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Positive bias in bird strikes to engines on left side of aircraft

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Abstract: Previous studies have indicated more birds collide with communication towers equipped with red warning lights than with towers equipped with lights of shorter wavelengths. We used the U.S. Federal Aviation Administration's National Wildlife Strike Database to determine if a similar relationship exists for turbine-powered jet aircraft with 2 underwing- or fuselage-mounted engines and bird strikes. We compared bird strikes reported to engine #1 (left side = red lighting) or to engine #2 (right side = green lighting) using chi-square tests ($\alpha = 0.05$). For both underwing- and fuselage-mounted engines, more ($P \leq 0.04$) strikes were reported for engine #1 compared to engine #2 during Day, Night, and Dawn/Dusk flights. These findings suggest that modifying red navigation lights to include shorter wavelengths and the use of supplemental lights specifically designed for avian vision could enhance detection and reduce bird strikes.

Key words: bird strikes, jet aircraft, navigation lights, vision, warning lights, wavelengths

Aircraft collisions with birds (i.e., bird strikes) are an increasingly serious economic and safety concern worldwide (DeVault et al. 2013, Dolbeer et al. 2015). Efforts to reduce strikes have primarily involved integrated wildlife management programs at airports to remove habitat and food sources attractive to birds that pose a risk to aviation safety and to disperse these birds with various harassment techniques (Cleary and Dolbeer 2005). While these efforts have been successful in reducing damaging strikes in airport environments, they have little effect on strikes beyond airport fences (Dolbeer 2011, Dolbeer et al. 2015).

Modern commercial and business aircraft, with quieter turbofan engines, may not be as easily detected by birds compared to older propeller and jet-powered aircraft (Burger 1983, Kelly et al. 1999, 2001). Thus, another approach recommended for reducing strikes is to make aircraft more visibly detectable by birds. Bernhardt et al. (2010) demonstrated that the predominance of bird strike injuries on the ventral surface of bird carcasses was indicative of evasive behavior in response to approaching aircraft. To this end, recent studies have been conducted on avian visual perception with the goal to enhance aircraft detection and avoidance by birds (Blackwell et al. 2012, DeVault et al. 2015).

Previous studies have reported that communication towers equipped with red warning lights have more bird collisions than towers equipped with lights of shorter wavelengths (Gehring et al. 2009, Sheppard 2011, Patterson 2012). These results may be related to vision in birds being generally less sensitive than in humans to the red end of the spectrum (Varela et al. 1993). Gauthreaux and Belser (2006) used a marine radar to demonstrate that more night migrants flew in circular flight patterns near a guyed communication tower (>305 m above ground level [AGL]) with a combination of blinking and nonblinking red lights than near a guyed tower of similar height equipped only with white strobe lights. Munro et al. (1997) demonstrated in laboratory experiments that Tasmanian silvereyes (*Zosterops lateralis*) oriented in the appropriate migratory direction under white (full spectrum) and green light (571 nm) but were disoriented under red (633 nm) light.

Based on these findings, the U.S. Federal Aviation Administration (FAA) has made changes to obstruction lighting standards to reduce bird mortality from collisions, including the elimination of steady-burning red lights from several obstruction lighting configurations (Patterson 2012, Federal

Aviation Administration 2015*a*). We used the FAA's National Wildlife Strike Database (NWSD; Dolbeer et al. 2015) to determine if a similar relationship exists for turbine-powered jet aircraft with 2 underwing- or fuselage-mounted engines and bird strikes. We tested the hypothesis that aircraft navigation lights (red on left wing and green on right wing; Figure 1) would result in a positive bias in bird strikes to left side of aircraft. We note that because of various lamp types and filters on aircraft, our use of green and red broadly considers spectral composition from approximately 495–570 nm and 620–750 nm, respectively.

Figure 1. An aircraft on final approach (about 400 m above ground level, 3 km from runway) at night into Cleveland-Hopkins International Airport, Ohio, USA, demonstrates the position of landing lights (center) and navigation lights (red on left wing, green on right wing). (*Grayscale version of cell phone photo by R. A. Dolbeer*)

Methods

We used bird strike reports in the NWSD from January 1990 to July 2015. The FAA Form 5200-7 for reporting strikes provides boxes to check indicating part(s) of aircraft struck. The only parts related to right or left side of aircraft are engines (i.e., engine #1, #2, #3, or #4). We selected strikes involving all commercial transport and business aircraft in the database that have 2 underwing- or fuselage-mounted turbine-powered jet engines (Tables 1 and 2). We then selected those records that had a bird strike reported to engine #1 (left side) or to engine #2 (right side), excluding records with no engine strike or a strike involving both engines.

There are situations where an engine strike is reported but the engine position is not indicated. In these cases, the database manager enters engine #1 as "default" and indicates in the Remarks section of the record that the

Table 1. Bird strikes by engine position (Eng #1, left; Eng #2, right) and time of day for civil transport aircraft with 2 underwing-mounted turbine-powered engines, USA, January 1990 to July 2015. Strike data are from Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015).

	Day		Night		Dawn/Dusk		All times[a, b]	
Aircraft series[c]	Eng #1	Eng #2	Eng #1	Eng #2	Eng #1	Eng #2	Eng #1	Eng #2
B-737	1,212	1,017	427	374	16	15	2,124	1,817
A-318 to 330	242	257	104	117	36	31	546	555
B-757	143	114	68	57	12	6	293	247
A-300/310	43	37	56	54	186	141	201	191
EMB-170/190	72	64	22	21			146	135
B-767	65	50	41	24	15	7	172	128
B-777	14	17	3	7	8	11	32	37
Dornier 328J	6	5			1		7	6
B-787	1	1			2	1	1	5
Total	1,798	1,562	721	654	276	212	3,522	3,121

[a] Includes strikes with time of day not reported.

[b] There were 56,142 strike reports involving birds for these aircraft, of which 49,178 had strikes to aircraft parts other than engines and 321 had strikes to both engines. The remaining 6,643 reports with a strike to engine #1 or #2 were used in the analyses.

[c] Aircraft manufacturers: B = Boeing, A = Airbus, EMB = Embraer.

Table 2. Bird strikes reported by engine position (Eng #1, left; Eng #2, right) and time of day for civil transport aircraft with 2 fuselage-mounted turbine-powered engines, USA, January 1990 to July 2015. Strike data are from Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015).

	Day		Night		Dawn/Dusk		All times[a, b]	
Aircraft series[c]	Eng #1	Eng #2	Eng #1	Eng #2	Eng #1	Eng #2	Eng #1	Eng #2
DC-9/MD-80s	155	88	81	50	29	26	294	193
CRJ 100 to 900	97	100	40	34	11	13	164	165
EMB-135/145	78	69	28	25	14	10	144	124
Learjet-31/60	85	53	16	9	20	18	124	85
Cessna Citation	122	89	25	31	25	11	199	156
DA-10/200	28	16	5	5	4	6	41	28
Hawker 800/4000	23	24	7	6	3	2	40	38
BE-400 BJET	24	28	6	5	6	3	37	36
CL-600/604	19	10	5	6	4	4	28	22
Fokker 100/F28	14	18	2	7	2	5	19	30
Gulfstream III/IV	6	7	3	3	5	3	18	13
B-717-200	11	7	3	5	1	1	17	15
Gulfstream 200/V	11	6	4		1	1	17	8
IAI Astra/Galaxy	11	9	2		3	1	16	11
BAe-125-700/800	8	5	2	1	3	1	13	8
Challenger 300	3	4	3		2	1	10	5
MU-300	4	4	1				5	4
Sabreliner-65/80A	4	2	1				5	2
Miscellaneous [d]	5	4	2	1			9	6
Total	708	543	236	188	133	106	1,200	949

[a] Includes strikes with time of day not reported.

[b] There were 33,119 strike reports involving birds for these aircraft, of which 30,822 had strikes to aircraft parts other than engines and 148 had strikes to both engines. The remaining 2,149 reports with a strike to engine #1 or #2 were used in the analyses.

[c] Aircraft manufacturers: DC/MD = McDonnell Douglas, CRJ = Canadair Regional Jet, EMB = Embraer, DA = Dassault, BE = Beechcraft, CL = Canadair/Bombardier, B = Boeing, IAI = Israel Aerospace Industries, BAe = British Aerospace, MU = Mitsubishi.

[d] Raytheon 390, Embraer 500, Aerospatiale SN601, Global Express, and Embraer Phenom 100/300.

engine number was not known and engine #1 was the default entry. To eliminate these records from analysis, we then selected only the reports that were submitted on Form 5200-7 (which has specific data fields for engine position) or were submitted by multiple sources that included at least one Form 5200-7 (see Table 4 of Dolbeer et al. 2015). Then we searched the Remarks field of these records and removed all records where engine #1 had been entered as a default.

We conducted one-tailed chi-square tests ($\alpha = 0.05$) to determine the probability that the distribution of strikes between the 2 engine positions was not random for underwing-mounted engines and fuselage-mounted engines, assuming a null hypothesis of 50% of the strikes to each engine position. We used a one-tailed test because we *a priori* established an expectation of more strikes to the left side of aircraft based on findings from communication towers. We examined these distributions for strikes reported during Day, Night, Dusk/Dawn, and all times (including records in which time of day was not indicated).

Table 3. Chi-square (X^2) values for actual and expected number of reported bird strikes by engine position (#1, left; #2, right) for civil transport aircraft with 2 underwing-mounted turbine-powered engines (see Table 1), USA, January 1990 to July 2015. Strike data are from Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015).

		Number (%) of bird strikes to engine			
Time of strike	Engine	Reported	Expected[a]	X^2 value	*P* value[b]
Day	#1	1,798 (54)	1,680 (50)	16.58	<0.001
	#2	1,562 (47)	1,680 (50)		
	Total	3,360 (100)			
Night	#1	721 (52)	688 (50)	3.27	0.035
	#2	654 (48)	688 (50)		
	Total	1,375 (100)			
Dawn/Dusk	#1	276 (57)	244 (50)	8.39	0.002
	#2	212 (43)	244 (50)		
	Total	488 (100)			
All times[c]	#1	3,522 (53)	3,322 (50)	24.21	<0.001
	#2	3,121 (47)	3,322 (50)		
	Total	6,643 (100)			

[a] Assuming a 50% probability for each engine.
[b] One-tailed P value because the *a priori* test was that the #1 engine would have more strikes ($P = 0.05$ for X^2 value of 1.92).
[c] Includes strikes with time of day not reported.

Results

Underwing-mounted engines

Overall (for all times of day), 3,522 (53%) of the strikes were recorded for engine #1 compared to 3,121 (47%) for engine #2 (Tables 1 and 3). This difference of 401 strikes was highly significant ($P < 0.001$) compared to the expected probability of 50% of strikes for each engine. For all 3 categories of time of day (Day, Night, Dawn/Dusk), more strikes were recorded for engine #1 compared to engine #2 ($P \leq 0.035$). Night differed the least ($P = 0.035$). Boeing aircraft, especially the B-737 series, had the largest bias for strikes to engine #1 (Table 1). Airbus aircraft did not show a bias.

Fuselage-mounted engines

The overall bias toward strikes to engine #1 was even more pronounced for fuselage-mounted engines compared to underwing-mounted engines. For all times of day, 1,200 (56%) of the strikes were recorded for engine #1 compared to 949 (44%) for engine #2, a difference of 251 strikes (Tables 2 and 4; $P < 0.001$). For all 3 categories of time of day (Day, Night, Dawn/Dusk), more strikes were recorded for engine #1 compared to engine #2 ($P \leq 0.04$). Dawn/Dusk had the least difference ($P = 0.04$). The McDonnell Douglas DC-9/MD-80 series of aircraft had the largest bias for strikes to engine #1 (Table 2) whereas Canadair Regional Jet aircraft showed no bias. Fokker aircraft, which had a small sample size of only 49 incidents, had 30 strikes reported for engine #2 compared to 19 for engine #1.

Combined data for underwing- and fuselage-mounted engines

When we combined the datasets, the bias toward birds striking engine #1 compared to engine #2 was even more pronounced (Table 5). For all times of day, 4,722 (54%) of the

Table 4. Chi-square (X^2) values for actual and expected number of reported bird strikes by engine position (#1, left; #2, right) for civil transport aircraft with 2 fuselage-mounted turbine-powered engines (see Table 2), USA, January 1990 to July 2015. Strike data are from Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015).

		Number (%) of bird strikes to engine			
Time of strike	Engine	Reported	Expected[a]	X^2 value	*P* value[b]
Day	#1	708 (57)	626 (50)	21.76	<0.001
	#2	543 (43)	626 (50)		
	Total	1,251 (100)			
Night	#1	236 (56)	212 (50)	5.43	0.01
	#2	188 (44)	212 (50)		
	Total	424 (100)			
Dawn/Dusk	#1	133 (56)	120 (50)	3.05	0.04
	#2	106 (44)	120 (50)		
	Total	239 (100)			
All times[c]	#1	1,200 (56)	1,075 (50)	29.32	<0.001
	#2	949 (44)	1,075 (50)		
	Total	2,149 (100)			

[a] Assuming a 50% probability for each engine.
[b] One-tailed *P* value because the *a priori* test was that the #1 engine would have more strikes ($P = 0.05$ for X^2 value of 1.92).
[c] Includes strikes with time of day not reported.

strikes were recorded for engine #1 compared to 4,070 (46%) for engine #2, a difference of 652 strikes ($P < 0.001$). For all 3 categories of time of day (Day, Night, Dawn/Dusk), more ($P \leq 0.003$) strikes were recorded for engine #1 compared to engine #2.

Discussion

This analysis provides evidence of a bias toward birds striking the left side of aircraft where a red navigation light is located compared to the right side where a green light is located. Our findings suggest greater robustness of avian visual capability at middle wavelengths compared to longer wavelengths (see also Moore et al. 2012). It was surprising that the bias was least prevalent at night and dusk/dawn when aircraft lighting would be expected to have the largest influence. However, achromatic and chromatic contrast of aircraft to ambient background conditions is critical to assessing saliency of light stimuli (Blackwell et al. 2012, Doppler et al. 2015). Because 99% of strikes occur at <3,000 m AGL (Dolbeer et al. 2015) when landing lights typically are on, day or night (Federal Aviation Administration 2015*b*, paragraph 4-3-23c), this difference for strikes in low-light conditions compared to full-daylight strikes may be explained by the brightness of landing lights overwhelming the navigation lights under these low-light conditions. Anti-collision strobe lights used on some aircraft may also overwhelm navigation lights at night.

An alternative explanation for the bias could be behavioral lateralization in escape behavior by birds (Ventolini et al. 2005). Behavioral studies of birds at airports and necropsies of birds struck by aircraft indicate that birds take evasive maneuvers in attempts to avoid being struck by aircraft (Kelly et al. 1999, 2001, Bernhardt et al. 2010). Bernhardt et al (2010)

Table 5. Chi-square (X^2) values for actual and expected number of reported bird strikes by engine position (#1, left; #2, right) for civil transport aircraft with 2 underwing- (Table 1) or fuselage-mounted (Table 2) turbine-powered engines, USA, January 1990 to July 2015. Strike data are from Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015).

		Number (%) of bird strikes to engine			
Time of strike	Engine	Reported	Expected[a]	X^2 value	*P* value[b]
Day	#1	2,506 (54)	2,306 (50)	34.87	<0.001
	#2	2,105 (46)	2,306 (50)		
	Total	4,611 (100)			
Night	#1	957 (53)	900 (50)	7.35	0.003
	#2	842 (47)	900 (50)		
	Total	1,799 (100)			
Dawn/Dusk	#1	408 (56)	363 (50)	11.42	<0.001
	#2	317 (44)	363 (50)		
	Total	725 (100)			
All times[c]	#1	4,722 (54)	4,396 (50)	48.35	<0.001
	#2	4,070 (46)	4,396 (50)		
	Total	8,792 (100)			

[a] Assuming a 50% probability for each engine.

[b] One-tailed *P* value because the *a priori* test was that the #1 engine would have more strikes ($P = 0.05$ for X^2 value of 1.92).

[c] Includes strikes with time of day not reported.

found a greater incidence of major injury to the left side compared to right side of a sample of 92 birds struck by aircraft.

Our results support previous findings suggesting that modifying red navigation lights to include shorter wavelengths specifically designed for avian detection, the use of supplemental lights such as full-spectrum anti-collision strobe lights or pulsating lights, or even paint schemes on the frontal area of aircraft could enhance detection and reduce bird strikes (Fernández-Juricic et al. 2011, Blackwell et al. 2009, 2012; Doppler et al. 2015).

Management implications

Our empirical results, based on reported bird strikes to the right and left side of aircraft, support the hypothesis that aircraft lighting can influence the ability of birds to avoid collisions with aircraft. We recommend that some simple operational changes in commercial aircraft procedures, such as using the leading-edge wing illumination lights at night, especially during periods of nocturnal bird migration, could enhance bird avoidance of the aircraft. The use of supplemental or modified lighting systems such as full-spectrum anti-collision strobe or pulsating lights may also enhance detection and avoidance. However, additional research is needed to document bird escape behavior during encounters with aircraft and road vehicles to provide better bird strike mitigation guidance.

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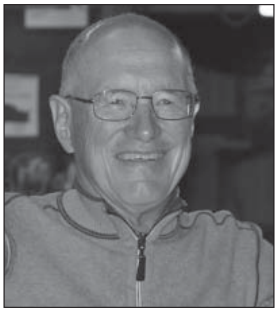

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