avoidance seems promising, such installations work only temporarily around air bases as noted in Reference 7. After birds become accustomed to the flashing lights they will sometimes perch upon them and there have been incidents where birds have built nests in the vicinity of beacon lights.

The effectiveness of strobe lights will be well established by the AF Weapon's Laboratory since they are monitoring strobe light installation on squadrons of T37, T38, and F-111 aircraft as noted in Reference 53.

Solman reported (Reference 67) on observations that had taken place at the Winnipeg Airport in 1969 regarding migratory geese of flock sizes of 300-500 birds. These observations made of radar units such as the PPI and PAR occurred at a time of dense commercial aircraft landing traffic. On two occasions when aircraft were on final approach with landing lights on, it appeared that the geese saw the aircraft and turned back to avoid collisions. In one case a flock turned back, regrouped, started across again and was again faced with an oncoming aircraft, again turned back to avoid collisions, and finally when there were no aircraft on final approach they crossed the flight pattern and flew north. After these incidents, one major Canadian Airline made the suggestion that its pilots fly with their landing lights on at all times below 10,000 feet. The results of this effort was encouraging since the number of night strikes at this locality was reduced from 11 in 1969 to 6 in 1970.

Microwave Radiation Systems

Limited studies and experiments have been conducted to evaluate the capability of microwave radiation to clear the aircraft flight path. Radiation generated by airborne equipment would temporarily STUN all birds in the flight path and they would fall to clear the airspace. The experiments to date were conducted with radar and laser produced microwaves.

Tanner (Reference 68) experimented with a radar horn antenna at power levels of 10-30 millowatts per square centimeter at a frequency of 16,000 pulses per second. In his experiment he used chickens (old English games), pigeons and ringbill seagulls. Each chicken registered a startled reaction and sustained extensor activity of wings and legs a few seconds after the onset of radiation. The effect on pigeons and seagulls was less dramatic. The wings of the chicken did not return to their normal position for at least an hour after exposure. The seagulls registered considerable distress but shrugged off the muscular disturbance by repeatedly flapping their wings.

The experiment described above was expanded by Turner, Davie, et al. (Reference 69) to include the effects of radiation on birds in flight. Birds were trained to traverse a forty-foot long tunnel for food. Once trained, they were exposed to K-band radiation (16 GHz, pulsed at 8400 pps with pulse width of 0.20 microseconds, average power of 100W). Under normal laboratory environmental conditions and with increased humidity, no unusual behavior was observed. With the onset of radiation, the majority of birds avoided the tunnel, ceased eating, or returned to their starting cages.

The tests were concluded with the following hypothesis to be resolved:

a) determination of the microwave field that has the greatest effect on birds for the least expenditure of power;

b) installation of the appropriate equipment for in-flight applications;

c) provision of an electromagnetic field at airports to serve as a bird deterrent but without human or other hazard.

These experiments demonstrate that their are behaviorial EEG and EMG changes and that environmental factors play an important role in the effectiveness of a particular microwave field. The use of microwave radiation appears promising for the solution of bird hazard problem to aircraft.

Lustick of the Ohio State University presented a paper at the 1973 Conference on Transparent Aircraft Enclosures pertaining to the use of high-intensity laser light as a means of decreasing the bird strike hazard to aircraft. He evaluated the effects of continuous and pulsed light on the behavior and physiology of starlings, mallard ducks, and geese. It was found that a concentrated laser beam of 0.2 cm in diameter at a power above 0.5 W would cause an avoidance response in all the bird species tested. After the initial response to pulsing laser light intensity -- beam 2 to 14 inches -- the gulls and starlings habituated.

Conclusions and Pertinent Findings

1. Myres, Reference 71, lists 268 radar studies of birds dating as far back as 1939. The group of radar studies randomly selected for this study repeatedly showed that bird movements could be detected by using radar systems.

   It was shown that each system had peculiarities that were adaptable and could be used in the determination of bird movements.

2. As noted in Section III, over 1000 birdstrikes occur annually for the combination of US Commercial Airlines, USAF, and USN. In these

studies it was surprising to find that both the FAA and USAF were making every effort to eliminate bird echoes or "angels" from their radar systems.

3. The continued study of bird migratory paths is not necessarily germane to the development of a bird warning system. Bird migratory movements vary only slightly from year to year and daily movements vary depending only on the direction birds must travel for food.

4. Based on the vast amount of radar bird studies that have been accomplished during the past 10 years in North America, it is recommended that the USAF immediately establish bird warning systems. The CONUS is saturated with USAF radar installations, including CORAD, that should be integrated into a total bird warning system. The various installations must have direct communication links with a telex procedure as a minimum. Prior to the fall migrations, some time in August, CORAD units along the Canadian border should establish contact with the Canadian radar bird-tracking groups. Each time the Canadian groups observed bird movements, CORAD should be notified.

   CORAD should track the flocks, determine local weather conditions, determine bird flight directions, and contact USAF radar stations so that the birds could be tracked to their final destinations. Generally any migratory bird groups will take several days to weeks to make the complete journey from the Canada border to their summer homes. Flight and Flight Operations Officers at the USAF bases enroute should be notified of the migrations so that flight schedules could be adjusted to reduce the bird strike potential.

   The AFWL-Ecosystems group should be informed of these migrations and weather conditions, and given all known pertinent facts so that a bird map could be developed. Undoubtedly, the initiation of such procedures would be cumbersome, errors would occur, but the real time problems would evolve that could be identified and solutions developed.

5. Many USAF bases are located in the close proximity to the winter homes of waterfowls, gulls and other birds. Once the fall migrations are under way and/or completed the local radar units should at regular intervals determine the movements from roost to feeding areas. All operational groups should be informed so flight plans could be adjusted to avoid these bird hazards.

6. The procedures recommended in 4 and 5 above should be reversed for the spring migrations.

7. Radar systems specifically designed for bird acquisition and tracking should be developed. RCA has a radar system under development to NASA with the capability of determining the movement of perching birds in the proximity of air bases.

8. Strobe lights should be installed on all military aircraft and their use established as mandatory. The exact type and installation locations should be predicated on the results of current USAF service evaluation tests. While the use of strobe lights is not considered a total solution, its role in reducing the frequency of aircraft/bird strikes, based on current observations, cannot be ignored.

9. The development of microwave radiation systems should be confined to the laboratory until the ramifications on its widespread use are determined. In particular, the indiscriminate use of airborne laser systems poses a distinct hazard to man and his environment that is perhaps, far more severe than the known hazard of aircraft/bird collisions.

SECTION IX

BIRD STRIKE DESIGN SUMMARY

The salient points of Sections II through VIII were combined to establish broad relationships to minimize the bird hazards to future USAF aircraft.

It is recommended that these relationships are considered during the planning and initial conceptual design phases for future USAF aircraft.

The data presented are applicable to most aircraft designs. However, they are not applicable to many helicopter designs.

The pertinent details for this presentation are the following categories:

- Risk associated with not designing windshield/canopies and supporting structure to bird impact requirements.
- Related critical factors associated with designing enclosures for bird impact requirements.
- Definition of acceptable bird impact damage to transparencies for mission completion.
- Selection of critical operational requirements.
- Design requirements for windshields/canopies and supporting structure, verification testing and associated costs.
- Bird impact avoidance systems.
- Miscellaneous bird strike design considerations.

Risk Associated with Not Designing Windshield/Canopies and Supporting Structure to Bird Impact Requirements

It was shown that the USAF could expect 29 bird strikes per year on windshields/canopies. Since 1965 there have been seven fatalities, and five major and 26 minor injuries to the flight crews as a result of bird impacts. For each new aircraft design, decisions must be made regarding the design and verification testing costs for bird impact. Each aircraft necessarily will have certain peculiarities such as expected life, and annual flight time utilization that must be considered at the time of planning phases. To establish a risk factor that would be applicable to the design of all aircraft models is virtually impossible.

To illustrate how a risk factor might be determined, the DC9 commercial versions and the USAF C9A aircraft were used as an illustrative example since the two aircraft types are operated from different air bases and have different mission profiles. Each aircraft is assumed to have a minimum expected life of 30,000 hours. From Figures 44 and 45, the 1972 bird strike data were assumed to be typical of the number of strikes that could be expected annually as:

	DC9	C9A
No. of Strikes	25	3
Hours Flown	922,436	27,559
No. Aircraft (for study)	366	20

Conservatively, the windshields on the DC9/C9A represents 4.2% of the aircraft frontal area. From Figure 49 it is easily shown that a maximum of 31.5% of the bird strikes could occur on the windshield.

Strikes per year and per hour were calculated as:

DC9: 25 strikes x 31.5% = 7.875 strikes/year

C9A: 3 strikes x 31.5% = .945 strikes/year

DC9: $\frac{7.875}{922,436} = 8.537 \times 10^{-6}$ strikes/hour

C9A: $\frac{.945}{27,559} = 3.429 \times 10^{-5}$ strikes/hour

The number of strikes during the life of the aircraft is:

DC9: 30,000 hours x $(8.537 \times 10^{-6}) = .256$

C9A: 30,000 hours x $(3.429 \times 10^{-5}) = 1.0287$

The probability of at least one strike during the expected life of the aircraft is calculated using Poisson's law:

DC9: $1-e^{-.256} = .226$

C9A: $1-e^{-1.0287} = .643$

Therefore, the probability of a bird strike during the minimum expected life of a DC9 was .226 or a 22.6% chance; while the probability of a bird strike during the minimum expected life of a C9A was .643 or a 64.3% chance.

These probability predictions, for transport type aircraft, show ample justification for designing the crew compartment for bird impact requirements.

Related Critical Factors Associated with Designing Enclosures for Bird Impact Requirements

Too frequently, during the lofting definition phases for aircraft shape development, the nose shape is directed exclusively toward meeting aerodynamic requirements. Perhaps features of equivalent importance that should be considered when shaping the nose, are vision requirements per MIL-STD-850 including considerations for the angle of attack of the aircraft during landing, optical requirements specified by the various transparency specifications and Design Handbooks DH-1 and DH-2, optical distortion problems associated with radical shapes, and requirements to meet bird impact.

Frequently, bird impact requirements dictate that the windshield and windows must be a laminate of materials resulting in a number of dissimilar indices of refraction. Usually, other requirements can include radar reflective films, electrical conductive coatings for anti-icing and/or defogging, abrasion resistant coatings, anti-reflective coatings, and reflective coatings for head-up displays. Each coating reduces the amount of light transmission through the windshield or window and the greater the sighting angle of incidence the more difficult it becomes to accurately determine distances and shapes of objects beyond the aircraft. Therefore, a prime consideration should be the acceptance of an aerodynamic drag weight for a shape that would permit the best possible relationships of these requirements.

The drag weights, necessarily, would have to be converted to define the reduction in the performance of the aircraft's range and speeds.

In the event that drag weights are unacceptable, it is recommended that low light level TV systems be investigated for use to enhance critical visibility requirements and allow the amount of transparent area to be proportionately reduced.

Definition of Acceptable Bird Impact Damage to Transparencies for Mission Completion

Aircraft flight crew functional requirements must be defined, based upon the type of aircraft being considered.

For each type of aircraft, decisions must be made regarding the type of failures that can be allowed for mission completion after the occurrence of a bird impact. Vision loss, pressurization loss, and loss of escape provisions are initial considerations. A more important consideration would be the capability of the failed windshield to withstand an additional bird impact.

The amount of vision loss that would be permissible is largely dependent upon the type of aircraft, the number of windows, and whether there is one or two crew members capable of flying the aircraft. For transport and trainer type aircraft it is believed a minimum amount of forward vision is required to land the aircraft.

Bomber or fighter type aircraft would require that the vision loss be limited to 50% to allow the crew to see the target and land the aircraft. The allowable pressurization leakage rate resulting from bird impact should be established for each specific aircraft. It is suggested that bird impact damage to transparencies or structure be a minimum to allow pressurization to 15,000 feet or mission completion altitude, whichever is established as a requirement.

Normal egress and/or emergency escape provisions should be thoroughly evaluated. Aircraft such as transports having operable windows that are also used as emergency escape exits would be allowed to have one side or the other jammed as a result of bird impact but not both. Fighters and bombers may have only one egress for the flight crew and must be designed to withstand a bird impact and remain operable.

As a matter of procedural policy the pilot should have established criteria so that rational decisions can be made after an initial bird impact. Frequently, small birds, when struck, will smear over most of a window surface without causing structural damage. Providing that there is sufficient vision, the mission should be completed. When a laminated construction is used in the design, a bird strike will frequently cause a failure of one or more plies of the laminate. Decisions should be made as to how many failed plies can safely be allowed for mission completion. Although the probabilities for a second bird strike during a single mission may be insignificant, considerations should be given to the feasibility of the windshields/canopies to withstand a second bird impact without resulting in a catastrophic failure.

Selected Critical Operational Requirements

During the preplanning phases and design phases of a new aircraft, consideration should be given to minimizing exposure to birds during takeoff by designing the aircraft for minimum takeoff rolls and maximum climb angles to at least 3000 feet and establish cruise altitude above 8000 feet minimum.

During design and verification testing evaluate the probability and consequences of hitting a bird weighing up to 8 pounds. Safe speeds should be established and so noted in the Flight Manuals. When the aircraft is operational during bird migratory seasons the aircraft should not exceed these minimum safe speeds.

The speeds established during verification testing of a four-pound bird impact should be documented in the Flight Manual to assist in defining operational flight speeds and procedures.

Restricted speeds to compensate for damage caused by an initial bird strike during intended mission should be defined and documented in the Flight Manual.

Even though an aircraft is designed and verification tested to maximum speeds, it is recommended that up to 8000 feet (AGL) the flight speeds be reduced, similar to the current commercial limitations of 250 knots below 10,000 feet in CONUS. Thus, in the event of a bird strike the aircraft will suffer little or no damage.

It is recommended that mission planning for all training mission take into account the time of year when birds are most prevalent and schedule flights to minimize the potential bird strike hazard.

Frequently, after an aircraft is in service it becomes necessary to redefine certain aspects regarding defects that can occur to a production transparency. Defects such as malfunctions to an electrical anti-icing/defogging system, cracked plies in a laminated transparency, and delaminations nearly always occur. It is recommended that the bird impact verification testing be accomplished for these specific defects and safe speed limitations determined and so noted in the Flight Manuals.

Design of Windshields/Canopies and Support Structure, Verification Testing, and Associated Costs

It is recommended that future USAF aircraft are designed to the following:

> The windshields, windows, canopy, and all supporting structure ahead of and protecting the pilot and crew shall be designed to withstand, without penetration, the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane flight path) is equal to the maximum operational true airspeed, plus 60 knots, which can be achieved up to 8000 feet with the most adverse temperatures selected after considering the maximum hot temperatures (including aerodynamic heating), anti-icing system maximum temperature, and the coldest temperature expected on the windshield/windows at 8000 feet.

The verification test program should be thoroughly planned in an endeavor to test all conditions that will be required for operational usage.

Each aircraft will be different, but the C9A was shown as an illustrative example and the rationale described for the selection of testing requirements.

The commercial DC9 was tested to the FAA requirements and was designed to the technological concept that the windshields would be required to bag the bird; i.e., the bird strike would crack the glass laminates and the polyvinyl buteral interlayer would absorb the energy during stretching.

To accomplish this bagging concept it was necessary to heat the vinyl interlayer to 100°F at the required V_C speeds at sea level, which also met the requirement for anti-icing on the windshields.

Figure 66 was shown to illustrate the locations deemed necessary for bird impacting to meet the FAA requirements.

Shot location A was selected to show the affect of impact on the windshields where the maximum deflections would occur.

Impact testing was conducted as noted in Section V, Table XXX, with the anti-ice electrical system operating and temperatures monitored to determine that the windshield was heated. Additional shots were performed when the windshields were cold soaked to determine a maximum allowable operational speed below 10,000 feet (AGL) in the event the electrical system becomes inoperative. Although testing was not accomplished with cracked glass plies or delamination between the plies, it is recommended that such testing be accomplished for future designs.

Shot location B was selected to show the effect of impact on the windshields when the maximum stiffness would occur and where the effect of structural damage could be determined.

Testing was conducted similar to that noted for shot location A and the results are noted in Section V, Table XXX. The testing revealed that there was a crack in the windshield in the proximity of the intersection of the structural joints as a result of testing. Although not a requirement for the DC9, it is recommended that such tests be required for new designs and an acceptable pressurization leakage rate established and documented in the Flight Manuals.

Shot location C was selected to demonstrate the effect of impacting the structure at a location that was supported by the adjacent openable window and to determine the effect on window operation. The testing was accomplished without failure and results noted in Section V, Table XXX.

The openable clearview window was constructed of stretched acrylic material per MIL-P-25690 and laminated with polyvinyl buteral similar to MIL-P-25374. Test shot D was selected to determine the effect of impacting the window and the supporting latching mechanism. The testing was successful, the bird was bounced, with no adverse effects. The results are noted in Section V, Table XXX.

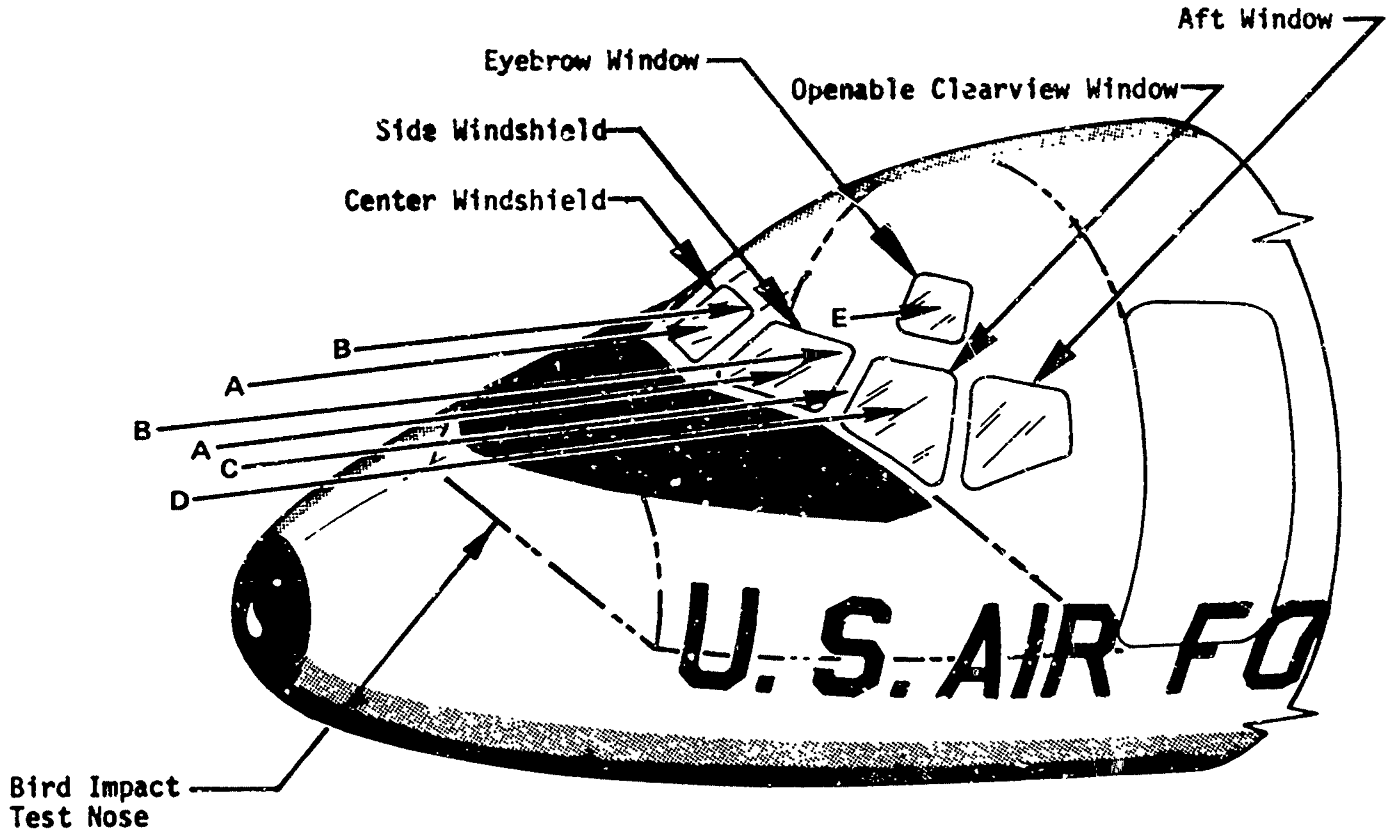


FIGURE 66

Recommended Bird Impact Locations for Bird Impact Design Substantiation

The eyebrow window is similar in construction to the operable clearview window. It was tested at shot location E at the point of maximum deflection and bounced the bird with no adverse effects. The results are noted in Section V, Table XXX

The aft window was not tested because any flying debris would have been behind the pilot/copilot.

The costs associated with bird impact testing vary considerably, depending on the conditions to be tested. Some of the costs associated with bird testing are detailed in the following paragraphs, assuming a conservative approach to the costs.

1. Representative structure should be used. The actual DC9 first production article of nose structure was used as noted in phantom in Figure 66. Manufacturing costs vary depending on the materials and manufacturing methods. The structural weight was approximately 1000 pounds for the DC9, and assuming the manufacturing costs could easily vary between $50 and $100 per pound or more. The costs for a nose specimen of this type could be $100,000 or more. It is recommended that an actual production configuration be used to obtain the full effect of windshields/canopies as well as supporting structure.

2. Assuming that the initial design selection for the windshields and windows was correct, 12 specimens would be required for testing. The costs per specimen could vary between $1500 and $20,000 or more, depending on the materials and design complexity.

3. The design engineering and test engineering manhours involved could easily exceed 5000 hours for the test vehicle design, test planning, instrumentation design and installations, equipment calibration, data reduction, testing, removal and replacement of specimens, repairs that result from testing, and report writing.

4. Anthropomorphic dummies to represent pilot/copilot would be required and positioned in the enclosure to determine the potential hazards to flight crews. These dummies cost approximately $2,000 each.

5. Calibration movies would be required to determine the bird speeds and to determine the condition of the specimen prior to impact and its deflection after impact.

6. Movies from outside and inside would be required to show that the bird/package was intact at impact.

7. Calibration movies require at least four 16 mm cameras capable of taking 5000 frames per second. If not available the costs would be at least $8000 each.

When a test is planned and programmed there may be more accurate equipment available that would measure the dynamic responses to impact. If so it should be a part of the test program.

The cost of bird impact testing could easily vary between $250,000 and $1,000,000. Considering the potential losses of aircraft and crew, these costs are negligible.

Bird Impact Avoidance Systems

Caldera (Reference 65) and Golden (Reference 66) have shown that the bird strikes were almost eliminated on commercial aircraft that had flashing, anti-collision lights installed. Currently, testing programs are being monitored by AFWL of strobe light installations on squadrons of T37, T38, and F111 aircraft. During the definition phases of a new design it is highly recommended that anti-collision lights be required. The type and installation location should be selected based on tests concluded by AFWL. Such installations would serve multi-purposes of the seen/be seen concept between aircraft and would allow birds to see the lights (approximately 7 miles) and possibly avoid oncoming aircraft.

During the definition phases of a new aircraft design it is recommended that the selected on-board radar units include the capability of recognizing birds during flight.

For each new aircraft design it is recommended that representative simulators be designed and procured. These simulator designs should be programmed for at least normal flight characteristics, systems malfunctions affecting flight, and representative training mission flights. Visual aids should also be a part of the system relating to landing, takeoff, and training mission terrains.

A sufficient quantity of these units should be a major requirement for each operational squadron using the specific aircraft. During heavy bird migrations and inclement weather conditions it should be mandatory that the simulators be used in lieu of the actual aircraft.

The current estimated costs for simulators would be approximately three to four million dollars each.

It has been proven by the commercial airlines with the current series of jumbo jets that simulators may be used 24 hours per day and that 95% of a pilot's FAA approved training takes place in the simulator. The cost advantage to the airlines is extensive since the fuel, servicing, and maintenance costs are eliminated during pilot training, and the aircraft can be used for its intended purpose of carrying passengers.

Miscellaneous Bird Strike Design Considerations

Other critical components on aircraft are also vulnerable to bird strikes which could result in a catastrophic failure.

During the selection and design of engines, consideration should be given to the test requirements of the FAA requirements (AC 33-1B) for Turbine Engine Certification.

It is recommended that critical systems components are not installed in the leading edges of wings and empennage sections. The application of the FAA eight-pound bird impact requirement on empennage structure is not recommended since less than 3% of the bird strikes occur on the tail sections. It is recommended, however, that consideration be given to the design of redundant systems located aft of spars for fail-safe operation in the event a bird strike should occur. The systems should be spread apart to preclude the possibility of a single bird strike destroying more than one system.

Conclusions and Pertinent Findings

1. Because of a lack of detailed information regarding expected design life and yearly utilization for the various USAF models of aircraft, it was virtually impossible to establish a risk factor related to bird impact for all aircraft.

2. The probability of a bird strike during the minimum expected life of the DC9 was established as .226, while the probability of a bird strike during the minimum expected life of the USAF equivalent C9A was established as .643 .

3. Historically, aerodynamics have been the prime requisite for establishing the lofted shape of an aircraft nose. Other important features that should be emphasized include vision requirements, optical deviations, optical distortions, bird impact, and various coating requirements that affect light transmission.

4. For each type of aircraft, decisions must be made regarding acceptable failures resulting from bird impact to be allowed for mission completion. Vision loss, pressurization loss, loss of escape provisions and the capability of the windshield to withstand an additional bird impact are initial considerations.

5. All future aircraft should be designed for minimum takeoff rolls and maximum climb angles to 3000 feet to minimize exposure to birds during takeoff.

6. Safe operational flight speeds should be established through verification testing for the impact of a four and eight-pound bird and documented in the Flight Manual to assist in defining operational procedures.

7. During training mission planning the prevalence of local birds and migratory bird seasons should be considered.

8. Below 8000 feet (AGL) it is recommended that USAF flight speeds be restricted similar to the FAA requirements of 250 knots maximum below 10,000 feet for commercial aircraft.

9. Bird impact verification testing should include the effects of impacting windshields/windows with allowable defects, including cracked plies and safe flight speeds established and documented in the Flight Manual.

10. The costs associated with bird impact verification testing of the crew compartment windshield/windows would vary between $250,000 and $1,000,000 depending on the complexity of the design.

11. An assessment should be made of the AFWL flashing anti-collision lights and the best installation considered for usage on any new USAF aircraft designs.

12. Future on-board radar systems should include the capability of recognizing birds during flight.

13. The design and procurement of flight simulators should be an integral part of programming for any new USAF aircraft.

14. Maximum use should be made of flight simulators during inclement weather and heavy bird migration periods.

15. During the design of future USAF aircraft, other critical components such as engines and empennage sections should be designed for fail-safe in the event of bird ingestions or impacts.

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

This report is a presentation of the problems associated with bird hazards to aircraft directed toward defining design criteria for windshields and supporting structure.

It was found in the CONUS there are over 600 species of birds with a combined total of twenty billion birds. Apparently, 200 of these species are regularly involved with aircraft/bird incidents. The most frequently struck birds are the gulls, ducks, vultures, pigeons, hawks, and the perching birds (300 species).

The USAF incident reports studied for the years 1965-1972 indicated that 50% of the collisions occurred during takeoff/landing, 22% occur during low-level training missions, 14% occur during normal flight conditions, and 14% of the collisions occur at unknown geographic locations. Specific altitudes (AGL) were established for USAF aircraft/bird collisions as being significant. These altitudes and aircraft/bird collisions were established as 22% up to 100 feet, 60% up to 1000 feet, 90% up to 3000 feet, 95% up to 5000 feet. Less than 5% of the aircraft/bird collisions occur above 5000 feet, with less than 2% occurring above 8000 feet.

Since 1965 USAF flight crews have suffered seven fatalities, five major injuries, and 26 reported minor injuries due to bird strikes. The USAF has lost at least seven high performance jet trainers and fighter type aircraft. Repair costs since 1966 for the USAF aircraft due to bird strikes were at least $20,000,000. The bird strikes since 1965 that identified the components struck showed that 11.56% struck the windshields and canopies, 31.40% were ingested in the engines, 25.11% struck the wings, and 2.74% struck the empennage.

The average number of bird strikes occurring on USAF aircraft during the past seven years (1966-1972) was determined as 356 strikes per year. Of this total, the number of strikes occurring on the crew compartment enclosure for the entire USAF fleet averaged 29.4 strikes per year.

A model was developed from the data for three selected aircraft (C9A, DC8, and F4) to depict to a 95% confidence level, the percentage of component frontal area versus the percentage of bird strikes. Three additional aircraft (B727, A7, and A4) were selected for comparison that tended to validate the model. From this model it was determined that upward of 33% of the strikes could occur on the crew compartment enclosure.

The USAF data (1965-1972) and the FAA data (1971-1972) were plotted and curve fitting equations developed comparing bird weights versus cumulative bird strike frequencies. It was found that approximately 92% of the birds weighed less than four pounds, which compares with the 94.5% as developed by ICAO, and data noted in Reference 23 and 27.

The same USAF and FAA data were treated as data samples and analyzed using descriptive statistical methodologies and normal distribution theory. It was concluded that the average bird weight taken from any future sample data would be between 1.034 and 2.684 pounds. Large sample sizes greater than 600 should show an average bird weight of 2.154 pounds. It was assumed that between 0 and each median the weights represent 50% of all birds struck and the median was established as the 50% confidence level. Standard deviations were calculated from the two medians and upper limit of the FAA estimated median. Subsequent calculations were made to establish confidence levels for four, six and eight-pound birds. The range of confidence levels for these bird weights were respectively 72.97% to 83.22%, 93.85% to 97.63%, and 99.32% to 99.87%.

Historic data revealed no catastrophic failures due to bird strikes on windshields/canopies and support structures that were designed to the FAA requirements for impact of a four-pound bird at V_C speeds at sea level.

A comparative analysis should be made of the windshields/windows installed in the current inventory of USAF aircraft to determine ratings for safe flight speeds below 8000 feet (AGL) based on comparisons to known bird impact tested windshields.

Flight Safety and Flight Operations Offices should treat waterfowl migrations with the same respect as thunderstorms, and every effort should be made to schedule flights to avoid areas where flocks may be expected during migration seasons. Mission planning should include complete coordination with the AFWL Environics Group and others regarding predictions for migratory bird movements. To minimize the frequency of bird strikes on present aircraft in USAF inventory it is recommended that the proposed interim and unique criteria, presented in Section V, be adopted and implemented whenever possible.

For all flights and low-level training missions, unique criteria for current USAF aircraft should include minimum take-off rolls and maximum climb angles to 3000 feet altitude (AGL), and maintain flights above 3000 feet altitude to reduce the chance of bird impact by upward of 90%.

It is recommended that the windshields/windows and support structure be designed to withstand the impact of a four-pound bird at maximum operational true airspeed, plus 60 knots, which can be achieved up to 8000 feet, and as required, be verification tested to environmental temperatures including the effects of aerodynamic heating. Each transparency located where critical fragmentation would injure the pilot and crew shall be tested to show that fragmentation is of such low order as to not cause injury to the crew. The loss of total vision area shall be limited to 50% and structural damage shall not prevent the mission completion.

The windshield/windows and supporting structure should be verification tested with a four-pound bird at the maximum speed possible that would not result in injury to the pilot and crew. The speed obtained should be reduced by a factor of 1.414, less 60 knots, and the aircraft placarded for a safe speed when flying below 8000 feet (AGL) during migration season of heavier birds such as the Canada Goose.

For each type of aircraft, decisions must be made regarding acceptable failures resulting from bird impact to be allowed for mission completion. Vision loss, pressurization loss, loss of escape provisions and the capability of the windshield to withstand an additional bird impact are initial considerations.

Since less than 3% of all bird strikes occur on the empennage, the FAA requirement for withstanding the impact of an 8-pound bird seems excessive. However, because of fail-safe requirements regarding controls necessary to flight safety, consideration should be given to a requirement of withstanding a 4-pound bird at maximum speed expected up to 8000 feet.

In an effort to reduce the 50% frequency of bird strike occurrences on takeoff and landing, it is recommended that each air base determine those elements that attract birds to the air base, and jointly, with representatives from AFWL, eliminate these undesirable elements. Canada has clearly shown that the reduction of attractions for birds around airdromes has greatly reduced the frequency of bird collisions and the costs of repairs to both military and civil aircraft.

Based on the vast amount of radar bird studies that have been accomplished during the past 10 years in North America, it is recommended that the USAF immediately establish bird warning systems. The CONUS is saturated with USAF radar installations, including CORAD, that should be integrated into a total bird warning system. Prior to the fall migrations, sometime in August, CORAD units along the Canadian border should establish contact with the Canadian radar bird-tracking groups. Each time the Canadian groups observe bird movements, CORAD should be notified. CORAD should track the flocks, determine local weather conditions, bird flight directions, and contact USAF radar stations so that the birds could be tracked to their final destinations. Flight and Flight Operations Officers at the USAF bases enroute should be notified of the migrations so that flight schedules could be adjusted to reduce the bird strike potential. The AFWL-Ecosystems group should be informed of these migrations and weather conditions, and given all known pertinent facts so that a bird map could be developed. It is highly recommended that the present radar systems be utilized and local radar operators trained to recognize bird movements on their radar sets. Aircraft crews in the area should be notified of pending bird hazards.

It is recommended that additional studies be conducted and development accomplished for on-aircraft radar systems, and radar bird-tracking and prediction systems. An assessment of the value of strobe lights on aircraft as a means of detering birds is also recommended, as is the development of other mechanical devices that could be used to reduce bird hazards to aircraft.

It is recommended that those USAF squadrons having strobe lights installed on their aircraft, attempt to determine if the birds recognize the lights and change their flight direction. Whenever possible the crew should report the altitude (AGL) at which the birds are observed; the approximate size of the bird; the type of bird if it can be recognized; and the number of birds in the group. When flocks of migratory birds are known to be in an area, it is suggested that training missions include a cautious rendezvous with these flocks in an attempt to determine the distance the birds can recognize the strobe lights and observe the birds' reactions. A documented report should be prepared each time birds are observed. It should be submitted to the AFWL-Environics group so that future assessments of strobe lights can be made.

Historically, aerodynamic considerations have been the prime requisites for establishing the shape of an aircraft nose. Other important features that should be emphasized during design include vision requirements, optical deviations, optical distortions, bird impact, and various coating requirements that affect light transmission.

It is recommended that the USAF Office of Operational Analysis and the Defense Mapping Agency Aerospace Center develop future training routes and flight altitudes that will minimize bird strikes. Flights during

October-November should be kept to a minimum.

Below 8000 feet (AGL) it is recommended that USAF flight speeds be restricted similar to the FAA requirements of 250 knots maximum below 10,000 feet for commercial aircraft.

The design and procurement of flight simulators should be an integral part of programming for any new USAF aircraft. Maximum use should be made of these flight simulators during inclement weather and heavy bird migration periods.

During the design of future USAF aircraft, other critical components such as engines and empennage sections should be designed for fail-safe in the event of bird ingestions or impacts.

USAF bird impact verification test reports in the future should include the following: a description of the windshields/windows tested; a description of the windshield/window support structure including section properties; type of edge attachment; true angle between the surface of the test specimen and the path of the bird; maximum deflection at the point of impact; failure mode, if any; damage to the anthropomorphic dummies; temperature of test specimen and ambient temperature; and speed and weight of the bird. During any series of bird impact tests, sufficient data should be collected for subsequent study that could lead to the establishment of design criteria for bird impact requirements. Perhaps this could ultimately eliminate the need for extensive bird impact verification testing.

REFERENCES

1. "Damage to Aircraft Caused by Bird Strikes - U.S. 1971 National Summary of Bird Strike Data", FAA Letter IGIA 73/3.2C, Interagency Group on International Aviation, Washington, D. C., 30 October 1972.

2. "Damage to Aircraft Caused by Bird Strikes - U.S. 1972 National Summary of Bird Strike Data", FAA Letter IGIA 73/3.2D, Interagency Group on International Aviation, FAA, Washington, D.C., 25 June 1972.

3. USAF Aircraft Collisions With Birds Study NR 14-66, 1 Jan 1965 Thru 31 Dec 1965, Directorate of Aerospace Safety, Deputy Inspector General for Inspection & Safety, USAF, Norton AFB, Ca.

   USAF Aircraft Collisions With Birds Study NR 12-67, 1 Jan 1966 Thru 31 Dec 1966, Directorate of Aerospace Safety, Deputy Inspector General for Inspection & Safety, USAF, Norton AFB, Ca.

   USAF Aircraft Collisions With Birds Study NR 21-68, 1 Jan 1967 Thru 31 Dec 1967, Directorate of Aerospace Safety, Deputy Inspector General for Inspection & Safety, USAF, Norton AFB, Ca.

   USAF Aircraft Collisions With Birds #3-69, 1 Jan 1968 Thru 31 Dec 1968, Directorate of Aerospace Safety, Deputy Inspector General for Inspection & Safety, USAF, Norton AFB, Ca.

   USAF Aircraft Collisions With Birds, 1 Jan 1969 Thru 31 Dec 1969, Directorate of Aerospace Safety, Air Force Inspection & Safety Center, USAF, Norton AFB, Ca.

   USAF Aircraft Collisions With Birds, 1 Jan 1970 Thru 31 Dec 1970, Directorate of Aerospace Safety, Air Force Inspection & Safety Center, USAF, Norton AFB, Ca.

   USAF Bird Strike Summary, 1 Jan 1971 Thru 31 Dec 1971, Directorate of Aerospace Safety, Air Force Inspection & Safety Center, USAF, Norton AFB, Ca.

   USAF Bird Strike Summary, 1 Jan 1972 Thru 31 Dec 1972, Directorate of Aerospace Safety, Air Force Inspection & Safety Center, USAF, Norton AFB, Ca.

4. Praeger, Otto, Three-Year Summary of Bird Strikes on B-52 Aircraft, 1965-1966-1967, No. D3-7710, Customer Operations Flight Safety Group, The Boeing Co., Wichita, Kansas, 19 January 1968.

5. Kaiser, G, "Weights of a Number of Birds", Field Note No. 51, CM4-S.17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, May 1970.

REFERENCES (CON'T)

6. Robbins, C. S., Bruun, B., m, H. S., Birds of North America, Western Publishing Co., Wisconsin, 1966

7. Seaman, E. A., "Birdstrike", Aerospace Safety, March 1970, pp 18-21

8. Bellrose, Frank C., Migration Corridors of Waterfowl in the United States, FAA Report No. FAA-RD-71-71, August 1971, Department of Transportation, Federal Aviation Administration, Systems Research & Development Service, Washington, D.C.

9. Saunders, David, Sea Birds, Grosset & Dunlap, New York, 1973

10. Allen, Arthur A., American Bird Biographies, Comstock Publishing Company, Inc., Ithaca, N. Y., 1935.

11. Cogswell, H. L., "Gulls and Solid Waste Disposal in the San Francisco Bay Area, California", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 423-438.

12. Drury, W. H. and Nisbet, I. C. T. "Strategy of Management of a Natural Population: The Herring Gull in New England", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada,

13. Pearson, T. Gilbert, Editor, Birds of America, Double Day & Co., Garden City, N. Y., 1936.

14. Kuhring, M. S. & Gunn, W. W. H., "Birds/Radar/Weather", Field Note No. 29, CM4-S-17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, April 1965.

15. Allen, R. P. & Truslow, F. K., "Our Only Native Stork - The Wood Ibis", The National Geographic Magazine, Vol. 125, No. 2, National Geographic Society, Washington, D. C., February 1964, pp 294-306.

16. Allen, R. P. & Truslow, F. K. "Whooping Cranes Fight for Survival", The National Geographic Magazine, Vol. CXVI, No. 5, National Geographic Society, Washington, D. C., November 1959, pp 650-669.

17. Truslow, F. K., "Eye to Eye with Eagles in the Everglades", The National Geographic Magazine, Vol. 119, No. 1, National Geographic Society, Washington, D. C., January 1961, pp 123-148.

18. Craighead, John, "Sharing the Lives of Wild Golden Eagles", The National Geographic Magazine, Vol 132, No. 3, National Geographic Society, Washington, D. C., September 1967, pp 420-439.

REFERENCES (CON'T)

19. Robin, J. D. G. & Gunn, W. W. H., "Whistling Swans near Wallaceburg, Ontario, Spring 1971", Field Note No. 60. Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, November 1971.

20. Sladen, W. J. L., "Studies on the Migrations of the Whistling Swan, 1969", Proceedings of World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, 1969. pp 231-244.

21. Sladen, William J. L., Studies of the Bird/Aircraft Collision Problem AD720889, John Hopkins University, March 1971

22. Truslow, F. K., "Return of the Trumpeter Swan", The National Geographic Magazine, Vol. 118, No. 1, National Geographic Society, Washington, D.C. July 1960, pp 134-150.

23. Kangas, Pell and Pigman, George L., Collision of Birds with a Scheduled Commercial Operations in the Continental United States Development of Aircraft Windshields to Resist Impact with Birds, Part I, CAA Tech. Dev. Rpt. No. 62, Jan 1949.

24. "Analysis of Bird Strike Reports on Transport Category Airplanes Operating in Continental Limits of the United States", FAA Advisory Circular No. AC20-49, 27 July 1966.

25. Bryant, H. E., "Bird Hazards to Aircraft", Paper AIR C-WP/431, presented to the ICAO Airworthiness Committee Ninth Meeting in Montreal, Canada, 16 Nov - 4 Dec 1970.

26. Survey of Bird Strikes, 1963 Through 1967, KLM Royal Dutch Airlines, Flight Operations Division, Flight Safety Department, 9 September 1968.

27. Fowler, H. S., "Bird Distribution & Strike Data", Field Note No. 42, CM4-S.17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, January 1967.

28. Haines, B. W. and Jones, V. A., Analysis of Navy Bird Strikes, Technical Note 73-2, April 1973, U. S. Naval Safety Center, Norfolk, Va.

29. Hild, J., "Bird Strikes in the German Air Force", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 31-42.

30. Jacoby, V. E. "Bird Strikes in USSR", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 101-113.

REFERENCES (CON'T)

31. Hart, P. F. "Military Bird Strikes in the United Kingdom", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, pp 21-30.

32. Jacoby, V. E., "Analysis of Bird Strikes Against Aircraft", Field Note No. 55, Associate Committee on Bird Hazards to Aircraft National Research Council of Canada, Ottawa, 1971.

33. Solman, V. E. F., "Bird Control & Air Safety", Studies of Bird Hazards to Aircraft, Report Series No. 14, Canadian Wildlife Service, Ottawa, 1971.

34. Boulter, M. J., Bird-Aircraft Collisions in the U. S. Air Force, AFWL-TR-72, Air Force Weapons Laboratory, Kirtland, AFB, New Mexico, 1973 (Working Paper)

35. Courtney, J. L., "Canadian Airport Problems With Birds", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada,

36. "Bird Strikes in Low Level Cruise Flight", TAC Report TAC OA WP-71-23, USAF, Headquarters Tactical Air Command, Langley AFB, Va., December 1971.

37. Bersch, C. F., Letter AIR-52032: CFB/4 to Douglas Aircraft Company, April 1973.

38. Macaulay, G. A., "Some Thoughts on the Forces Associated With a Bird Strike", Field Note No. 24, CM4-S.17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada. January 1965.

39. Metcalf, J. M., Development of a Turbine Engine Inlet Device For Protection Against Bird Ingestion, Report No. DS-69-9, Washington, D.C.: Federal Aviation Administration, July 1969.

40. Mitchell, J., "More Thoughts on Forces Associated With a Bird Strike", Field Note 37, Associate Committee on Bird Hazards to Aircraft National Research Council of Canada, Ottawa, March 1966.

41. Aerodrome Manual, Part 5, "Equipment, Procedures and Services", Vol. II, International Civil Aviation Organization, 1969.

42. Seubert, J. L., Control of Birds on and Around Airports, SRDS Report No. RD-68-62, AD683291, U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Division of Wildlife Research, Washington, D.C., October 1968.

43. Seubert, J. L., Control of Birds on and Around Airports, SRDS Report No. RD-67-52, U.S. Department of Interior, Bureau of Sport Fisheries and Wildlife, Division of Wildlife Research, Washington D.C., June 1967.

REFERENCES (CON'T)

44. Solman, V. E. F., "Airport Design & Management to Reduce Bird Problems", Field Note No. 50, LM4-S.17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, September 1969.

45. DeJong, A. P. Lt. Col. (Royal Netherlands Air Force), "Their Airspace or Ours?", Shell Aviation News #390, 1970.

46. Solman, V. E. F., "Use of Falcons for Airport Bird Control", Field Note No. 33, CM4-S.17-2, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, October, 1965.

47. Austin-Smith, P. J. and Lewis, H. F., "Alternative Vegetative Ground Cover", Proc. of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 153-160.

48. Hild, J., "Agricultural Provisions Against Birds on Airfields", Proceedings of the World Conference on Bird Hazards to Aircraft, National Research Council, Kingston, Ontario, Canada, 1969, pp 195-202.

49. Bird Control on Aerodromes, Dat Paper No. 14, Department of Trade & Industry - Aerodromes Technical Directorate, August 1971.

50. Langley, M., "The Bird Strike Problem", Science Journal, August 1970, pp 55-60.

51. Langley, Marcus, "Bird Strike", Air Safety, July 1970, pp 21-24.

52. "DUCK!", Interceptor, Oct. 1972.

53. Brink, B. W., "Military Airlift Command Bird Strike Control Programme", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 121-125.

54. Van Tets, G. F., Vestjens, W. J. M., and Slater, E., "Orange Runway Lighting May Help Reduce the Bird Hazard to Aircraft on Airfields", Proc. of World Conference on Bird Hazards to Aircraft, National Research Council, Kingston, Ontario, Canada, 1969, pp 183-185.

55. Blokpoel, H., and Desfosses, P. P., Radar Observations of Local Bird Movement near Calgary, Alberta, Field Note No. 53, National Research Council, Ottawa, Canada, October 1970.

56. Blokpoel, H., "An Attempt to Forecast the Intensity of Nocturnal Fall Migration", Proc. of World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 285-298.

57. Blokpoel, H., "Progress Report on Operation Bird Track 1964 through 1969", Field Note No. 59, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, November 1971.

58. Blokpoel, H., "Observations on the Spring Migration of Lesser Snow & Blue Geese Through Southern Manitoba", Field Note. No. 56, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, November 1971.

59. Richardson, John W., "Temporal Variations in the Ability of Individual Radars in Detecting Birds", Field Note No. 61, Associated Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, January 1972.

60. Bellrose, F. C., "Waterfowl Migration Corridors East of the Rocky Mountains in the United States", Illinois Natural History Survey, Biological Notes No. 61, Urbana, Illinois, 1968.

61. Flock, W. L., and Bellrose, F. C., "A Radar Study of Bird Migration in the Central United States", Proc. of World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 273-283.

62. Jackson, W. B., and Fiedler, L. K., "Radar Studies of Crow Flocks at the Toledo Airport", Proc. of World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 253-264.

63. Williams, T. C., Williams, J. M., Teal, J. M., and Kanwisher, J. W., "Tracking Radar Studies of Bird Migration in or near Cloud Layers", Field Note No. 58, Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, Ottawa, November 1971.

64. Flock, W. L.,"Flight Safety Aspects of Precision Radar Near Air Bases in Bird-Aircraft Collision Avoidance",AFWL-TR-72-25, AD751985 AFWL, Kirtland Air Force Base, New Mexico, October 1972.

65. Caldera, J. D., Major-General, "The Birds as a Menace to Flight Safety", Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, 1969, pp 111-119.

66 Golden, J. G., "Strobe Lighting - A Strengthening Factor for the "See & Be Seen" Backbone of Collision Avoidance", Airline Pilots Association, Elmhurst, New York, 11 November 1969.

67. Solman, V. E. F., "How to Reduce Bird Hazards to Aircraft", paper presented to Tenth Annual Conference on Environmental Effects on Aircraft & Propulsion Systems, Trenton, New Jersey, May 19, 1971.

REFERENCES (CON'T)

68. Tanner, J. A., "The Effect of Microwave Radiation on Birds - Some Observations and Experiments", Field Note No. 31, CM4-S.17-2. Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada, May 1965.

69. Tanner, J. A., Davie, S. J., Romero-Sierra, C., & Villa, F., "Micro-waves - A Potential Solution to the Bird Hazard Problem in Aviation", Proceedings of World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, 1969, pp 215-221.

70. Myres, M. T., "The Detection of Birds and Insects, and The Study of Bird Movements, with Radar", (Bibliography Included) Proceedings of the World Conference on Bird Hazards to Aircraft, Kingston, Ontario, Canada, National Research Council, Sept. 1969, pp 501-519.

71. Wolf, Frank L., Elements of Probability & Statistics, McGraw-Hill Book Co., Inc., 1962.

72. Hald, A., Statistical Theory with Engineering Application, John Wiley & Sons, Inc., Canada, 1952, pp 90-95.