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Bird strikes and aircraft fuselage color: a correlational study

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Abstract: Collisions between birds and aircraft (bird strikes) pose safety risks to the public, cost airports and airlines money, and result in liability issues. Recent research suggests that aircraft visibility could be enhanced to increase detection and avoidance by birds. We questioned whether aircraft color scheme might play a role in bird-strike frequency. We used public records of bird strikes along with information on flights that were gathered by federal agencies in the United States. We estimated the bird-strike rates and compared them among airline companies using different fuselage color schemes, while controlling for aircraft type. Using an avian vision modeling approach, we first corroborated the hypothesis that brighter colors would contrast more against the sky than darker colors. We found differences in bird-strike rates among airline companies with different color schemes in 3 out of the 7 aircraft types investigated: Boeing 737, DC-9, and Embraer RJ145. With each of these aircraft, we found that brighter aircraft were associated with lower bird-strike rates. Brighter fuselages might increase the contrast between the aircraft and the sky and enhance detection and avoidance behavior by birds. Our findings are not conclusive but suggest a specific hypothesis and prediction about bird responses to aircraft with different color schemes that deserves empirical testing in the future.

Key words: aircraft color scheme, antipredator behavior, avian vision, bird strike, chromatic contrast, human–wildlife conflicts

Since the late 1960s, various measures have been put forward to mitigate wildlife collisions with aircraft, particularly on airports (e.g., Cleary and Dolbeer 2005, Blackwell et al. 2009*a*). Seventy-two percent of wildlife–aircraft collisions (primarily involving birds) that were reported to the U.S. Federal Aviation Administration (FAA) from 1990 to 2008 occurred at or below 152 m above ground level (AGL; Dolbeer et al. 2009) and within the airspace above the air operations area of an airport.

Anecdotal information and recent research suggests that enhancing avian detection and avoidance of aircraft is possible (e.g., see review by Blackwell 2002). Specifically, research efforts have concentrated on exploiting avian vision, the primary sensory path for birds (Walls 1942, Sillman 1973) via aircraft lighting (Blackwell and Bernhardt 2004, Blackwell et al. 2009*b*) to enhance detection and avoidance behaviors. Findings from Blackwell et al. (2009) also indicate that ambient light conditions play a key role in how birds respond to vehicle lighting. Additionally, Bernhardt et al. (2010) showed that the distribution of injuries on a sample of birds known to have been struck by aircraft (bird strikes) indicates evidence of anti-predator behavior, implying that birds responded to the approaching aircraft as a threat.

The possibility of enhancing aircraft visibility relative to ambient light conditions depends upon certain attributes of avian vision. Bird vision is different from human vision. Birds have eyes whose vitreous humor allows ultraviolet light to reach the photoreceptors, which have 4 different types of visual pigments (compared to the 3 types found in humans; Cuthill 2006). As a result, birds can perceive a wider range of the visual spectrum than humans. Additionally, as opposed to humans, birds have oil droplets within their photoreceptors that filter light before it gets into the visual pigment. Oil droplets are believed to facilitate distinguishing subtle differences between wavelengths (Martin and Osorio 2008). The implication is that birds may perceive aircraft fuselages differently from the way humans do.

There are theoretical models (Endler and Théry 1996, Vorobyev et al. 1998) that can estimate the degree to which an object stands out from the visual background from the visual perspective of a bird (i.e., chromatic contrast; Endler 1990). Chromatic contrast varies in relation to the spectrum of ambient light, the peak sensitivities of the photoreceptors and oil droplets in the avian retina, and the degree to which the target object and the visual background reflect ambient light (Endler 1990). For instance, the chromatic contrast of the golden-headed manakin (*Pipra erythrocephala*) male plumage varies at different heights in the forest due to the incidence of light that is absorbed and reflected to different degrees by vegetation. When males display to attract females, they choose perching heights that increase chromatic contrast; whereas, when they try to hide from predators, they perch in branches that would reduce the chromatic contrast in relation to the background (Heindl and Winkler 2003).

In this study, we asked whether the aircraft color scheme might play a role in bird-strike frequency (as per Philiben and Blackwell 2005). The assumption is that fuselages differing in color would have different spectral properties that would be perceived differently by birds. Darker aircraft color schemes (i.e., color schemes reflecting little light) could potentially reduce the contrast between aircraft and the visual background (e.g., sky). Therefore, darker aircraft may potentially reduce the ability of birds to detect aircraft in sufficient time to avoid a strike. We then predicted that the frequency of bird strikes would be higher in aircraft with darker color schemes and lower in those with brighter color schemes. We used public records on bird strikes along with information on flights gathered by federal agencies in the United States. We estimated bird-strike rates and compared them among airlines with different fuselage color schemes but with the same aircraft type to minimize confounding factors associated with airframe aerodynamics.

Methods

We tested our hypothesis that darker coloration would be more difficult for birds to detect from the background first by using a chromatic contrast model. Next, we tested whether there could be an association between fuselage and bird-strike rates, using a correlational approach with public records of bird strikes (see below). Our approach was to compare fuselage color schemes within a given aircraft type to reduce confounding factors, such as design, maneuverability, and engine capabilities.

Test of the hypothesis

We tested whether a gradient from white to blue coloration would be perceived differently by birds through the estimation of chromatic contrast, following Endler and Mielke's (2005) approach. The species frequently struck by aircraft (e.g., Passeriformes; Dolbeer et al. 2009) have visual systems with different sensitivity in the short wavelengths (Hart and Hunt 2007); therefore, we used the 2 types of avian visual systems (VS and UVS) in the chromatic contrast calculations. The violet-sensitive (VS-type) avian visual system represents species in which 1 cone type has the peak sensitivity in the violet regions of the spectrum. The ultraviolet sensitive (UVS-type) avian visual system is similar to the VS-type, but the peak sensitivity of 1 cone type is the ultraviolet region of the spectrum. We used the sensitivities of the visual pigments and oil droplets as noted by Endler and Mielke (2005): (1) VS model: VS = 412 nm, SWS = 452 nm (oil droplet = 459 nm), MWS= 505 nm (oil droplet = 525 nm), and LWS = 565 nm (oil droplet = 588 nm); and (2) UVS model: UVS = 367 nm, SWS = 444 nm (oil droplet = 426 nm), MWS = 501 nm (oil droplet = 529 nm), and LWS = 564 nm (oil droplet = 591 nm).

We used the Tetrahedral Avian Colorspace program (Stoddard and Prum 2008) to estimate chromatic contrast. We measured irradiance (i.e., the amount of photons at each wavelength) and reflectance of the background (i.e., the percentage of light transmitted, rather than absorbed, by the sky at each wavelength) at a golf course under both sunny and partly cloudy light conditions, and entered them into the model. We used 3 objects that provided a gradient from dark to bright coloration: the white of a sheet of plastic, the light blue color of a plastic container, and the blue cover of a notebook. We took multiple readings (range 5 to 10) of irradiance and reflectance and averaged them. We acknowledge that these objects are not representative of the actual aircraft fuselage materials or color, but were used only to estimate if a brighter color would stand out more from the background from the perspective of the avian visual system.

We used a Stellarnet EPP2000 portable spectroradiometer (Tampa, Fla.) to measure reflectance and irradiance. We recorded reflectance every 0.5 nm (range 300-700 nm). We used a micron fiber optic probe with a tungsten krypton light source housed in a black plastic block sheath. The probe was positioned at a 45˚ angle to prevent glare. Prior to each measurement, the probe was calibrated with a flat white standard and a dark current. We recorded irradiance every 0.5 nm (range 300 to 700 nm) in Watts m-2 using a cosine corrected sensor calibrated with a standardized light source, and later converted to μMol m-2s-1nm-1 for analysis. We placed the irradiance probe 45 cm above the substrate and took readings with the probe facing up, north, south, east, and west.

We calculated chromatic contrast by considering the interaction among ambient light (irradiance), the spectral properties of the object (reflectance of the background and the objects), and the properties of both avian visual systems (e.g., absorbance of the cone outer segment, transmission spectra of the oil droplets, cross-section area of the inner cone segment; see Endler and Mielke's [2005] appendix for specific photon-capture values). We calculated the light spectra reaching the individual's eye using the formula

$$Q(\lambda, X) = I(\lambda)R(\lambda)T(\lambda, X) + V(\lambda),$$

where Q(λ, X) represents the radiance spectrum of light reaching the eye at distance X, where I is the irradiance spectrum, R is the reflectance spectrum, T(λ, X) is the transmission spectrum of wavelength λ at distance X, and V is the veiling light (Endler and Mielke 2005). The transmission spectrum is the amount of light transmitted at a particular wavelength and distance. Veiling refers to impurities in the air (e.g., fog, particulates) that can scatter light of a particular wavelength. We assumed that V(λ) = 0, and T(λ, X) = 1 (Endler and Mielke 2005). To determine the total photon capture for each single cone type, we used the equation

$$Q_r(X) = \int_{300}^{700} Q(\lambda, X) C_r$$

where $Q_r(X)$ is the total photon capture at distance X of 1 cone type, Q(λ, X) is the total radiance spectra reaching the eye, and Cr is the photon capture probability spectrum of each cone class.

We scaled the summed Q(X) for the 4 avian cones types to 1 (following Uy and Endler 2004). The values were plotted in a tetrahedral space with a height of one. To determine the chromatic contrast between an object (Qr_o) and background (Qr_b), the Euclidian distance between the points in the tetrahedral space was calculated with the following equation:

Contrast =

$$\sqrt{(Qr_{1b} - Qr_{1o})^2 + (Qr_{2b} - Qr_{2o})^2 + (Qr_{3b} - Qr_{3o})^2 + (Qr_{4b} - Qr_{4o})^2}$$

Empirical test of the prediction

We used public records on bird strikes and number of movements from 2 databases: (1) the Federal Aviation Administration (FAA) Wildlife Strike Database (<http://wildlife-mitigation.tc.faa.gov/wildlife/default.aspx>), and (2) the Bureau of Transportation Statistics TranStats (<http://www.transtats.bts.gov>). The FAA Wildlife Strike Database lists every reported wildlife strike occurring at U.S. civil and joint-use (i.e., civil and military) airports and to U.S. civil aircraft struck at foreign airports since 1990 (Dolbeer et al. 2009).

The number of bird strikes is, in part, a function of the number of aircraft movements, which varies among airlines. Therefore, we standardized the number of bird strikes per 10,000 movements, following previous studies (e.g., Dolbeer 1999; see also Dolbeer 2006). Per each aircraft type and airline, we obtained the total number of bird strikes for a given year and standardized it by 10,000 movements of that aircraft type and airline during the same period of time to estimate a bird-strike rate. We note that reported strikes spanned daytime and nighttime hours, but standardizing our analysis by ambient light conditions was not possible. We compiled information on the proportion of bird strikes occurring at different times of the day for each aircraft type based on the FAA database. We found that the proportions did not vary substantially for the 3 aircraft types in which we found differences in bird-strike rates among airlines: Boeing 737 (dawn, 0.05; day, 0.72; dusk, 0.06; night, 0.08; no data available, 0.09), DC-9 (dawn, 0.07; day, 0.88; dusk, 0.05), and Embraer RJ145 (dawn, 0.06; day, 0.72; dusk, 0.10; night, 0.09; no data available, 0.03).

We used these annual bird-strike rates per airline as our raw data to establish differences among aircraft with different fuselage color schemes. We used TranStats (Bureau of Transportation Statistics 2010) database to determine number of movements per aircraft type, airline, and year, along with the U.S. states from which these airlines departed and landed. We compiled data on movement numbers and states from 1990 to 2009. Specifically, we used the database titled, "T-100 Domestic Segment (U.S. Carriers)."

To standardize our analysis, we chose 7 bird species. Dolbeer and Wright (2009) provided a classification of species that were involved in bird strikes based on ≥25 or more reported strikes, per species, with civil aircraft in the United States (1990 to 2007), and we ranked them in 6 categories. We chose 1 species having the highest number of strikes from each of the following categories: extremely high (Canada goose [*Branta canadensis*]); very high (mallard [*Anas platyrhynchos*]); high (rock pigeon [*Columba livia*]); low (killdeer [*Charadrius vociferous*]); and very low (American kestrel [*Falco sparverius*]). From the moderate category, however, we chose 2 species (mourning dove [*Zenaida macroura*] and European starling [*Sturnus vulgaris*]) due to their high number of strikes compared to the other species in the same category. Originally, we intended to run a separate analysis for each of these species; however, the species-specific sample sizes were too low to compare strike rates among airlines. Consequently, we decided to pool data for these 7 species and conducted a single analysis.

Because we did not have access to aircraft from each airline by which to estimate the reflectance spectra (using a spectrometer), we used digital photographs to quantify dark and bright fuselage color schemes. Here, we define the perceived brightness of a color pattern from a digital photograph as the sum of the reflected light intensity (i.e., photon flux) from the specific aircraft color pattern (see below). We obtained the pictures of the aircraft from Airliners.net (2010). We searched every one of the aircraft registration numbers on this website that was involved in a bird strike and that was available, allowing us to determine its color scheme in the year of the strike. Some airlines used different color schemes from 1990 to 2009, so we removed from the analysis those airlines that markedly changed the fuselage color over this period of time. For example, Delta Airlines changed its color scheme several times over that period of time; thus, associating a given bird-strike rate to a single color scheme for that airline would have biased our results. We also included in our analysis airlines with a degree of variability in brightness among them to test our prediction. Based on all the aforementioned criteria, we chose the following airlines in each aircraft type: Boeing 737 (Southwest Airlines, United Airlines, US Airways, American Airlines, America West Airlines, Continental Airlines, Frontier Airlines), DC-9 (US Airways, Continental Airlines), and Embraer RJ145 (American Eagle, Express Jet).

To assess the variation in color scheme between airlines, we avoided using pictures that had dawn and dusk illumination that could bias dark-bright estimates. We gathered information in the RGB color space (following Villafuerte and Negro 1998), which provides an index of the intensity of light in the red (R), green (G), and blue (B) spectra. The RGB is an additive color model where red, green, and blue lights are combined to reproduce various colors.

We used the ImageJ computer program (<http://rsbweb.nih.gov/ij>) to calculate the mean RGB values using 10 photographs of different aircraft from each airline. For each photograph, we obtained values from the front and rear sectors of the fuselage because they provided a larger number of pixels to get accurate estimates of RGB values than other parts of the aircraft. Within each sector, we sampled from 3 spots (top, middle, and bottom, each one 55 × 25 pixels in the Boeing 737 and 40 × 20 pixels in the DC-9 and Embraer RJ145), and then averaged them. We obtained the RGB values from the color histogram option in ImageJ. We added the R, G, and B values to estimate an

Table 1: Chromatic contrast values estimated following Endler and Mielke's (2005) approach for birds with ultraviolet sensitive visual pigments (UVS model) and violet sensitive visual pigments (VS model). We estimated chromatic contrast under sunny and cloudy conditions. See text for details on model calculation.

Real ambient light conditions	UVS model		VS model	
	Sunny	Cloudy	Sunny	Cloudy
White	0.221665	0.211145	0.212571	0.203676
Light blue	0.208721	0.206317	0.179116	0.176330
Blue	0.135695	0.134670	0.105625	0.104323

RGB index in which low values represent dark colors and high values represent bright colors. The RGB color model does not include the ultra violet sector of the spectrum to which many bird species are sensitive; however, we used the RGB values to estimate a relative index of darkness-brightness to compare fuselage color schemes among airlines within a given aircraft type. In this context, the RGB values served as an index of relative visibility of the aircraft. A recent study showed that human vision can actually provide a reasonably good estimate of general aspects of avian visual perception (Seddon et al. 2010). However, we caution that future empirical studies should take reflectance measurements on the colors actually used by the airlines and use avian visual models, as the one presented in the previous section, to determine how birds would perceive these different color schemes.

Statistical analysis

Besides the aircraft selection criteria described above, we chose aircraft with ≥65 bird strikes (based on all the bird species selected and pooled together) across years for statistical tests. That condition narrowed down the list of aircraft to the following: Airbus 319 (65 bird strikes), Airbus 320 (142 bird strikes), Boeing 727 (132 bird strikes), Boeing 737 (1,029 bird strikes), Boeing 757 (189 bird strikes), DC-9 (133 bird strikes), and Embraer RJ145 (111 bird strikes). Within each aircraft type, we used ANOVAs to determine whether there were differences among airlines in bird-strike rates. If the difference was significant ($P < 0.05$), we then measured RGB values on those aircraft and estimated differences among airlines in the degree of darkness-brightness with an ANOVA. We did not further analyze aircraft types that did not show differences in bird-strike rates due to logistical limitations in the availability of data to normalize bird-strike data per 10,000 flights and also due to the post-hoc approach of this study (see Discussion). In other words, our post-hoc approach necessitated that there be differences in strike rates before we proceeded with quantifying RGB values. We used Fisher LSD post-hoc tests to assess pair-wise differences in bird-strike rates and RGB values. We used a Pearson product moment correlation to establish the association among bird-strike rates and RGB scores for the Boeing 737 aircraft.

Results

Using chromatic contrast estimates, we found that, at least from a visual modeling perspective, birds would be able to detect the gradient from blue (dark) to white (bright) colors. Under sunny and cloudy conditions, birds with UVS and VS visual pigments were expected to detect white as more contrasting chromatically than light blue and blue (Table 1). This finding suggests that a whiter fuselage would stand out more against the sky from the perspective of the avian visual system.

Based on the reported data on bird strikes, we found that 4 of the 7 aircraft types analyzed did not differ significantly in bird-strike rates among airlines: Airbus 319, Airbus 320, Boeing 727, and Boeing 757 (Table 2). However, 3 aircraft types differed significantly in bird-strike rates among airlines (Table 2): Boeing 737 (Figure

Table 2: Variations in bird-strike rates among airlines companies for different aircraft types. Results from ANOVA tests.

Aircraft type	F	df	P
Airbus 319	1.09	4, 49	0.37
Airbus 320	1.26	5, 71	0.29
Boeing 727	1.52	11, 90	0.14
Boeing 737	2.54	6, 117	0.02
Boeing 757	0.96	9, 141	0.47
DC-9	20.69	1, 20	< 0.001
Embraer RJ145	8.30	1, 23	0.008

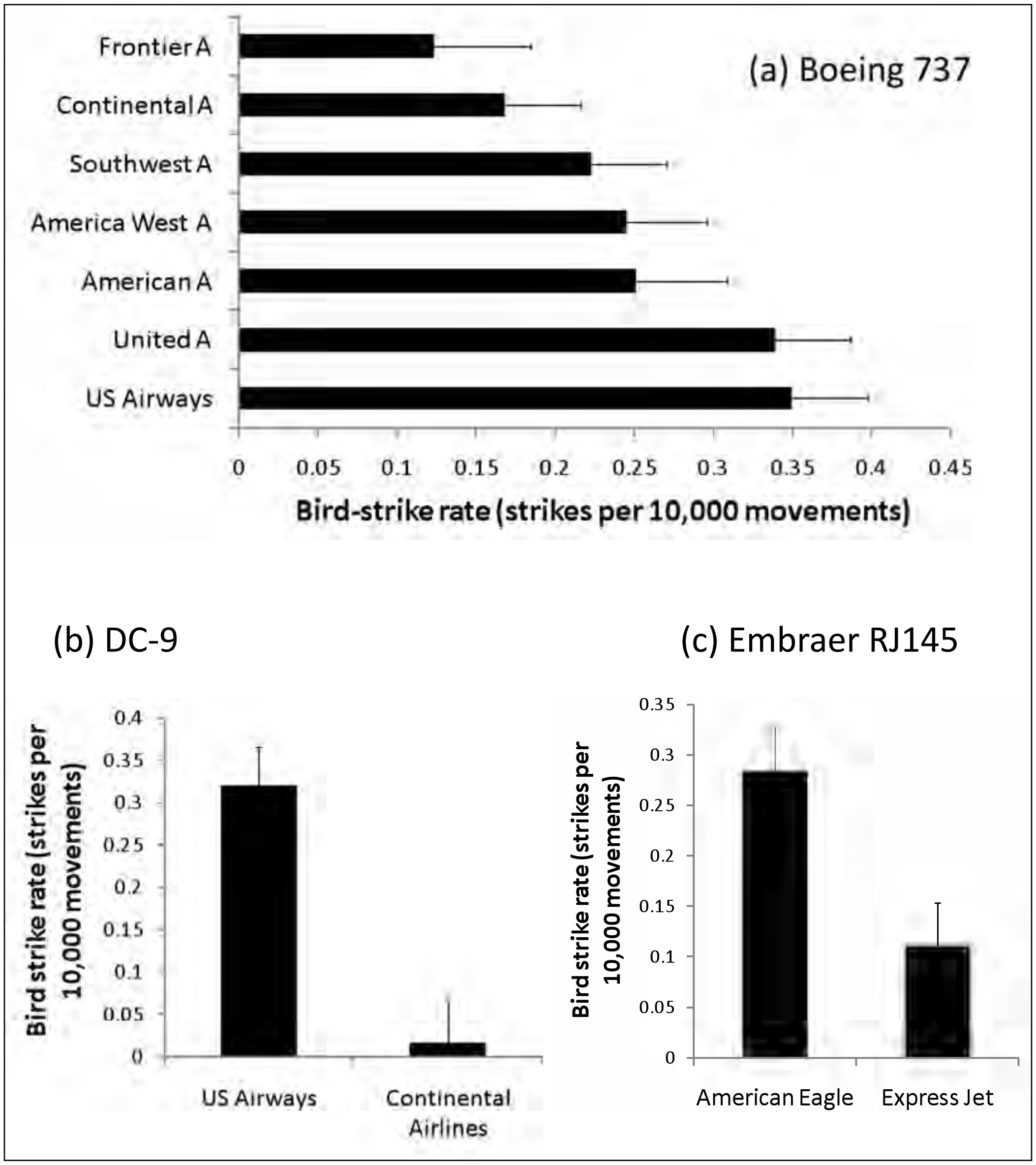

Figure 1. Bird-strike rates estimated as number of bird–aircraft collisions per 10,000 departures or movements in different airlines (**a**) within 3 different aircraft types: (**a**) Boeing 737, (**b**) DC-9, and (**c**) Embraer RJ145. Shown are $\bar{x}$ ± SE.

1a), DC-9 (Figure 1b), and Embraer RJ145 (Figure 1c). The airlines using these 3 aircraft types departed and landed from 35 to 50 states in the United States, and were represented in the FAA bird-strike database from 10 to 20 years. However, the patterns of departures and landings are not necessarily representative of all air traffic movements in the states through which these aircraft flew. Instead, the movements of these aircraft are representative of the widespread geographic extent of many commercial airline routes. Overall, we believe that the data analyzed had broad geographic representation within the United States.

Boeing 737

For the Boeing 737, our post-hoc tests showed that bird-strike rates were significantly higher for US Airways than Continental Airlines (P = 0.008) and Frontier Airlines (P = 0.004), and for United Airlines than Continental Airlines (P = 0.01) and Frontier Airlines (P = 0.007; Figure 1a).

All other pair-wise comparisons were not significant ($P > 0.05$).

Using the RGB scale, we found variation in the degree of brightness among airline color schemes. For the Boeing 737, the degree of darkness in the color scheme varied significantly in the front fuselage ($F_{6, 203} = 4.59$, $P < 0.001$; Table 3), with (1) American Airlines being darker than Frontier Airlines ($P = 0.012$), (2) Southwest Airlines being darker than American West Airlines ($P = 0.001$), American Airlines ($P = 0.048$), Continental Airlines ($P < 0.001$), and Frontier Airlines ($P < 0.001$), (c) United Airlines being darker than Continental ($P = 0.049$) and Frontier Airlines ($P = 0.007$), and (d) US Airways being darker than Frontier Airlines ($P = 0.009$). The degree of darkness in the airline color scheme also varied significantly in the rear fuselage (F 6, 203 = 9.57, $P < 0.001$; Table 4), with (1) Southwest Airlines being darker than American West Airlines ($P < 0.001$), American Airlines ($P = 0.046$), Continental Airlines ($P < 0.001$), and Frontier Airlines, (2) United Airlines being darker than American West Airlines ($P = 0.001$), Continental Airlines ($P < 0.001$), and Frontier Airlines ($P < 0.001$), (3) US Airways being darker than American West Airlines ($P < 0.001$), Continental Airlines ($P < 0.001$), and Frontier Airlines ($P < 0.001$), and (4) American Airlines being darker than Continental Airlines ($P = 0.023$), Frontier Airlines ($P < 0.001$), and American West Airlines ($P = 0.0028$).

Bird-strike rates were negatively, but not significantly, associated with the RGB score in the front fuselage ($r = -0.56$, $P = 0.192$; Figure 2a). However, we found a significant and negative association among bird-strike rates and the RGB score in the rear fuselage ($r = -0.75$, $P = 0.05$), by which airlines with brighter color schemes were associated with lower bird-strike rates (Figure 2b). We emphasize that these results have no bearing on whether the birds perceived the aircraft as a whole or its different parts. These results present differences in color in some aircraft parts based on the analysis of photographs from each airline.

Table 3: Mean RGB (i.e., red, green, and blue values) scores for the front and rear fuselage of Boeing 737 aircraft belonging to airline companies with different fuselage color schemes. Higher values indicate brighter color schemes.

	Front fuselage	Rear fuselage
Southwest Airlines	301.62 ± 20.66	293.77 ± 21.63
United Airlines	367.24 ± 32.13	333.59 ± 30.47
US Airways	370.82 ± 14.04	314.25 ± 25.14
American Airlines	373.92 ± 22.25	380.39 ± 30.19
America West Airlines	422.71 ± 26.99	475.87 ± 37.65
Continental Airlines	439.01 ± 24.83	479.02 ± 34.69
Frontier Airlines	466.30 ± 33.72	534.67 ± 31.07

DC-9

For the DC-9, US Airways had a significantly higher bird-strike rate than Continental Airlines (Table 2; Figure 1b). The front fuselage was significantly darker in US Airways (RGB score 343.48 ± 26.25) than in Continental Airlines (RGB score 484.00 ± 21.90; $F_{1, 58} = 16.89$, $P < 0.001$). Similarly, the rear fuselage was significantly darker in US Airways (RGB score 297.34 ± 20.62) than in Continental Airlines (RGB score 538.71 ± 30.10; $F_{1, 58} = 43.75$, $P < 0.001$). Thus, relative to our limited data, the airline with the brighter fuselage (front and rear) had lower bird strike rates than the one with the darker fuselage.

Embraer RJ145

For the Embraer RJ145, American Eagle had a significantly higher number of bird strikes than Express Jet flying with Continental Airlines design (Table 2, Figure 1c). There was a non-significant trend ($F_{1, 58} = 1.37$, $P = 0.25$) for American Eagle (RGB score 465.06 ± 27.31) to have a darker front fuselage than Express Jet (RGB score 507.39 ± 23.63). However, the rear fuselage of American Eagle (RGB score 503.84 ± 29.62) was significantly darker than that of Express Jet (RGB score 583.50 ± 25.20; $F_{1, 58} = 4.19$, $P = 0.05$). Therefore, the airline with the brighter rear fuselage had lower bird strike rates than the one with the darker fuselage.

Discussion

Our results indicate a trend for 3 aircraft types with a brighter fuselage (rear or both front and rear) to be associated with lower bird-strike rates: Boeing 737, DC-9, and Embraer RJ145.

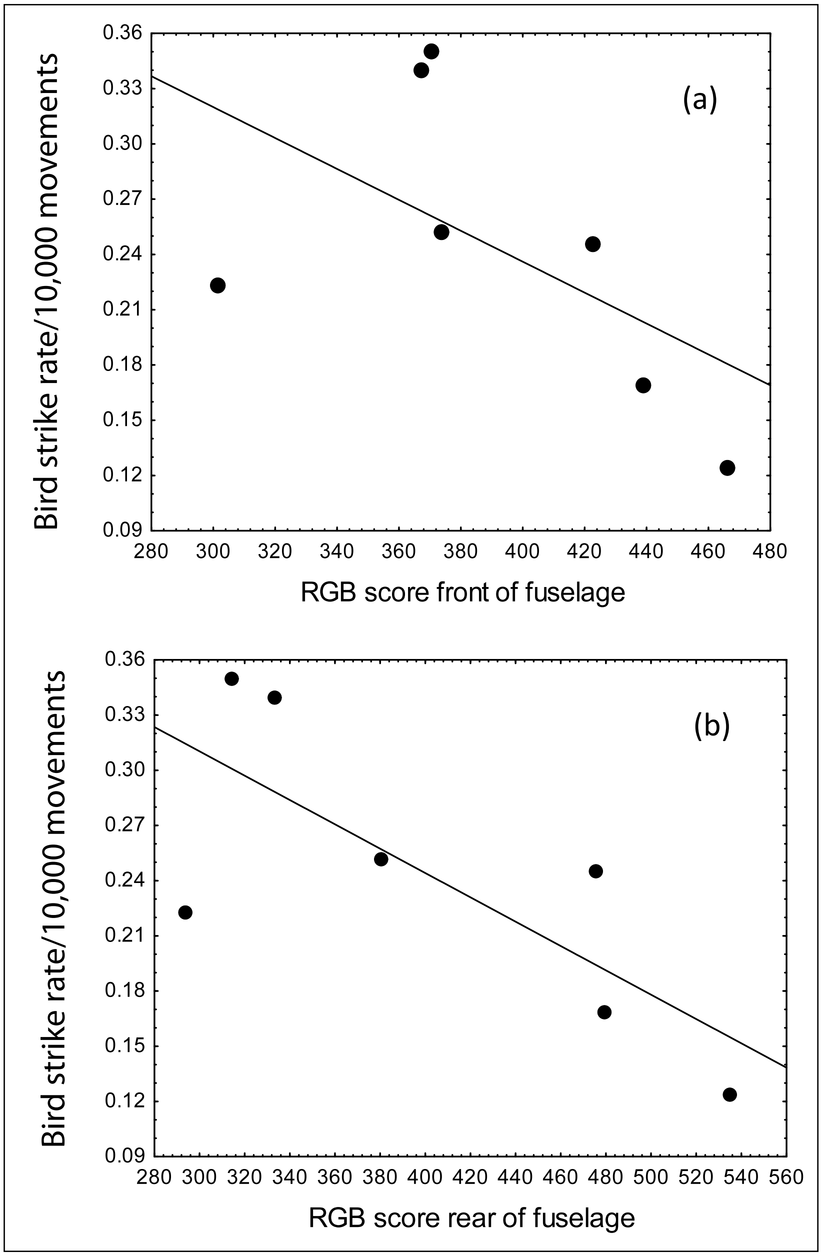

Figure 2. Relationship between bird-strike rates (estimated as number of bird–aircraft collisions per 10,000 departures or movements) and RGB (red, green, blue) score from the (1) front and (2) rear of the fuselage of Boeing 737 aircraft belonging to different airlines. Higher RGB values indicate brighter colors, whereas, lower RGB values indicate darker colors.

These trends are not general, as other aircraft types studied with various fuselage color schemes did not show significant variation in bird-strike rates.

Our findings should be taken with care because we conducted a correlational study with public reports on bird strikes and, thus, could not establish cause-effect relationships of any kind. Additionally, there are some sources of bias in the data sets. First, reporting a bird strike is voluntary in the USA; therefore, the FAA Wildlife Strike Database is based on a reporting rate of approximately 39% (Dolbeer 2009). Second, reporting rates may vary among airlines and, potentially, among aircraft types. The implication is that many unreported bird strikes that may be of lesser importance in terms of damage may not have been included in our study, which could have affected the number of strikes per aircraft type and airline that we considered. Third, our study did not examine the multiple confounding factors that may have affected the association between fuselage color scheme and bird-strike rate, such as temperature, ambient light conditions, altitude, exact geographic location and time of the bird strike, airport type, and wildlife management strategy at airports. Some of these factors were available in the database, but not for all strike records. Had we included the records with all the potential confounding factors, we would not have had a sample size sufficient to run some of the analyses. Fourth, we estimated the relative degree of darkness-brightness using digital photographs and the RGB color space. This methodology has some limitations, as it does not include part of the spectrum to which birds are sensitive (i.e., ultraviolet), and the accuracy of the color measurements depends to a large extent on ambient light conditions (e.g., dusk lighting can modify colors substantially) and the resolution of the digital picture (Montgomerie 2006). We tried to minimize these sources of bias as much as possible, and it is worth noting the several ecological studies have estimated color based on digital photographs (e.g., Villafuerte and Negro 1998, Wiebe and Bortolotti 2002). We believe that we calculated an appropriate relative measure of a gradient between darkness and brightness given that access to the studied aircraft types and airlines to measure reflectance spectrometrically was not logistically possible.

Despite all the potential biases associated with the databases we used, we think that this study proposes a specific hypothesis and prediction about avian response to aircraft that can be tested empirically in the future. Although our fids are not conclusive, they suggest that there might be a problem with the visibility of darker fuselages and timing of detection by birds. Our estimates of chromatic contrast confirmed, at least theoretically, that bird species with different visual systems (i.e., violet- and ultraviolet-sensitive) would be able to detect whiter coloration better than darker coloration. This does not mean that darker aircraft would go undetected. One possibility is that, although darker aircraft may be detected, they may be more difficult for birds to distinguish at high aircraft speeds, thus, reducing time necessary for birds to initiate avoidance maneuvers. A recent study showed that birds do try to avoid aircraft before collision (Bernhardt et al. 2010), suggesting a limited window of opportunity to reduce the chances of a collision. The implication is that enhancing aircraft visually through a bright color scheme might facilitate a bird's ability to detect and distinguish aircraft shape in time to perform avoidance behaviors.

Previous studies have assessed the behavioral reactions of birds in enclosures upon the approach of a vehicle (e.g., Blackwell et al. 2009*b*). Future research could use this experimental approach to measure avian responses to radio-controlled aircraft with different color schemes, taking into consideration the visual system of the model species (Blackwell et al., unpublished manuscript). If this manipulative research confirms our findings, there are other important applied questions that should be addressed. First, which specific bright colors enhance avian detection and avoidance? Second, what is the degree of brightness that is necessary in the fuselage; and does tha include the entire body or just parts? If painting the undersides or just the rear of the aircraft would also enhance detection and avoidance (Beason 2003), that approach would reduce implementation costs and allow the airlines to retain their commercial image. Third, could darker fuselages increase visibility by incorporating a lighting system instead of changing the color scheme (e.g., Philiben and Blackwell 2005)? The use of lighting technology to reduce bird strikes is under investigation (Blackwell and Bernhardt 2004, Blackwell et al. 2009b), but this research has not yet considered the interaction between lights and fuselage coloration. Answering these questions experimentally can strengthen the interaction between wildlife research and the aviation industry to promote coexistence between birds and aircraft and enhance safety.

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