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DETERMINATION OF BODY DENSITY FOR TWELVE BIRD SPECIES

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Body density, mass, wingspan, and circumference measurements were completed on 12 bird species to better understand the bird/aircraft collision hazard. Body densitites for the 12 species ranged from 0.602-0.918 g/cm^3 dry, 0.743-0.947 g/cm^3 wet, and 0.880-1.050 g/cm^3 plucked. The mean length-to-diameter ratio of the 12 species was 4.8 ± 0.3. Significant negative correlations were found between dry density ($\underline{N}$ = 144) and wingspan ($r = -0.52$, $\underline{P} < 0.001$), dry circumference ($r = -0.229$, $\underline{P} < 0.006$), or body length ($r = -0.264$, $\underline{P} < 0.001$). The percent of body mass represented by feathers differed among species, but not by sex or sex x species. Herring Gulls, Turkey Vultures, and Laughing Gulls had 9-10 % of their body mass in feathers while seven other species had 2-4 % of their body mass in feathers. An understanding of avian body density is essential to 1) aid standardization of international birdstrike testing techniques, 2) establish the acceptability and validity of using "artificial" birds for aircraft birdstrike testing, 3) establish birdstrike resistance standards for aircraft components, and 4) aid computer modeling of bird bodies.

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FOREWORD

This report was prepared by the Aircrew Protection Branch, Vehicle Subsystems Division, Flight Dynamics Directorate, Wright Laboratory, Wright-Patterson AFB, Ohio and the United States Department of Agriculture (USDA), Denver Wildlife Research Center (DWRC), Sandusky, Ohio. The effort documented herein was performed in Sandusky, Ohio in support of the USAF Windshield Systems Program Office (WSPO), the Arnold Engineering and Development Center, Arnold Air Force Base, Tennessee, and other users of bird measurement data. The report was written from January to April 1993, by Lt. David M. Hamershock, Aircraft Flight Hazard Analyst, WSPO, Mr. Thomas W. Seamans, Biological Science Technician, USDA, DWRC, and Mr. Glen E. Bernhardt, Biological Science Technician, USDA, DWRC.

A goal of the WSPO is to find solutions to reduce the potential for costly aircraft birdstrikes. One approach to resolve the aircraft birdstrike problem is to design aircraft components which will survive birdstrikes, allowing for safe operation until the aircraft can be landed. The most vulnerable components, transparencies and jet engines, are designed and evaluated using computer models and full scale tests. These testing techniques utilize bird measurement data. Due to a lack of available data, bird density has been assumed constant by test scientists and engineers. This report provides a valid source of density, mass, volume, circumference, length, and wingspan data for 12 bird species often struck by USAF aircraft.

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SECTION 1

INTRODUCTION

Each year, birdstrikes with military and civil aircraft worldwide result in tens of millions of dollars of damage and occasional pilot/passenger injuries and deaths (Thorpe 1990a, b). United States Air Force (USAF) aircraft average 3,000-3,500 bird/aircraft collisions each year resulting in annual costs > $65 million. Since 1987, seven USAF personnel have died as a result of bird/aircraft birdstrikes (Hamershock 1992). The USAF Windshield Systems Program Office (WL/FIVR) and other military and civilian organizations simulate bird/aircraft collisions to test the resistance of aircraft components. Present techniques and standards were established using incomplete biological data.

Current USAF bird/aircraft collision tests use euthanized Domestic Chickens (*Gallus gallus*) wrapped (wrapping and chicken = 1.8 kg) and fit within a 13.3-cm-diameter "sabot" (balsa structure). The sabot, used to protect the bird during acceleration through the "gun" barrel, is stopped at the end of the barrel allowing the bird to be projected accurately toward the test fixture. How the density, length, and diameter of Domestic Chickens compare with that of bird species most often involved in collisions is unknown. How these possible differences affect interpretations of bird/aircraft collision tests is also indefinite.

Little published information exists regarding density of birds. Allcock and Brough (1967) studied body density for seven wild and one domestic bird species. They measured the density of 70 Japanese Quail (*Coturnix coturnix*); however, the sample sizes of the remaining seven species were less than four. They concluded that the average density of the seven wild bird species studied was 0.98 g/cm^3. The density of 23 aquatic bird species, as calculated from a buoyancy study by Lovvorn and Jones (1991) was 0.68 g/cm^3. Welty and Baptista (1988) reported the relative density of a duck to be 0.9 g/cm^3, compared to a density of approximately 1.0 for humans. Challita (1981) reported a density of 0.96 g/cm^3 as being "similar to the density of real birds and equal to the density of . . . substitute birds."

International discussions of replacing Domestic Chickens with a more representative "artificial bird" have occurred for many years (Devaux 1992); however, an agreement on the standards for an acceptable substitute has not been accomplished. Data from avian density studies should assist in developing an international standard for an artificial bird to replace the Domestic Chicken for bird/aircraft collision testing. In addition, such density data may be useful in various ornithological studies. Our objective was to determine densities for 12 bird species to aid in developing modelling standards for simulated bird/aircraft collisions. Bird density and its relationship to length, diameter, and wingspan was also determined.

SECTION 2

METHODS

Data were collected from 6 July - 4 November, 1992 on 12 individuals of each of the following 12 species: Brown-headed Cowbird (*Molothrus ater*), Canada Goose (*Branta canadensis*), Common Grackle (*Quiscalus quiscula*), Domestic Chicken, European Starling (*Sturnus vulgaris*), Herring Gull (*Larus argentatus*), House Sparrow (*Passer domesticus*), Laughing Gull (*L. atricilla*), Mallard (*Anas platyrhynchos*), Ring-billed Gull (*L. delawarensis*), Rock Dove (*Columba livia*), and Turkey Vulture (*Cathartes aura*). Species tested were chosen due to their wide range of mass and their frequency of collision with USAF aircraft. We attempted to test six males and six females of each species; however, due to limitations in pretest sex identification and availability, this sample was not achieved for six species.

Laughing Gulls were obtained from John F. Kennedy International Airport, New York (Dolbeer et al. 1993). Domestic Chickens were obtained from the USAF Bird Strike Testing Facility, Arnold Air Force Base, Tennessee. The remaining 10 species were captured in northern Ohio. Capture techniques included decoy traps, rocket nets, alpha-chlorolose, shotguns, and round up of flightless birds. All birds collected alive were euthanized the same day with CO_2. Birds were measured within 1 h after euthanization. When it was not possible to test an individual on the day of its death, the bird was frozen. Herring Gulls, Laughing Gulls, and Turkey Vultures that were shot were frozen 1-8 h after death. To determine the effects of freezing on density, we euthanized and froze eight cowbirds for 7-25 days and compared their density with that of 12 cowbirds killed and immediately tested.

Bird densities were determined using water displacement, similar to the technique used for humans (Consolazio et al. 1963). Our apparati consisted of PVC-pipes that were from 0.6-1.2 m tall and 7.6, 10.2, 15.2, and 25.4 cm in diameter. Each tube, fitted with a support base, had an overflow spout located 7.6-28.0 cm down the side which directed displaced water into containers. Bird immersion cages made of welded wire were fitted for each tube.

Each day before birds were measured, we tested our techniques with samples of titanium alloy Ti-6Al-4V. Validation of Ti-6Al-4V sample composition was accomplished using a Japanese Electron Optics, Ltd. (JEOL)-840 scanning electron micrograph with Noran Energy Dispersive Analysis and a JEOL-733 electron microprobe with metal standards (Wood and Favor 1972). A 122-g sample was used for the 7.6- and 10.2-cm tubes and a 1,948-g sample for the 15.2- and 25.4-cm tubes.

The afternoon before a day of testing, we filled a large container with tap water which allowed the water to be at room temperature (22.3 ± 2.4°C, mean ± SD) by the next morning. One drop (0.02 ml) of detergent was added to 2 L of water to reduce the capillary action of water and therefore reduce water retained in the overflow spout. Each tube, on a day of its use, was filled with the tap water. The empty immersion cage was lowered to its fixed position inside the tube. Five minutes were allowed for the water to stabilize, after which the cage was slowly raised completely out of the water, but not out of the tube. The appropriate titanium block was placed into the immersion cage and then slowly lowered into the water to its fixed position. Displaced water was collected in a preweighed catch basin. Five minutes were allowed for complete displacement of water by the titanium. The catch basin and water were then weighed and the mass of the catch basin subtracted to determine the mass of the displaced water. Mass of the displaced water was converted to cubic centimeters. This process was repeated up to two times until we were within 5 percent of the known density of the titanium. At the end of each day, used tubes were emptied and allowed to dry.

Birds ≤ 1000 g were weighed to the nearest 0.1 g. Birds > 1000 g were weighed to the nearest 1.0 g. For each bird, mass was recorded before the dry, wet, and plucked volume measurements.

All body measurements were taken to the nearest mm. Total length was measured from the tip of the bill to the tip of the longest retrix when each bird was laid on its back and just enough force was used to stretch the neck to full length. The length of the tail was measured from the tip of the longest retrix to the point where it emerged from the skin. Body length was calculated by subtracting tail from total length. Wingspan was measured from wing tip to wing tip while the bird was placed on its back with wings fully extended (Pettingill 1967). Circumference was measured around the mantle and chest before and after the bird was plucked. Feather mass was determined by subtracting mass of plucked birds from that of dry, unplucked birds.

Dry-bird volume was measured using the same procedure as for the verification tests with titanium. Each bird was placed in the immersion cage head-first with its wings folded back to reduce air trapped under its wings. Canada Geese, Herring Gulls, and Turkey Vultures had rubber bands wrapped around their bills to prevent water from entering the esophagus. Only the dry and plucked tests were done on the Domestic Chicken.

Each bird, after completion of the dry test, was immersed in a container of water containing surfactant at the same concentration as the test water. Feathers were then stroked from posterior to anterior to remove air trapped in the feathers and to completely wet the feathers. The bird was removed from the water and stroked from anterior to posterior to remove excess water from the feathers. The bird was placed in the catch basin and weighed. The bird was placed from the catch basin into the immersion cage and into the tube where wet bird volume was measured using the same procedure as for the dry measurement.

After wet-bird volume was obtained, all feathers were removed to determine plucked-bird volume using the same procedure. Birds >160 g were usually plucked using poultry wax;

birds <160 g were usually plucked without using wax. Except for Domestic Chickens, three volume tests were completed for each bird: dry, wet, and plucked. Domestic Chickens were prepared as for USAF birdstrike testing (Jennings 1989).

After volume measurements were completed, each bird was necropsied to determine sex. Density (g/cm^3) was calculated using the formula:

$$\underline{D} = \underline{m}/\underline{V}$$

where, $\underline{D}$ = body density, $\underline{m}$ = body mass, and $\underline{V}$ = body volume.

We used the General Linear Models procedure (SAS Inst. Inc. 1988) to determine differences between density and feather mass among species and between sexes within species. Because the use of two or more related response variables (i.e., three measurements of density), to address a single hypothesis increases the probability of committing a type I error, we used the Bonferroni inequality technique to ensure the experimentwise type I error rate was ≤ 0.05 (Beal and Khamis 1991). To maintain this probability level, alpha (0.05) was divided by the number of response variables (3) tested resulting in significant differences at $\underline{P} \leq 0.017$. If differences occurred, Tukey tests were used to determine which means differed. We used a t-test to determine if differences ($\underline{P} < 0.05$) occurred between frozen and fresh-killed Brown-headed Cowbirds. Correlation analysis was done between total length, wingspan, dry circumference, and dry density.

SECTION 3

RESULTS

Mean dry densities ranged from 0.602-0.918 g/cm^3 (Table 1) for the 12 species whereas wet densities ranged from 0.743-0.947 g/cm^3 (Table 2), and 0.880-1.050 g/cm^3, and plucked (Table 3). Domestic Chickens were either the most dense or among the most dense species. they were more dense than wild birds of similar mass. The European Starling was one of the three most dense wild species in all three measurements. Herring Gulls were either the least or among the three least dense species in each density measure. There were no differences between sexes in the three measures of density. Density of frozen and fresh-killed Brown-headed Cowbirds was similar (t = 0.67, 18 df, $P > 0.5$).

The mean length-to-diameter ratio of the 12 species was 4.8 ± 0.3 (Table 4). Significant negative correlations were found between dry density (N = 144) and wingspan (r = -0.52, $P < 0.001$), dry circumference (r = -0.229, $P < 0.006$), or body length (r = -0.264, $P < 0.001$).

The percent of body mass represented by feathers differed (F = 25.3; 11, 120 df; $P < 0.05$) among species but not by sex (F = 0.07; 1, 11 df; $P > 0.79$) or sex x species (F = 1.47; 11, 1 df; $P > 0.15$) (Table 5). Herring Gulls, Turkey Vultures, and Laughing Gulls had 9-10 percent of their body mass in feathers whereas seven other species had 2-4 percent of their body mass in feathers.

Total length, tail length, wingspan, dry circumference, and plucked circumference results are in Tables 6 and 7.

Table 1. The mean density (g/cm^3) and mass (g) of 12 birds of 12 species when dry (standard deviation). Species with statistically similar mean densities (within the density column) share common letters (Tukey test $P < 0.0167$).

Species	Density[a]	Mass
Domestic Chicken	0.918 (0.041) A	1798.0 (0.0)
Common Grackle	0.809 (0.030) B	96.3 (15.3)
European Starling	0.776 (0.035) BC	71.7 (5.0)
House Sparrow	0.751 (0.042) CD	23.1 (2.3)
Brown-headed Cowbird	0.750 (0.029) CD	41.9 (5.7)
Mallard	0.739 (0.040) CD	1328.5 (150.7)
Turkey Vulture	0.700 (0.018) DE	1856.6 (165.0)
Laughing Gull	0.700 (0.043) DE	321.7 (27.2)
Canada Goose	0.669 (0.041) EF	3975.6 (671.0)
Rock Dove	0.648 (0.032) EFG	323.0 (46.1)
Ring-billed Gull	0.644 (0.031) FG	425.8 (52.1)
Herring Gull	0.602 (0.053) G	1043.7 (190.4)

[a]Species were different ($F = 64.14$; 11, 120; $P < 0.0001$). Sexes within species were not different ($F = 1.0$; 1, 120; $P > 0.32$) nor was there a species and sex interaction ($F = 1.12$; 11, 120; $P > 0.35$).

Table 2. The mean density (g/cm^3) and mass (g) of 12 birds of 12 species after soaking in water. Species with statistically similar mean densities (within the density column) share common letters (Tukey test $P < 0.0167$).

Species	Density [a]	Mass
European Starling	0.947 (0.024) A	81.1 (5.3)
Common Grackle	0.924 (0.023) A	113.0 (17.0)
Brown-headed Cowbird	0.915 (0.024) AB	49.1 (6.9)
House Sparrow	0.913 (0.035) AB	26.5 (2.7)
Mallard	0.877 (0.026) B	1479.9 (162.3)
Laughing Gull	0.831 (0.027) C	421.4 (38.9)
Canada Goose	0.807 (0.023) CD	4643.8 (748.6)
Turkey Vulture	0.803 (0.024) CD	2291.3 (215.1)
Rock Dove	0.802 (0.020) CD	375.3 (50.7)
Ring-billed Gull	0.786 (0.028) D	531.7 (65.2)
Herring Gull	0.743 (0.046) E	1313.3 (208.6)

[a]Species were different ($F= 66.54$; 10, 110; $P< 0.0001$).

Table 3. The mean density (g/cm[3]) and mass (g) of 12 birds of 12 species after plucking all feathers (standard deviation). Species with statistically similar mean densities (within the density column) share common letters (Tukey test $P < 0.0167$).

Species	Density[a]	Mass
House Sparrow	1.050 (0.032) A	22.5 (2.1)
Domestic Chicken	1.044 (0.011) AB	1700.3 (9.4)
Brown-headed Cowbird	1.042 (0.028) AB	40.8 (5.5)
European Starling	1.027 (0.020) ABC	70.2 (5.4)
Common Grackle	1.005 (0.024) BC	94.2 (14.4)
Rock Dove	0.987 (0.022) CD	311.6 (44.8)
Mallard	0.959 (0.016) DE	1296.9 (147.2)
Laughing Gull	0.935 (0.038) E	293.9 (27.3)
Ring-billed Gull	0.928 (0.034) E	399.4 (49.9)
Canada Goose	0.917 (0.023) EF	3830.9 (597.9)
Turkey Vulture	0.916 (0.025) EF	1693.3 (140.3)
Herring Gull	0.880 (0.055) F	941.8 (174.8)

[a]Species were different ($F = 46.83$; 11, 120; $P < 0.0001$)

Table 4. The mean (standard deviation) length-to-diameter (L/D) ratio of 12 birds of 12 species.

Species	L/D Ratio
Mallard	6.0 (0.3)
Canada Goose	5.8 (0.5)
Ring-billed Gull	5.3 (0.2)
Laughing Gull	5.2 (0.2)
Herring Gull	5.1 (0.3)
House Sparrow	4.6 (0.5)
European Starling	4.6 (0.3)
Common Grackle	4.3 (0.3)
Domestic Chicken	4.2 (0.2)
Turkey Vulture	4.1 (0.2)
Brown-headed Cowbird	4.0 (0.2)
Rock Dove	4.0 (0.2)
Average of All/Wild Bird Average	4.8 (0.3)

Table 5. Feather mass represented as the percent of total body mass for 12 birds of 12 species (standard deviation). Rows that do not share a common letter are significantly (Tukey test $P < 0.05$) different.

Species	%
Herring Gull	9.8 (2.4) A
Turkey Vulture	8.7 (2.4) AB
Laughing Gull	8.6 (3.8) AB
Ring-billed Gull	6.2 (1.2) BC
Domestic Chicken	5.4 (0.5) CD
Rock Dove	3.5 (1.0) CDE
Canada Goose	3.3 (2.6) DE
Brown-headed Cowbird	2.6 (1.4) E
Mallard	2.3 (2.4) E
House Sparrow	2.3 (1.3) E
European Starling	2.2 (1.6) E
Common Grackle	2.1 (1.5) E

Table 6. The mean (standard deviation) total body length, tail length, and wingspan (in mm) for 12 birds of 12 species.

Species	Total Length	Tail Length	Wingspan
House Sparrow	155.1 (4.6)	51.3 (4.9)	239.2 (5.9)
Domestic Chicken	464.2 (14.6)	90.9 (14.4)	703.9 (13.1)
Brown-headed Cowbird	186.1 (9.4)	69.9 (4.6)	320.1 (14.1)
European Starling	219.9 (8.8)	62.3 (1.8)	381.5 (8.1)
Common Grackle	282.8 (21.5)	113.3 (10.5)	414.3 (24.6)
Rock Dove	350.5 (13.7)	116.3 (13.0)	690.1 (12.3)
Mallard	612.3 (29.2)	95.2 (8.6)	868.3 (114.3)
Laughing Gull	420.7 (14.2)	121.2 (4.5)	1049.9 (22.0)
Ring-billed Gull	454.7 (23.4)	132.7 (6.6)	1149.9 (47.6)
Canada Goose	918.8 (59.1)	153.4 (30.7)	1627.2 (68.1)
Turkey Vulture	692.8 (19.1)	281.8 (18.1)	1729.9 (36.6)
Herring Gull	613.2 (39.5)	182.8 (13.2)	1458.3 (55.6)
Average of All	447.6 (21.4)	122.6 (10.9)	886.0 (35.2)
Wild Bird Average	446.1 (22.0)	125.5 (10.6)	902.6 (37.2)

Table 7. The mean (standard deviation) dry circumference and plucked circumference (in mm) for 12 birds of 12 species.

Species	Dry Circumference	Plucked Circumference
House Sparrow	76.2 (4.8)	71.0 (4.1)
Domestic Chicken	294.0 (13.1)	277.8 (8.4)
Brown-headed Cowbird	99.8 (6.9)	92.1 (5.7)
European Starling	116.5 (9.0)	107.8 (5.5)
Common Grackle	130.8 (8.0)	123.3 (7.1)
Rock Dove	193.3 (11.9)	185.7 (11.2)
Mallard	291.8 (16.3)	269.8 (13.2)
Laughing Gull	189.4 (7.2)	179.9 (4.4)
Ring-billed Gull	210.5 (10.0)	190.1 (8.5)
Canada Goose	486.5 (32.7)	411.2 (32.7)
Turkey Vulture	343.5 (22.0)	313.4 (11.3)
Herring Gull	302.1 (19.1)	265.5 (12.9)
Average of All	227.9 (13.4)	207.3 (10.4)
Wild Bird Average	221.9 (13.4)	200.9 (10.6)

SECTION 4

DISCUSSION

Bird density appears to reflect life history. Gulls and waterfowl, both associated with long, continuous flights and floating on water, were among the least dense species tested. Turkey Vultures were a low density species that exhibit good soaring efficiency. European Starlings, House Sparrows, Common Grackles, and Brown-headed Cowbirds, among the most dense species, do not depend upon these qualities for survival.

Domestic Chickens are primarily terrestrial birds and have been bred to increase the muscle mass they carry (r. Muir, Ohio State Univ., pers. comm.). They were more dense than most of the wild bird species tested. Therefore, use of the Domestic Chicken as an aircraft birdstrike test species may be appropriate as it represents a worst case due to its high density. Herring Gulls and Mallards, also used in aircraft birdstrike testing (T. Alge, General Electric Aircraft Engines, pers. com.), had significantly lower densities than chickens. Babish (1992) determined that objects of varying densities that strike an aircraft traveling at consistent speed gave varying results; therefore, bird species of different densities will give varying results.

The percent of body mass represented by feathers also seemed dependent upon life style as the three species (Herring Gull, Turkey Vulture, and Laughing Gull) with the highest proportions of feather mass are notable for soaring, aquatic habitats, or both. However, the Canada Goose and Mallard did not differ from the Brown-headed Cowbird, House Sparrow, European Starling, or Common Grackle in feather mass as a percentage of body mass. Canada Geese and Mallards were captured during the flightless period of their postbreeding molt, which likely reduced the total mass of feathers.

The high density of the smaller birds (e.g., Brown-headed Cowbirds) tested supports the theory of a high speed-small bird (feathered bullet) phenomenon (Urzi 1988) whereby a single, small bird could cause damage to an aircraft traveling at high speed. Also, as these birds generally travel in flocks they may represent a serious threat to aircraft due to the combined density and mass of a flock as they strike an aircraft. A Learjet crashed near Atlanta, Georgia in 1973, killing eight people, after striking a flock of Brown-headed Cowbirds (U. S. National Transportation Safety Board 1973).

Engineers have previously used a 2:1 length-to-diameter ratio for artificial birds in aircraft birdstrike testing (Challita 1981). This ratio may be inappropriate because the smallest ratio we measure for 12 species was 4.0:1. A 4.8:1 ratio (the mean for the 12 species studied) would more accurately reflect the dimensions of birds that strike aircraft.

An understanding of avian body density is essential to 1) aid standardization of international birdstrike testing techniques, 2) establish the acceptability and validity of using "artificial" birds for aircraft birdstrike testing, 3) establish birdstrike resistance design standards for aircraft components, and 4) aid computer modeling of bird bodies. Further density studies on birds from around the world would enhance the development of an "artificial" bird, thereby resulting in more valid birdstrike test results. Also, a correlation of carcass composition (protein, fat, and ash) and whole body density would help build a more complete model for an artificial bird.

SECTION 5

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