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Strike hazard posed by columbids to military aircraft

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Abstract: Wildlife–aircraft strikes threaten both human and animal safety and result in hundreds of millions of dollars per year in aircraft damage and lost flight hours. Large-bodied birds are especially hazardous to aircraft. However, given high-speed flight at low altitudes, military aircraft may be especially vulnerable to strikes and more susceptible to damage even when encountering small birds. We summarized all wildlife–aircraft strike records from Randolph Air Force Base (San Antonio, Texas, USA) over a 25-year period and compared the number and cost of strikes across avian species and species groups. Because columbids (i.e., pigeons and doves) are among the most frequently struck species by both civilian and military aircraft and because several columbid species have demonstrated marked population increases over the past decade, we also quantified characteristics (i.e., month, time of day, precipitation patterns, phase of flight, altitude) of columbid strikes. White-winged doves (*Zenaida asiatica*) have undergone a substantial northward range expansion over the past 60 years and are now numerous in San Antonio. Given local interest, we also highlighted characteristics of aircraft strikes involving this species. Though columbids were not the most frequently struck species group during the survey period (1990–2014), they were the most costly. Columbid strikes were more frequent from May to July than during other months and often occurred during morning hours, especially from 0800–1000 hours, with a smaller afternoon peak from 1500–1700 hours. Columbid strikes occurred during landing more often than during other phases of flight, typically at ≤152 m above ground level (AGL), though white-winged doves were more likely to be struck on takeoff than expected. To reduce costs and safety concerns where columbids are prevalent, military flight planners, aircrews, and wildlife managers can reduce air travel, increase vigilance during takeoffs and landings, and implement on-the-ground hazing techniques in morning and late afternoon hours during spring and summer months.

Key words: airfield management, bird strike, columbid, military aircraft, Texas, white-winged dove, wildlife–aircraft strike, *Zenaida asiatica*

Wildlife–aircraft strikes threaten both human and animal safety and result in hundreds of millions of dollars per year in aircraft damage and lost flight hours (Allan 2000, Richardson and West 2000, Thorpe 2012, Dolbeer et al. 2016). In an effort to inform airfield managers and reduce the risk of wildlife–aircraft strikes, researchers have used data regarding the severity of strikes to develop relative hazard rankings for species and species groups (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011). Birds comprise the majority of wildlife–aircraft strikes (e.g., 96% in Dolbeer et al. 2016), and relative hazard rankings suggest strikes with large-bodied birds (e.g., raptors, waterfowl) are more likely to result in damage to aircraft than strikes with smaller birds (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011). Similarly, flocking species may be more hazardous to aircraft than solitary species (Dolbeer and Eschenfelder 2003). Consequently, much of the research and management regarding wildlife–aircraft strike mitigation focuses on habitat and population management techniques intended to minimize hazards posed by large, flocking birds within airport environments (e.g., Dolbeer et al. 1993, York et al. 2000, Guerrant et al. 2013).

Though relative hazard rankings can be informative, most published hazard scores are calculated using national-scale data (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011). Thus, they do not account for characteristics of local airfield operations that can influence the level

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of hazard posed by particular species or species groups. For instance, general aviation aircraft (e.g., gliders, business jets) and military aircraft used in flight training and combat exercises are smaller and narrower than most commercial aircraft. Though these aircraft are involved in fewer strikes with wildlife than larger planes (e.g., Burger 1983, 1985; Shaw and McKee 2008), they are more likely to incur damage, even when encountering small birds (e.g., Anderson et al. 2005, Dolbeer et al. 2016). Similarly, military aircraft often operate at lower altitudes and higher speeds than civilian aircraft, which may make them more vulnerable to strikes and more susceptible to damage when strikes occur (Neubauer 1990, Tedrow 1998, Eschenfelder 2005). For example, U.S. Air Force (USAF) military aircraft averaged 61 strikes per year with eastern meadowlarks (*Sturnella magna*) from 1995 to 2016 (USAF 2018), with an average annual cost for damages that was 7.6 times greater than that resulting from the average 65 eastern meadowlark strikes with civilian aircraft each year over a similar period (1990–2015; Dolbeer et al. 2016).

Characteristics of local avifauna (e.g., species' abundance, distribution, movement patterns, and behavioral ecology) can also influence the potential risk posed by particular species or species groups at a given airport. Members of the family Columbidae (i.e., pigeons, doves) are among the species most frequently struck by aircraft in the United States, and they account for the greatest number of strikes involving multiple birds (Dolbeer et al. 2016). Nonetheless, columbids are considered less hazardous to aircraft compared to larger species because fewer columbid strikes nationwide result in substantial damage (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011). That said, several columbid species demonstrate characteristics that suggest they could pose a significant hazard to aircraft at local scales, particularly in urban environments. Columbids are widely distributed in North America, and several species have demonstrated marked range expansions with concomitant population increases over the past decade (Sauer et al. 2017). Columbids readily exploit or adapt to urban environments (e.g., Blair 1996, Kark et al. 2007, Conole and Kirkpatrick 2011), and synurbic populations often have higher densities than rural populations, decreased migratory behavior, and prolonged breeding seasons (Luniak 2004, Francis and Chadwick 2012). Moreover, many columbids demonstrate flocking behavior when traveling to and from foraging and drinking locations (Leopold 1953, Cade 1965, Lefebvre 1985).

As a case study to demonstrate the potential strike hazard columbids can pose to military aircraft at a local scale, we examined wildlife–aircraft strike data collected at a USAF base near San Antonio, Texas, USA. The location was ideal because white-winged doves (*Zenaida asiatica*) have undergone a substantial northward range expansion in Texas over the past 60 years (Small et al. 2006, Veech et al. 2011, Butcher et al. 2014), with the largest population now found in San Antonio (West et al. 1993, Schwertner et al. 2002). We first summarized all wildlife–aircraft strike data and compared the number and cost of strikes across avian species and species groups. We then quantified characteristics associated with columbid strikes (i.e., month, time of day, precipitation patterns, phase of flight, altitude) to inform flight planners and land managers looking to reduce the impacts of columbid-aircraft strikes. We also highlighted characteristics of white-winged dove strikes separately, given their local importance and continued range expansion both in and outside of Texas (Butcher et al. 2014, Sauer et al. 2017).

Study area

Randolph Air Force Base (AFB; UTM 14N 569946/3266974) is a 1,168-ha military training installation located ~20 km northeast of downtown San Antonio in Bexar County, Texas. It is currently the only Air Force base offering advanced training in instructor skills for pilots qualified to fly trainer aircraft and additionally offers coursework in aircraft fighter fundamentals, weapons systems, remotely piloted aircraft, and basic sensor operations, among other topics. To facilitate the training mission at Randolph AFB, 2 parallel north-south-directed runways flank an improved area (i.e., permanent structures, lawns, and other landscaping) to the east and west. Climate in the region is humid and subtropical, with an average annual precipitation of ~73 cm and an average annual temperature of ~21°C (National Oceanic and Atmospheric Administration [NOAA] 2018). Rainfall tends to be greatest in May, June, and September, and temperatures are typically greatest in July and August, but there is notable variation between years (NOAA 2018).

Methods

Wildlife–aircraft strike data

We used records obtained from USAF's Bird/wildlife Aircraft Strike Hazard (BASH) database to summarize wildlife–aircraft strikes that occurred at Randolph AFB from 1990 to 2014. The USAF BASH dataset identified each wildlife–aircraft strike as occurring on or off base. We excluded all off-base records as well as those lacking information regarding proximity to the base. We also excluded on-base records with reported altitudes >457 m (1,500 ft) above ground level (AGL), which we considered as outside the airport environment where management actions could be focused (Dolbeer and Begier 2012). We classified the remaining on-base records as involving birds, bats, or lacking identifying information. We then further categorized all records that specifically indicated bird involvement into 7 species groups based on shared life history characteristics, behaviors, and habitat use. Species groups included waterbirds (ducks, pelicans, wading birds), raptors (vultures, hawks, falcons), shorebirds (plovers, curlews, sandpipers, woodcocks), columbids (pigeons and doves), swifts and hummingbirds, nightjars, and perching birds (e.g., flycatchers, vireos, swallows, thrushes, sparrows, blackbirds, warblers).

We calculated the total number of wildlife–aircraft strikes and the number and percentage of strikes resulting in aircraft damage across the survey period. We also calculated total numbers and percentages by taxa for strike events involving birds and identified the species and species groups most frequently reported. We then compared the distribution of all strikes involving birds with that of damaging bird strikes by species group using a Monte Carlo multinomial test with chi-square as a measure of goodness-of-fit (Engels 2015). We also calculated the total and average costs of aircraft damage resulting from wildlife–aircraft strikes overall and bird strikes in particular and identified the most costly species and species groups. We considered damages costing ≥$20,000 to be substantial (similar to damage classes A–D defined in USAF AFI91-204).

Factors influencing wildlife–aircraft strikes

For all statistical tests described below, we first considered all wildlife–aircraft strikes, then subsets of the data representing only strikes involving columbids and only strikes involving white-winged doves. We calculated standard deviation (SD) for all means and reported minimum and maximum values for all metrics. We used the open source statistical program R (R Core Team, Vienna, Austria) to conduct all analyses.

Information regarding aircraft movements at Randolph AFB during our survey period was limited. However, the 12th Operations Support Squadron was able to provide us with the annual number of flight operations within Randolph AFB's airspace from 2003 to 2014 and the number of monthly flight operations from 2011 to 2014. In addition, the Air Force Flight Standards Agency provided data on flight operations at the base by time of day (i.e., 6-hr time blocks) from 2010 to 2014. Where possible, we used this information to provide context for temporal analyses of wildlife–aircraft strike data.

We first calculated the mean number of strikes per year over the survey period and used generalized least squares regression to determine if annual strike totals corresponded with annual flight activity from 2003 to 2014. We then examined monthly trends as well as other factors that could influence the frequency or severity wildlife–aircraft strikes—specifically, time of day, precipitation, phase of flight (e.g., takeoff, landing), and altitude. For each analysis, we classified records according to categories (detailed below) and determined the number and percentage of strikes in each category. We then used chi-square or Monte Carlo multinomial tests of goodness-of-fit (depending on sample sizes) to determine if strikes were distributed among categories as expected (Engels 2015). We calculated Cramer's *V* as a measure of effect size for all goodness-of-fit tests. We performed a one-way analysis of variance test with Tukey's Honest Significance Difference test to evaluate differences in the number flight operations by month from 2011 to 2014 and calculated Pearson's correlation coefficients to determine if monthly strike patterns corresponded to differences in monthly flight activity.

We classified each strike as occurring during daylight hours or at night according to the reported event time. We considered strikes occurring between 0600 and 1800 hours to be daytime events and strikes occurring between 1800 and 0600 hours to be nighttime events. We further divided daytime events into early (0600–1200) and late (1200–1800) intervals corresponding with the 6-hour blocks in the available dataset. We then identified the number and percentage of strikes according to these categories and compared values against the expected distributions given aircraft activity. We assumed the distribution of flight operations by time of day from 2010 to 2014 was similar across the entire survey period.

We obtained daily and monthly precipitation data recorded at San Antonio International Airport (UTM 14N 55152/3266958; NOAA 2018), ~20 km east of Randolph AFB. We analyzed the daily precipitation data according to 3 levels: ≥0.25 cm, ≥1.27 cm, and ≥2.54 cm (as in Gabrey and Dolbeer 1996). At each level, we grouped days into 1 of 7 categories according to the number of days since rainfall. We assigned a "0" for days when rainfall occurred and a "6" if ≥6 days had passed since a rainfall event (Gabrey and Dolbeer 1996). Because it was rare for multiple strikes to occur on a single day, we determined the number of days in each category at each level during the survey period as well as the number of days in each category at each level on days with strikes and compared the distributions as described above. In addition, we calculated Pearson's correlation coefficients to examine relationships between monthly rainfall totals and the number of strikes.

We considered all strike events occurring on the ground, except those involved in takeoff and landing, as ground operations (e.g., passenger loading, taxiing, maintenance). We included initial climb in the takeoff category and initial and final approach, traffic pattern, and final landing in the landing category. We considered all other activities to be low-level flight as they occurred on or in close proximity to the base at altitudes ≤457 m AGL. To simplify comparisons when analyzing strike altitudes, we only included records reported in units AGL, which we grouped into 3 152-m (500-ft) intervals: ≤152 m AGL, 153–304 m AGL, and 305–457 m AGL and compared as described above.

Results

Summary of wildlife–aircraft strikes by taxa

We analyzed 2,130 wildlife–aircraft strikes that occurred on Randolph AFB from 1990 to 2014; 75% (n = 1,594) included no identifying information about the organisms involved, 24% (n = 516) identified birds, and 1% (n = 20) identified bats (Table 1). Among the records specifically identifying birds, perching birds were the most commonly reported species group (55%), followed by columbids (25%) and raptors (7%; Table 1). Strike records indicated 55 bird species involved in wildlife–aircraft strikes over the survey period (Table 1), with barn swallows (*Hirundo rustica*; 16%), mourning doves (*Zenaida macroura*; 14%), scissor-tailed flycatchers (*Tyrannus forficatus*; 8%), and white-winged doves (8%) being the most common (Table 1).

Eighteen percent (n = 378) of all wildlife–aircraft strikes resulted in aircraft damage, with 16% of those resulting in substantial damage (i.e., ≥$20,000; $\bar{x}_{substantial}$ = $166,454 ± 467,221 SD; range $20,487–3,539,930). Among the records specifically identified as bird strikes, 26% (n = 132) resulted in aircraft damage, with 11% of those resulting in substantial damage. The distribution of damaging bird strikes among species groups was as expected given that of all bird strikes by species group (P = 0.12, V = 0.11), with perching birds accounting for 48% of damaging strikes by birds, and columbids and raptors accounting for 27% and 11%, respectively. However, the distribution of bird strikes with substantial damage differed from that expected given the distribution of all bird strikes by species group (P = 0.03, V = 0.52). Though proportionally more strikes with nightjars, bats, and raptors resulted in damage (i.e., 6 of 10, 9 of 20, and 14 of 38, respectively), the potential for substantial damage during damaging strikes was greatest for columbids (12 of 35), unidentified organisms (44 of 237), and raptors (1 of 14; Table 1). Columbids were involved in 80% (n = 12) of bird strikes with substantial damage. White-winged doves accounted for the greatest number (n = 7), followed by mourning doves (n = 4), with 1 strike each for rock pigeons (*Columba livia*), merlins

Table 1. Number of strikes (strikes with damage)[a], total cost of damages, and mean cost of damage per damaging strike by species and species group for wildlife–aircraft strikes occurring at Randolph Air Force Base, near San Antonio, Texas, USA (1990–2014).

Common name	Taxonomic name	No. of strikes	Total damage costs	Mean cost of damage per damaging strike
Waterbirds	—	1 (1)	$25	$25
Redhead	*Aythya americana*	1 (1)	$25	$25
Raptors	—	35[a] (14)	$83,403	$5,213
Black vulture	*Coragyps atratus*	11 (3)	$2,662	$887
Turkey vulture	*Carthartes aura*	5 (0)	—	—
Osprey	*Pandion haliaetus*	1 (1)	$11,309	$11,309
Sharp-shinned hawk	*Accipiter striatus*	2 (1)	$16	$16
Swainson's hawk	*Buteo swainsoni*	3 (0)	—	—
Red-tailed hawk	*Buteo jamaicensis*	6 (4)	$3,056	$764
American kestrel	*Falco sparverius*	6 (4)	$8,478	$2,120
Merlin[b]	*Falco columbarius*	1 (1)	$57,882	$57,882
Shorebirds	—	14[a] (4)	$64	$16
Killdeer	*Charadrius vociferus*	12 (2)	$32	$16
Long-billed curlew	*Numenius americanus*	1 (1)	$16	$16
American woodcock	*Scolopax minor*	1 (1)	$16	$16
Columbids	—	129 (35)	$1,401,947	$40,056
Rock pigeon[b]	*Columbia livia*	11 (6)	$64,306	$10,718
White-winged dove[b]	*Zenaida asiatica*	42 (9)	$885,566	$98,396
Mourning dove[b]	*Zenaida macroura*	71 (19)	$452,049	$23,793
Mixed pigeons and doves	—	5 (1)	$16	$16
Swifts and Hummingbirds	—	38[a] (9)	$9,948	$1,105
Chimney swift	*Chaetura pelagica*	36 (7)	$9,916	$1,417
Ruby-throated hummingbird	*Archilochus colubris*	2 (2)	$32	$16
Nightjars	—	10 (6)	$10,080	$1,680
Lesser nighthawk	*Chordeiles acutipennis*	1 (1)	$16	$16
Common nighthawk	*Chordeiles minor*	9 (5)	$10,064	$2,013
Perching birds	—	269[a] (63)	$417,077	$6,620
Western kingbird	*Tyrannus verticalis*	5 (0)	—	—
Scissor-tailed flycatcher	*Tyrannus forficatus*	40 (17)	$15,892	$935
Horned lark	*Eremophila alpestris*	17 (4)	$17,311	$4,328
Purple martin	*Progne subis*	6 (1)	$2,000	$2,000
Tree swallow	*Tachycineta bicolor*	2 (0)	—	—
Bank swallow	*Riparia riparia*	4 (2)	$32	$16

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Cliff swallow	*Petrochelidon pyrrhonota*	21 (3)	$96	$32
Cave swallow	*Petrochelidon fulva*	6 (0)	—	—
Barn swallow	*Hirundo rustica*	80 (18)	$5,368	$298
Unknown swallow	—	5 (0)	—	—
Blue-gray gnatcatcher	*Polioptila caerulea*	11 (2)	$197	$99
Swainson's thrush	*Catharus ustulatus*	5 (1)	$5,000	$5,000
Wood thrush	*Hylocichla mustelina*	1 (1)	$16	$16
American robin	*Turdus migratorius*	12 (2)	$32	$16
European starling	*Sturnus vulgaris*	1 (1)	$16	$16
Cedar waxwing	*Bombycilla cedrorum*	2 (0)	—	—
House sparrow[b]	*Passer domesticus*	1 (1)	$293,097	$293,097
House finch	*Haemorhous mexicanus*	2 (0)	—	—
Vesper sparrow	*Pooecetes gramineus*	1 (1)	$16	$16
Eastern meadowlark	*Sturnella magna*	5 (1)	$40	$40
Western meadowlark	*Sturnella neglecta*	1 (1)	$16	$16
Red-winged blackbird	*Agelaius phoeniceus*	2 (1)	$16	$16
Brown-headed cowbird	*Molothrus ater*	5 (2)	$266	$133
Common grackle	*Quiscalus quiscula*	2 (0)	—	—
Unknown blackbird	—	2 (0)	—	—
Yellow-rumped warbler	*Setophaga coronata*	2 (2)	$232	$116
Unknown perching bird[b]	—	26[a] (3)	$82,434	$27,478
Bats	—	20 (9)	$9,766	$1,085
No identifying information[b]	—	11,594 (237)	$8,516,927	$35,936
TOTAL	—	2,130 (378)	$10,449,237	$27,643

[a] Excludes species with only 1 reported strike and no reported damage (i.e., 3 raptors [*Caracara cheriway*, *Buteo lineatus*, and an unknown], 3 shorebirds [*Calidris subruficollis*, *C. pusilla*, and an unknown], 1 unknown hummingbird, and 11 perching birds [*Lanius ludovicianus*, *Vireo solitarius*, *V. olivaceus*, *Anthrus spragueii*, *Passerculus sandwichensis*, *Zonotrichia leucophyrs*, *Cardellina pusilla*, *Pheucticus ludovicianus*, an unknown flycatcher, an unknown thrush, and an unknown sparrow]).
[b] At least 1 individual of species was involved with a substantial strike (i.e., strike resulting in ≥$20,000 in aircraft damage).

(*Falco columbarius*), house sparrows (*Passer domesticus*), and unknown perching birds.

Aircraft damage resulting from strikes with all wildlife at Randolph AFB cost $10,449,237 ($\bar{x}$ = $24,643 ± 192,804 SD; range $5–3,539,930) over the survey period (Table 1). Eighteen percent of the damage costs during the survey period were associated with records identified as bird strikes ($1,922,544; $\bar{x}$ = $14,565 ± 49,112 SD; range $5–322,434). Columbids were the most costly avian species group, accounting for 73% of the total cost of all reported bird strikes ($1,401,947). Columbids also had the highest average cost per damaging bird strike ($\bar{x}$ = $40,056 ± 75,242 SD; range $16–322,434). Perching birds and raptors accounted for the majority of the remaining damage costs among bird strikes (Table 1). The most costly species over the survey period included white-winged doves, mourning doves, and house

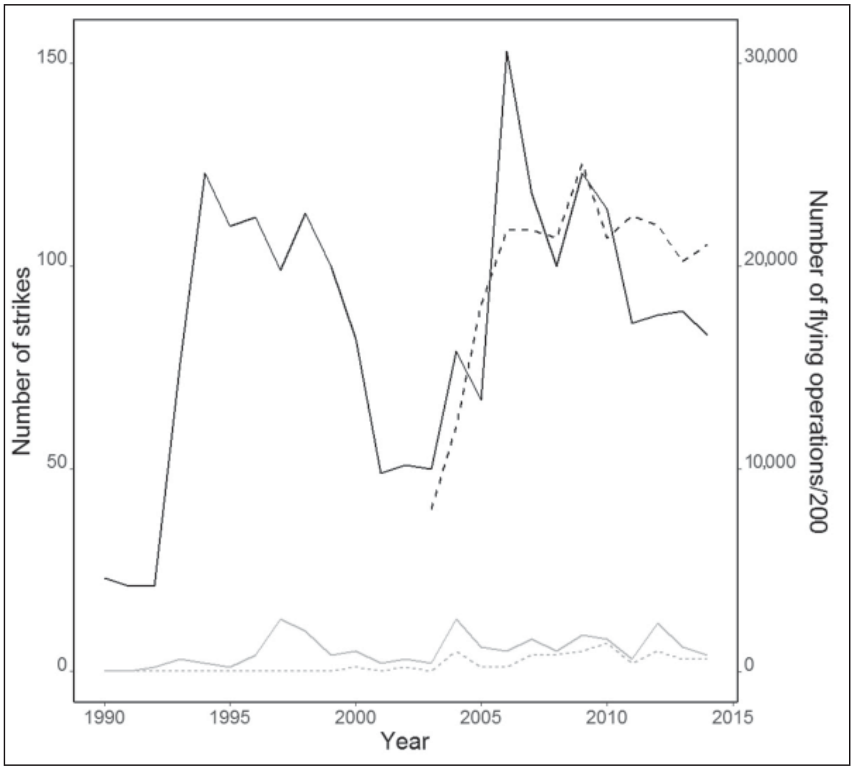

Figure 1. Number of wildlife–aircraft strikes (*n* = 2,130; solid black), columbid strikes (*n* = 129; solid gray), and white-winged dove strikes (*Zenaida asiatica*; *n* = 42; dashed gray) at Randolph Air Force Base near San Antonio, Texas, USA (1990–2014) with the number of flight operations (divided by 200) from 2003 to 2014 (dashed black).

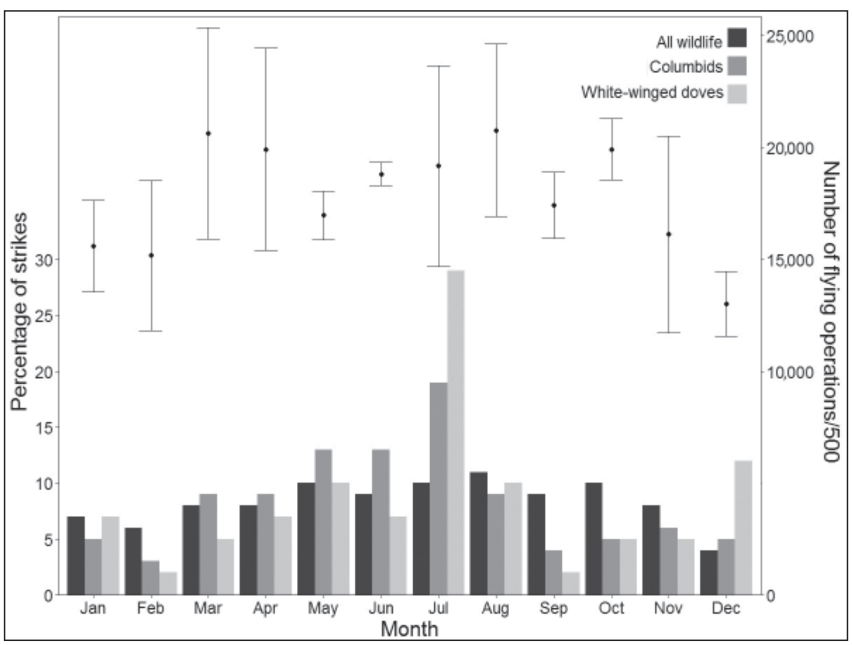

Figure 2. Percentage of wildlife-aircaft strikes with military aircraft at Randolph Air Force Base, near San Antonio, Texas, USA by month (1990–2014) involving all wildlife (*n* = 2,130), columbids only (*n* = 129), and white-winged doves (*Zenaida asiatica*) only (*n* = 42) and mean number of aircraft flight operations per month (divided by 500) from 2011 to 2014 (points) with 95% confidence intervals (error bars).

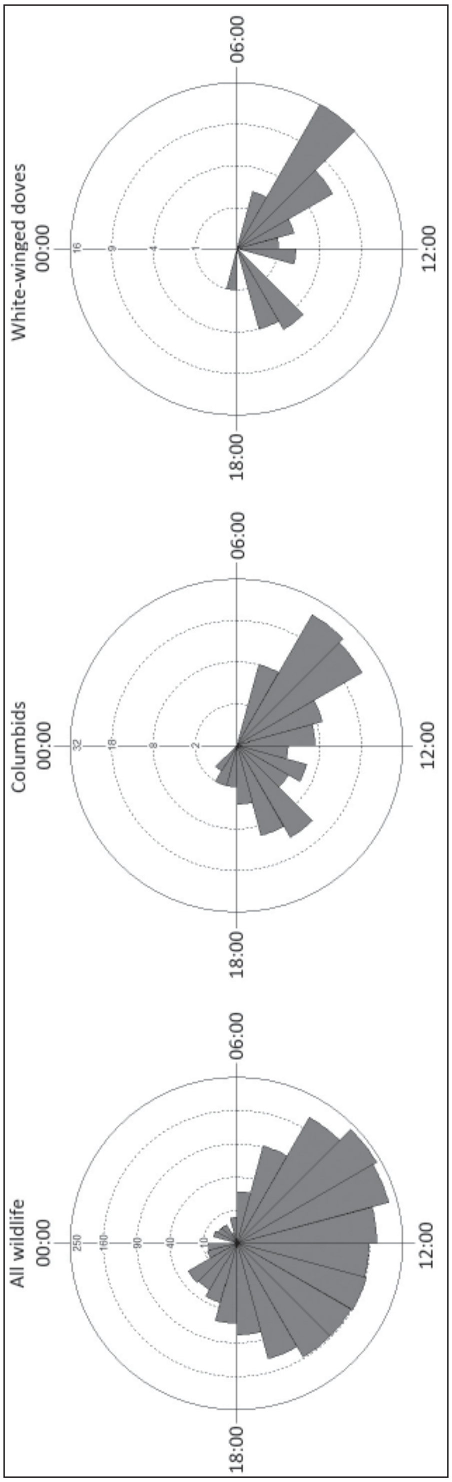

Figure 3. Distribution of wildlife–aircraft strikes (n = 1,953) at Randolph Air Force Base, near San Antonio, Texas, USA (1990–2014) by hour, with a breakdown showing timing for strikes with all columbids (n = 119) and white-winged doves (*Zenaida asiatica*; n = 40) alone.

sparrows (Table 1). The average cost per strike when damage occurred was greatest for house sparrows, but the cost was associated with a single strike and did not represent a trend. After excluding house sparrows and other species with only 1 damaging strike over the survey period, white-winged and mourning doves had greater average costs per damaging strike than all other avian species (Table 1).

Factors influencing wildlife–aircraft strikes

Temporal factors. The number of annual wildlife–aircraft strikes reported over the survey period varied from a low of 21 (1991 and 1992) to a high of 153 (2006; $\bar{x}$ = 85 strikes/yr ± 34 SD; Figure 1). There was a linear relationship between the number of wildlife–aircraft strikes and the number of flight operations for the years when flight activity data were available (i.e., 2003–2014; $R^2 = 0.70$, $F_{1,10} = 23.19$, $P \leq 0.01$). Columbid strikes were reported every year starting in 1992 ($\bar{x}$ = 6 strikes/yr ± 4 SD, range 1–13), and white-winged dove strikes were first reported in 2000 and then at least once annually from 2004 to 2014 ($\bar{x}$ = 3 strikes/yr ± 2 SD, range 1–7). However, neither the annual number of strikes involving all columbids ($R^2 = 0.00$, $F_{1,10} = 0.01$, $P = 0.91$) nor the annual number of strikes with white-winged doves ($R^2 = 0.01$, $F_{1,9} = 0.07$, $P = 0.80$) varied according to annual flight activity.

Overall wildlife–aircraft strike frequency varied across months ($\chi^2_{11} = 110.71$, $P \leq 0.01$, $V = 0.07$), with peaks in July and August and a low in December (Figure 2). The frequency of columbid strikes also differed by month ($P \leq 0.01$, $V = 0.16$), but the distribution varied from that expected given the monthly distribution of all wildlife–aircraft strikes ($P = 0.02$, $V = 0.13$). Most columbid strikes occurred from May to July, and the fewest occurred in fall and winter months (Figure 2). The frequency of strikes with white-winged doves varied by month as expected given the monthly distribution of columbid strikes ($P = 0.62$, $V = 0.14$; Figure 2). Monthly flight operations varied significantly across months from 2011 to 2014 ($F_{11,36} = 6.17$, $P \leq 0.01$, $\eta^2 = 0.65$), with significantly less aircraft activity in December compared to most months (Figure 2). However, we found no correlations between monthly flight operations and the number of wildlife–aircraft strikes (r = 0.13, P = 0.38), columbid strikes (r = 0.08, P = 0.58), or white-winged dove strikes (r = -0.02, P = 0.88) during the years for which flight information was available (i.e., 2011–2014).

Nighty-two percent (n = 1,953) of all wildlife–aircraft strike records included information regarding event time. Strikes were not distributed as expected, assuming the distribution of flight operations from 2010–2014 was consistent for the duration of the survey period (χ^2_1 = 13,459.00, $P \leq 0.01$, V = 2.65). Less than 1% of flight operations occurred at night (i.e., 18:00–06:00 hrs), compared to 8% of wildlife–aircraft strikes. Daytime strikes (n = 1,789) were distributed as expected during the early (53%) and late (47%) periods given aircraft activity (41% and 59%; = 0.14, P = 0.71, V = 0.01). Event times were available for 92% (n = 119) and 95% (n = 40) of columbid strikes and white-winged dove strikes, respectively. Four percent of columbid strikes and 3% of white-winged dove strikes occurred at night. Columbids (χ^2_1 = 6.59, P = 0.01, V = 0.24) and white-winged doves (χ^2_1 = 5.53, P = 0.01, V = 0.38) were more likely to be struck earlier in the day rather than later given daily aircraft activity. There were no distinct hourly peaks when considering all wildlife–aircraft strikes (Figure 3). However, peak hours for columbid strikes occurred from 0800–1000, with a smaller afternoon peak from 1500–1700 (Figure 3). Hourly peaks in white-winged dove strikes were consistent with columbid strikes, but with relatively fewer strikes occurring during the 0900–1000 interval (Figure 3).

Precipitation. Rainfall ≥0.25 cm, ≥1.27 cm, and ≥2.54 cm occurred on 12%, 5%, and 3% of days during the survey period (n = 9,131). Mean daily rainfall during the survey period was 0.09 cm ± 0.38 SD (range 0–11.26 cm), and mean daily rainfall was 0.08 cm ± 0.35 SD (range 0–5.73 cm) on days with wildlife–aircraft strikes (n = 1,707), 0.10 cm ± 0.31 SD (range 0–1.99 cm) on days with columbid strikes (n = 124), and 0.16 cm ± 0.45 SD (range 0–1.99 cm) on days with white-winged dove strikes (n = 39). Rainfall patterns on days with wildlife–aircraft strikes were as expected for all rainfall levels given rainfall patterns on all days during the survey period (≥0.25 cm: χ^2_6 = 8.97, P = 0.17, V = 0.03; ≥1.27 cm: χ^2_6 = 6.25, P = 0.40, V = 0.02; ≥2.54 cm: χ^2_6 = 5.61, P = 0.47, V = 0.02). Similarly, rainfall patterns on days with columbid strikes were distributed as expected given rainfall on all survey days (≥0.25 cm: P = 0.98, V = 0.04; ≥1.27 cm: P = 0.80, V = 0.06; ≥2.54 cm: P = 0.86, V = 0.06), as were rainfall patterns on days with white-winged dove strikes (≥0.25 cm: P = 0.87, V = 0.10; ≥1.27 cm: P = 0.31, V = 0.17; ≥2.54 cm: P = 0.23, V = 0.18). Monthly rainfall was weakly correlated with the number of strikes when considering all wildlife–aircraft strikes (r = 0.13, P = 0.02), but not when considering columbid strikes (r = 0.07, P = 0.25) or white-winged dove strikes (r = 0.03, P = 0.66).

Phase of flight. Wildlife–aircraft strikes (n = 919) did not occur equally among phases of flight (χ^2_3 = 336.40, $P \leq 0.01$, V = 0.35). Most strikes occurred during landing (49%) and takeoff (26%). Columbids were struck more often during these phases than expected given the distribution of all wildlife–aircraft strikes by phase of flight ($P \leq 0.01$, V = 0.30; 55% and 41%, respectively). No records indicated strikes with columbids when aircraft were engaged in low-level flight. Strikes involving white-winged doves (n = 35) only occurred during the takeoff and landing phases of flight, but the distribution of strikes among these phases was different than expected given that of all columbid strikes ($P \leq 0.01$, V = 0.53), with 69% of strikes occurring during takeoff and 31% during landing.

Altitude. Altitude of wildlife–aircraft strikes (n = 648) varied ($P \leq 0.01$, V = 0.74), with 82% of strikes occurring at ≤152 m AGL, 5% from 153–304 m AGL, and the remaining 13% from 305–457 m AGL. Mean altitude of all wildlife–aircraft strikes during the survey period was 86 m AGL ± 120 SD (range 0–457 m AGL). The distribution of columbid strikes (n = 92) by height category differed from that expected given all wildlife–aircraft strikes ($P \leq 0.01$, V = 0.92), with 95% of strikes occurring at ≤152 m AGL, 3% from 153–304 m AGL, and 2% at 305–457 m AGL. Mean altitude of columbid strikes with aircraft was 50 m AGL ± 69 SD (range 0–366 m AGL). All but 1 aircraft strike involving white-winged doves (n = 33) occurred at ≤152 m AGL, with an altitude distribution as expected given that of all columbid strikes (P = 0.62, V = 0.14). Mean altitude of aircraft strikes with white-winged doves was 46 m AGL ± 60 SD (range 0–305 m AGL).

Discussion

Though columbids are often considered less hazardous to aircraft than larger birds (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011), our results support DeVault et al.'s (2018) strike risk assessment, which accounted for both frequency and severity of strikes and ranked 2 columbid species among the top 5 greatest strike risks nationwide. Columbids were not the most frequently struck species group at Randolph AFB. However, columbid strikes were common and they comprised the majority of strikes that resulted in substantial damage during the survey period. From an economic perspective, strikes with columbids cost ~3 times and ~17 times more than strikes with perching birds and raptors, and the average cost per columbid strike was ~6 times and ~8 times greater than strikes with perching birds and raptors.

Strike records identified 55 bird species during the survey period. Though white-winged doves were involved in only 8% of bird strikes, they accounted for the majority of bird strikes resulting in substantial damage. Nationally, aircraft strikes with white-winged doves are infrequent enough that the species is not included in rankings of relative hazard (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011) or risk (DeVault et al. 2018). However, white-winged dove populations are expanding throughout the southern United States (Butcher et al. 2014), and our results indicate this species has the potential to be a hazard locally.

Each of the columbid species struck by aircraft at Randolph AFB have resident populations, but in winter, northern migrants may join residents, such that local abundance is greatest in winter (Schwertner et al. 2002, Otis et al. 2008). On-the-ground surveys of white-winged doves flying over the eastern runway at Randolph AFB in 2017 and 2018 seem to support this (A. M. Long, unpublished report). Nonetheless, the number of strikes involving columbids was lowest in fall and winter, which could suggest that local abundance is not a major factor influencing strike frequency. Alternatively, the decline in strikes in winter could be a function of reduced aircraft activity in December, though we found no correlation between the number of strikes and monthly aircraft activity. Regular avian monitoring would better facilitate interpretations of seasonal strike patterns in relation to species abundance.

Resident columbids at Randolph AFB can breed year-round, but they demonstrate peak breeding behavior in spring (Murton and Westwood 1977, West et al. 1993, Swank 1995), such that recruitment of hatch-year birds is greatest in summer (e.g., Collier et al. 2013) when the number of strikes with columbid species at Randolph AFB was greatest. Naïve young birds may be less able to avoid collisions and could, therefore, pose a greater strike risk than experienced adults (e.g., Mumme et al. 2000, Anderson et al. 2005, Caister 2009). However, avoidance responses vary across species (e.g., Blackwell et al. 2009, Husby and Husby 2014), and though the timing of juvenile recruitment of doves corresponds to a peak in columbid strikes at the base, evidence suggests that experience does not increase the likelihood of successful vehicle avoidance for at least 1 columbid species (i.e., rock pigeon; DeVault et al. 2017). Increased foraging needs by females during breeding (e.g., West 1993) or shifting distributions of preferred food resources (see Neill 2016) could also explain the greater number of columbid strikes in spring and summer months.

Less than 1% of flying operations at Randolph AFB occurred at night, and consequently, the majority of wildlife–aircraft strikes on the base occurred during the day. Though wildlife–aircraft strikes generally followed the distribution of aircraft activity throughout the day, columbids were struck more than expected earlier, particularly between the hours of 0800 and 1000. There was also a second smaller peak in columbid strikes in the afternoons from 1500–1700. These peaks likely corresponded to columbids traveling to and from foraging and drinking locations. White-winged doves, for example, exhibit consistent daily activity patterns during breeding, with males foraging and drinking early in the mornings and females foraging and drinking when males return and until late afternoon (Arnold 1943, Elder 1956, Schacht et al. 1995). Though our results were consistent with other studies (e.g., Burger 1985, Linnell et al. 1996), it is important to note that reporting of strikes may be reduced at night and early in the morning when visibility is low (Linnell et al. 1999).

Wildlife–aircraft strikes may be more likely to occur on days with rain because of reduced visibility or increased ambient noise (e.g., Steele 2001) or following rainfall events when standing water can act as an attractant (Blokpoel 1976, Buckley and McCarthy 1994, Gabrey and Dolbeer 1996). However, we found no evidence that wildlife–aircraft strikes, in general, or columbid strikes, in particular, were more likely to occur at Randolph AFB on days with precipitation or within the days following rainfall events than would be expected given the general pattern of rainfall over the survey period. Linnell et al. (1996) suggested that cumulative rainfall could result in increased strikes through increased food production on or near the airfield. Though we found a weak positive correlation between the number of wildlife–aircraft strikes and monthly precipitation, we found no relationship between columbid strikes and monthly rainfall, and further research would be needed to determine how monthly rainfall affects the abundance and distribution of food resources within the airfield environment and what, if any, effects it has on strike frequency.

Wildlife–aircraft strikes at Randolph AFB occurred during all phases of flight, but like others (e.g., Burger 1985, Linnell et al. 1996, Dolbeer et al. 2016), we found that strikes were more likely to occur during landing than takeoff. Planes are quieter on arrival than during departure (Burger 1983), which could account for the greater number of strikes during landing at the base. Surprisingly, white-winged dove strikes were twice as likely to occur during takeoff than landing. The greater average cost of damage we observed for white-winged dove strikes compared to strikes with other species may be a function of the greater severity of strikes that occur during takeoff compared to landing (Richardson 1994). Not surprisingly given phase of flight when strikes occurred, and as expected given Dolbeer (2006), the majority of wildlife–aircraft strikes at Randolph AFB occurred at low altitudes (i.e., ≤152 m AGL). However, few strikes occurred during low-level flights on base at ≤457 m AGL during the survey period. As such, we were unable to examine the impacts of wildlife–aircraft strikes, in general, or columbid strikes, in particular, on military aircraft engaged in such flights. Further investigations should include analyses of low-level flight within military training routes (≤3,048 m mean sea level [MSL]) where military aircraft can operate at speeds in excess of 250 knots indicated airspeed (KIAS; FAA 1990).

Management implications

Estimation of strike risk by species assemblage is important for identifying appropriate management actions to reduce the likelihood of wildlife–aircraft strikes. Though not the most frequently struck species assemblage, columbids were regularly struck at Randolph AFB and represented a significant strike risk, accounting for more than half of all strikes that resulted in substantial damage. White-winged doves were the most damaging and costly columbid species, perhaps because strikes with this species were most common during takeoff, when strike damage may be more severe (Richardson 1994). Rock pigeons and mourning doves are common columbid species found in urban areas in North America, and white-winged dove populations are increasing throughout the southern United States (Butcher et al. 2014), suggesting that the risk associated with dove strikes could be widespread (see DeVault et al. 2018). Limiting suitable foraging and nesting habitats for columbids near runways may reduce exposure to these species, while reducing aircraft activity, increasing vigilance during takeoff and landing, and implementing on-the-ground hazing techniques in morning and late afternoon hours during spring and summer months may help to minimize the frequency of columbid strikes and reduce associated safety and economic concerns.

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