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Original Article

Wildlife Strikes With Military Rotary-Wing Aircraft During Flight Operations Within the United States

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ABSTRACT Wildlife–aircraft collisions (wildlife strikes) with civilian and military aircraft pose notable risks and economic losses. The 4 military services within the U.S. Department of Defense maintain records regarding wildlife strikes with military aircraft. Although rotary-wing aircraft operations comprise important mission components within all 4 military services, no assessment of wildlife strikes to military rotary-wing aircraft has been conducted. The objectives of this project were to 1) conduct a comprehensive analysis of data available from all military services regarding wildlife strikes with rotary-wing aircraft, and 2) provide recommendations to reduce the frequency and negative impacts of these strikes. We acquired all available wildlife strike records and parsed our database to include only wildlife strikes to military rotary-wing aircraft occurring within the contiguous United States, Alaska, Hawaii, or within near-shore areas along the coasts. We assessed the effects of year, month, time of day, event location (i.e., on- or off-airfield), and wildlife group involved on the frequency of wildlife strikes with rotary-wing aircraft. The frequency of wildlife strikes was highest during autumn (Sept–Nov; 41.6% of all strikes) and lowest during winter (Dec–Feb; 10.4%). Wildlife strikes occurred most often when aircraft were traveling en route (38.3%) or were engaged in terrain flight (28.9%). Raptors and vultures were commonly associated with wildlife strikes that caused damage to aircraft. Wildlife strikes to military rotary-wing aircraft during flight operations within the United States are both costly (averaging US$12,184–$337,281/strike event among the military services) and deadly (2 pilots were killed). Published 2014. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS airfields, helicopters, military, rotary-wing aircraft, wildlife strikes.

Wildlife collisions with aircraft (of which 97% involve birds) pose increasing risks and economic losses to aviation worldwide. Annual economic losses from such strikes with civil aircraft are conservatively estimated to exceed US$1.2 billion worldwide and US$718 million in the United States (U.S.) alone (Allan 2002, Dolbeer et al. 2012). The U.S. military also incurs substantial losses from wildlife strikes. From 1985 to 1998, bird strikes cost the U.S. Air Force (USAF) alone an average of US$35 million annually (Zakrajsek and Bissonette 2005). Worldwide, wildlife strikes have resulted in the loss of >276 human lives and >200 military and civil aircraft since 1988 (Thorpe 2010, Dolbeer et al. 2012).

Patterns and characteristics of wildlife strikes likely vary among types of aircraft (i.e., between fixed-wing and rotary-wing aircraft). A fixed-wing aircraft is a vehicle capable of flight using wings that generate vertical lift due to forward airspeed (typically produced by an engine) and the shape of the wings (Montgomery and Foster 2006). A rotary-wing aircraft is supported in flight using lift generated by wings, called rotor blades, which revolve around and are typically mounted on a single mast (e.g., rotor; Montgomery and Foster 2006). Helicopters are the most common class of rotary-wing aircraft, both in the military and civilian applications. A tilt-wing aircraft, such as the Bell-Boeing V-22 Osprey (Bell Helicopter Textron, Hurst, TX and Mobility Division of Boeing Military Aircraft, Ridley Park, PA), is an aircraft that uses a pair of powered rotors mounted on rotating shafts for lift and propulsion (Eden 2004, Montgomery and Foster 2006). For the purposes of this report, we classified tilt-wing aircraft as rotary-wing aircraft.

Several examinations of wildlife strikes with fixed-wing aircraft (both civilian and military) have been conducted (examples include Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, DeVault et al. 2011, Dolbeer et al. 2012). Previous studies of fixed-wing aircraft (Dolbeer 2006, 2011) and civil helicopters (Washburn et al. 2013) have shown that clear differences exist in patterns of wildlife strikes occurring within airport environments (i.e., on-airfield) and those that

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occur while aircraft are traveling away from an airfield (i.e., off-airfield). Furthermore, management practices to reduce the frequency and severity of wildlife strike events within airport environments and those occurring away from airfields vary in regard to applicability (Dolbeer 2011, DeVault et al. 2013).

Although rotary-wing aircraft operations comprise important mission components of all 4 military services, no assessment of wildlife strike to military rotary-wing aircraft has been conducted. Thus, our purpose was to provide a comprehensive analysis of wildlife strikes to rotary-wing aircraft among all military services so as to provide an understanding of the nature and extent of this issue. The objectives of this project are to 1) compare the number of wildlife strikes within the United States to rotary-wing aircraft from all 4 U.S. military services among years, months, time of day, geographic locations, aircraft categories, aircraft phases of flight, wildlife groups involved, and strike event location (i.e., on- vs. off-airfield); and 2) provide recommendations for reducing the frequency and negative impacts of wildlife strikes to military flight operations.

METHODS

We acquired all available wildlife strike records to rotary-wing aircraft from the 4 military services (i.e., U.S. Army [ARMY] during 1990–2011, USAF during 1994–2011, U.S. Navy and U.S. Marine Corps [NAVY] during 2000–2011, and U.S. Coast Guard [USCG] during 1979–2011). In addition, we reviewed narrative records and other information regarding wildlife strikes and created a new inclusive strike database. We conducted a line-by-line review of each wildlife strike record in the inclusive database to ensure data integrity and consistency. Because of the diverse nature of the data fields contained within the military databases, we also extracted data from narrative records, accident reports, and incident information (e.g., pilot commentary). We examined each wildlife strike record and (when possible or necessary) recoded or classified wildlife strike information to allow for consistency in terminology or categories among military services strike records for variables (e.g., the phase of flight the aircraft was in when the wildlife strike occurred). We parsed our inclusive database to include only wildlife strikes to military rotary-wing aircraft that occurred within the contiguous United States, Alaska, Hawaii, or within near-shore areas along the coasts (i.e., <16 km from the U.S. coastline). Many wildlife strike reports were incomplete and specific fields of information were missing, unknown, or we were unable to effectively obtain the information from report narratives; thus, sample sizes varied for individual variables and among specific analyses.

We determined the time of day each wildlife strike event occurred based on the reported local time of the event. Wildlife strikes occurring between 0800 hours and 1800 hours local time were categorized as "day," whereas strike events between 2000 hours and 0600 hours were categorized as "night." "Dawn" strike events occurred during 0600 hours to 0800 hours and "dusk" during 1800 hours to 2000 hours.

The aircraft category for each rotary-wing aircraft was determined from the designation provided for that aircraft (Eden 2004). For example, an AH-64 would be designated into the "attack" category, whereas a CH-47 would be designated into the "cargo" aircraft category. The aircraft category relates the variant for the airframe and the specific configuration of that aircraft (e.g., weapons systems, equipment).

Phase of flight was defined as the phase of flight the aircraft was in at the time the wildlife strike occurred (FAA 2000, U.S. Army 2012). Aircraft in the "en route" phase of flight were flying at an altitude >305 m (1,000 ft) Above Ground Level (AGL). Rotary-wing aircraft that were flying (moving forward) at an altitude of ≤305 m AGL were classified as being in "terrain flight." "Hovering" rotary-wing aircraft were off the ground (but ≤305 m AGL) and stationary (i.e., no horizontal movement). Aircraft on "approach" were in early stages of the landing process of landing (at >30.5 m [100 ft] AGL and moving forward), typically on or over an airfield. "Landing" rotary-wing aircraft were in the final stages of landing and were ≤30.5 m AGL. Rotary-wing aircraft that were "taxiing" were moving along the ground or just above the ground (<3.1 m [10 ft] AGL) in a transition from one part of the airfield to another (e.g., traversing from the hanger to an active helipad). Aircraft in the "take-off" phase were in the process of leaving the ground and ascending upward (≤30.5 m AGL). Rotary-wing aircraft in the "climbout" phase were in the later stages of taking off (>30.5 m AGL and moving forward), typically on or over the airfield.

A wildlife strike event was determined to be on-airfield if the aircraft was within the horizontal delineation of an airfield when the strike occurred (if the location was known). Off-airfield strikes were defined as wildlife strike events that were reported to have occurred when the aircraft was not on or flying over an airfield (e.g., an aircraft traveling en route to a specified destination).

If information regarding the identity of the animals involved in a strike event was available within the strike record, the animal(s) involved in each wildlife strike event was assigned to 1 of 28 wildlife groups. In cases where the wildlife involved was actually identified to the species level, we assigned that wildlife strike to the appropriate wildlife group based on the species involved (e.g., Canada geese [*Branta canadensis*] would be assigned to the "Waterfowl" wildlife group). Wildlife groups were based on taxonomic groupings of related wildlife species and families (DeGraff et al. 1985) and species groups used in previous analyses of wildlife strike data (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, DeVault et al. 2011). Wildlife strike events to rotary-wing aircraft involving more than one individual animal (e.g., a flock of birds) were treated the same as wildlife strike events that involved only one animal, because the number of individuals involved was not available from the majority of reported wildlife strikes.

We defined a wildlife strike event as a damaging strike if there was any amount of damage to the rotary-wing aircraft reported. Damaging strikes varied greatly in the amount of actual damage the aircraft incurred, ranging from minor abrasions on the airframe or aircraft component to the complete destruction of the aircraft.

We obtained flight information (i.e., no. of flight-hrs) for rotary-wing aircraft from each of the 4 military services. We summarized these data and determined the total number of flight-hours/year for each military service. In addition, we calculated the proportion of ARMY rotary-wing aircraft flight-hours that occurred during day- and nighttime periods.

Statistical Analyses

Our investigation included identification of temporal and spatial trends in wildlife strikes with military rotary-wing aircraft for each military service. We used linear regression analyses and analysis of variance to examine potential trends in the number of reported wildlife strikes to military rotary-wing aircraft by year (Zar 1996). We used chi-squared analysis (Zar 1996) to compare the number of wildlife strikes with military rotary-wing aircraft of each of the military services among months and times of day. Descriptive statistics were used to quantify the frequency of wildlife strikes that occurred among geographic locations of strikes, aircraft categories, and aircraft phases of flight.

We summarized wildlife strikes occurring on-airfield separately from those that occurred during flight operations "off" airfield. Descriptive statistics were used to quantify the frequency of wildlife strikes that occurred among wildlife groups involved and estimates of the financial costs of wildlife strikes (in US$). We compared the proportion of damaging wildlife strikes relative to all wildlife strikes among the military services using comparison of proportion tests (Zar 1996). Data are presented as mean $\pm$ 1 standard error (SE).

RESULTS

Temporal Patterns in Wildlife Strikes

A total of 2,511 reported wildlife strikes with military rotary-wing aircraft during flight operations within the United States were found within the 4 military services' wildlife strike databases. Of these events, 318 wildlife strikes involved ARMY rotary-wing aircraft, 845 involved NAVY rotary-wing aircraft, 1,071 involved USAF rotary-wing aircraft, and 277 involved USCG rotary-wing aircraft.

An average of 14.5 ($\pm$1.6 SE) wildlife strikes to ARMY rotary-wing aircraft was reported annually during 1990–2011 (Fig. 1). During this 22-year time period, the annual number of strikes to ARMY rotary-wing aircraft decreased ($y = -0.65x + 1{,}320.3$; $R^2 = 0.33$, $F_{1,21} = 10.0$, $P = 0.005$) by 85%. An average of 1,008,645 ($\pm$36,471 SE) flight-hours/year were conducted by ARMY rotary-wing aircraft during 1990–2011.

During 1994–2011, an average of 59.5 ($\pm$5.5 SE) wildlife strikes with USAF rotary-wing aircraft occurred annually (Fig. 2). From 1994 to 2004, the annual number of strikes to USAF rotary-wing aircraft increased ($y = 6.99x - 13{,}924.5$; $R^2 = 0.85$, $F_{1,10} = 52.6$, $P < 0.001$) by 1,030%. However, strikes/year to USAF rotary-wing aircraft decreased ($y = -6.0x - 12{,}119.1$; $R^2 = 0.77$, $F_{1,18} = 16.4$, $P = 0.01$) by 22% during 2004–2010. An average of 59,228 ($\pm$624 SE) flight-hours/year were conducted by USAF rotary-wing aircraft during 1990–2011.

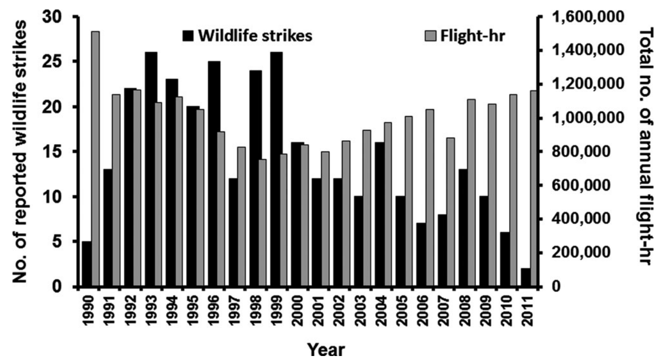

Figure 1. Number of reported wildlife strikes with U.S. Army (ARMY) rotary-wing aircraft in the United States and total number of annual flight-hours by ARMY rotary-wing aircraft during 1990–2011.

An average of 76.8 ($\pm$9.3 SE) wildlife strikes to NAVY rotary-wing aircraft was reported annually during 2001–2011 (Fig. 3). During this 11-year time period, wildlife strikes to NAVY rotary-wing aircraft increased ($y = 7.63x - 15{,}223.5$; $R^2 = 0.67$, $F_{1,10} = 18.4$, $P = 0.002$) by 367%. An average of 718,948 ($\pm$22,789 SE) flight-hours/year were conducted by NAVY rotary-wing aircraft during 2001–2011.

During 1979–2011, an average of 8.5 ($\pm$1.0 SE) reported wildlife strikes with USCG rotary-wing aircraft occurred annually (Fig. 4). Wildlife strikes with USCG rotary-wing aircraft each year remained similar ($y = 0.14x - 272.3$; $R^2 = 0.06$, $F_{1,32} = 2.0$, $P = 0.18$) during this 33-year time period. An average of 75,328 ($\pm$960 SE) flight-hours/year were conducted by USCG rotary-wing aircraft during 1998–2011.

Wildlife strikes with military rotary-wing aircraft varied among months (season) for ARMY ($\chi^2 = 32.2$, df $= 11$, $P < 0.001$), USAF ($\chi^2 = 204.3$, df $= 11$, $P < 0.001$), NAVY ($\chi^2 = 120.9$, df $= 11$, $P < 0.001$), and USCG ($\chi^2 = 21.3$, df $= 11$, $P = 0.03$) flight operations. For all 4 military services, the highest numbers of strikes occurred during

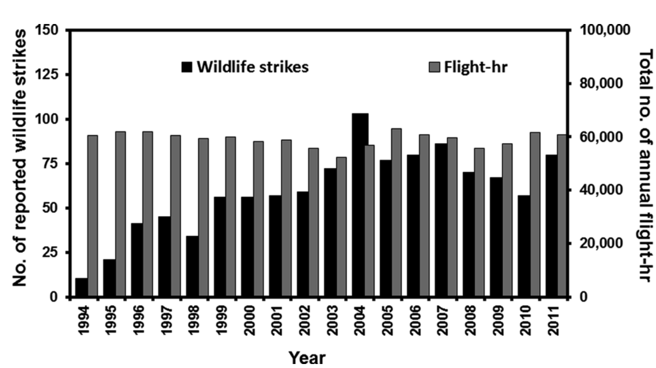

Figure 2. Number of reported wildlife strikes with U.S. Air Force (USAF) rotary-wing aircraft in the United States and total number of annual flight-hours by USAF rotary-wing aircraft during 1994–2011.

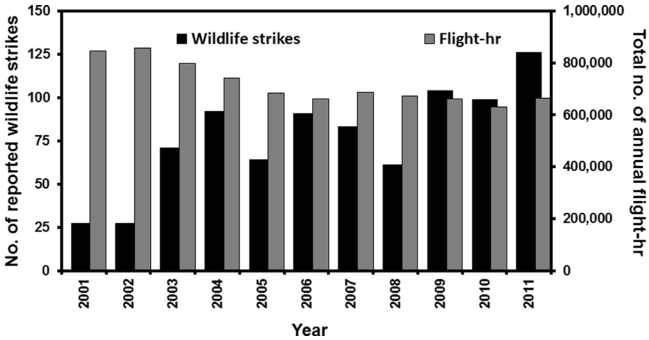

Figure 3. Number of reported wildlife strikes with U.S. Navy and U.S. Marine Corps (NAVY) rotary-wing aircraft in the United States and total number of annual flight-hours by NAVY rotary-wing aircraft during 2001–2011.

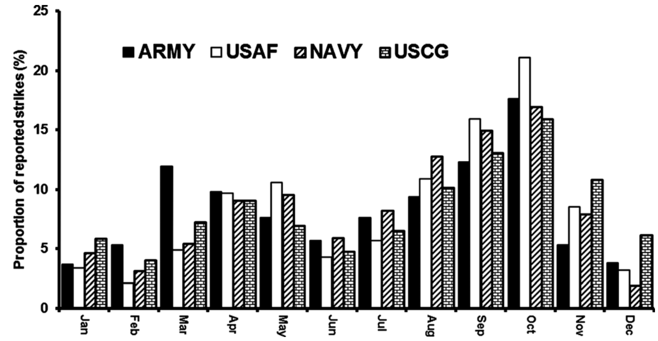

Figure 5. Proportion (%) of wildlife strikes (by month) in the United States for military rotary-wing aircraft reported from each military service during 1979–2011.

September and October, whereas the lowest number per month was found in December and January (Fig. 5).

Wildlife strikes varied across time of day for ARMY ($\chi^2 = 38.3$, df = 3, $P < 0.001$), USAF ($\chi^2 = 123.5$, df = 3, $P < 0.001$), and NAVY ($\chi^2 = 68.4$, df = 3, $P < 0.001$) rotary-wing aircraft. For these 3 military services, most wildlife strikes occurred during day- and nighttime periods and relatively few during dawn or dusk (Fig. 6). Although the occurrence of strikes during day- and nighttime periods was similar for ARMY ($\chi^2 = 2.8$, df = 1, $P = 0.10$) and NAVY ($\chi^2 = 0.03$, df = 1, $P = 0.87$) rotary-wing aircraft, more ($\chi^2 = 312.4$, df = 1, $P < 0.001$) strikes were reported during the night than during the day for USAF rotary-wing aircraft (Fig. 6).

Although approximately 71.7% of ARMY rotary-wing aircraft flying hours occurred during the day, only approximately half (51.9%) of the reported wildlife strikes occurred during the day. Notably, 45.3% of reported wildlife strikes occurred at night even though less than one-third (28.9%) of the ARMY rotary-wing aircraft flight-hours were conducted during nighttime (Fig. 6). Unfortunately, the distribution of flight-hours among times of day was not available for the other Military Services to allow for similar comparisons.

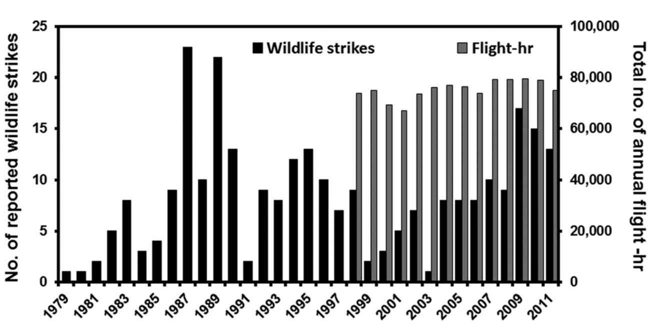

Figure 4. Number of reported wildlife strikes with U.S. Coast Guard (USCG) rotary-wing aircraft in the United States during 1979–2011 and total number of annual flight-hours by USCG rotary-wing aircraft during 1998–2011.

Geographic Location, Aircraft Category, and Phase of Flight

Among the 2,283 wildlife strikes with military rotary-wing aircraft for which the specific geographic location (i.e., state) could be determined, the majority was reported from Florida ($n = 617$), New Mexico ($n = 204$), Georgia ($n = 192$), California ($n = 183$), Virginia ($n = 171$), Alabama ($n = 151$), and Maryland ($n = 107$). Wildlife strikes were reported in all U.S. states and the District of Columbia except Vermont.

All records contained information regarding the aircraft category of the rotary-wing aircraft struck (Table 1). Across all military services, 30.4% of the aircraft categories were search and rescue, 19.8% were multi-mission, 18.9% were utility, and 13.0% were training. Although search and rescue

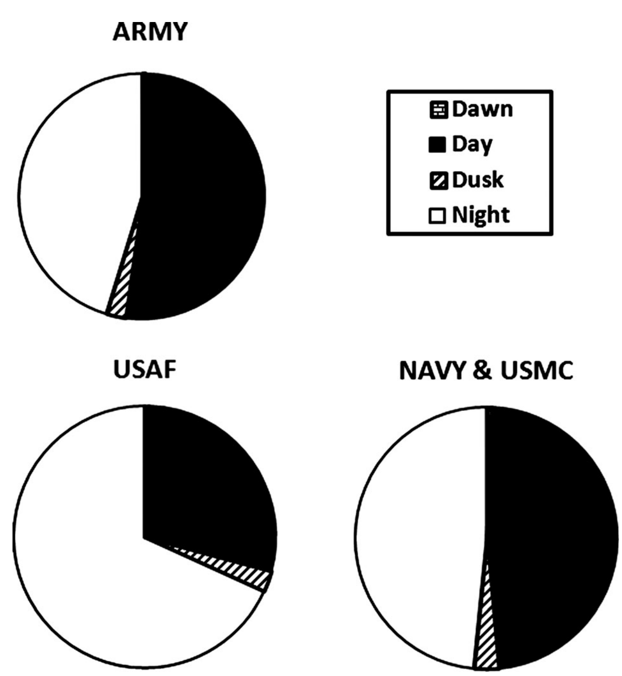

Figure 6. Proportion (%) of wildlife strikes (by time of day) in the United States for military rotary-wing aircraft reported from each military service during 1990–2011.

was the aircraft category of 49.3% and 71.8% of USAF and USCG aircraft, respectively, training accounted for 33.4% of NAVY rotary-wing aircraft strikes. Aircraft categories for ARMY rotary-wing aircraft were more diverse than the other military services, and included the only observation and electronic aircraft categories as well as the majority of attack category aircraft (Table 1).

Wildlife strikes to military rotary-wing aircraft were reported during all phases of (aircraft) flight. When the phase of flight was reported ($n = 1{,}596$), wildlife stuck military rotary-wing aircraft most frequently when the aircraft were traveling en route or engaged in terrain flight (Table 2). Overall, the proportion of wildlife strikes that occurred with rotary-wing aircraft during the en route and terrain flight (combined phases) of flight was 74.5% for ARMY, 72.7% for USAF, 53.6% for NAVY, and 74.2% for USCG rotary-wing aircraft. Notably, approximately one-half of wildlife strikes to ARMY rotary-wing aircraft and about three-quarters of strikes to USCG rotary-wing aircraft occurred en route.

Wildlife Groups Involved

Across all strike records, 32.3% (812 of 2,511) contained information regarding the identity of the animal struck. Birds accounted for 91.0% of strikes, whereas mammals (i.e., bats) accounted for the remaining 9.0%. The wildlife groups most frequently colliding with military rotary-wing aircraft varied among the military services. Warblers (16.8%), bats (11.5%), and perching birds (12.0%) were the wildlife groups most commonly struck by USAF rotary-wing aircraft, whereas gulls (18.2%), seabirds (14.9%), shorebirds (13.4%), and raptors and vultures (12.6%) were most frequently struck by NAVY rotary-wing aircraft.

Although limited information is available regarding wildlife strikes with ARMY rotary-wing aircraft (88% of ARMY wildlife strike records had no wildlife species or group information), raptors and vultures (41.6%), waterfowl (34.1%), and gulls (17.1%) were the most frequently struck groups. Also, these same groups most frequently caused damage to ARMY rotary-wing aircraft. The USCG wildlife strike database did not contain information regarding wildlife species or group information or location information to allow us to determine whether an individual wildlife strike occurred on-airfield or off-airfield.

On-airfield.—Among the "on-airfield" strike records, 40.3% (295 of 732) contained information regarding the identity of the animal struck. Birds accounted for 93.9% of on-airfield strikes, whereas mammals (i.e., bats) accounted for the remaining 6.1%. Warblers, thrushes and thrashers, larks, doves and pigeons, bats, and sparrows were the most common wildlife groups colliding with USAF rotary-wing aircraft operating on-airfield; whereas, gulls, raptors and vultures, shorebirds, and seabirds were most frequently struck by NAVY rotary-wing aircraft (Table 3).

When only "on-airfield" damaging strikes are considered, doves and pigeons and raptors and vultures were the most commonly struck wildlife groups that caused damage to USAF rotary-wing aircraft (Table 3). Strikes with raptors and vultures, gulls, and perching birds caused damage to NAVY rotary-wing aircraft operating within airfield environments (Table 3).

Off-airfield.—Among "off-airfield" strike records, 38.8% (484 of 1,247) contained information regarding the identity of the animal struck. Birds accounted for 90.1% of off-airfield strikes, whereas mammals (i.e., bats) accounted for the remaining 9.9%. Warblers, perching birds, bats, sparrows, and thrushes and thrashers were the most common wildlife groups colliding with USAF rotary-wing aircraft operating off-airfield; whereas, seabirds, shorebirds, gulls, perching birds, and raptors and vultures were most frequently struck by NAVY rotary-wing aircraft (Table 4).

When only "off-airfield" damaging strikes are considered, bats and waterbirds were the most common wildlife groups colliding with USAF rotary-wing aircraft. In contrast, raptors and vultures, shorebirds, and finches caused damage to NAVY rotary-wing aircraft (Table 4).

Table 1. Number of reported wildlife strikes, by aircraft category, in the United States for military rotary-wing aircraft for each military service and for all services combined during 1979–2011.

Aircraft category	ARMY[a]	USAF[b]	NAVY[c]	USCG[d]	All services
Attack	76	1	19		96
Cargo	19	29	44		92
Electronic	7				7
Multi-mission	9	199	259	31	498
Observation	68				68
SAR[e]		528	37	199	764
Submarine			184		184
Training	18	25	283		326
Utility	121	289	17	47	474
VIP[f]			2		2

[a] ARMY refers to rotary-wing aircraft from the U.S. Army.
[b] USAF refers to rotary-wing aircraft from the U.S. Air Force.
[c] NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.
[d] USCG refers to rotary-wing aircraft from the U.S. Coast Guard.
[e] SAR refers to search and rescue missions.
[f] VIP refers to very important person missions.

Table 2. Proportion (%) of reported wildlife strikes, by phase of flight, in the United States for military rotary-wing aircraft for each military service during 1979–2011.

Phase of flight	ARMY[a]	USAF[b]	NAVY[c]	USCG[d]
En route	52.3	31.3	28.6	73.6
Terrain flight	22.2	41.4	25.0	0.6
Hovering	1.8	4.2	4.2	1.9
Approach	14.7	7.2	12.7	8.8
Pattern		5.3	7.1	3.8
Landing	1.1	3.3	4.0	3.1
Taxiing	1.1	2.3	5.1	
Touch and go		0.2	2.2	1.9
Take-off	3.2	2.7	5.5	1.9
Climbout	3.6	2.1	5.6	4.4

[a] ARMY refers to rotary-wing aircraft from the U.S. Army.
[b] USAF refers to rotary-wing aircraft from the U.S. Air Force.
[c] NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.
[d] USCG refers to rotary-wing aircraft from the U.S. Coast Guard.

Table 3. Number of all wildlife strikes and damaging wildlife strikes where the aircraft was reported as being "on-airfield," by wildlife group, in the United States for military rotary-wing aircraft for each military service[a] during 1990–2011.

	ARMY[b]		USAF[c]		NAVY[d]	
Wildlife group	**All strikes**	**Damaging strikes**	**All strikes**	**Damaging strikes**	**All strikes**	**Damaging strikes**
Bats			17		1	
Blackbirds and starlings			7		1	
Corvids			1		1	
Cuckoos			5			
Doves and pigeons	1		19	3	8	
Finches			6			
Gulls	1	1	2		21	2
Herons, egrets, and ibises			1		3	
Larks			19			
Nightjars			4		2	
Owls					1	
Perching birds			17	1	6	2
Raptors and vultures	5	2	3	2	16	4
Seabirds					10	
Shorebirds			6	1	12	1
Sparrows			17		2	
Swallows			9	1	1	1
Swifts and hummingbirds			4		1	
Terns					1	
Thrashers and thrushes			20		1	
Vireos			2			
Warblers			26		1	
Waterbirds			2		1	
Waterfowl	3	2	4		3	
Woodpeckers			1			
Unidentified spp.	89	28	234	2	114	12

[a] Wildlife species or group information is not identified within the U.S. Coast Guard wildlife strike database.
[b] Wildlife species or group information is not identified within the U.S. Army (ARMY) wildlife strike database. However, for a few records the species or group involved in the strike event was identified from pilot or aircrew comments.
[c] USAF refers to rotary-wing aircraft from the U.S. Air Force.
[d] NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.

Aircraft damages and losses.—The proportion of reported wildlife strikes that damaged military rotary-wing aircraft were 42.4%, 3.8%, 12.7%, and 40.6% for ARMY, USAF, NAVY, and USCG flight operations, respectively. The proportion of damaging strikes was higher when the strikes occurred off-airfield compared with on-airfield for ARMY ($z = 4.86$, $P = 0.03$) and USAF ($z = 4.21$, $P = 0.04$) rotary-wing aircraft (Table 5). In contrast, the proportion of damaging strikes was similar ($z = 1.20$, $P = 0.27$) for NAVY rotary-wing aircraft for on-airfield and off-airfield incidents (Table 5).

The average cost of a damaging strike (i.e., estimate [US$] of damaged parts and repair costs) to a military rotary-wing aircraft varied among the 4 military services. The average cost of a strike to ARMY rotary-wing aircraft was $25,926/incident (highest reported = $553,763), to USAF rotary-wing aircraft was $14,852/incident (highest reported = $150,000), to NAVY rotary-wing aircraft was $337,281/incident (highest reported = $24,800,000), and to USCG rotary-wing aircraft was $12,184 (highest reported = $331,734). For on-airfield strikes, the average cost to ARMY rotary-wing aircraft was $28,872/incident (highest reported = $248,709), to USAF rotary-wing aircraft was $16,873/incident (highest reported = $128,960), and to NAVY rotary-wing aircraft was $1,156/incident (highest reported = $10,000). The average cost of an off-airfield damaging strike to ARMY rotary-wing aircraft was $24,944/incident (highest reported = $553,763), to USAF rotary-wing aircraft was $14,245/incident (highest reported = $150,000), and to NAVY rotary-wing aircraft was $476,805/incident (highest reported = $24,800,000).

Wildlife strikes to military rotary-wing aircraft operating in the United States resulted in 8 human injuries and 2 human fatalities during 8 wildlife strike events during off-airfield flight operations within the United States. In all 8 strike events, the aircraft involved was damaged or destroyed. All human injuries occurred during 6 wildlife strike incidents with ARMY rotary-wing aircraft and 1 incident with an USCG rotary-wing aircraft. All human injuries consisted of cuts, lacerations, and/or bruising to pilots and copilots when a bird (or birds) impacted the windscreen of the aircraft, shattering the windscreen of the aircraft and sending glass and bird remains into the aircraft cabin and impacting the aircrew. During one wildlife strike incident a pilot was incapacitated from the impact of the bird remains to his face.

The only known human fatalities that involved wildlife strikes to military rotary-wing aircraft within the United States occurred when a red-tailed hawk (*Buteo jamaicensis*) collided with a USMC AH-1W "Super Cobra" attack helicopter (Bell Helicopter Textron) in California during 2011. The hawk impacted the main rotor system and damaged it to the point that the main rotor separated from

Table 4. Number of all wildlife strikes and damaging wildlife strikes where the aircraft was reported as being "off-airfield," by wildlife group, in the United States for military rotary-wing aircraft for each military service[a] during 1990–2011.

	ARMY[b]		USAF[c]		NAVY[d]	
Wildlife group	**All strikes**	**Damaging strikes**	**All strikes**	**Damaging strikes**	**All strikes**	**Damaging strikes**
Bats			43	4	5	
Blackbirds and starlings			4			
Cuckoos			2		2	2
Doves and pigeons			6		1	
Finches			11		3	3
Gulls	6	3	2		19	2
Herons, egrets, and ibises	1	1	4	1	3	1
Larks			18			
Nightjars			2		2	
Owls			2			
Perching birds			52		14	2
Raptors and vultures	12	7	6	1	13	6
Seabirds					24	1
Shorebirds			7	1	19	3
Sparrows			28	1	1	
Swallows			13		1	
Swifts and hummingbirds			17		1	
Terns			1		3	
Thrashers and thrushes			26			
Vireos			11		2	1
Warblers			62		1	
Waterbirds	1		4	3	1	
Waterfowl	11	7	9	1	6	
Woodpeckers			1		1	
Unidentified spp.	186	83	314	19	263	32

[a] Wildlife species or group information is not identified within the U.S. Coast Guard wildlife strike database.
[b] Wildlife species or group information is not identified within the U.S. Army (ARMY) wildlife strike database. However, for a few records the species or group involved in the strike event was identified from pilot or aircrew comments.
[c] USAF refers to rotary-wing aircraft from the U.S. Air Force.
[d] NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.

the airframe while the aircraft was in flight. Two servicemen (the pilot and copilot) were lost during this strike event, which also resulted in the total destruction of the aircraft (monetary loss of $24.8 million) when it crashed.

Table 5. Number of reported wildlife strikes, without or with damage where the strike occurred "on-airfield" or "off-airfield," in the United States for military rotary-wing aircraft for each military service[a] during 1990–2011.

Location	ARMY[b]	USAF[c]	NAVY[d]
On-airfield			
Non-damaging	66	416	185
Damaging	33	10	22
% damaging[e]	33%	2%	11%
Off-airfield			
Non-damaging	116	614	332
Damaging	101	31	53
% damaging	47%	5%	14%

[a] The location (e.g., "on" or "off" an airfield) was not reported for wildlife strikes in the U.S. Coast Guard database.
[b] ARMY refers to rotary-wing aircraft from the U.S. Army.
[c] USAF refers to rotary-wing aircraft from the U.S. Air Force.
[d] NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.
[e] The proportion of wildlife strikes where damage to the rotary-wing aircraft was reported among all reported wildlife strikes to rotary-wing aircraft (within the specified categories).

DISCUSSION

Overall, the total number of reported wildlife strikes with ARMY rotary-wing aircraft decreased over time, as flight operations within the United States (which accounted for most flight operations in the 1990s) were replaced by flights (e.g., combat operations) during overseas deployments of ARMY rotary-wing squadrons to Iraq and Afghanistan during the early and late 2000s.

Annual increases in wildlife strikes to USAF and NAVY rotary-wing aircraft were likely due to increased aircrew and aircraft maintenance crew awareness and a heightened emphasis on the need for reporting of wildlife strikes to USAF and NAVY aircraft. Consequently, we believe this represents a reporting bias through time within these data. Both the USAF and NAVY have comprehensive bird or animal aircraft strike hazard (BASH) programs that emphasize the collection of wildlife strike information, including the collection of biological samples to allow for the identification of the wildlife species involved. In contrast, the ARMY and USCG currently do not have formal BASH programs; thus, pertinent reporting requirements and protocols, logistical support, and identification of strike remains (i.e., to determine the species of wildlife involved) are unavailable or unused, reducing the amount and quality of wildlife strike reporting. Thus, we suspect there is a strong reporting bias within these data. Although the information contained in the ARMY and USCG wildlife strike databases is extensive, there was no information identifying the wildlife species involved in those strike incidents. Furthermore, there was no specific information to suggest whether wildlife strikes with USCG rotary-wing aircraft occurred on-airfield or off-airfield. These details are critical to understanding and alleviating the risk of wildlife strikes to military rotary-wing aircraft.

Temporal patterns of wildlife strikes to military rotary-wing aircraft operating within the United States are evident, and as observed with fixed-wing aircraft (Dolbeer et al. 2012) and civil helicopters (Washburn et al. 2013), wildlife strike events occur with the greatest frequency during the autumn migration period of birds. Similar to wildlife strikes with civil helicopters flying in the United States (Washburn et al. 2013), a disproportionate number of wildlife strikes to ARMY rotary-wing aircraft (and likely other military services) occur at night.

Compared with USAF and NAVY aircraft, the percentage of damaging strikes to ARMY and USCG rotary-wing aircraft was very high. Although the exact reason for this difference is unknown, we believe that damaging wildlife strikes to ARMY and USCG aircraft are more likely to be reported than non-damaging strikes. Personnel within the USCG are not required to report wildlife strikes unless there is actual damage to the aircraft (B. Potter, United States Coast Guard, personal communication). In contrast, it appears a much higher proportion of non-damaging wildlife strikes to USAF and NAVY rotary-wing aircraft are being reported. Information gained from non-damaging wildlife strikes is important for understanding the nature and extent of wildlife strikes to military aircraft and to allow for the development of effective BASH plans and programs to alleviate the risk of wildlife strikes. For example, the occurrence of a high frequency of shorebird strikes that do not result in damage to aircraft at a particular airfield might indicate the presence of wetland habitats. Notably, such habitats might also be used by birds more hazardous to aircraft, such as waterfowl (e.g., Canada geese), resulting in a higher risk of damaging strikes to aircraft operating at that installation. Thus, non-damaging strike information can provide critical insight and increase the effectiveness of BASH plans and programs.

Any efforts to increase the wildlife reporting rates for ARMY and USCG military aircraft, especially non-damaging strikes, would be invaluable for a better understanding and development of effective mitigation strategies to reduce the frequency and damage resulting from wildlife strikes. When considering only those strikes to military aircraft where the animal(s) involved were identified, birds accounted for the vast majority of wildlife–aircraft collisions; however, bats also collided with military rotary-wing aircraft during nighttime flight operations.

Although variation among the military services was expected because of the diverse geographic areas within the United States where flight operations occur, warblers, perching birds, shorebirds, seabirds, and bats were the wildlife groups that collided with military rotary-wing aircraft most often. However, raptors and vultures, doves and pigeons, and gulls caused the most damage to military rotary-wing aircraft operating within airfield environments. During flight operations away from military airfields, raptors and vultures, shorebirds, and waterbirds caused the most damage.

For ARMY and USAF aircraft, more wildlife strikes were reported during flight operations off-airfield than during on-airfield flight procedures. This is potentially due to these aircraft spending a greater proportion of flight time off-airfield, engaged in terrain flight or traveling en route, than conducting landing procedures or other on-airfield activities. In contrast, strikes with NAVY aircraft occurred with similar frequency on-airfield and off-airfield. Relative to the other military services, the majority of military rotary-wing aircraft within the "training" aircraft category was NAVY aircraft. We suspect that NAVY rotary-wing aircraft (especially training model airframes) spend proportionately more time conducting on-airfield flight operations (e.g., take-offs, landings, pattern work) than rotary-wing aircraft from the other military services that have different mission types.

The majority of strikes occurred during the en route and terrain flight phases of flight. This is in contrast to wildlife strikes to civil fixed-wing aircraft, because the frequency of wildlife strikes to fixed-wing aircraft is typically lowest during the en route phase of flight (Dolbeer 2006, Dolbeer et al. 2012). However, fixed-wing aircraft flying en route to a destination would typically be at a much higher altitude than rotary-wing aircraft and consequently above the airspace (and altitudes) typically used by birds and bats during their normal flight activity patterns (DeVault et al. 2005, Dolbeer 2006, Washburn and Olexa 2011).

Aircrews from military rotary-wing aircraft would benefit from an increased understanding of the negative consequences of wildlife strikes to military aircraft. Aircrews could familiarized themselves with details and summaries of past wildlife strike events that occurred within the areas where they will be conducting flight operations, thus providing an increased awareness of potential BASH issues. Further, aircrews could use modeling systems, such as the USAF Avian Hazard Advisory System (Kelly et al. 2000), to determine the relative levels of risks posed by wildlife while conducting flight operations (e.g., training missions) within defined areas during specified time periods. Given the critical need for reporting of wildlife strike data, especially non-damaging strikes, aircrews should make reporting of wildlife strikes to rotary-wing aircraft a priority. In particular, key fields of information (such as the altitude or phase of flight the aircraft was in at the time of the strike event) would be useful and important facts that could be provided by military aircrews. We recommend the development and implementation of wildlife strike identification protocols, logistical tools (e.g., kits useful for collecting wildlife strike remains), and reporting regulations to allow for the identification of wildlife species involved in strikes to ARMY and USCG aircraft to be determined and included in the appropriate safety databases.

Flight and mission planners have the potential to reduce the number and severity of wildlife strikes to military aircraft during off-airfield flight operations by considering what wildlife hazards might exist along military training routes or within military operation areas used for flight training operations. For example, conducting low-level flights (e.g., terrain flight operations) over or near landfills and other known wildlife attractants should be avoided when possible to decrease the risk of wildlife–aircraft collisions.

Airfield managers at military airfields and installations have the potential to reduce the number and severity of on-airfield wildlife strikes to military aircraft during on-airfield flight operations by implementing an integrated wildlife damage management program (Transport Canada, 1994, MacKinnon et al. 2001, Cleary and Dolbeer 2005). Evaluation of existing wildlife strike data, identification and mitigation of wildlife attractants (e.g., wildlife forages [Washburn et al. 2011] and water management structures [Blackwell et al. 2008]), effective management of airfield plant communities to reduce wildlife hazards (Washburn and Seamans 2004, 2012), effective exclusion of large mammals from airfields (DeVault et al. 2008), non-lethal harassment (Baxter and Allan, 2009), wildlife population control methods (Dolbeer et al. 1993), and other methods and techniques are critical components of an effective BASH program (DeVault et al. 2013). Consultations with qualified airport wildlife biologists, would be particular helpful for identifying such wildlife attractants.

MANAGEMENT IMPLICATIONS

Our efforts to understand and evaluate the unique threats posed to military rotary-wing aircraft from wildlife strikes will provide the basis for the development of strategies to reduce such incidents and thus provide a safer flying environment for military personnel within all military services. Furthermore, a reduction in wildlife strikes to military rotary-wing aircraft will also reduce mortality of many bird species, potentially including wildlife species of state and/or federal threatened and endangered species status and other large charismatic birds that hold considerable public interest and concern, such as bald eagles (*Haliaeetus leucocephalus*) and ospreys (*Pandion haliaetus*).

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