February 2002

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

Richard A. Dolbeer
USDA, National Wildlife Research Center

Paul Eschenfelder
Air Line Pilots Association, Spring, Texas

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Richard A. Dolbeer
USDA, National Wildlife Research Center, Sandusky, Ohio
Paul Eschenfelder
Air Line Pilots Association, Spring, Texas

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

Proc. 20th Vertebr. Pest Conf. (R. M. Timm and R. H. Schmidt, Eds.)
Published at Univ. of Calif., Davis. 2002. Pp. 161-169.

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[a]	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})

[a] 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[a]:		
		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)*

[a] 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[a]:		
		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)*

[a] 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 aide 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% 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 Budgey 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 geese 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).

ACKNOWLEDGEMENTS

This research was supported by the FAA, William Hughes Technical Center, Atlantic City, New Jersey under agreement DTFA03-99-X-90001. Opinions expressed in this study do not necessarily reflect current FAA policy decisions regarding the control of wildlife on or near airports. We appreciate the support and advice of FAA employees S. Agrawal, E. C. Cleary, and M. Hoven. We gratefully acknowledge the assistance of G. A. Baldassarre, S. C. Barras, G. E. Bernhardt, B. T. MacKinnon, J. L. Seubert, R. J. Sowden, and R. A. Stehn who provided body mass and population data and advice on the manuscript. S. E. Wright assisted with the analysis of bird strike data.

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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 adamsii*			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 artica*			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		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 albifrons*	5.96	5.41		7.10	USFWS (2001a)
Wood stork	*Mycteria 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)	Population Status				Comments
			Years Covered	Trend	MAPC[a]	Pop. Estimate[b]	
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 (200
3	California condor	22.28	1987-2002	Increase		58	Wild pop. increased from 0 (1987) to 58 (Jan 2002); 125 captive
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	15.65	1970-2001	Increase	1.7	189,000	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	12.13	1996, 2001	Unknown		~25,000	Alaska pop. estimated at ~3,000 in 2001
10	Bald eagle	11.79	1966-2000	Increase	8.0	100,000	Breeding pop. in contiguous USA:1,582 (1974), 11,896 (1998)
11	Golden eagle	10.83	1980-2000	Increase	4.8		
12	Canada goose	9.22	1966-2000	Increase	10.5	4,900,000	Estimate for resident USA population is about 3,000,000
13	Common loon	9.11	1966-2000	Increase	2.9	>500,000	Majority of pop.is in Canada; USA pop. >20,000
14	Brown pelican	8.16	1980-2000	Increase	2.1	93,000	Breeding pop. in USA
15	Greater flamingo	7.80	1970s-2000	Increase		>245,000	Caribbean Islands, coastal Yucatan & Venezuela
16	Snow goose[c]	7.61	1980-2000	Increase	3.1	3,927,000	Greater (eastern) subspecies has MAPC of 8.2 %, 1970-2000
17	Arctic loon	7.40	2001	Unknown		>100	About 100 individuals nest in extreme W and NW Alaska
18	Laysan albatross	7.12	1962-1995	Increase	4.4	>775,708	Estimate for Midway Atoll (71% of total pop in 1996)
19	Greater sage grouse	7.03	1980-1999	Decline		>140,000	Estimated decline from 1980 to 1999 was 35-80%.
20	Black-footed albatross	6.94	1958-1998	Increase	2.2	>170,000	Pop. trend estimate for Midway Atoll (40,480 birds in 1998)
21	Northern gannet	6.76	1959-1988	Increase	6.1	155,000	Pop. trend estimate for 1959-1988, pop. estimate for 2001
22	Emperor goose	6.05	1984-2001	Stable		84,000	
23	Greater white-fronted goose	5.96	1980-2001	Increase	8.2	1,375,000	Trend is for Pacific pop.; total pop for Pacific & Mid-continent
24	Wood stork	5.96	1983-2000	Increase	>2.4	>32,000	USA pop. is about 12,000
25	Great blue heron	5.68	1966-2001	Increase	2.4	>83,000	Breeding pop. only
26	Red-faced cormorant	5.57	2001	Stable		<50,000	Breeding pop. only
27	Double-crested cormorant	5.15	1966-2000	Increase	10.1	>744,000	Gr. Lakes nesting pop. increased from <200-190,000, 1972-1997
28	Great cormorant	5.03	2001	Unknown		11,600	Breeding pop. only
29	Snowy owl	5.02	1959-1988	Stable		>20,000	20,000 estimated on Banks Is., Canada (64,000 km^2) in 1950s
30	Common eider	4.89	2000	Unknown		>600,000	Winter population estimate is 600,000-750,000
31	Black vulture	4.79	1966-2000	Increase	2.7		
32	Brandt's cormorant	4.64	2001	Stable		151,000	
33	Masked booby	4.62	2001	Unknown		~100,000	Body mass data from Hawaii; Pop. data from Caribbean/Hawaii
34	Pelagic cormorant	4.48	1966-2000	Stable		130,000	
35	Turkey vulture	4.21	1966-2000	Increase	1.5		
36	Great black-backed gull	4.03	1966-2000	Decline	-2.0	121,000	Breeding population

[a] 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).

[b] Most recent population estimate for most species represents adult breeding population and does not include subadult birds.

[c] 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 behavior[a]	Reported strikes			
			Total strikes	Strikes causing damage[b]	Strikes involving >1 bird[c]	Strikes involving >1 bird causing damage
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	3	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	0	0	0
Common eider	4.89	Strong flocking	2	2	2	1 (50)
Greater white-fronted goose	5.96	Strong flocking	1	1	1	0
Great cormorant	5.03	Strong flocking	1	1	1	1 (100)
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
Laysan 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)[d]			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.