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Short communication

Fatal injuries to birds from collisions with aircraft reveal anti-predator behaviours

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Between 1990 and 2008, more than 87 000 bird–aircraft collisions (hereafter, bird strikes) were reported to the US Federal Aviation Administration (FAA) and represented more than US$600 million in direct and indirect costs to US civil aviation annually (Dolbeer *et al.* 2009). Worldwide, the costs to civil aviation associated with bird strikes exceed US$1.2 billion annually (Allan & Orosz 2001). In the United States, 381 avian species have been reported as struck by civil aircraft, with gulls (Laridae 19%), doves/pigeons (Columbidae 15%), raptors (including New-World Vultures, Cathartidae 13%) and waterfowl (Anatidae 8%) the most frequently reported non-passerine bird groups (Dolbeer *et al.* 2009).

The possibility that necropsies of struck birds could provide information on behaviour at the point of collision (e.g. evidence of avoidance response) has received little attention. For example, to our knowledge only unpublished reports by Lyne *et al.* (1998) and Sheehy *et al.* (2005) document results of detailed necropsies on birds found dead on runways. Findings from those reports indicate that injuries to birds due to vehicle strikes were largely concentrated on the ventral surface; as a consequence, the authors suggest that a generic avoidance response was initiated prior to impact.

Clearly, an aircraft poses a hazard to birds (Blackwell *et al.* 2009a, Dolbeer *et al.* 2009) and there is empirical evidence that birds utilize anti-predator strategies in response to human disturbance similar to strategies used when encountering a predator (e.g. Frid & Dill 2002, Møller *et al.* 2008, Blackwell *et al.* 2009b). Thus, in an applied context, anti-predator behaviours can help us to understand the mechanisms behind the responses of wildlife to different types of human activities (Fernández-Juricic *et al.* 2001, Blackwell *et al.* 2009b).

We questioned, therefore, whether information obtained via necropsy of struck birds would indicate not only a behavioural response to the aircraft, but distinct anti-predator behaviours (e.g. Lima 1993, Hedenström & Rosén 2001, Blackwell *et al.* 2009b). If so, necropsies of struck birds could provide information useful in understanding avian response to aircraft approach and, potentially, in the development of predictive methods intended to reduce the frequency of bird strikes. Our objectives were to determine whether injuries associated with a strike were discernible from those incurred due to impact with the ground, and whether injuries to birds within phylogenetic groups and foraging guilds (cohorts) were distinctive, thus indicating cohort-specific response behaviours. We assumed that if a fatal injury occurred because of a strike (i.e. a strike not involving engine ingestion), but the carcass received further damage due to impact with the ground or crushing by ground vehicles, the location of injuries would be randomly distributed. In contrast, the location of strike injuries alone is likely to be governed by either a generic avoidance response (e.g. Sheehy *et al.* 2005) or species-specific anti-predator behaviours, and therefore be clumped.

Across all birds examined in our study, fatal injury locations were generally posterior, ventral and on the left side. Because of the predominant ventral distribution of injuries we conclude that the birds had taken evasive action in response to the aircraft, reflecting known aspects of anti-predator behaviour.

METHODS

Carcass recovery

During 2000 and 2001, staff at John F. Kennedy International Airport (JFK), New York, USA, recovered carcasses of birds reported to the FAA as killed in collisions with aircraft at the airfield, as well as those presumed so given the location at recovery. We obtained the FAA strike reports for those birds recovered as a result of a reported strike. The carcasses were recovered during five to 10 daily sweeps of the runways, taxiways and ground within 250 feet of the runways. Upon recovery, the carcasses were frozen and sent to the US Department of Agriculture's (USDA) National Wildlife Research Center, Ohio Field Station, and assigned a unique number before examination. We excluded from our sample of birds those which were severely desiccated, partly

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consumed by flesh-eating insects, in advanced stages of deterioration or otherwise compromised.

Necropsies

We performed necropsies on 92 birds and determined injuries by examining each bone and muscle group using a simplified version of the necropsy performed by Lyne *et al.* (1998). We first examined a bird externally, then removed the skin and examined the bird for subcutaneous injuries. We examined internal organs for superficial (indicated by bruising) or gross damage. Sex and stomach contents data were not considered in this analysis because of limited sample sizes within some cohorts.

We grouped birds into cohorts that reflected both phylogenetic relationships and similar foraging behaviour (Erlich *et al.* 1988) and converted the detailed record of injuries into a summary of injuries considered fatal (e.g. severe trauma to the head/neck, lacerations or crushing of the thoracic area). We then broadly located fatal injuries using a coordinate system involving three axes through the body of the bird (i.e. anterior–posterior, dorsal–ventral and right–left), such that the planes representing each axis divided the bird into eight segments (Chiasson 1972, Fig. 1). Thus, each injury was represented by a point that corresponded to each of the three axes. If injuries were centralized on an axis, or equally distributed on both ends of an axis, they were recorded as centred. We scored injuries as follows: anterior = +1, posterior = −1, dorsal = +1, ventral = −1, right = +1, left = −1 and centred = 0. We omitted wing injuries because the wings could have been in a variety of positions relative to the body when the strike occurred.

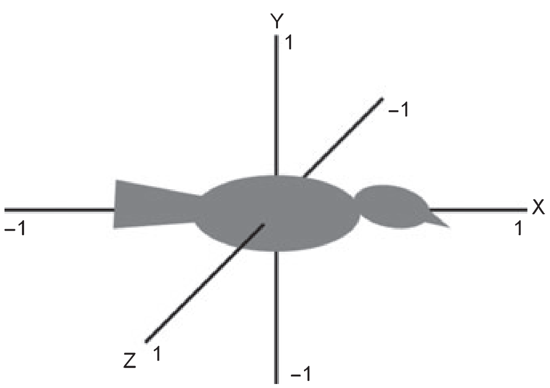

Figure 1. Injuries considered fatal were located on bird carcasses recovered from JFK using a coordinate system involving three axes through the body of the bird (i.e. anterior–posterior, dorsal–ventral and right–left), such that the planes representing each axis divided the bird into eight segments (see Chiasson 1972).

Analysis

Birds that composed a flock struck by an aircraft were not independent. However, because our sample size of recovered carcasses was limited, we assumed that individual birds represented experimental units and conducted a broad comparison of injury locations (i.e. the three coordinates noted above) vs. random points across all birds. The random points represented a random distribution of injuries that we assumed would be consistent with a struck bird that received further damage due to impact with the ground or crushing by ground vehicles. We also made a similar comparison for gulls and terns, then collectively for all other cohorts that comprised six or more specimens. Because of the limited number of specimens within cohorts we did not conduct paired comparisons.

For each bird we calculated the Cartesian distance between the coordinates for the major injury and a random point based on the three axes as:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

RESULTS

We recovered 92 individuals from 32 species and assigned individuals to 13 cohorts (Table 1). Strike reports indicated multiple birds involved in a single collision for five species (Table 1). Certain injuries, including deep lacerations, multiple shallow lacerations and amputations, were easily identified as having been caused by aircraft contact. Some abrasions, deep bruises and other concussive injuries were known to have been caused by contact with an aircraft because the strike was corroborated by an official FAA strike report. Furthermore, in some cases physical evidence such as blood, feathers or other tissues was found on the aircraft and used by the FAA to identify the bird (e.g. Dove *et al.* 2008).

Across all birds, major injuries were most frequently observed on the posterior (39%), ventral surface (53%) and left axis (44%), and differed from random points (Wilcoxon two-sample test, $n = 92$, $Z = 11.8$, $P < 0.0001$; Table 1). Injuries scored as centred were most prominent on both the anterior–posterior (27% of birds in the sample) and right–left axes (26%) vs. the dorsal–ventral axis (17%). Gulls and terns also showed injuries that were located predominantly on the posterior (51%), ventral surface (57%) and left axes (49%), and that differed from random points ($n = 35$, $Z = 7.2$, $P < 0.0001$; Table 1). We also observed centred injuries for gulls and terns on each of the three axes: anterior–posterior axis (26% of birds), dorsal–ventral axis (11%) and the right–left axis (20%). For all cohorts with six or more specimens, other than gulls and terns, major

Table 1. Location of fatal injuries to 92 birds involved in bird–aircraft collisions (bird strikes) or presumed struck by aircraft at John F. Kennedy International Airport, New York, 2000–2001.

Cohort[a]	Species	*n*	No. of birds/strike	Axis[b] AP	DV	RL	Mean (sd) distance[c]
Podicipedidae, Anatidae (in part) & Rallidae	*Podilymbus podiceps*	1	1	1	−1	−1	2.5 (0.6)
	Anas platyrhynchos	2	1	1	−1	*	
	Fulica americana	1	1	1	−1	−1	
Ardeidae	*Ardea herodias*	2	1	*	*	*	2.2 (0.7)
	Ardea alba	1	1[d]	1	−1	−1	
	Nycticorax nycticorax	2	1	*	−1	*	
Anatidae (in part)	*Branta canadensis*	1	1[d]	−1	−1	1	1.4
Accipitridae & Falconidae	*Falco sparverius*	1	1	−1	1	0	1.6 (0.5)
	Pandion haliaetus	2	1	*	*	*	
Charadriidae, Haematopodidae & Scolopacidae	*Pluvialis dominica*	1	1	1	1	−1	1.8 (0.8)
	Charadrius semipalmatus	2	2	0	0	0	
	Haematopus palliatus	4	1	*	−1	1	
	Catoptrophorus semipalmatus	2	1[d]	*	*	1	
Laridae	*Sterna forsteri*	2	1	*	*	*	2.0 (0.8)
	Larus atricilla	10	1	−1	−1	1	
	Larus delawarensis	1	1	0	−1	−1	
	Larus argentatus	18	2[d]	−1	−1	−1	
	Larus marinus	4	1	−1	0	−1	
Columbidae	*Columba livia*	5	2	1	1	1	1.3 (1.0)
	Zenaida macroura	1	1	1	−1	−1	
Tytonidae & Strigidae	*Tyto alba*	3	1	*	0	*	1.6 (0.5)
	Asio flammeus	1	1	−1	0	0	
Picidae	*Colaptes auratus*	1	1	1	−1	−1	3.0
Hirundinidae	*Tachycineta bicolor*	1	1	1	−1	−1	1.5 (1.3)
	Hirundo rustica	2	1	1	1	1	
Alaudidae & Emberizidae (in part)	*Eremophila alpestris*	2	1[d]	*	1	0	1.7 (0.6)
	Plectrophenax nivalis	7	6[d]	0	−1	0	
Icteridae (in part) & Sturnidae	*Molothrus ater*	7	6[d]	−1	−1	−1	2.1 (0.6)
	Sturnus vulgaris	1	1	0	−1	−1	
Miscellaneous	*Gavia immer*	1	1	0	0	0	1.6 (0.6)
	Phasianus colchicus	1	1[d]	1	−1	−1	
	Dumetella carolinensis	1	1	1	−1	−1	
	Zonotrichia albicollis	1	1	0	1	−1	
All birds				−1	−1	−1	1.9 (0.8)

[a]Cohorts reflect phylogenetic relationships, as well as similar foraging behaviour.
[b]Injuries were located on a bird relative to three axes: AP, anterior–posterior; DV, dorsal–ventral; RL, right–left. If injuries were centralized on an axis, or equally distributed on both ends of an axis, we recorded them as centred. Mode of injuries within species was scored as follows: anterior = +1, posterior = −1, dorsal = +1, ventral = −1, right = +1, left = −1 and centred = 0; * = no mode could be calculated.
[c]Mean cohort Cartesian distance between injury location (x_1, y_1 and z_1, representing the three axes) and a random point (x_2, y_2 and z_2) calculated as $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$.
[d]Number of birds reported by pilot or ground crew to the FAA as involved in a single strike incident.

injuries were observed equally on the anterior and posterior (31%, respectively), ventral surface (47%) and equally on the right and left axes (34%, respectively), and differed from random points (Wilcoxon two-sample test, $n = 32$, $Z = 6.8$, $P < 0.0001$; Table 1). Centred injuries also occurred on each of the three axes: anterior–posterior axis (38% of birds), dorsal–ventral axis (22%) and the right–left axis (31%).

DISCUSSION

The predominance of strike injuries on the ventral surface of bird carcasses recovered at JFK is indicative of evasive behaviour in response to an approaching aircraft. Specifically, for the primary point of contact between an aircraft and bird to be on the ventral surface and along the posterior axis, a bird must be climbing while moving towards the aircraft, dropping while moving away from the aircraft, or banking away while moving horizontally across the aircraft's path. These results, particularly the ventral and posterior injuries observed in gulls and terns, are supported by Lima's (1993) observations that larger gulls dodge predators by pulling up just before impact. In addition, smaller flocking species, such as the passerines and Scolopacidae, use diversionary flight in response to predator trajectory and speed (e.g. Buchanan *et al.* 1988, Cresswell 1993, Kullberg *et al.* 1998, Lind *et al.* 2002). The observed fatal injuries to cohorts comprising smaller species are consistent with flight in response to aircraft approach that was at an angle to, or opposite the direction of, the aircraft, thus exposing the anterior–posterior axis. The frequency of injuries to the ventral surface is consistent with climbing and banking. However, the distribution of injuries along the anterior–posterior axis, as well as the frequency of centred injuries, suggests that in smaller species, impact with an aircraft probably affects a greater proportion of the bird's body, in contrast to more localized injuries on larger birds.

With regard to injuries located on the right–left axis, there is evidence for behavioural lateralization (i.e. specialization within the two brain hemispheres; see Vallortigara 2000, MacNeilage *et al.* 2009) in avian vigilance (Franklin & Lima 2001), and differential use of visual hemifields in foraging (Ventolini *et al.* 2005) and social interactions (Ventolini *et al.* 2005, Zucca & Sovrano 2008). Laterality in escape behaviour has been observed for multiple taxa (Cantalupo *et al.* 1995, Bisazza *et al.* 1997, Vallortigara & Rogers 2005).

In light of our findings, we concur with Blackwell *et al.* (2009b) that avian anti-predator behaviour is applicable in efforts to better understand factors contributing to bird strikes. Moreover, we suggest that data obtained from necropsies of struck birds, in combination with knowledge of avian anti-predator strategies, could prove useful in developing predictive models of avian response to aircraft approach, given factors such as habitat heterogeneity on or near an airport, aircraft movements and species composition.

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