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A decade of U.S. Air Force bat strikes

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Abstract: From 1997 through 2007, 821 bat strikes were reported to the U.S. Air Force (USAF) Safety Center by aircraft personnel or ground crew and sent to the National Museum of Natural History, Smithsonian Institution, for identification. Many samples were identified by macroscopic and or microscopic comparisons with bat specimens housed in the museum and augmented during the last 2 years by DNA analysis. Bat remains from USAF strikes during this period were received at the museum from 40 states in the United States and from 20 countries. We confirmed that 46% of the strikes were caused by bats, but we did not identify them further; we identified 5% only to the family or genus level, and 49% to the species level. Fifty-five of the 101 bat-strike samples submitted for DNA analysis have been identified to the species level. Twenty-five bat species have been recorded striking USAF planes worldwide. The Brazilian free-tailed bat (*Tadarida brasiliensis*; *n* = 173) is the species most commonly identified in USAF strike impacts, followed by the red bat (*Lasiurus borealis*; *n* = 83). Bat strikes peak during the spring and fall, with >57% occurring from August through October; 82% of the reports that included time of strike were recorded between 2100 and 0900 hours. More than 12% of the bat strikes were reported at >300 m above ground level (AGL). Although <1% of the bat-strike reports indicated damage to USAF aircraft, cumulative damage for 1997 through 2007 totaled >$825,000 and >50% of this sum was attributable to 5 bat-strike incidents. Only 5 bats from the 10 most damaging bat strikes were identified to the species level, either because we did not receive remains with the reports or the sample was insufficient for identification.

Key words: aircraft, altitude, bat, Chiroptera, human–wildlife conflicts, migration, safety, season, strike, wildlife

Williams and Williams (1967) conducted the first organized survey of bats involved in aircraft strikes to assist the U.S. Air Force (USAF) with bat collisions involving T-38 aircraft in the vicinity of Randolph Air Force Base (RAFB), Texas. Bats became suspect when collisions increased after dusk and during the month of August 1967, coinciding with visual observations of bats flying in the area. USAF reports examined by Williams and Williams (1967) indicated that during August, 5% of aircraft flights incurred a wildlife strike, and 11% of flights between dusk and dawn had a wildlife strike at RAFB. Williams and Williams (1967) studied bat activity in the vicinity of RAFB using a combination of radar, ultrasonic bat detectors, calculations of altitude and flock density based on sightings from helicopter flights and the identification of strike remains using light microscopy to distinguish hair from feather fragments. They found that while some bat species congregated around light sources, the Brazilian free-tailed bat (*Tadarida brasiliensis*) occurred at a constant density across the airfield, regardless of lighting conditions. Sightings by pilots paired with radar observations documented the mass emergence of Brazilian free-tailed bats rising to altitudes between 300 and 450 m above ground level (AGL) over Bracken Cave, a nursery colony located just 19 km north of RAFB. At sunset, the Bracken Cave colony produced a cloud of bats >10 km wide in <1 hour (Williams and Williams 1967). Approximately 20 million bats have been estimated to occupy this cave during the summer (Wilson 1997). Williams and Williams (1967) concluded that radar could provide a useful tool to help airfield managers and pilots avoid certain areas during times when densities of flying wildlife are high. Subsequent investigations have revealed the surprising densities, altitudes, and speeds at which some bats fly, as Williams et al. (1973) documented for the Brazilian free-tailed bat.

Although it has been long recognized that aircraft strike bats in flight, no cumulative study of long-term trends in bat-strike data has been reported. The Division of Birds, National Museum of Natural History, Smithsonian Institution, Washington, D.C., has received remains of wildlife for identification from USAF strikes since the early 1960s. Samples containing mammals have been transferred to the museum's Division of Mammals for identification. An increased volume of mammal identifications has been made possible because of interest and support over the last 10 years by the U.S. Geological Survey (USGS), Patuxent Wildlife Research Center, Biological Survey Unit, stationed within the National Museum of Natural History.

This report is a summary of the trends in USAF bat strikes over the >10-year period extending through 2007. We identified the species involved; the times, seasons, and altitudes of strike events; and the damage to the aircraft resulting from these impacts. Because this is the first attempt to analyze long-term bat data from the USAF database, we also discuss some problems we encountered when interpreting bat-strike reports and make recommendations for future improvement.

Methods

Reports of and remains from all USAF wildlife strikes are sent to the Division of Birds, National Museum of Natural History, Smithsonian Institution, as required by USAF protocol. Wildlife remains are reviewed upon arrival at the museum by the Smithsonian Institution's Feather Identification Lab. Samples containing mammals are forwarded to the USGS staff in the Division of Mammals, who compare these remains with museum specimens in the mammal division research collections. Hair samples are mounted on labeled glass slides following the preparation methods in Laybourne and Dove (1994) and marked with the USAF strike report number. Slides are examined under Reichart Diastar, Zeiss, and Leitz compound comparison light microscopes at 100 to 400x magnification. Copies of USAF strike reports are filed in the Division of Mammals with references and comments about how identifications are made for difficult cases. Some bat-strike remains were sufficiently large and complete to warrant accessioning into the scientific collections of the Division of Mammals where they serve as voucher specimens, provide DNA samples, and aid in future identifications. Since 2006, samples received that lacked sufficient material for species-level identifications using traditional morphological methods were submitted for DNA analysis using the same protocol applied to birds (Dove et al. 2008). Nomenclature follows Wilson and Reeder (2005) and Hoofer et al. (2006).

Although records were kept for all bat-strike identifications performed by USGS personnel from 1997 through 2007, many cases were not transferred from the Division of Birds to USGS because samples were determined to be too minute for species identification. We requested that the USAF Safety Center Headquarters query all bat-strike records reported from 1997 through 2007, including all information on location, time, date, cost, altitude, phase of operation, identification, awareness, impact points, along with any remarks and comments. During our initial examination of the data, we discovered several discrepancies among fields, so we compared the database against copies of identification reports housed in the Division of Mammals and deleted records with conflicting data. In some cases, a single strike report included >1 sample from multiple impact points. In these cases, we treated each sample received for identification as representing a single strike event. The total number of samples also includes bats found on the ground that were assumed to have been struck by aircraft. Personnel at some USAF bases do periodic runway sweeps, which can greatly increase the number of impact events reported from those bases. One strike-report sample included 15 intact bats representing 3 genera that were found dead during a runway sweep on a single night.

We analyzed the database of 821 bat strikes to compile summaries of the overall numbers of strikes, species involved, and months when strikes occurred. To examine specific times and altitudes of flight we further limited the database to include 174 bat strikes in North America where the pilot or crew was aware of the strike in flight and noted a time of impact. Strike reports with multiple impact points were counted only once for times, altitudes, and damage associated with bat strikes.

Table 1. Identifications of bats involved in U.S. Air Force aircraft strikes between 1997 and 2007. We identified 25 species representing 5 families of bats from 821 aircraft strikes.

Identification	Number identified
Family Pteropodidae	
Lesser dawn bat *(Eonycteris spelaea)*	1
Ryuku flying fox *(Pteropus dasymallus)*	1
Family Hipposideridae	
Geoffroy's trident leaf-nosed bat *(Asellia tridens)*	1
Bicolored leaf-nosed bat *(Hipposideros bicolor)*	1
Family Emballonuridae	
Unidentified bat	1
Naked-rumped pouched bat *(Saccolaimus saccolaimus)*	1
Family Molossidae	
Unidentified bat	10
Pocketed free-tailed bat *(Nyctinomops femorosaccus)*	3
Brazilian free-tailed bat *(Tadarida brasiliensis)*	173
Family Vespertilionidae	
Unidentified bat	8
Subfamily Vespertilioninae	
Tribe Eptesicini	
Big brown bat *(Eptesicus fuscus)*	15
Tribe Lasiurini	
Red bat *(Lasiurus borealis)*	83
Hoary bat *(Lasiurus cinereus)*	32
Northern yellow bat *(Lasiurus intermedius)*	1
Seminole bat *(Lasiurus seminolus)*	25
Unidentified bat *(Lasiurus* sp.*)*	10
Tribe Nycticeiini	
Evening bat *(Nycticeius humeralis)*	7
Tribe Pipistrellini	
Western pipistrelle *(Parastrellus hesperus)*	1
Eastern pipistrelle *(Perimyotis subflavus)*	16
Javan pipistrelle *(Pipistrellus javanicus)*	1
Kuhl's pipistrelle *(Pipistrellus kuhlii)*	17
Nathusius's pipistrelle *(Pipistrellus nathusii)*	1
Common pipistrelle (*Pipistrellus pipistrellus)*	2
Unidentified bat *(Pipistrellus* sp.*)*	7
Tribe Vespertilionini	
Savii's pipistrelle *(Hypsugo savii)*	1
Particolored bat *(Vespertilio murinus)*	1
Subfamily Myotinae	
Silver-haired bat *(Lasionycteris noctivagans)*	18
Southeastern myotis *(Myotis austroriparius)*	1
Bechstein's myotis *(Myotis bechsteini)*	1
Little brown bat *(Myotis lucifugus)*	2
Unidentified bat *(Myotis* sp.*)*	2
Family unknown	
Unidentified bat	377
Total	821

Results

Numbers, species, and locations of strikes

Bat-strike reports were received from 40 states in the United States and from 20 other countries. Reports from the United States were more numerous across the southern portion of the country, with the highest number of impacts reported from the states of Georgia (n = 114), Arkansas (n = 65), New Mexico (n = 55), Texas (n = 45), and California (n = 45). This variation in the distribution of strikes is probably due to a combination of factors. These factors may include, for example, (1) the proximity of bases to and the number of USAF flights in areas during times of concentrated bat activity, (2) whether or not runway sweeps are done, (3) higher concentrations of bats flying along migration routes across these areas, and (4) the large colonies of Brazilian free-tailed bats distributed across the southern United States.

Of the bat remains that were submitted for

Table 2. Common and scientific names of bat species involved in aircraft strikes between 1997 and 2007 in order of highest occurrence, followed by total number of identifications, damages, and the number of strikes (*N*) contributing to these damages.

Common Name	Scientific Name	Number Identified	Damages (US $)	*N*
Unidentified bat	Order Chiroptera	377	451,474	18
Brazilian free-tailed bat	*Tadarida brasiliensis*	173	75,566	10
Red bat	*Lasiurus borealis*	83	228,243	4
Hoary bat	*Lasiurus cinereus*	32	45,340	5
Seminole bat	*Lasiurus seminolus*	25		
Silver-haired bat	*Lasionycteris noctivagans*	18	500	1
Kuhl's pipistrelle	*Pipistrellus kuhlii*	17		
Eastern pipistrelle	*Perimyotis subflavus*	16		
Big brown bat	*Eptesicus fuscus*	15	13,886	1
Unidentified bat	Family Molossidae	10		
Unidentified bat	*Lasiurus* sp.	10		
Unidentified bat	Family Vespertilionidae	8	300	1
Evening bat	*Nycticeius humeralis*	7		
Unidentified pipistrelle	*Pipistrellus* sp.	7		
Pocketed free-tailed bat	*Nyctinomops femorosaccus*	3		
Common pipistrelle	*Pipistrellus pipistrellus*	2		
Little brown bat	*Myotis lucifugus*	2		
Unidentified myotis	*Myotis* sp.	2		
Geoffroy's trident leaf-nosed bat	*Aselia tridens*	1		
Lesser dawn bat	*Eonycteris spelaea*	1	6,000	1
Bicolored leaf-nosed bat	*Hipposideros bicolor*	1		
Northern yellow bat	*Lasiurus intermedius*	1		
Southeastern myotis	*Myotis austroriparius*	1		
Bechstein's myotis	*Myotis bechsteini*	1	4,200	1
Western pipistrelle	*Parastrellus hesperus*	1		
Javan pipistrelle	*Pipistrellus javanicus*	1		
Nathusius's pipistrelle	*Pipistrellus nathusii*	1		
Savii's pipistrelle	*Hypsugo savii*	1		
Ryuku flying fox	*Pteropus dasymallus*	1		
Naked-rumped pouched bat	*Saccolaimus saccolaimus*	1		
Particolored bat	*Vespertilio murinus*	1		
Unidentified bat	Family Emballonuridae	1		
Total		821	825,509	42

identification, 46% were confirmed as bats but unidentified to the species level, 5% were identified only to family or genus levels, and 49% were identified to the species level (Table 1). Fifty-four percent of the 101 bat-strike remains submitted for DNA analysis were identified to the species level. Brazilian free-tailed bats are the most common species of bats involved in USAF aircraft strikes, followed by 4 species of tree-roosting bats, i.e., red bats (*Lasiurus borealis*), hoary bats (*Lasiurus cinereus*), Seminole bats (*Lasiurus seminolus*), and silver-haired bats (*Lasionycteris noctivagans*). With the exception of the Seminole bat (see Wilkins 1987), all of these North American species are documented as migratory or presumed to be migratory (Cryan 2003, Findley and Jones 1964, Timm 1989, Villa R. and Cockrum 1962). The sixth most commonly identified bat species involved in aircraft strikes was the Kuhl's pipistrelle (*Pipistrellus kuhlii*), which occurs in the Middle East (Table 2) and has been identified in strikes since 2002 due to increased USAF activity in the region. This species is considered to be nonmigratory, roosts in buildings, and feeds on insects that swarm over water and around light sources. Kuhl's pipistrelle also is undergoing rapid northward range expansion (Sachanowicz et al. 2006).

Table 3. Bats identified in daytime aircraft strikes in North America between 1997 and 2007 with associated time, month, state, altitude, damages, and identification.

Time	Month	State	Altitude (m)	Damages (US $)	Identification
0800	Dec	Tex.	60		Bat
0940	Apr	Calif.	150		Brazilian free-tailed bat
1000	Sep	Calif.	150		Bat
1025	Feb	Miss.			Brazilian free-tailed bat
1032	Sep	N.M.	180	4,241	Brazilian free-tailed bat
1105	Aug	Ark.	150		Bat
1130	Sep	Ark.	400		Bat
1307	Aug	Pa.	20		Bat
1329	May	Nebr.			Bat
1330	Oct	Calif.	340		Brazilian free-tailed bat
1347	Sep	Ill.	460		Silver-haired bat
1420	Aug	O.			Bat
1550	Aug	N.M.	470	15,100	Brazilian free-tailed bat
1600	Jul	Miss.	490		Bat
1620	Nov	Calif.	240		Bat
1630	Sep	Ark.	180		Bat
1700	Oct	Ark.	0		Bat
1720	Feb	Tex.	550		Bat
1752	Jul	N.C.	0		Red bat

Seasons, times, and altitudes of strikes

We found that bat strikes peaked during the spring and fall, with >57% occurring between August and October. Less than 2% of the strikes took place between December and February. Over 82% of all bat strikes with a known time of impact occurred between 2100 and 0900 hours. A query of our filtered database of 174 bat strikes in the United States for which time and place of impact were known also revealed that >84% of these strikes occurred between 1901 and 0200 hours. Entries for 19 strikes reported the time of strike to be during the daytime. Species identified in these daytime strikes include the Brazilian free-tailed bat, the silver-haired bat, and the red bat; two of these strikes caused damage to the aircraft. The remains recovered from 2 daytime strikes contained both bats and birds. Multiple bats of the same species have been reported in aircraft strikes for Brazilian free-tailed bats, red bats, Seminole bats, and silver-haired bats. Two species of bats were identified in the same strike incident: a big brown bat and a hoary bat in one, and in another a hoary bat and 2 silver-haired bats.

Altitudes were originally recorded in feet AGL, then converted to approximate meter equivalents. In the original, unfiltered database, >12% of the bat strikes were reported to have occurred ≥300 m AGL. Our filtered database that included only those strikes that occurred in the United States in which the pilot and crew reported awareness of a strike and recorded the time and altitude retrieved 147 records. Thirty-six percent of these occurred between 300 and 3,000 m AGL, with the average altitude reported as 345 m AGL. Sixteen of these strikes were reported during low-level phases of flight, thirteen when flying traffic-holding patterns, eight during initial or final approach, eight while en route, three during air work, one during air refueling, and three when landing.

Damaging strikes

Although <1% of the bat-strike reports indicated damage to USAF aircraft (Figure 1) during this >10-year period, the resulting damage was reported at >$825,000. More than half of this sum was attributed to just 5 strikes. Only five of the bats causing the 10 most damaging strikes were identified to the species level. Unidentified bats caused >$450,000 in damage in 18 strikes. Although the most commonly identified species involved in bat strikes is the Brazilian free-tailed bat, red bats caused $228,000 in damage from just 4 strikes. Damage from 10 strikes with Brazilian free-tailed bats totaled >$75,000 (Table 2).

Discussion

We summarize information gleaned from >10 years of bat-strike data. It became obvious during our analysis of these data that uncritical acceptance of the information on these strike reports could lead to erroneous conclusions. Although we have gained much information from this analysis, it underscores the fact that bat strikes are underreported or reported with incomplete or conflicting data. In addition, many of the bats involved have not been identified to the species level.

Linnell et al. (1999) compared the numbers of aircraft strikes reported to the number of carcasses found during runway sweeps at a commercial airport and estimated that pilots reported only 25% of all wildlife strikes. The FAA estimates that between only 11 and 21% of all strikes that occur are reported to the National Wildlife Strike Database (Cleary et al. 2006, Dolbeer and Wright 2009). Williams and Williams (1967) also concluded that many more strikes occurred than were reported, based on their count of approximately 150 dents on the leading wing edges of a 2-year-old aircraft at RAFB. Bat strikes may be underreported due to several factors. These include the misconception that only birds involved in strikes are of interest or simply because the pilot and crew were unaware that a strike had occurred. For a period of time, the USAF Safety Center did not require strike reports for ground-found remains presumed to be from strikes with unidentified aircraft. Different management practices at USAF bases undoubtedly influenced the number and locations of strikes reported.

One of the biggest problems with interpreting data retrieved from aircraft strikes is that often it is not known where and when the strike occurred (Dale 2009). The extreme distances over which strike remains continue to adhere to the aircraft is exemplified by Leader et al. (2006). They reported that the remains of an African fruit-bat-strike to a commercial Boeing 767 had been transported across 3 continents. Based on the identification of the bat and previous flight plans for the aircraft, the strike was presumed to have occurred in Ghana, and was transported to London, England, where it was undetected. It then went on to Ben-Gurion International Airport, Israel, before the ground crew discovered the bat-strike remains and associated damage to the aircraft. The USAF strike database contains similar records of species reported from base localities where the bats are not known to occur. The geographic locations of strikes that occurred when the pilot and crew were unaware of a strike in flight must be treated as unknown. When the flight is known to have been local, the strike can be considered to have been in the general vicinity of the base. The remains of small animals, such as bats, could be overlooked during maintenance inspections after flight, only to be found during a subsequent inspection.

Figure 1. Damage to the AN/AAQ-17 Infrared Detecting Set on an MC-130H aircraft resulting from a strike with a Lesser dawn bat (*Eonycteris spelaea)* in Thailand. (*Photo courtesy Major T. R. Murphy, Chief of Flight Safety, 353rd Special Operations Unit, U.S. Air Force*)

Over 1,000 bat species are currently recognized (Wilson and Reeder 2005). Yet, only 25 species have been recorded in air strikes with USAF planes worldwide. Many species of bats occur locally and many of these only in the tropics where USAF bases are uncommon. The highly diverse genus *Myotis,* with 15 species in North America, is represented in only 6 USAF aircraft strikes. Williams and Williams (1967) detected a species of *Myotis* flying around buildings and light sources, but did not report encountering any in aircraft strikes at RAFB. It seems likely that the bats struck by aircraft are flying in more open space and at greater heights while migrating or feeding, and the locally common, resident bats infrequently encounter flying aircraft.

Evidence retrieved from bat strikes with aircraft provides a unique means of providing information about seasonal migration patterns of bats. Bat strikes are reported year-round, 24 hours per day, at altitudes at which many bats fly. Migration patterns of bats are not well-known, and the fact that North American bats are primarily nocturnal makes observation of their movements difficult and further complicated by the fact than many North American bats are difficult to identify in hand. Correct identification may require examination of dental and cranial features. Bat banding allowed researchers to study migration patterns in some bat species before the banding program was terminated in the early 1970s (Peurach 2004). This method was most informative for cave-roosting species that easily could be located and banded in great numbers, such as the Brazilian free-tailed bat (Villa R. and Cockrum 1962, Glass 1982). Tree roosting bats (e.g., *Lasiurus* and *Lasionycteris*) are typically solitary and difficult to locate, making them poor subjects for bat banding and migration studies. Collection data from museum voucher specimens in natural history collections have been used to examine movement patterns between summer and winter roost sites for tree bats of the genera *Lasiurus* and *Lasionycteris* (Findley and Jones 1964, Cryan 2003), but collections do not accurately reflect population densities throughout the year at different locations. Bat-strike reports are in accord with Villa R. and Cockrum (1962), who suggested that the southward migration of Brazilian free-tailed bats occurs very rapidly, covering 32 km or more per night, whereas the springtime return is much more gradual. Similar patterns were also seen by Zin and Baker (1979) for hoary bats migrating through Florida. Cryan (2003) reported finding few records of silver-haired bats and hoary bats from the southeastern United States during spring and summer months, with numbers increasing during the fall. Closer examination of USAF bat-strike data for tree-roosting bats also indicates dramatically fewer strikes for these species in the southeastern United States in the spring and summer, but a few records do exist (i.e., hoary bats from Missouri on March 27, 2003, and North Carolina on April 23, 2007; silver-haired bats from Arkansas on May 8, 2006, and May 22, 2007, and from Missouri on June 11, 2003).

Daytime flights of mixed bat species, as well as bat flights with birds, are uncommon and not well-documented. Aircraft strike data may provide the means to document this phenomenon (Table 3). Flocks of bats have been reported flying during daylight hours by several researchers (Hall 1946, Howell 1908, Mearns 1898). Three closely related species of tree bats (*Lasiurus seminolus*, *L. borealis*, and *Lasiurus intermedius*) were reported flying with flocks of migrating birds (Neuweiler 2000), and flocks of mixed species of bats and birds were seen in New England flying along the coastline during the day (Saunders 1930).

The altitude of bat and bird flight is of interest to aviation and of increasing interest to the wind-turbine industry. Until recently, not much has been known about the altitudes at which bats fly. Williams and Williams (1967) and Linnell et al. (1999) suggest that most bat strikes occur <300 m AGL during take-off and landing. Clearly bat strikes are not limited to 300 m AGL and often may occur at altitudes higher than previously thought. The bat-strike data demonstrate that these bats are flying at higher altitudes, up to 2,500 m AGL. High-altitude flights of the Brazilian free-tailed bat have been documented in several publications (Williams and Williams 1967, Williams et al. 1973). Peurach (2003) reported a hoary bat from a USAF strike at 2,500 m AGL, which is the highest known for this species.

In general, bats do not cause as much damage to USAF aircraft as do birds, but the potential for damaging strikes still exists, especially when flying newly designed aircraft or when flying in unfamiliar areas, as was reported by Williams and Williams (1967). Dove and Peurach (2001) reported damage to a USAF T-37-B aircraft caused by a Brazilian free-tailed bat approximating $10,000. The USAF database includes several additional bat strikes that have caused even greater damage (Table 2). Forty-three percent of the bats in strike reports that listed associated damage were unidentified because of insufficient material recovered. Proper understanding of the importance of bat strikes to aviation can be achieved only if we get positive identifications and accurate associated information.

Our knowledge and understanding of bat densities and migration patterns across the southern part of the United States, paired with radar data and bird avoidance models, has reduced the incidents of bat strikes in that region. Bat strikes are still occurring, however, sometimes causing damage and sometimes at surprisingly high altitudes. These strikes occur both with bats and birds, and, occasionally, at times not expected for primarily nocturnal bats. The information gleaned from bat-strike reports may be used to prevent future damage.

Management implications

Carefully documented bat-strike reports provide an unequalled opportunity to determine locations, seasons, times, and altitudes at which bats are flying. To maximize the utility of the data, we make the following recommendations. First, critical data fields are date, time, location, and altitude; however, if information for any of these is unknown, they should be marked unknown. It is important not to make assumptions about these fields or enter default information that is not accurate. Secondly, because we cannot make identifications unless we receive strike remains, we recommend that all bat-strike remains from military and civilian aircraft strikes be submitted for identification to the Smithsonian Institution, National Museum of Natural History, Washington, D.C.

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