AMPLIFIED BIRD-STRIKE RISKS RELATED TO POPULATION INCREASES OF LARGE BIRDS IN NORTH AMERICA

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Abstract

Bird-aircraft collisions (bird strikes) are an increasing safety and economic concern to the civil aviation industry worldwide, costing well over $1 billion each year. To reduce risks associated with strikes, the U.S. 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 for most components. We determined that 36 of the approximately 650 bird species that nest in North America have average body masses greater than 4 lbs. Of the 31 species for which population trend data were available, 24 (77%) showed population increases over the past 20-40 years, only 2 showed declines and 5 were stable. Of most importance, 13 of the 14 species with body masses over 8 lbs (3.64 kg) showed population increases. At least 294 strikes with >4-lb birds caused substantial damage to civil aircraft in the USA, 1990-2002; 30% of these strikes involved multiple birds. Over 6,022 strikes occurred at heights >1,000 feet above ground level of which at least 1,986 (33%) involved >4-lb birds. We conclude that airworthiness standards, as well as proposals to allow high-speed (>250 knots [288 miles/hour]) operations below 10,000 feet, should be reevaluated to address the threat posed by increased populations of large flocking birds. Also, increased research and development is needed in the deployment of bird-detecting radar to warn pilots of flocks of migrating birds and in techniques to make aircraft more visible to birds. Finally, wildlife biologists should increase efforts to reduce or disperse populations of these large birds in airport environments. For certain overabundant large species such as non-migratory Canada geese (*Branta Canadensis*), management programs may be needed to reduce populations regionally.

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

1. Introduction

Aircraft collisions with birds (bird strikes) are a serious economic and safety problem. Cleary et al. (2002) estimated wildlife strikes (98% involving birds) cost the civil aviation industry in the USA over $400 million/year, 1990-2001. ALLAN & OROSZ (2001) 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 1990-2002 (THORPE 1996, 1998, RICHARDSON & WEST 2000; DOLBEER, unpublished data).

About 71% of bird strikes to civil aircraft occur below 500 feet above ground level (AGL) 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 & 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, including shielding of important aircraft systems, that ensure aircraft can operate safely in the event of a bird strike. A third component involves the restriction of airspeeds to 250 knots (288 miles/hour) below 10,000 feet when birds are present (Code of Federal Regulations 2002).

The U.S. 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 engines currently in service. The engine does not have to keep operating after a 4-lb bird ingestion to pass these standards; rather, the engine must contain the damage, not catch fire, and be capable of shut-down [*Tabel 1*]. MACKINNON et al. (2001) provide a more detailed discussion of airworthiness standards related to bird strikes.

Aggressive programs by natural resource and environmental organizations during the past 30 years (e.g. pesticide regulation, expansion of wildlife refuge systems, wetlands restoration), coupled with land-use changes, have resulted in dramatic increases in populations of many wildlife species in North America (DOLBEER 2000) and Europe (BUURMA 1996, ALLAN & FEARE 1996). In addition, certain of these wildlife species that are a proven threat to aviation, such as Canada geese (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 (e.g. MACKINNON et al. 2001, ESCHENFELDER 2001), an FAA/European Joint Aviation Authority (JAA) working group (Aviation Rulemaking Advisory Committee) has proposed a new standard requiring future large engines to demonstrate 20 minutes of run-on after ingestion of an 8-lb bird. Finally, these population increases of large birds should be factored into risk analyses regarding proposals to allow commercial aircraft to use high-speed (over 250 knot) operations below 10,000 feet to facilitate air traffic flow (Code of Federal Regulations 2002, National Transportation Safety Board 1999).

To help clarify these issues, 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, 1990-2002 and the damage characteristics of these strikes. Finally, we determined the reported number

of strikes at heights from 1,000-10,000 feet and above 10,000 feet AGL for all bird species and for species >4 lbs. 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.

2. 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 1966-2001 for BBS data, 1970-2001 for CBC data; SAUER et al. 2002, National Audubon Society 2003a). 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 (1995-2002) population estimate (BELANT & 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 and characteristics of reported strikes to civil aircraft in the USA involving these species, 1990-2002 (CLEARY et al. 2002, S.E. WRIGHT, U.S. Department of Agriculture, unpublished data).

3. Results

3.1 Population increases of large birds

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.

3.2 Flocking characteristics of large birds

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

3.3 Reported bird strikes with large birds

Twenty-one of the 36 species were identified as involved in a total of 1,234 reported strikes with civil aircraft in the USA, 1990-2002 [*Appendix 3*]. In addition, there were 561 strikes reported that involved >4-lb birds (i.e. geese, vultures, eagles, pelicans, swans, cormorants, albatrosses, cranes, loons) in which the species was not identified. In these 1,795 reports of strikes with >4-lb birds, 894 (50%) indicated damage and 294 (16%) indicated substantial damage to the aircraft [*Table 3*]. Multiple birds were involved in 536 (30%) of the reported strikes. Birds with body masses >8 lbs were involved in 1,205 strikes of which 615 (51%) indicated damage and 190 (15%) indicated substantial damage. Multiple birds were involved in 468 (39%) of the strikes with >8-lb species. Sixteen (76%) of the 21 struck species with body masses >4 lbs have exhibited population increases; all 9 (100%) of the struck species with body masses >8 lbs showed population increases. Nineteen (90%) of the 21 struck species exhibit strong (14) or limited (5) flocking behavior.

3.4 Reported bird strikes with large birds at heights >1,000 feet AGL

From 1990-2002, 6,022 (19%) of the 31,453 reported bird strikes (where height AGL was indicated) were at heights >1,000 feet AGL [*Table 4*]. The species or species group was identified in only 1,299 (22%) of these 6,022 cases. Because 427 (33%) of the 1,299 identified birds were species with body masses >4 lbs, we estimate that 1,559 (33%) of the 4,723 unknown birds struck at >1,000 feet AGL were species with body masses >4 lbs. Thus, we projected that a total of 1,986 reported strikes at >1,000 feet AGL involved >4-lb birds and that 1,963 of these strikes occurred between 1,001-10,000 feet. Substantial damage was indicated in 313 of the strikes above 1,000 feet, with 95% (298) of these substantial-damage strikes occurring between 1,001-10,000 feet. The 3,000-foot vertical zone between 1,001 and 4,000 feet contained 75% of the strikes within the 9,000-foot zone from 1,001 to 10,000 feet.

4. Discussion

Populations of most large (>4-lb) bird species in North America, including at least 13 of the 14 species with body masses >8 lbs, have shown substantial increases during the past 20-40 years. A few of these species, such as sage grouse and yellow-billed loons, are unlikely to be struck by aircraft. However, many of these large species, such as Canada geese, turkey vultures, great blue herons, bald eagles, snow geese, brown pelicans, sandhill cranes, and double-crested cormorants, have been struck numerous times during the past 13 years in the USA. These strikes have often involved multiple birds and substantial damage. We also note that 57% the 45,341 bird-strike reports in the FAA Wildlife Strike Database, 1990-2002, list the species struck as unknown (see 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 [*Tables 3, 4, Appendix 3*] should be considered an index of strikes and not an actual measure of strike rates. Undoubtedly, there have been many strikes with >4-lb birds (including some of the 15 species with no strikes recorded) that either have not been reported or reported as unknown species. Finally, we note that population increases of large-bird species have not been restricted to North America. Populations of large species such as great cormorants and Canada geese have shown dramatic increases in Europe over the past decade (BUURMA 1996, ALLAN & FEARE 1996).

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.

Yet, our data for 1990-2002 indicate 30% of strikes with >4-lb birds and 39% of strikes with >8-lb birds have involved multiple birds (see also BUDGEY & 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. Such an incident occurred with a Boeing 707 (E-3 AWACS) aircraft that crashed at Elmendorf Air Force Base, Alaska, after ingesting Canada geese into 2 engines during take off in 1995 (CLEARY &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. 2002) should be invaluable in objectively guiding decisions regarding bird-strike airworthiness standards for transport, commuter, and general-aviation aircraft (e.g. MARTINDALE & 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 1999). Furthermore, even if standards are revised and engineering improvements are made, it will be impossible to completely “bird-proof” engines and airframes against high-speed collisions with birds of large mass or flocks of smaller birds. For example, a 4-lb bird struck by a transport aircraft going 150 knots generates about 14,000 lbs of impact force whereas the same airplane striking the same bird at 250 and 350 knots generates impact forces of about 38,000 and 74,000 lbs, respectively (MACKINNON et al. 2001). A collision with a 15-lb bird at these respective speeds generates forces of 20,000, 57,000 and 111,700 lbs. Obviously, if airframe and engine design cannot be altered, the manner in which the aircraft are operated must be changed.

Proposals to allow commercial aircraft to use high-speed (over 250 knot) operations below 10,000 feet AGL to facilitate air traffic flow (National Transportation Safety Board 1999) should be reevaluated in light of the documented increase in populations of large-mass birds and the substantial number of bird strikes that occur between 1,000-10,000 feet (5,792 reported for civil aircraft in USA since 1990 of which an estimated 1,963 involved >4-lb birds and at least 101 resulted in substantial damage to the aircraft). Because of a fundamental relationship between energy (e), mass (m), and velocity (v) expressed in the equation $e = ½ mv^2$, 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 (e.g. from 250 to 300 knots) results in a 44% increase in energy imparted. An incident in which a Boeing 727 aircraft was heavily damaged after striking 3-5 snow geese at 6,000 feet during a high-speed (280-knot) departure from Houston, Texas in January 1998 confirmed the danger to aircraft of high-speed impacts with large birds (CLEARY & DOLBEER 1999).

Another potential means of reducing strikes with large birds involves the enhancement of sensory cues emitted by aircraft that are relevant to birds (e.g. light at certain pulse rates or wavelengths). Previous research has indicated that birds are less able to avoid quieter, modern jet aircraft (Chapter 3, International Civil Aviation Organization 1993) than older, noisier (Chapter 2) aircraft (BURGER 1983, KELLY et al. 1999). With quieter aircraft in operation today (Chapter 2 aircraft engines will be phased out by 2005), new technologies are needed to enhance the visibility of aircraft to birds. Research into the behavioral response of birds to approaching aircraft (KELLY et al. 1999) and avian vision (BLACKWELL 2002) may lead to practical methods of enhancing the ability of birds to avoid aircraft. Finally, it is imperative that aviation regulatory agencies worldwide develop and maintain rigorous standards for bird-hazard management programs at airports that emphasize the threat posed by birds and the need to minimize their presence in the airport environment

(CLEARY & DOLBEER 1999, DOLBEER et al. 2000). Aggressive management programs at airports carried out by professional biologists have been successful in reducing strikes (e.g. DOLBEER 1999). For certain overabundant large species, such as non-migratory Canada geese in North America, management programs may be needed to reduce populations regionally (COOPER & KEEFE, 1997). In addition, 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 & MACKINNON 2001).

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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 (summarized from MacKinnon et al. 2001)*

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 V_C
Transport	Windshield	Part 25.775	1977	4	Withstand impact of 4-lb bird w/o penetration at Vc
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 [see Appendices 2, 3]*

Body-mass category	Number of species	*Species exhibiting population:*				Species exhibiting[a]:		
		In-crease	De-crease	Sta-bility	Un-known	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. *Number of reported strikes and damaging strikes to civil aircraft in USA from 1990-2002 for species of birds in North America that have mean body mass >4 lbs [see Appendix 3 and CLEARY et al. (2002) for more detailed data on individual species]*

Species group	Reported strikes			
	Total number	**With damage**	**With substantial damage [a]**	**No. (%) involving >1 bird [b]**
Total (all strikes with species or species group >4 lbs) [c]	1,795	894	294	536 (30)
Total (all strikes with species or species group >8 lbs) [c]	1,205	615	190	468 (39)

[a] 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).

[b] Twenty-six strike reports (18 for birds >8 lbs) did not indicate whether or not multiple birds were involved. These reports were excluded from total strikes when calculating percent of strikes involving >1 bird.

[c] Assuming all albatross, vulture and cormorant strikes in which the species was not identified were with birds >4 lbs and all unidentified swan, pelican, eagle, crane, loon, and goose strikes were with birds >8 lbs.

Table 4. *Number of reported bird strikes with civil aircraft at heights >1,000 feet above ground level (AGL) for all birds and for identified species with mean body masses >4 lbs, USA, 1990-2002. In addition to the data presented in this table, there were 25,431 reported strikes at 0-1,000 feet AGL and 13,888 reported strikes in which height was not indicated.*

Height (feet AGL)	Number of reported strikes (all birds) [a]			Number of reported strikes (identified species with body mass >4 lbs) [b]		
	Total	With damage	With substantial damage [c]	Total	With damage	With substantial damage [c]
1,001-2,000	2,288	587	138	195	147	48
2,001-3,000	1,340	337	92	118	91	30
3,001-4,000	691	148	31	42	29	9
4,001-5,000	495	99	13	24	20	6
5,001-6,000	354	75	6	17	9	3
6,001-7,000	239	47	6	11	8	3
7,001-8,000	169	38	6	8	5	2
8,001-9,000	91	20	4	4	2	0
9,001-10,000	125	28	2	3	2	0
(1,001-10,000)	**5,792**	**1379**	**298**	**422**	**313**	**101**
>10,000	230	93	15	5	4	0
Total (>1,000)	**6,022[a]**	**1472**	**313**	**427 [a]**	**317**	**101**

[a] Of the 6,022 bird strikes reported at heights >1,000 feet AGL, the species or species group was identified in only 1,299 cases (22%) and was classified as unknown bird in 4,723 cases (78%). Because 427 (33%) of the 1,299 identified birds were species with body masses > 4 lbs, we estimate that 1,559 (33%) of these 4,723 unknown birds were species with body masses >4 lbs. Thus, we estimate a total of 1,986 reported strikes at >1,000 feet AGL involved birds >4 lbs and that 1,963 of these strikes occurred between 1,001-10,000 feet.

[b] Includes all strikes with vultures, cormorants, swans, pelicans, eagles, albatrosses, and geese that were not identified to species.

[c] See footnote [a] in *Table 3*.

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	Fe-male	Unk sex	Maxi-mum	
Mute swan	*Cygnus olor*	26.0	21.3		31.3	NELSON (1999), PERRY et al. (2001), PETRIE (2002), SAUER et al. (2002)
Trumpeter swan	*Cygnus buccinator*	25.1	22.7			CAITHAMER (2001)
California condor	*Gymnogyps californianus*	22.3			31.3	California Department of Fish and Game (2002)
Wild turkey	*Meleagris gallopavo*	16.3	9.3			DICKSON (2001), National Wild Turkey Federation (2003)
Tundra swan	*Cygnus columbianus*	15.7	13.7		21.2	U.S. Fish and Wildlife Service (2002)
American white pelican	*Pelecanus erythrorhynchos*			15.4	30.0	Sauer et al. (2002), KUSHLAN et al. (2002)
Whooping crane	*Grus americana*			12.8	14.0	MEINE & ARCHIBALD (1996), U.S. Geological Survey (2003)
Sandhill crane	*Grus canadensis*	12.8	11.8		14.8	MEINE & ARCHIBALD (1996), SAUER et al. (2002),), International Crane Foundation (2003)
Yellow-billed loon	*Gavia adamsii*			12.1	14.1	EARNST (2001)
Bald eagle	*Haliaeetus leucocephalus*	9.1	11.8		14.1	BUEHLER (2000), SAUER et al. (2002), U.S. Fish and Wildlife Service (2003a)
Golden eagle	*Aquila chrysaetos*	7.7	10.8			SAUER et al. (2002)
Canada goose	*Branta canadensis*	9.2	7.8		10.4	SEUBERT (2002), SAUER et al. (2002), U.S. Fish and Wildlife Service (2002)
Common loon	*Gavia immer*			9.1	9.9	MCINTYRE & BARR (1997), SAUER et al. (2002),
Brown pelican	*Pelecanus occidentalis*	8.2	8.1			SAUER et al. (2002), KUSHLAN et al. (2002)
Greater flamingo	*Phoenicopterus ruber*	7.8	5.6		9.0	ESPINOZA et al. (2000), BALDASSARRE & AGENGO (2000)
Snow goose	*Chen caerulescens*	7.6	6.8			U.S. Fish and Wildlife Service (2002)
Arctic loon	*Gavia artica*			7.4	7.5	North American Loon Fund (2001)
Laysan albatross	*Phoebastria immutabilis*	7.1	6.3		9.0	FISHER (1966), Dolbeer et al. 1996, U.S. Fish and Wildlife Service (2003b), N. A. Waterbird Conservation Plan (2001)
Greater sage grouse	*Centrocercus urophasianus*	7.0	3.9			Braun (1999)
Black-footed albatross	*Phoebastria nigripes*			6.9		Rice (1959), U.S. Fish and Wildlife Service (2003b), KUSHLAN et al. (2002)
Northern gannet	*Morus bassanus*	6.5	6.8		8.0	National Audubon Society (2003a), KUSHLAN et al. (2002)
Emperor goose	*Chen canagica*			6.1	6.9	U.S. Fish and Wildlife Service (2002)
Greater white-fronted goose	*Anser albifrons*	6.0	5.4		7.1	U.S. Fish and Wildlife Service (2002)
Wood stork	*Mycteria americana*	6.0	4.5			University of Georgia (2003), KUSHLAN et al. (2002)

Continued

Appendix 1 (Continued)

Common name	Scientific name	Mean body mass (lbs)				Source of information on population status
		Male	Fe-male	Unk sex	Maxi-mum	
Great blue heron	*Ardea herodias*	5.7	4.9			SAUER et al. (2002), KUSHLAN et al. (2002)
Red-faced cormorant	*Phalacrocorax urile*	5.6	3.9		5.6	KUSHLAN et al. (2002), National Audubon Society (2003b)
Double-crested cormorant	*Phalacrocorax auritus*	5.2	4.5		6.4	TYSON et al. (2000), SAUER et al. (2002), KUSHLAN et al. (2002)
Great cormorant	*Phalacrocorax carbo*	5.0	4.3		5.9	KUSHLAN et al (2002)
Snowy owl	*Nyctea scandiaca*	4.0	5.0		6.5	PARMELEE (1992), National Audubon Society (2003a)
Common eider	*Somateria mollissima*	4.9	4.2		6.4	GOUDIE et al. (2000)
Black vulture	*Coragyps atratus*	4.8	4.4			SAUER et al. (2002)
Brandt's cormorant	*Phalacrocorax penicillatus*			4.6		AINLEY et al. (1994), KUSHLAN et al. (2002)
Masked booby	*Sula dactyl latra*	4.1	4.6		5.2	KUSHLAN et al. (2002)
Pelagic cormorant	*Phalacrocorax pelagicus*	4.5	3.8		5.4	AINLEY et al. (1994), Hobson (1997), Sauer et al. (2002), KUSHLAN et al (2002)
Turkey vulture	*Cathartes aura*	4.0	4.2		4.7	SAUER et al. (2002)
Great black-backed gull	*Larus marinus*	4.0	3.3		5.0	SAUER et al. (2002), KUSHLAN et al (2002)

Appendix 2. *Population status for 36 bird species in North America that have mean body mass for at least 1 gender >4 lbs [see Appendix 1 for detailed mass data and sources of information]*

Rank	*Species*	Mean mass (lb)	*Population status*				Comments
			Years covered	Trend	MAPC[a]	Most recent population estimate[b]	
1	Mute swan	26.0	1966-2001	Increase	9.6	22,600	Maryland population increased from 5 (1962) to 4,500 (2001)
2	Trumpeter swan	25.1	1968-2000	Increase	5.9	23,647	Population increased from about 3,722 (1968) to 23,647 (2000)
3	California condor	22.3	1987-2002	Increase		74	Wild population increased from 0 (1987) to 74 (Nov 2002); 126 captive
4	Wild turkey	16.3	1959-2000	Increase	6.0	5,400,000	Population increased from 500,000 (1959) to 5,400,000 (2000)
5	Tundra swan	15.7	1970-2002	Increase	2.0	163,000	Both western and eastern population are increasing
6	American white pelican	15.4	1980-2001	Increase	3.5	>120,000	USA population had 5.6% MAPC, USA/Canada breeding population estimate
7	Whooping crane	12.8	1966-2002	Increase	5.6	297	Wild population increased from 42 in 1966 to 297 in 2002
8	Sandhill crane	12.8	1966-2001	Increase	6.8	650,000	
9	Yellow-billed loon	12.1	1996, 2001	Unknown		~25,000	Alaska population estimated at ~3,000 in 2001
10	Bald eagle	11.8	1966-1999	Increase	8.5	100,000	Breeding population in contiguous USA:1,582 (1974), 12,208 (1999)
11	Golden eagle	10.8	1980-2001	Increase	3.8		
12	Canada goose	9.2	1966-2002	Increase	10.5	5,377,000	Estimate for resident USA population is about 3,500,000
13	Common loon	9.1	1966-2001	Increase	2.7	>500,000	Majority of population is in Canada; USA population >20,000
14	Brown pelican	8.2	1980-2001	Increase	5.9	193,000	
15	Greater flamingo	7.8	1970s-2000	Increase		>245,000	Caribbean Islands, coastal Yucatan and Venezuela
16	Snow goose[c]	7.6	1980-2002	Increase	3.5	3,883,000	Greater (eastern) subspecies has MAPC of 7.5 %, 1970-2001
17	Arctic loon	7.4	2001	Unknown		>100	About 100 individuals nest in extreme W and NW Alaska
18	Laysan albatross	7.1	1962-1995	Increase	4.4	1,00,000	776,000 estimated at Midway Atoll in 1996
19	Greater sage grouse	7.0	1980-1999	Decline		>140,000	Estimated decline from 1980 to 1999 was 35-80%.
20	Black-footed albatross	6.9	1958-1998	Increase	2.2	>148,000	Population trend estimate for Midway Atoll (40,480 birds in 1998)
21	Northern gannet	6.8	1970-2001	Increase	13.2	155,000	Population estimate for 2001
22	Emperor goose	6.1	1984-2002	Stable		59,000	
23	Gr. white-fronted goose	6.0	1979-2002	Increase	7.2	1,070,000	Trend is for Pacific population; total population for Pacific and Mid-continent
24	Wood stork	6.0	1983-2000	Increase	>2.4	>32,000	USA population is about 12,000
25	Great blue heron	5.7	1966-2001	Increase	2.2	>83,000	Breeding population only

Continued

Appendix 2 (continued)

Rank	*Species*	Mean mass (lb)	*Population status*				Comments
			Years covered	Trend	MAPC[a]	Most recent population estimate[b]	
26	Red-faced cormorant	5.6	2001	Stable		130,000	Breeding population estimated at <50,000
27	Double-cr. cormorant	5.2	1966-2001	Increase	10.3	>744,000	Great Lakes nesting population increased from <200 in 1972 to 230,000 in 2000
28	Great cormorant	5.0	2001	Unknown		11,600	Breeding population only
29	Snowy owl	5.0	1970-2001	Stable		>20,000	20,000 estimated on Banks Island, Canada (64,000 km^2) in 1950s
30	Common eider	4.9	2000	Unknown		>600,000	Winter population estimate is 600,000-750,000
31	Black vulture	4.8	1966-2001	Increase	2.8		
32	Brandt's cormorant	4.6	2001	Stable		151,000	
33	Masked booby	4.6	2001	Unknown		~100,000	Body mass data from Hawaii; Population data from Caribbean/Hawaii
34	Pelagic cormorant	4.5	1966-2001	Stable		130,000	
35	Turkey vulture	4.2	1966-2001	Increase	1.5		
36	Great black-backed gull	4.0	1966-2001	Decline	-2.1	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 & DOLBEER 1993).

[b] 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 = 6.1 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 lbs ranked by number of reported strikes to civil aircraft in USA from 1990-2002 involving these species.*

Species	Mean mass (lb)	Flocking/ soaring behavior [a]	Reported strikes			
			Total number	With damage	With sub-stantial damage[b]	No. (%) involving >1 bird [c]
Canada goose	9.2	Strong flocking	668	339	112	297 (45)
Turkey vulture	4.2	Limited flocking/soaring	157	93	33	9 (6)
Great blue heron	5.7	Limited flocking	105	18	3	2 (2)
Snow goose	7.6	Strong flocking	45	33	17	23 (51)
Bald eagle	11.8	Limited flocking/soaring	45	17	2	5 (11)
Sandhill crane	12.8	Strong Flocking	42	16	6	14 (34)
Great black-backed gull	4.0	Strong flocking	32	5	5	1 (5)
Snowy owl	5.0	Solitary	32	3	2	0
Wild turkey	16.3	Strong flocking (on ground)	24	5	1	3 (13)
Double-crested cormorant	5.6	Strong flocking	23	11	5	4 (17)
Brown pelican	8.2	Strong flocking	22	11	2	2 (10)
Black vulture	4.8	Strong flocking	15	8	5	3 (20)
Common loon	9.1	Limited flocking	7	4	2	0
Tundra swan	15.7	Strong flocking	3	3	3	2 (67)
Greater white-fronted goose	6.0	Strong flocking	3	3	3	1 (33)
Mute swan	26.0	Strong flocking	2	0	0	1 (50)
Golden eagle	10.8	Solitary/soaring	2	1	1	0
Wood stork	6.0	Strong flocking	2	0	0	0
Common eider	4.9	Strong flocking	2	2	2	1 (50)
Great cormorant	5.0	Strong flocking	2	1	1	2 (100)
Pelagic cormorant	4.5	Strong flocking	1	0	0	0
Trumpeter swan	25.1	Strong flocking	0	0	0	0
California condor	22.3	Solitary /soaring	0	0	0	0
American white pelican	15.4	Strong flocking	0	0	0	0
Whooping crane	12.8	Strong flocking	0	0	0	0
Yellow-billed loon	12.1	Limited flocking	0	0	0	0
Greater flamingo	7.8	Strong flocking	0	0	0	0
Arctic loon	7.4	Limited flocking	0	0	0	0
Laysan albatross	7.1	Strong flocking	0	0	0	0
Greater sage grouse	7.0	Limited flocking (on ground)	0	0	0	0
Black-footed albatross	6.9	Strong flocking	0	0	0	0
Northern gannet	6.8	Strong flocking	0	0	0	0
Emperor goose	6.0	Strong flocking	0	0	0	0
Red-faced cormorant	5.6	Strong flocking	0	0	0	0
Brandt's cormorant	4.6	Strong flocking	0	0	0	0
Masked booby	4.6	Limited flocking	0	0	0	0
Total (all strikes identified to species)			**1,234**	**573**	**205**	**370 (30)**

Continued

Appendix 3 (continued)

Species	Mean mass (lb)	Flocking/ soaring behavior [a]	Reported strikes			
			Total number	With damage	With sub-stantial damage [b]	No. (%) involving >1 bird [c]
Geese (unknown species)	>8	Strong flocking	359	204	53	140 (40)
Vultures (unknown species)	>4	Limited flocking/soaring	167	100	28	21 (13)
Cranes (unknown species)	>8	Strong flocking	12	4	1	2 (18)
Eagles (unknown species)	>8	Limited flocking/soaring	8	4	2	2 (25)
Pelicans (unknown species)	>8	Strong flocking	6	3	2	0
Swans (unknown species)	>8	Strong flocking	2	1	0	0
Cormorants (unknown species)	>4	Strong flocking	3	1	0	1 (33)0
Loons (unknown species) (	>8	Limited flocking	3	3	3	0
Albatrosses (unknown species)	>4	Strong flocking	1	1	0	0
Total (all strikes with species or species group >4 lbs)			**1,795**	**894**	**294**	**536 (30)**
Total (all strikes with species or species group >8 lbs) [d]			**1,205**	**615**	**190**	**468 (39)**

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

[d]

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