Composition or encounter? Decomposing the altitude and night-time damage premiums in United States wildlife strikes, 1990 to 2026

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Abstract

Damaging wildlife strikes in the United States are known to be commoner higher above the ground and, for some taxa, after dark. Both patterns are usually read as composition: altitude and darkness change which animals an aircraft can meet, and large animals damage aircraft. That reading has not been tested, because the published height and light-condition tables are marginal — they pool every taxon. Using the full FAA National Wildlife Strike Database (354,564 reports, 22,210 damaging), this paper decomposes both premiums within animal family and within species. The night premium is partly composition: in general aviation the crude odds ratio of 1.41 falls to 1.20 once strata are taxon-matched, and white-tailed deer account for most of the difference. It does not vanish — a residual of about 1.2 persists in general aviation and is unchanged by adjustment in the commercial segment (1.17 crude, 1.22 adjusted). The altitude premium is not composition at all. Taxon-matching *raises* the odds ratio in both segments (general aviation 2.92 to 3.20; commercial 2.12 to 2.39), so the assemblage struck at altitude masks rather than creates the effect, and the association holds inside 22 of 23 individually identified species with adequate sample (median odds ratio 3.60). Within a species, a strike above 500 ft is several times likelier to damage the aircraft than a strike at or below it. Whether the residual reflects encounter energy or a reporting asymmetry cannot be settled from a voluntary-reporting record, and both readings are stated.

Keywords: bird strikes; wildlife-aircraft collisions; damage severity; flight altitude; confounding; airport ecology

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1. Introduction

A wildlife strike damages an aircraft, or it does not, and the applied literature has spent three decades establishing what makes the difference. The answer that has held up is body size. Dolbeer, Wright and Cleary (2000) ranked 21 species groups in the FAA National Wildlife Strike Database (NWSD) by the share of strikes that caused damage and showed that the most-struck species are not the most hazardous. DeVault et al. (2011) extended the ranking to 77 species and found the probability of damage strongly associated with body mass, saturating above about 1,125 g; DeVault et al. (2016) fitted the same relationship off the airport boundary, and DeVault et al. (2018) and Ross et al. (2025) updated the hazard scores through 2015 and 2023. Rafe and Das (2026) have since modelled the same 1990–2025 record with an ordered-probit severity model and again find body mass dominant. The species-level question is settled well enough that re-describing it adds nothing.

Two circumstantial patterns have been reported alongside it and have not been given the same treatment. Damaging strikes are commoner above 500 ft than below (Dolbeer, 2006, 2011), and, for some taxa, commoner at night: white-tailed deer are struck mostly after dark and at dusk (Biondi et al., 2011), and bats almost exclusively so (Biondi et al., 2013). Both patterns appear in the FAA serial report as marginal tables — damage by height band, damage by light condition — pooled over every animal in the record.

A marginal table cannot separate two very different claims. The first is composition: altitude and darkness change *which* animals are available to be struck, large-bodied birds and mammals are over-represented among them, and the damage rate rises for that reason alone. The second is encounter: for the *same* animal, a strike higher up or in the dark is more likely to damage the aircraft, whether because closing energy is greater, because the crew has less warning, or because a strike that is not noticed at the time enters the record only when damage is found later. The two have opposite management implications. If composition is the whole story, the lever is which species use the airfield and its approaches. If it is not, altitude and light condition carry information about outcome that species identity does not.

This paper tests the two readings directly, by stratifying both premiums on animal family and then on species. It makes no new claim about body mass, adds no new hazard ranking, and re-describes no species list.

2. Data

The analysis uses the FAA National Wildlife Strike Database, a voluntary reporting system for strikes to civil aircraft in the United States (Dolbeer et al., 2018; FAA, 2025), in the public export of 2026-09-06, aggregated with an open pipeline into freeze `2026-09-07`. The corpus holds 354,564 reports, of which 22,210 (6.26 per cent) are coded as damaging. Reports arriving into 2026 make that calendar year incomplete; complete incident years span 1990 to 2025.

The record is voluntary and incomplete. Dolbeer (2015) estimated that about 47 per cent of strikes were reported in 2009–2013, and reporting is not neutral with respect to outcome: damaging strikes are reported more completely than minor ones (Dolbeer & Wright, 2009), pilot reports under-represent small birds (Linnell, Conover & Ohashi, 1999), and species identification from remains has improved over the period (Dove et al., 2008). Every count here is a lower bound, and Section 6 returns to what that costs the result.

3. Methods

Damage. A report is damaging if `DAMAGE_LEVEL` is one of `M`, `M?`, `S` or `D`. The uncertain-minor code `M?` is counted as damaging throughout; excluding it lowers every rate but does not change the direction of any comparison below.

Segments. Aircraft are split on the FAA mass class. General aviation is `AC_MASS IN (1,2)` — aircraft up to 5,700 kg — and commercial is `AC_MASS IN (3,4,5)`. The two do not partition the corpus, and the residual is not a third fleet but a record-completeness artefact, so it is excluded from every analysis rather than pooled:

Table 1. Segment definitions, strike counts and damage rates in freeze `2026-09-07`.

Segment	Definition	Strikes	Damaging	Damage rate
Whole corpus	all records	354,564	22,210	6.26%
General aviation	`AC_MASS IN (1,2)`	30,418	7,219	23.73%
Commercial	`AC_MASS IN (3,4,5)`	223,737	14,797	6.61%
Aircraft mass not recorded	remainder	100,409	194	0.19%

The two segments are analysed separately and never pooled. Their baselines differ by nearly a factor of four (23.73 per cent against 6.61 per cent), because a given animal is far likelier to damage a light aircraft than an airliner. Reporting the corpus-wide 6.26 per cent as if it were a damage rate would be misleading on both counts: it mixes the two fleets and it is diluted by the 28.3 per cent of records where damage is essentially never coded (0.19 per cent).

Taxa. Animals are grouped into families by the leading characters of the FAA `SPECIES_ID`, two-character prefixes taking precedence over their one-character parents. Reports whose species is not identified — the `Unknown bird` codes and anything outside the listed prefixes — are kept as a single `Unidentified / other` stratum rather than dropped, because dropping them would silently condition the analysis on identification, which is itself associated with body size and with damage.

Buckets. Height above ground is bucketed as `ground` (a strike on the roll, a different situation from low flight), `1-500`, `501-1500`, `1501-3000` and `3000+` feet; `TIME_OF_DAY` is taken as the reporter recorded it. Rows with no height or no light condition form an explicit `unknown` bucket and are excluded from the contrasts below, not imputed.

Contrasts and adjustment. Two contrasts are computed: night against day, and above 500 ft against at-or-below 500 ft. For each, a 2×2 table is built per family, and the crude odds ratio pooled over families is compared with a Mantel–Haenszel odds ratio stratified on family. The comparison is the test. If the premium is composition, taxon-matching removes it and the adjusted ratio approaches 1. If the adjusted ratio holds or rises, the premium exists within taxon and composition is not the explanation. Families with fewer than 30 reports on either side of a contrast are omitted from the per-family tables but retained in the pooled estimates. Proportions carry Wilson 95 per cent intervals.

What was not done. No exposure denominator exists in this record: it counts reported strikes, not opportunities, so nothing here is a rate per movement, per hour or per bird. No body mass is attached to any species — the FAA size code is a three-level ordinal, not a mass, and this paper makes no mass claim. No trend over time is fitted. No model is fitted beyond the stratified odds ratio.

4. Results

4.1 Night: partly composition, and not only deer

In general aviation the crude night-versus-day contrast is 28.37 per cent against 21.92 per cent, an odds ratio of 1.41. Stratifying on family reduces it to 1.20. Roughly half the crude excess is therefore composition, and the per-family table shows where it comes from (Table 2): deer are struck at night far more often than by day, and damage in almost nine strikes out of ten whenever they are struck.

Table 2. Damage by animal family, night against day, general-aviation segment. Families with at least 30 reports on each side of the split; odds ratio undefined where a cell is empty.

Family	Night, n	damage % (95% CI)	Day, n	damage % (95% CI)	OR
Unidentified / other	5,000	17.8 (16.8–18.9)	8,687	17.1 (16.3–17.9)	1.05
Songbirds	424	13.4 (10.5–17.0)	2,501	6.0 (5.1–7.0)	2.45
Raptors	45	31.1 (19.5–45.7)	2,396	45.8 (43.8–47.8)	0.53
Gulls & terns	177	25.4 (19.6–32.3)	1,733	25.6 (23.6–27.7)	0.99
Waterfowl	664	67.6 (64.0–71.1)	713	52.6 (48.9–56.2)	1.88
Pigeons & doves	109	14.7 (9.2–22.5)	1,218	10.8 (9.1–12.6)	1.43
Deer	585	89.2 (86.5–91.5)	251	88.0 (83.5–91.5)	1.12
Shorebirds	89	15.7 (9.6–24.7)	367	9.0 (6.5–12.4)	1.89
Herons & egrets	31	58.1 (40.8–73.6)	298	17.1 (13.3–21.8)	6.71
Other mammals	194	25.3 (19.7–31.8)	118	17.8 (11.9–25.7)	1.56

The premium does not disappear, and the residual is not confined to mammals. Several bird families show a night effect of their own — herons and egrets, songbirds, waterfowl and shorebirds all have odds ratios above 1 with intervals that exclude it. Raptors run the other way, which is what a day-hunting group should do, on a small night sample.

The commercial segment separates the two components cleanly. There the crude ratio is 1.17 and the adjusted ratio 1.22: composition explains none of it, because the deer that drive the general-aviation shift are a negligible share of commercial strikes. A residual night effect of about 1.2 is thus present in both fleets and is the part that taxon does not account for.

4.2 Altitude: composition masks the effect rather than creating it

This is the marginal picture the published tables report, and on its own it cannot separate composition from encounter (Figure 1). The height contrast behaves in the opposite way. In general aviation the crude odds ratio is 2.92 (34.82 per cent above 500 ft against 15.45 per cent at or below it), and taxon-matching *raises* it to 3.20. The commercial segment repeats the pattern, 2.12 crude against 2.39 adjusted (Table 3).

Table 3. Damage by animal family, above 500 ft against at or below 500 ft, general-aviation segment. Inclusion rule as in Table 2.

Family	Above 500 ft, n	damage % (95% CI)	500 ft or below, n	damage % (95% CI)	OR
Unidentified / other	5,927	24.6 (23.6–25.8)	6,001	12.7 (11.9–13.5)	2.25

Family	Above 500 ft, n	damage % (95% CI)	500 ft or below, n	damage % (95% CI)	OR
Songbirds	551	17.8 (14.8–21.2)	2,332	4.9 (4.1–5.9)	4.17
Raptors	909	76.8 (73.9–79.4)	1,431	27.3 (25.1–29.7)	8.80
Gulls & terns	316	52.5 (47.0–58.0)	1,633	20.4 (18.5–22.4)	4.32
Waterfowl	669	75.0 (71.6–78.2)	832	49.0 (45.7–52.4)	3.12
Pigeons & doves	74	29.7 (20.5–40.9)	1,338	9.9 (8.4–11.7)	3.83
Shorebirds	32	43.8 (28.2–60.7)	457	7.4 (5.4–10.2)	9.68
Herons & egrets	34	73.5 (56.9–85.4)	290	14.8 (11.2–19.4)	15.96
Bats	74	5.4 (2.1–13.1)	40	0.0 (0.0–8.8)	—

Every family with a defined odds ratio shows the effect, and in several it is large. Bats are the one family the contrast cannot speak to: no strike below 500 ft in the general-aviation segment is coded as damaging at all, so the ratio is undefined rather than absent. Adjustment increases the pooled ratio because the assemblage struck at altitude is not uniformly more damaging than the one struck low: the low-altitude population is dominated by the same small passerines and doves that rarely damage anything, and holding taxon constant removes a dilution that was working against the association, not for it.

4.3 The same result inside single species

Family strata could still hide composition if the mix of species within a family shifted with height. They do not. Restricting to reports identified to a named species and requiring at least 100 reports on each side of the 500 ft split, the association holds in 22 of 23 species, with a median odds ratio of 3.60.

Table 4. Damage above 500 ft against at or below 500 ft within named species, general-aviation and commercial reports pooled. The 14 most-struck of the 23 species meeting the inclusion rule of at least 100 reports on each side are listed; the remaining 9 are in `wildlife_species_height_split.csv` in the freeze.

Species	Above 500 ft, n	damage % (95% CI)	500 ft or below, n	damage % (95% CI)	OR
Gulls	925	30.7 (27.82–33.75)	5,415	14.7 (13.78–15.67)	2.57
Mourning dove	154	17.53 (12.34–24.31)	4,938	3.77 (3.27–4.33)	5.43
European starling	134	6.72 (3.57–12.27)	3,291	4.28 (3.64–5.03)	1.61

Species	Above 500 ft, n	damage % (95% CI)	500 ft or below, n	damage % (95% CI)	OR
Sparrows	218	2.75 (1.27–5.87)	2,688	1.82 (1.38–2.4)	1.52
Rock pigeon	112	15.18 (9.7–22.97)	2,131	12.62 (11.28–14.1)	1.24
Red-tailed hawk	187	62.03 (54.9–68.68)	1,913	20.02 (18.29–21.87)	6.53
Canada goose	497	70.22 (66.06–74.07)	1,324	47.73 (45.05–50.43)	2.58
Hawks	299	46.15 (40.59–51.82)	1,073	16.22 (14.13–18.54)	4.43
Blackbirds	208	10.58 (7.09–15.49)	980	6.33 (4.97–8.03)	1.75
Turkey vulture	521	72.55 (68.57–76.21)	525	39.62 (35.53–43.86)	4.03
American robin	437	14.87 (11.84–18.52)	508	3.74 (2.41–5.77)	4.5
Chimney swift	326	2.76 (1.46–5.16)	591	0.17 (0.03–0.95)	16.75
Ducks	391	43.73 (38.9–48.69)	402	27.36 (23.23–31.92)	2.06
Perching birds (y)	264	4.55 (2.62–7.78)	459	1.31 (0.6–2.82)	3.6

A mourning dove is a mourning dove at 200 ft and at 800 ft. That its strikes damage aircraft 3.60 times more often, in odds, above the split than below is not a statement about which animals fly where.

5. Discussion

The two premiums that the literature reports side by side have different causes, and only one of them is the one usually assumed.

The night premium is, in general aviation, substantially a deer effect and therefore composition, exactly as Biondi et al. (2011) would predict. Reporting it from a pooled table, as the marginal tables do, overstates what light condition tells an operator about outcome. But it is not only deer: a residual of about 1.2 survives taxon-matching in both fleets, and several bird families carry it independently.

The altitude premium is not composition. It is present within every family and within nearly every species tested, and adjustment strengthens it. Two mechanisms remain compatible with that. The first is encounter energy: a strike at altitude happens at higher airspeed, and damage rises with the energy of the collision. The second is a reporting asymmetry that this record cannot rule out: a strike at altitude that causes no damage may simply never be noticed, whereas one on the runway is seen. The two are not separable here, and this paper does not claim to separate them. What can be said is that the effect is not explained by the animals involved, which is the explanation the marginal tables invite.

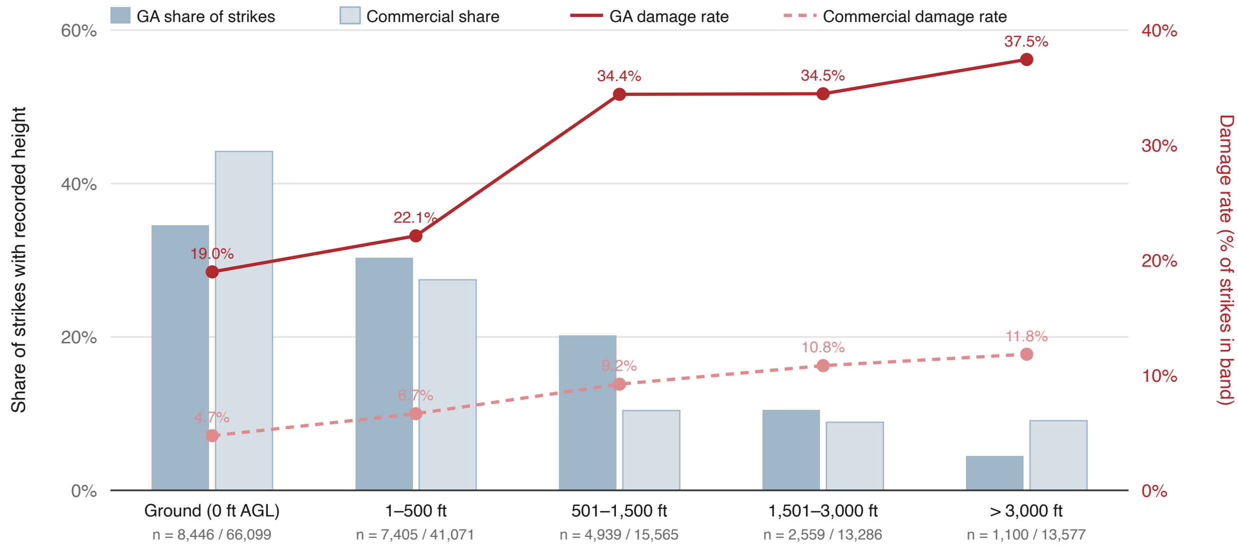

Figure 1: Strikes concentrate at or below 500 ft while the damage rate rises with height, in both segments (general aviation solid, commercial dashed). Bars are each segment's share of strikes with a recorded height; lines are the damage rate inside the band. Counts below each band are general aviation / commercial. Computed from freeze `2026-09-07`.

For management the practical consequence is narrow but real. Species identity remains the lever for the airfield itself. For the approach and departure corridors, where altitude bands above 500 ft are reached, the outcome distribution is worse than the species mix alone predicts, and a hazard assessment built only on which species are present will understate it.

6. Limitations

The record is voluntary, so every count is a lower bound and the reporting probability is itself associated with damage (Dolbeer, 2015; Dolbeer & Wright, 2009). This is the central threat to the altitude result specifically: if non-damaging strikes at altitude are less likely to be noticed and reported than non-damaging strikes on the ground, the observed odds ratio is inflated by an unknown amount. The within-species replication rules out taxon composition as the explanation; it does not rule out detection.

Height is missing or unrecorded on a substantial share of reports and those rows are excluded rather than imputed, so the contrast is conditional on height having been recorded — plausibly itself associated with how much attention the strike received. `TIME_OF_DAY` is as the reporter coded it and is not reconciled against date and location. Species identification has improved over the period (Dove et al., 2008) and is better for large animals, so the `Unidentified / other` stratum is not a random sample of the corpus. There is no exposure denominator (Dolbeer & Wright, 2009), so none of these figures is a risk per movement. Finally, the 1990–2026 window is treated as one population; no trend is fitted and none should be read into these tables.

7. Data availability

Every number in this paper is computed from freeze `2026-09-07`, published on Zenodo under CC BY 4.0 as version 2026-09-07 of the aggregated FAA wildlife-strike dataset: https://doi.org/10.5281/zenodo.22648954 for this version of record, and https://doi.org/10.5281/zenodo.21347859 as the concept DOI, which always resolves to the most recent version. `FREEZE.md` in that deposit records the export the freeze was built from and how its counts differ from the preceding version. The within-taxon cross-tabulations behind Sections 4.1 to 4.3 are deposited as `wildlife_within_taxon_time_of_day.csv`, `wildlife_within_taxon_height.csv` and `wildlife_species_height_split.csv`; the segment definitions and totals of Table 1 are in `wildlife_segment_totals.csv` and `FREEZE.json`. The aggregation and analysis scripts are published as an open code annex at https://gist.github.com/disclaimer8/330a1032781a68acb1e55181f05dc77c: `wildlife-aggregate.js` with `wildlifeGaCuts.js` produce the segment cross-tabs, `emit_within_taxon.py` writes the within-taxon files, `build_manuscript.py` computes the crude and Mantel-Haenszel odds ratios and fills every table in this paper from the freeze, and `make_tables.mjs` draws Figure 1 and re-checks each printed number against the freeze files.

8. Generative AI disclosure

The author used a generative AI assistant (Claude, Anthropic; 2026 model versions) to assist with drafting and editing the manuscript text and with writing the open-source processing scripts in the code annex. All data processing steps, statistics, and claims were reviewed and verified by the author, who takes full responsibility for the content of this article.

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