Have Population Increases of Large Birds Outpaced Airworthiness Standards for Civil Aircraft?

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Abstract: Bird-aircraft collisions (bird strikes) are an increasing safety and economic concern to the USA civil aviation industry, costing over $400 million each year. One approach to reducing risks associated with strikes is to require commercial aircraft components to meet certain standards of safe performance in the event of a bird strike. The Federal Aviation Administration has developed airworthiness standards for airframes, windshields and engines using a single 4-lb (1.82-kg) bird mass as the maximum that must be tested (with the exception of a single 8-lb bird for the empennage, 6-lb bird for certain mid-sized engines that may be developed in the future, and an 8-lb bird for certain large-intake engines on aircraft such as the Boeing 777). Because of concern within the aviation industry that populations of certain flocking bird species weighing more than 4 lbs, such as Canada geese (Branta canadensis), have increased dramatically, discussions are underway in the USA and Europe regarding the need to revise 4- and 8-lb test standards to heavier body masses or to include multiple strikes. To help clarify this issue, we surveyed the avian literature and determined that 36 and 14 of the approximately 650 bird species that nest in North America (north of Mexico) have average body masses (for at least 1 gender) greater than 4 and 8 lbs, respectively. Of the 31 species for which population trend data were available, 24 (77%) showed population increases over the past 20-40 years, 2 showed declines, and the other 5 were stable. Thirteen of the 14 species with mean body masses over 8 lbs showed population increases. At least 261 strikes with >4-lb birds caused substantial damage to civil aircraft in the USA, 1990-2001. Furthermore, multiple birds were involved in 31% of the strikes with >4-lb birds and 40% of the strikes with >8-lb birds. Therefore, we conclude that airframe, windshield, and engine standards, as well as proposals to allow high-speed (>250 knot) operations below 10,000 feet, should be reevaluated to address the threat posed by increased populations of large flocking birds. Finally, because most critical aircraft components are not designed to withstand strikes by birds greater than 4 lbs, wildlife biologists who work at airports should increase efforts to detect, remove and disperse these large birds from airport environments.

Key Words: aircraft, airframe, airport, bird strike, engine, Federal Aviation Administration, mass, safety, standards, windshield

INTRODUCTION

Aircraft collisions with birds (bird strikes) are a serious economic and safety problem. Cleary et al. (2002) estimated wildlife strikes (97.5% involving birds) cost the civil aviation industry in the USA over $400 million/year, 1990-2000. Allan (In Press) projected that bird strikes annually cost commercial aviation over $1.2 billion worldwide in 1999-2000. At least 138 people died worldwide as a result of bird strikes from 1990-2000 (Thorpe 1996, 1998; Richardson and West 2000; Dolbeer, unpublished data).

About 71% of bird strikes to civil aircraft occur below 500 feet during takeoff and landing (Cleary et al. 2002). Thus, implementation of integrated management programs to reduce bird populations in airport environments is essential to minimize bird strikes (Cleary and Dolbeer 1999). However, given the diversity and mobility of avian species, programs to manage bird hazards at airports will never exclude all birds from aircraft movement areas (e.g., Dolbeer 1999) and will do nothing to prevent strikes outside the airport environment. Therefore, a second critical component to reduce the hazards and economic costs of bird strikes is the development of airworthiness standards for airframes, windshields, and engines that ensure aircraft can operate safely in the event of a bird strike.

The Federal Aviation Administration (FAA) has developed airworthiness standards for airframes and windshields of transport aircraft (>19 passenger seats) using a single 4-lb (1.82 kg) bird as the maximum-sized mass that must be tested (with the exception of 8 lbs [3.64 kg] for the empennage). Standards for commuter aircraft (10-19 seats) are less stringent (Table 1). The maximum mass required for turbine-engine testing is a single 4-lb bird for most engines currently in service, a single 6-lb bird for certain mid-sized engines that may be developed in the future, and a single 8-lb bird for certain large-intake engines used on new wide-bodied aircraft such as the Boeing 777. The engine does not have to keep operating after a 4-, 6- or 8-lb bird ingestion to pass these standards, rather, the engine must contain the damage, not catch fire, and be capable of shut-down (Table 1). MacKinnon et al. (2001) provide a more detailed discussion of airworthiness standards related to bird strikes.

Aggressive programs by natural resource and environmental agencies and organizations during the past
Table 1. Maximum bird masses required in tests for airworthiness standards for airframes, windshields, and engines for transport- (>19 passenger seats) and commuter- (10-19 passenger seats) category aircraft, U.S. Federal Aviation Administration (FAA).

| Aircraft category | Aircraft component | Federal Aviation Regulation | Latest update of standard | Max. bird mass (lbs) | Comments |
|-------------------|--------------------|-----------------------------|---------------------------|----------------------|----------|
| Transport         | Airframe           | Part 25.571                 | 1978                      | 4                    | Safely complete flight after striking 1 4-lb bird at design cruise speed (V_C) |
| Transport         | Empennage          | Part 25.631                 | 1970                      | 8                    | Safely complete flight after striking 1 8-lb bird at design cruise speed (V_C) |
| Transport         | Windshield         | Part 25.775                 | 1977                      | 4                    | Withstand impact of 4-lb bird w/o penetration at design cruise speed (V_C) |
| Transport/commuter| Turbine engine     | Part 33.76                  | 2000                      | 4-8^                | Engine will not catch fire, have uncontained failure, or lose capacity to be shut down |
| Commuter          | Airframe/empennage |                             |                           |                      | No standards |
| Commuter          | Windshield         | Part 23.775                 | 1996                      | 2                    | Withstand impact of 1 2-lb bird at maximum approach flap speed (V_FE) |

^ One 4-lb bird for most existing aircraft engines, one 6-lb bird for certain mid-sized engines that may be developed in the future; one 8-lb bird for large-intake (3.9 m^2) engines (RR Trent, P&W 4084, GE90) for new wide-bodied aircraft such as Boeing 777.

Table 2. Summary of population trend estimates and flocking and soaring characteristics for 36 species of birds in North America with mean body masses >4 lbs for at least 1 gender (see Appendices 2, 3).

| Body-mass category | Number of species | Species exhibiting population: | Species exhibiting*: |
|--------------------|-------------------|---------------------------------|----------------------|
|                    |                   | Increase | Decrease | Stability | Unknown | Strong flocking | Limited flocking | Solitary behavior |
| 4-8 lbs            | 22                | 11       | 2        | 5         | 4       | 15 (0)          | 6 (2)             | 1 (0)              |
| >8 lbs             | 14                | 13       | 0        | 0         | 1       | 9 (0)           | 3 (1)             | 2 (2)              |
| Total              | 36                | 24       | 2        | 5         | 5       | 24 (0)          | 9 (3)             | 3 (2)              |

^ Values in parentheses are the number of species exhibiting soaring behavior.

Table 3. Summary of population trend estimates and flocking and soaring characteristics for 20 of the 36 species of birds in North America with mean body masses >4 lbs for at least 1 gender that have been identified as involved in reported strikes with civil aircraft in USA, 1990-2001 (see Appendices 2, 3).

| Body-mass category | Number of species | Species exhibiting population: | Species exhibiting*: |
|--------------------|-------------------|---------------------------------|----------------------|
|                    |                   | Increase | Decrease | Stability | Unknown | Strong flocking | Limited flocking | Solitary behavior |
| 4-8 lbs            | 11                | 7        | 1        | 1         | 2       | 7 (0)           | 3 (2)             | 1 (0)              |
| >8 lbs             | 9                 | 9        | 0        | 0         | 0       | 6 (0)           | 2 (1)             | 1 (1)              |
| Total              | 20                | 16       | 1        | 1         | 2       | 13 (0)          | 5 (3)             | 2 (1)              |

^ Values in parentheses are the number of species exhibiting soaring behavior.

30 years (e.g., pesticide regulation, expansion of wildlife refuge system), coupled with land-use changes, have resulted in dramatic increases in populations of many wildlife species in North America (Dolbeer 2000). In addition, certain of these wildlife species that are a proven threat to aviation, such as Canada geese (*Branta canadensis*) (Cleary et al. 2000), have adapted to urban environments (Smith et al. 1999), making the risk of wildlife strikes at airports much greater. Because of concern within the aviation industry with populations of large bird species, discussions are underway in North America (FAA and Transport Canada) and Europe (Joint
Aviation Authorities) regarding the need to revise the 4- and 8-lb test standards to heavier body masses or to include multiple strikes by these large birds as part of the standards (e.g., MacKinnon et al. 2001, Eschenfelder 2001).

To help clarify this issue, we surveyed the avian literature to determine the number, flocking characteristics, and population status of bird species with body masses greater than 4 and 8 lbs that inhabit North America. In addition, we determined the reported number of single and multiple bird strikes involving these species for civil aircraft in the USA, 1990-2001. Our goal is to provide objective data on the numbers, population trends, flocking characteristics, and strike patterns for these large bird species to aid regulatory bodies, engineers, and biologists in developing standards and strategies to reduce the costs and hazards of bird strikes.

METHODS

Alsop (2001) was our primary reference source to initially screen, from the approximately 650 bird species that nest in North America (USA, Canada and Caribbean Islands), those species having a mean body mass approximating 4 lbs or more. This list was refined by examining data on avian body masses from Dunning (1993) and other sources. Those species included in the final list had a mean body mass >4.0 lbs for at least one gender, or if data were unavailable by gender, a mean body mass >4.0 lbs for unknown gender.

We obtained population data (numbers of birds and mean annual % change in numbers) for each species from various sources such as the North American Breeding Bird Survey (BBS), Christmas Bird Counts (CBC), North American Waterfowl Survey reports, North America Waterbird Conservation Plan, and the scientific literature. For BBS or CBC data, populations were classified to be increasing or decreasing if a significant ($P < 0.05$) mean annual percent change was detected for the years considered (generally 1966-2000 for BBS data; 1959-1988 for CBC data; Sauer et al. 1996, 2001). For other species, we calculated the mean annual percent change from a baseline year (earliest year [1959-1987] for which a reliable population estimate was available) and the most current (1994-2001) population estimate (Belant and Dolbeer 1993). Sources of information and scientific names for each species are listed in Appendix 1.

We subjectively classified the social behavior of each species relevant to bird strikes as strongly flocking, limited flocking, or generally solitary based on our general knowledge of the species and discussions among ornithologists. We also classified each species as soaring or non-soaring. Finally, we determined the number of reported strikes to civil aircraft in the USA involving these species, 1990-2001 (Cleary et al. 2002, S. E. Wright, U.S. Department of Agriculture, unpublished data). We also noted for each reported strike event whether a single bird or multiple birds were struck and the degree of damage.

RESULTS

Thirty-six species, about 6% of the approximately 650 species that breed in North America, had mean body masses >4 lbs for at least 1 gender (Appendix 2). Of the 31 species for which a population trend could be estimated, 24 (77%) indicated increases, 2 (6%) indicated declines, and 5 (16%) were stable (Table 2). All 13 (100%) of the 14 species with body masses above 8 lbs for which a population trend could be estimated indicated population increases.

Twenty-four (67%) of the 36 species exhibit strong flocking behavior, 9 (25%) exhibit limited flocking behavior, and only 3 (8%) exhibit solitary behavior (Table 2, Appendix 3). Five (14%) of the species regularly exhibit soaring behavior.

Sixteen of the 36 species were not involved in a reported strike with civil aircraft in the USA, 1990-2001 (Appendix 3). The 20 species reported as struck were involved in 1,568 strikes of which 789 (50%) indicated damage and 261 (17%) indicated substantial damage to the aircraft. Multiple birds were involved in 431 (31%) of the reported strikes. The 9 struck species with body masses >8 lbs were involved in 1,062 strikes of which 549 (52%) indicated damage and 167 (16%) indicated substantial damage. Multiple birds were involved in 417 (40%) of the strikes with >8-lb species. Sixteen (80%) of the 20 struck species with body masses >4 lbs have exhibited population increases; all 9 (100%) of the species with body masses >8 lbs showed population increases (Table 3). Eighteen of the 20 struck species exhibit strong (13) or limited (5) flocking behavior.

DISCUSSION

Populations of most large (>4 lb) bird species in North America, including at least 13 of the 14 species with masses >8 lbs, have shown substantial increases during the past 20-40 years. Although some of these species are unlikely to be struck by aircraft, species such as Canada and snow geese, turkey vultures, great blue herons, bald eagles, and sandhill cranes have been struck numerous times during the past 12 years. Of significance is the fact that 31% of the >4-lb bird strikes and 40% of the >8-lb bird strikes involved multiple birds. We also note that 56% of the 33,500 bird-strike reports in the FAA Wildlife Strike Database, 1990-2000, list the species struck as unknown (Cleary et al. 2002). Furthermore, an estimated 80% of strikes to civil aircraft in the USA go unreported (Cleary et al. 2000). Thus, the number of strikes reported for large (>4 lb) species (Appendix 3) should be considered an index and not an actual measure of strike rates. Undoubtedly, there have been many strikes with >4-lb birds (including some of the 16 species with no strikes recorded) that either have not been reported or reported as unknown species.
Our analysis clearly indicates that aviation regulatory and industry groups need to reexamine existing airworthiness standards with regard to bird-strike tolerances. Many of the regulations have not been revised since the 1970s when large-bird (>4 lbs) populations were much lower. Of particular concern is that existing standards for transport aircraft regarding large birds (in most cases 4 lbs being the maximum tested) do not consider multiple-bird strikes into a single engine or multiple engine ingestions. Yet, our data for 1990-2001 indicate 31% of strikes with >4-lb birds and 40% of strikes with >8-lb birds have involved multiple birds (see also Budgery and Allan 1999). The fact that current large-bird standards for engines only require that the damage be contained and that the engine can be shut down safely has serious implications for multiple-bird strikes involving 2 engines. Such an incident occurred with a Boeing 707 aircraft that crashed at Elmendorf Air Force Base, Alaska after striking a flock of Canada geese during take off in 1995 (Cleary and Dolbeer 1999). Over 80% of transport aircraft in operation by 2010 will have only 2 engines (Dolbeer 2000). Although beyond the scope of this paper, detailed analysis of data from the long-term bird-strike databases that are now available (e.g., Cleary et al. 2000) should be invaluable in objectively guiding decisions regarding bird-strike airworthiness standards for transport, commuter and general-aviation aircraft (e.g., Martindale and Reed 1998).

Although revisions in airworthiness standards may be needed in response to increased populations of large flocking and soaring birds, existing aircraft and engines certified under current (single 4-lb bird) standards will remain in service for many years (Alge 1996). Furthermore, even if standards are revised and engineering improvements made, it will be impossible to completely “bird-proof” engines and airframes against high-speed collisions with birds of large mass. For example, a 4-lb bird struck by a transport aircraft going 150 knots at lift-off generates about 14,000 lbs of impact force (MacKinnon et al. 2001). Thus, it is imperative that aviation regulatory agencies in North America and elsewhere develop and maintain rigorous standards for bird hazard management programs at airports that emphasize the threat posed by these large birds and the need to minimize their presence in the airport environment (Cleary and Dolbeer 1999, Dolbeer et al. 2000). The deployment of bird-detecting radar systems to alert pilots and Air Traffic Control personnel may also prove useful in avoiding strikes with large flocking birds, especially during periods of migration (Kelly et al. 2001, Blokpoel and MacKinnon 2001).

As a final point, proposals to allow commercial aircraft to use high-speed (over 250 knot) operations below 10,000 feet to facilitate air traffic flow (National Transportation Safety Board 1999) should be reevaluated in light of increased populations of large-mass birds. Because of a fundamental relationship between energy (e), mass (m) and velocity (v) expressed in the equation $e = \frac{1}{2} mv^2$, aircraft velocity is even more critical than bird mass in determining the energy imparted to an aircraft by a strike. For example, a 20% increase in bird mass results in a 20% increase in energy on impact whereas a 20% increase in aircraft velocity results in a 44% increase in energy imparted. An incident in which a Boeing 727 was heavily damaged after striking 3-5 snow goose at 6,000 feet during a high-speed departure from a Houston, Texas airport in January 1998 confirmed the dangers to aircraft of high-speed impacts with large birds (Cleary and Dolbeer 1999).

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### Appendix 1

Scientific names and sources of information on population status for the 36 species of birds in North America (Canada, USA [including Hawaiian Islands], and Caribbean) that have mean body mass for at least 1 gender >4 lbs (body mass data from Dunning [1993] except for turkey vultures [Seamans et al. 1995] and double-crested cormorants from Ohio [Unpublished data, M. T. Bur, U.S. Geological Survey]).

| Common Name       | Scientific Name                  | Mean Body Mass (lbs) | Source of Information on Population Status |
|-------------------|----------------------------------|----------------------|-------------------------------------------|
|                   |                                  | Male | Female | Unk Sex | Max |                                      |
| Mute swan         | Cygnus olor                      | 26.01| 21.32  | 31.53   |     | CT DEP (1999), Sauer et al. (2001), Mute Swan Task Force (2001) |
| Trumpeter swan    | Cygnus buccinator                | 25.13| 22.71  |         |     | Caithamer (2001)                      |
| California condor | Gymnogyps californianus          | 22.28|        |         | 31.03| California Department of Fish and Game (2002) |
| Wild turkey       | Meleagris gallopavo              | 16.31| 9.31   |         |     | Dickson (1992, 2001)                  |
| Tundra swan       | Cygnus columbianus               | 15.65| 13.67  | 21.16   |     | USFWS (2001a)                         |
| American white pelican | Pelecanus erythrorhynchos     | 15.43|        | 29.98   |     | Sauer et al. (2001), NAWCP (2001)     |
| Whooping crane    | Grus americana                   | 12.84| 14.01  |         |     | Meine and Archibald (1996), USGS (2000) |
| Sandhill crane    | Grus canadensis                  | 12.78| 11.78  | 14.77   |     | Meine and Archibald (1996), Sauer et al. (2001) |
| Yellow-billed loon| Gavia adamsi                     | 12.13|        | 14.11   |     | Earnst (2001)                         |
| Bald eagle        | Haliaeetus leucocephalus         | 9.11 | 11.79  | 14.11   |     | Buehler (2000), Sauer et al. (2001), USFWS (2001b) |
| Golden eagle      | Aquila chrysaetos                | 7.67 | 10.83  |         |     | Sauer et al. (2001)                   |
| Canada goose      | Branta canadensis                | 9.22 | 7.75   | 10.42   |     | Alge (1999), Sauer et al. (2001), USFWS (2001a) |
| Common loon       | Gavia immer                      | 9.11 | 9.88   |         |     | McIntyre and Barr (1997), Sauer et al. (2001), |
| Brown pelican     | Pelecanus occidentalis           | 8.16 | 8.10   |         |     | Sauer et al. (2001), NAWCP (2001)     |
| Greater flamingo  | Phoenicopterus ruber             | 7.80 | 5.58   | 9.04    |     | Espinoza et al. (2000), Baldassarre and Agengo (2000) |
| Snow goose        | Chen caerulescens                | 7.61 | 6.81   |         |     | USFWS (2001a)                         |
| Arctic loon       | Gavia arctica                    | 7.40 | 7.50   |         |     | North American Loon Fund (2001)       |
| Laysan albatross  | Phoebastria immutabilis          | 7.12 | 6.29   | 9.04    |     | Fisher (1966), Dolbeer et al. 1996, USFWS (2001c), NAWCP (2001) |
| Greater sage grouse | Centrocercus urophasianus         | 7.03 | 3.85   |         |     | Braun (1999)                          |
| Black-footed albatross | Phoebastria nigripes            | 6.94 | 6.94   | 7.96    |     | Rice (1959), USFWS (2001c), NAWCP (2001) |
| Northern gannet   | Morus bassanus                   | 6.46 | 6.76   | 7.96    |     | Sauer et al. (1996), NAWCP (2001)     |
| Emperor goose     | Chen canagica                    | 6.05 | 6.88   |         |     | USFWS (2001a)                         |
| Gr. white-fronted goose | Anser albinfons              | 5.96 | 5.41   | 7.10    |     | USFWS (2001a)                         |
| Wood stork        | Mynerta americana                | 5.96 | 4.52   |         |     | University of Georgia (2001), NAWCP (2001) |
| Great blue heron  | Ardea herodias                   | 5.68 | 4.86   |         |     | Sauer et al. (2001), NAWCP (2001)     |
| Red-faced cormorant | Phalacrocorax urile             | 5.57 | 3.94   | 5.63    |     | NAWCP (2001), National Audubon Society (2001) |
| Double-crested cormorant | Phalacrocorax auritus        | 5.15 | 4.50   | 6.44    |     | Tyson et al. (1991), Sauer et al. (2001), NAWCP (2001) |
| Great cormorant   | Phalacrocorax carbo              | 5.03 | 4.27   | 5.92    |     | NAWCP (2001)                          |
| Snowy owl         | Nyctea scandiaca                 | 3.98 | 5.02   | 6.51    |     | Parmelee (1992), Sauer et al. (1996)  |
| Common eider      | Somateria mollissima             | 4.89 | 4.22   | 6.38    |     | Goudie et al. (2000)                  |
| Black vulture     | Coragyps atratus                | 4.79 | 4.38   |         |     | Sauer et al. (2001)                   |
| Brandt's cormorant | Phalacrocorax penicillatus     | 4.64 |        |         |     | Ainley et al. (1994), NAWCP (2001)    |
| Masked booby      | Sula dactylatra                  | 4.14 | 4.62   | 5.19    |     | NAWCP (2001)                          |
| Pelagic cormorant | Phalacrocorax pelagicus          | 4.48 | 3.75   | 5.38    |     | Ainley et al. (1994), Hobson (1997), Sauer et al. (2001), NAWCP (2001) |
| Turkey vulture    | Cathartes aura                   | 3.98 | 4.21   | 4.70    |     | Sauer et al. (2001)                   |
| Great black-backed gull | Larus marinus              | 4.03 | 3.28   | 5.01    |     | Sauer et al. (2001), NAWCP (2001)     |
Appendix 2. Population status for 36 bird species in North America that have mean body mass for at least 1 gender >4 pounds (see Appendix 1 for more detailed mass data and sources of information).

| Rank | Common Name           | Mean Mass (lb) | Years Covered | Trend  | MAPC<sup>a</sup> | Pop. Estimate<sup>b</sup> | Comments                                                                 |
|------|-----------------------|----------------|---------------|--------|------------------|---------------------------|--------------------------------------------------------------------------|
| 1    | Mute swan             | 26.01          | 1966-2000     | Increase | 13.9             | 7,000                     | Maryland pop. increased from 5 (1962) to 4,000 (1999)                   |
| 2    | Trumpeter swan        | 25.13          | 1968-2000     | Increase | 5.9              | 23,647                    | Pop increased from about 3,722 (1968) to 23,647 (2001)                 |
| 3    | California condor     | 22.28          | 1987-2002     | Increase | 58               | 189,000                   | Wild pop. increased from 0 (1987) to 58 (Jan 2002); Both western and eastern pop. are increasing |
| 4    | Wild turkey           | 16.31          | 1959-1994     | Increase | 6.1              | 4,000,000                 | Pop. increased from 500,000 (1959) to 4,000,000 (1994)               |
| 5    | Tundra swan           | 15.68          | 1970-2001     | Increase | 1.7              | 125 captive               | Both western and eastern pop. are increasing                             |
| 6    | American white pelican| 15.43          | 1980-2000     | Increase | 2.9              | 120,000                   | USA pop. had 4.8% MAPC, USA/Canada breeding pop. estimate              |
| 7    | Whooping crane        | 12.84          | 1966-2000     | Increase | 5.8              | 282                       | Wild pop. increased from 42 in 1966 to 282 in 2000                     |
| 8    | Sandhill crane        | 12.78          | 1966-2000     | Increase | 6.9              | 520,000                   | Total pop. estimate for 1995                                          |
| 9    | Yellow-billed loon    | 11.79          | 1966-2000     | Increase | 8.0              | 100,000                   | Breeding pop. in contiguous USA:1,552 (1974), 11,896 (1988)           |
| 10   | Bald eagle            | 10.83          | 1980-2000     | Increase | 4.8              | 10,000                    | Estimate for resident USA population is about 3,000,000               |
| 11   | Golden eagle          | 9.22           | 1966-2000     | Increase | 10.5             | 4,900,000                 | Majority of pop. is in Canada; USA pop. >20,000                      |
| 12   | Canada goose          | 9.11           | 1966-2000     | Increase | 2.9              | >500,000                  | Estimated decline from 1980 to 1999 was 35-80%                      |
| 13   | Common loon           | 8.16           | 1980-2000     | Increase | 2.1              | 93,000                    | Breeding pop. in USA                                                    |
| 14   | Brown pelican         | 7.80           | 1970s-2000    | Unknown   | 4.4              | 245,000                   | Caribbean Islands, coastal Yucatan & Venezuela                        |
| 15   | Greater flamingo      | 7.61           | 1980-2000     | Unknown   | 3.1              | 3,927,000                 | Greater (eastern) subspecies has MAPC of 8.2 %, 1970-2000             |
| 16   | Arctic loon           | 7.40           | 2001          | Unknown   | 10.5             | >100                      | About 100 individuals nest in extreme W and NW Alaska                 |
| 17   | Laysan albatross      | 7.12           | 1962-1995     | Increase | 4.4              | >775,708                  | Estimate for Midway Atoll (71% of total pop in 1996)                 |
| 18   | Greater sage grouse   | 7.03           | 1980-1999     | Decline   | 4.4              | >140,000                  | Estimated decline from 1980 to 1999 was 35-80%.                      |
| 19   | Black-footed albatross| 6.94           | 1958-1998     | Increase | 2.2              | >170,000                  | Pop. trend estimate for Midway Atoll (40,480 birds in 1998)           |
| 20   | Northern gannet       | 6.76           | 1959-1988     | Increase | 6.1              | 155,000                   | Pop. trend estimate for 1959-1988, pop. estimate for 2001             |
| 21   | Emperor goose         | 6.05           | 1984-2001     | Stable    | 8.2              | 84,000                    | Trend is for Pacific pop.; total pop for Pacific & Mid-continent      |
| 22   | Greater white-fronted goose | 5.96 | 1980-2001     | Increase | 8.2              | 1,375,000                 | USA pop. is about 12,000                                             |
| 23   | Wood stork            | 5.96           | 1983-2000     | Increase | >2.4             | >32,000                   | Breeding pop. only                                                     |
| 24   | Great blue heron      | 5.68           | 1966-2001     | Increase | 2.4              | >83,000                   | Breeding pop. only                                                     |
| 25   | Red-faced cormorant   | 5.57           | 1980-2000     | Stable    | <50,000          | Breeding pop. only                                                  |
| 26   | Double-crested cormorant | 5.15   | 1966-2000     | Increase | 10.1             | >744,000                  | Gr. Lakes nesting pop. increased from <200-190,000, 1972-1997       |
| 27   | Great cormorant       | 5.03           | 2001          | Unknown   | 8.2              | 11,600                    | Breeding pop. only                                                     |
| 28   | Snowy owl             | 5.02           | 1959-1988     | Stable    | 10.5             | >20,000                   | 20,000 estimated on Banks Is., Canada (64,000 km²) in 1950s          |
| 29   | Common eider          | 4.89           | 2000          | Stable    | 10.5             | >60,000                   | Winter population estimate is 600,000-750,000                          |
| 30   | Brandt's cormorant    | 4.79           | 1966-2000     | Increase | 2.7              | 151,000                   | Breeding pop. only                                                     |
| 31   | Masked booby          | 4.62           | 2001          | Stable    | 10.5             | 151,000                   | Body mass data from Hawaii; Pop. data from Caribbean/Hawaii            |
| 32   | Pelagic cormorant     | 4.48           | 1966-2000     | Stable    | 10.5             | 151,000                   | Breeding pop. only                                                     |
| 33   | Turkey vulture        | 4.21           | 1966-2000     | Increase | 1.5              | 151,000                   | Breeding pop. only                                                     |
| 34   | Great black-backed gull| 4.03         | 1966-2000     | Decline   | -2.0             | 121,000                   | Breeding population                                                  |

<sup>a</sup> MAPC = Mean annual percent change for years indicated based either on North American Breeding Bird Survey estimate or by calculating MAPC from estimated population in first and last year covered (Belant and Dolbeer 1993).

<sup>b</sup> Most recent population estimate for most species represents adult breeding population and does not include subadult birds.

<sup>c</sup> Body mass presented is for “greater” subspecies, “lesser” subspecies mean body mass = 6.05 lbs.
Appendix 3. Flocking and soaring behavior for 36 species of birds in North America that have mean body mass for at least 1 gender >4 pounds ranked by number of reported strikes to civil aircraft in USA from 1990-2001 involving these species.

| Species                  | Mean mass (lb) | Flocking/ soaring behavior | Reported strikes |             |             |           |
|--------------------------|----------------|----------------------------|------------------|-------------|-------------|-----------|
|                          |                |                            | Total number     | With damage | With substantial damage | No. (%) involving >1 bird |
|                          |                |                            |                  |             |             |           |
| Canada goose             | 9.22           | Strong flocking            | 578              | 294         | 96           | 258 (45)  |
| Turkey vulture           | 4.21           | Limited flocking/soaring   | 141              | 84          | 33           | 8 (6)     |
| Great blue heron         | 5.68           | Limited flocking           | 95               | 15          | 2            | 2 (2)     |
| Bald eagle               | 11.79          | Limited flocking/soaring   | 40               | 16          | 2            | 3 (8)     |
| Sandhill crane           | 12.78          | Strong Flocking            | 38               | 15          | 6            | 13 (35)   |
| Snow goose               | 7.61           | Strong flocking            | 38               | 28          | 15           | 20 (53)   |
| Snowy owl                | 5.02           | Solitary                   | 24               | 3           | 2            | 0         |
| Great black-backed gull  | 4.03           | Strong flocking            | 22               | 5           | 5            | 1 (5)     |
| Brown pelican            | 8.16           | Strong flocking            | 20               | 11          | 2            | 2 (11)    |
| Wild turkey              | 16.31          | Strong flocking (on ground)| 19               | 4           | 0            | 2 (11)    |
| Double-crested cormorant | 5.15           | Strong flocking            | 16               | 6           | 2            | 1 (6)     |
| Black vulture            | 4.79           | Limited flocking/soaring   | 11               | 4           | 3            | 3 (27)    |
| Common loon              | 9.11           | Limited flocking           | 4                | 2           | 0            | 0         |
| Tundra swan              | 15.65          | Strong flocking            | 3                | 3           | 2            | 2 (67)    |
| Mute swan                | 26.01          | Strong flocking            | 2                | 0           | 0            | 1 (50)    |
| Golden eagle             | 10.83          | Solitary/soaring           | 2                | 1           | 1            | 0         |
| Wood stork               | 5.96           | Strong flocking            | 2                | 2           | 2            | 1 (50)    |
| Common eider             | 4.89           | Strong flocking            | 2                | 2           | 2            | 0         |
| Greater white-fronted gnu| 5.96           | Strong flocking            | 1                | 1           | 1            | 0 (100)   |
| Great cormorant          | 5.03           | Strong flocking            | 1                | 1           | 1            | 0         |
| Trumpeter swan           | 25.13          | Strong flocking            | 0                | 0           | 0            | 0         |
| California condor        | 22.28          | Solitary/soaring           | 0                | 0           | 0            | 0         |
| American white pelican   | 15.43          | Strong flocking            | 0                | 0           | 0            | 0         |
| Whooping crane           | 12.84          | Strong flocking            | 0                | 0           | 0            | 0         |
| Yellow-billed loon       | 12.13          | Limited flocking           | 0                | 0           | 0            | 0         |
| Greater flamingo         | 7.80           | Strong flocking            | 0                | 0           | 0            | 0         |
| Arctic loon              | 7.40           | Limited flocking           | 0                | 0           | 0            | 0         |
| Layasan albatross        | 7.12           | Strong flocking            | 0                | 0           | 0            | 0         |
| Greater sage grouse      | 7.03           | Limited flocking (on ground)| 0               | 0           | 0            | 0         |
| Black-footed albatross   | 6.94           | Strong flocking            | 0                | 0           | 0            | 0         |
| Northern gannet          | 6.76           | Strong flocking            | 0                | 0           | 0            | 0         |
| Emperor goose            | 6.05           | Strong flocking            | 0                | 0           | 0            | 0         |
| Red-faced cormorant      | 5.57           | Strong flocking            | 0                | 0           | 0            | 0         |
| Brandt's cormorant       | 4.64           | Strong flocking            | 0                | 0           | 0            | 0         |
| Masked booby             | 4.62           | Limited flocking           | 0                | 0           | 0            | 0         |
| Pelagic cormorant        | 4.48           | Strong flocking            | 0                | 0           | 0            | 0         |
| Total (all strikes identified to species) | 1,058 | 495 | 176 | 318 (30) |
| Geese (unknown species)  | 343            | 195                         | 53               | 134 (40)    |
| Vultures (unknown species)| 152           | 91                          | 28               | 19 (13)     |
| Eagles (unknown species) | 7              | 4                           | 2                | 2 (29)      |
| Pelicans (unknown species)| 4            | 3                           | 2                | 0           |
| Swans (unknown species)  | 2              | 1                           | 0                | 0           |
| Cormorants (unknown species)| 1          | 0                           | 0                | 0           |
| Total (all strikes with species or species group >4 lbs) | 1,568 | 789 | 261 | 473 (31) |
| Total (all strikes with species or species group >8 lbs) | 1,062 | 549 | 167 | 417 (40) |

*a* Strong flocking = Birds normally associate in dense flocks while feeding, traveling or nesting; Limited flocking = Birds often found in small groups while soaring, migrating, feeding or breeding; Solitary = Birds normally feed and travel as individuals; Soaring = Birds typically soar while searching for food, often in loose flocks or “kettles” with other members of same species.

*b* Aircraft incurs damage or structural failure which adversely affects the structure strength, performance or flight characteristics of aircraft and which would normally require major repair or replacement of the affected component (excluded are: bent fairings or cowlings; small dents or puncture holes in skin; damage to wing tips; antenna, tires or brakes; engine blade damage not requiring blade replacement, International Civil Aviation Organization 1989).

*c* A total of 25 strike reports did not indicate whether or not multiple birds were involved: sandhill crane (1), Canada goose (6), brown pelican (1), great blue heron (2), turkey vulture (4), unidentified geese (10), unidentified vultures (1). These reports were excluded from total strikes when calculating percent of strikes involving >1 bird.

*d* Assuming all unidentified swan, pelican, eagle and goose strikes were with birds >8 lbs.