Aerodynamic Comparison of Bird-Inspired Wings

Using a DIY Wind Tunnel

Vivan Bhattacharjee[1]*

[1]Prospect High School, Arlington Heights, Illinois, USA

Mentor: Humberto Caldelas[2]

[2]Doctorate in Aerospace Engineering, Massachusetts Institute of Technology, USA

Corresponding author: vivan.14@outlook.com

Abstract

The purpose of this paper is to explore how different bird wing shapes affect lift and drag in a small wind tunnel experiment. I tested three 3D-printed wing models based on the eagle, hawk, and albatross at three fan speeds (low, medium, high) and three angles of attack (0°, 5°, 15°). Five trials were taken for each condition to calculate average lift and drag. The results showed that the eagle wing created the most lift but also the highest drag, the hawk wing was very responsive to angle of attack with moderate drag, and the albatross wing produced the least lift but also the lowest drag. These findings match what is seen in nature[13]: eagles are powerful soarers, hawks are agile hunters, and albatrosses are efficient long-distance gliders. The purpose of this paper is also to show how aeronautical engineers might study which shapes make the best airfoils in order to construct objects that can fly more effectively. This experiment demonstrates how ideas from nature can connect to real engineering problems.

Introduction

Aerodynamics is the study of how gases, such as air, interact with solid objects in motion and how these interactions produce forces that can help or resist movement. Aerodynamics is important in flight because it determines how lift and drag are generated, which are the key forces that allow an object to fly.[1] In nature, birds have evolved different wing shapes to match their environments—eagles with broad wings for soaring, hawks with shorter wings for speed and agility, and albatrosses with long, narrow wings for efficient gliding over oceans.[3]

Bird flight has inspired engineers for centuries, leading to the field of biomimicry, where natural designs are studied to solve human engineering problems.[24] For example, aircraft designers have borrowed from bird wing shapes to improve efficiency and stability.[4] According to research from NASA's Glenn Research Center, wings with higher aspect ratios (long and narrow) generate less induced drag and are more efficient for sustained flight.[1] My experiment applies these same aerodynamic principles to small-scale 3D-printed bird-inspired wings.

The purpose of this study is to test and compare the lift and drag characteristics of 3D-printed wings modeled after an eagle, a hawk, and an albatross in a custom-built wind tunnel.[5] I also tested how changes in angle of attack (0°, 5°, and 15°) and fan speed (low, medium, high) affect aerodynamic performance. This project helps visualize fundamental aerodynamic principles at a small scale while connecting them to real-world aircraft design challenges. Understanding these relationships can contribute to future biomimetic wing designs and provide insight into how aeronautical engineers might study which shapes make the best airfoils to construct objects that can fly more efficiently.[4]

A)

B)

Figure 1. Comparison of bird wing shapes.
(a) Hawk vs. Eagle: The hawk shows rounded, shorter wings adapted for speed and maneuvering, while the eagle shows a longer wingspan with fingered primaries suited for soaring. Source: Birda(2024).
(b) Wandering Albatross vs. Eagle: In contrast with the eagle's wings, the albatross displays extremely long, narrow wings adapted for dynamic soaring over oceans, compared to the eagle's shorter, broader wings, which offer a balance between efficiency and maneuverability. Source: Wikimedia Commons, CC BY-SA 3.0.

Methodology

Table 1 . Materials used.

Materials Used	List
1st wind tunnel	Cardboard box,Straws,Plastic sheet,Hot glue,Duct tape,fan
2nd wind tunnel	Acrylic sheets 4x,Acrylic cement,Straws,Fan,Duct tape
1st set of wings	Wax paper,Hot glue,Balsa wood
2nd set of wings	3d printer PLA filament

To build the first wind tunnel, four pieces of cardboard were cut into a trapezial shape (add measurements) and duct-taped together. This yielded the basic shape for the funnel that increases wind speed by a little bit. The next part was a little more complicated, I cut 4 more pieces into rectangular shapes but for 2 of the pieces; I cut out the middle leaving only an outer edge to connect to the other 2 sides, in the hole I created I hot glued in a piece of a plastic sheet that I had cut out from a larger sheet. After that I glued the straight rectangular prism to the cone shaped piece to create my wind tunnel. Straws were then used to make a grid. This created straightened, laminar airflow so the wing could generate the most amount of lift. Finally, to complete the wind tunnel, taped the fan to the larger opening of the tunnel.

Three wings were made by cutting balsa wood into (measurments) long pieces and gluing them together to create a larger piece of wood. From here, the cross section was cut into the shape of the desired bird 3 times to create a stable shape. I then connected all 3 cross section pieces together with two 10 inch pieces of balsa wood stacked on top of each other, which created a skeleton for the wing. To the skeleton I glued a piece of wax paper on top. This created the completed wing. I made an albatross, hawk, and eagle wing.

The second wind tunnel was made like this. Using a laser cutter, pieces as shown in Figure 3 were cut. . After this, acrylic cement was used to create the shape of the wind tunnel as outlined earlier. Then, the straw grid was made to straighten the airflow and window sealant was used on the larger mouth on the wind tunnel to stop any air leakage. The fan was then duct taped to the wind tunnel.

Since the old wings were asymmetrical, they were put out of use, and new ones were created using the materials listed above. A CAD file was made that contained my wings printed out. Once received, the wings were sanded down to create a smooth surface that air could stick to in order to create even more lift.

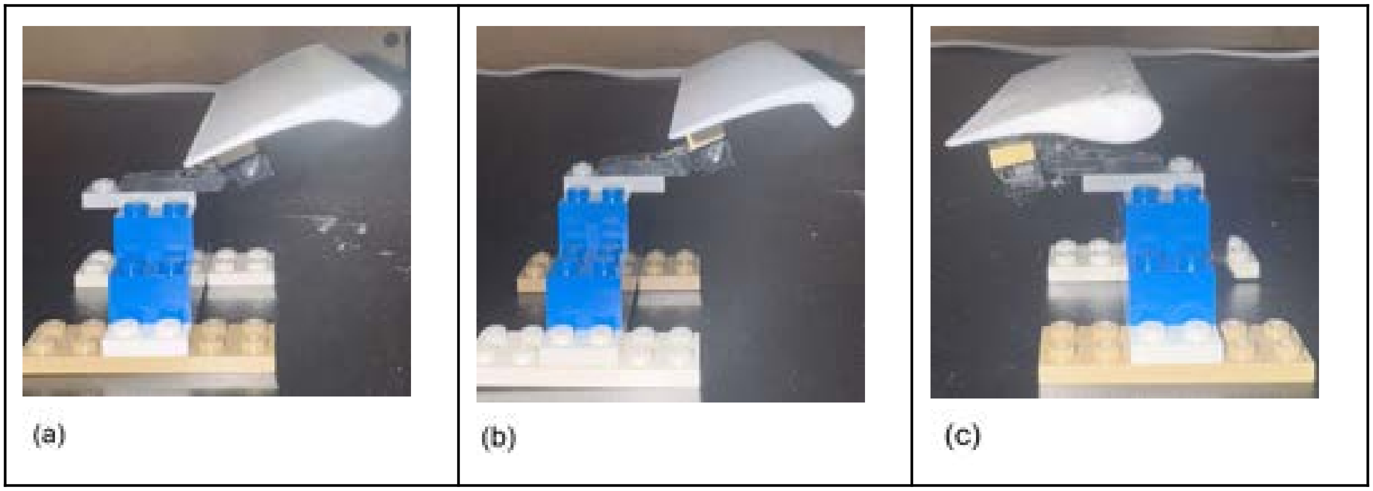

Figure 2. 3D-printed bird-inspired wing models used in wind tunnel testing.
(a) Albatross wing: long and narrow with a high aspect ratio, designed for efficient gliding.
(b) Hawk wing: shorter and broader with more camber, suited for speed and maneuverability.
(c) Eagle wing: broad with pronounced curvature and fingered tips, adapted for soaring and carrying heavy lift.

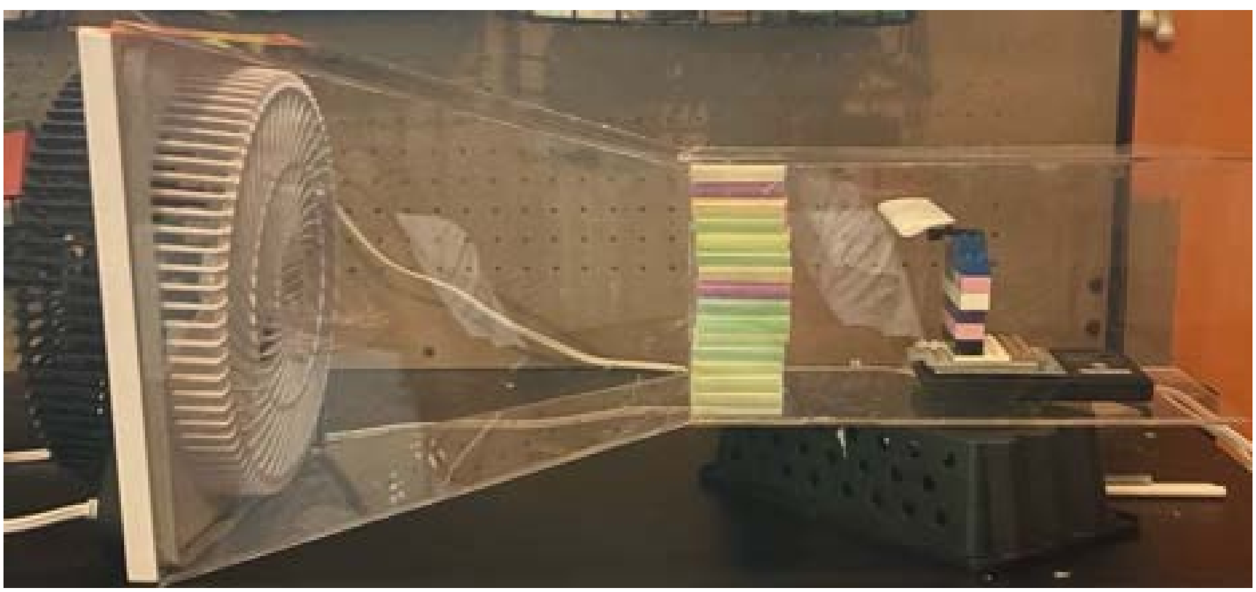

Figure 3 - Windtunnel setup.

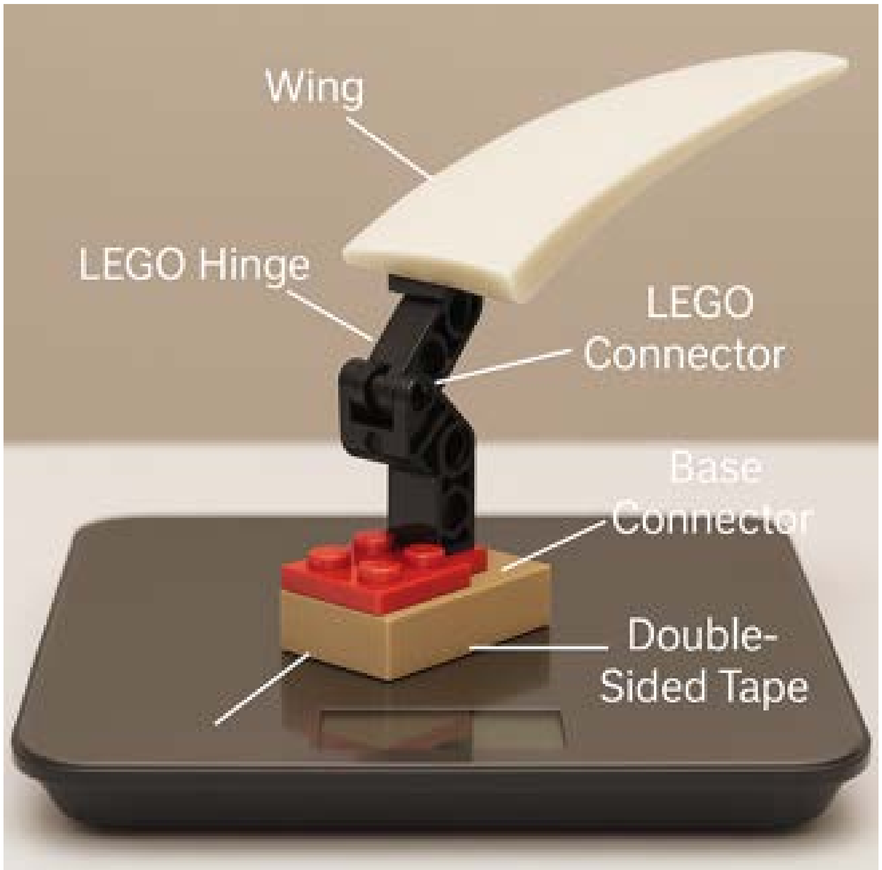

Figure 4 : Close setup of the wing.

To measure drag, each wing was mounted on a LEGO support at the wind tunnel centerline with its chord parallel to the airflow Angle of Attack or (AoA = 0°). A small LEGO pulley system was used to redirect the drag force downward onto a digital scale using a string and plunger setup. The scale was placed outside the test section to record only drag. After zeroing the scale, tests were run at different fan speeds and angles of attack —0°, 5°, 10°, 15° — and 3–5 repeated measurements were recorded for each condition to calculate the average drag.

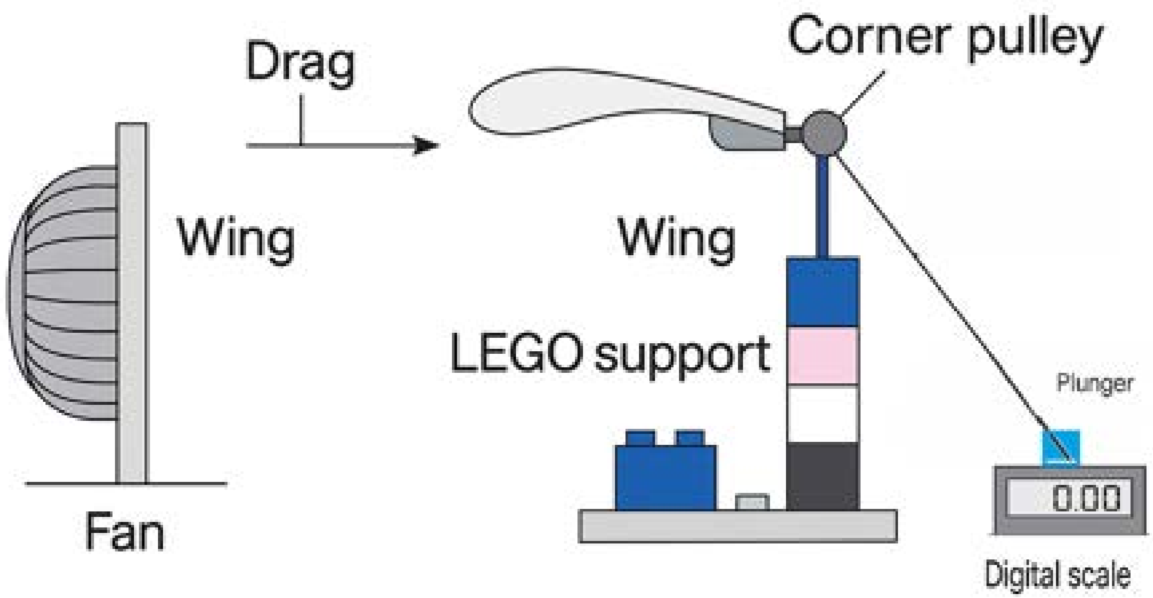

Figure 5 - Windtunnel setup to measure drag.

Airflow Measurement Approach

To measure airflow inside the wind tunnel, I used a fan with three fixed speed settings: low, medium, and high. Although the exact air velocity was not directly measured with an anemometer, the fan speeds provided consistent airflow conditions across all tests. A flow straightener made of drinking straws was placed after the fan to reduce turbulence and create a more uniform airflow before it reached the wing models. To visualize the airflow patterns around the wings, I introduced smoke using incense sticks placed at the tunnel inlet. The smoke made it possible to see how the air moved over the wing surface and around the wingtips, helping to confirm that the fan and flow straightener were producing a smooth flow.

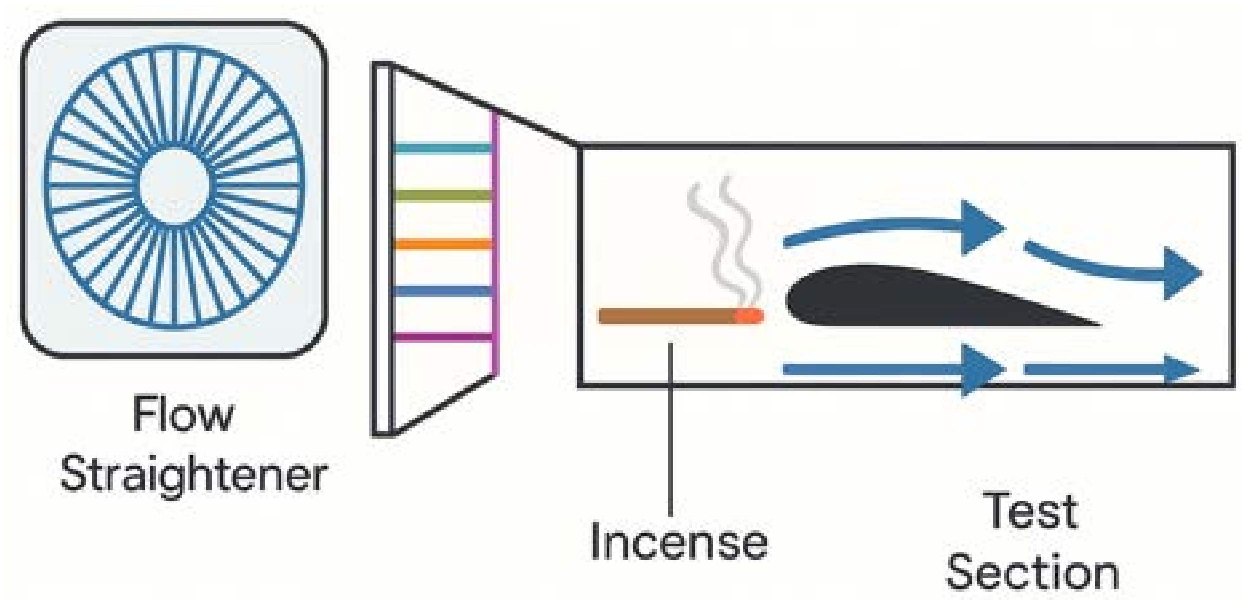

Figure 6 - Windtunnel setup to measure drag.

Results and Discussion

The results and analysis from the wind tunnel experiments conducted with three bird-inspired wing models—albatross, hawk, and eagle— are presented in this section. . Each wing was tested at three fan speeds —low, medium, and high — and three angles of attack (0°, 5°, 15°), with five repeated trials taken for every condition. Mean lift and drag values were calculated along with standard deviation to assess consistency.

Results Analysis: Low Fan Speed

At low fan speed, lift increased with angle of attack for all three wing types. The eagle consistently produced the highest lift across all AoA values (4.0–4.5 grams), while the hawk showed moderate lift gains (2.9–3.8 grams). The albatross produced the lowest lift (3.1–3.9 g), reflecting its efficiency-focused design.

Table 2. Mean lift (g) ± standard deviation for hawk, eagle, and albatross wings at 0°, 5°, and 15° angles of attack under low fan speed.

Wing Type	Fan Speed	AoA (°)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean Lift (g) ± SD
Hawk	Low	0	2.89	2.88	2.92	2.91	2.93	2.9 ± 0.02 g
Hawk	Low	5	3.79	3.63	3.94	3.93	3.91	3.8 ± 0.13 g
Hawk	Low	15	3.79	3.81	3.85	3.82	3.86	3.8 ± 0.03 g
Eagle	Low	0	4.12	3.99	3.98	4	4.15	4.0 ± 0.08 g
Eagle	Low	5	4.21	4.24	4.14	4.09	4.27	4.2 ± 0.07 g
Eagle	Low	15	4.53	4.49	4.56	4.52	4.47	4.5 ± 0.04 g
Albatross	Low	0	3.08	3.11	3.08	3.16	3.18	3.1 ± 0.05 g
Albatross	Low	5	3.47	3.45	3.48	3.43	3.46	3.5 ± 0.02 g
Albatross	Low	15	3.93	3.94	3.87	3.82	3.95	3.9 ± 0.06 g

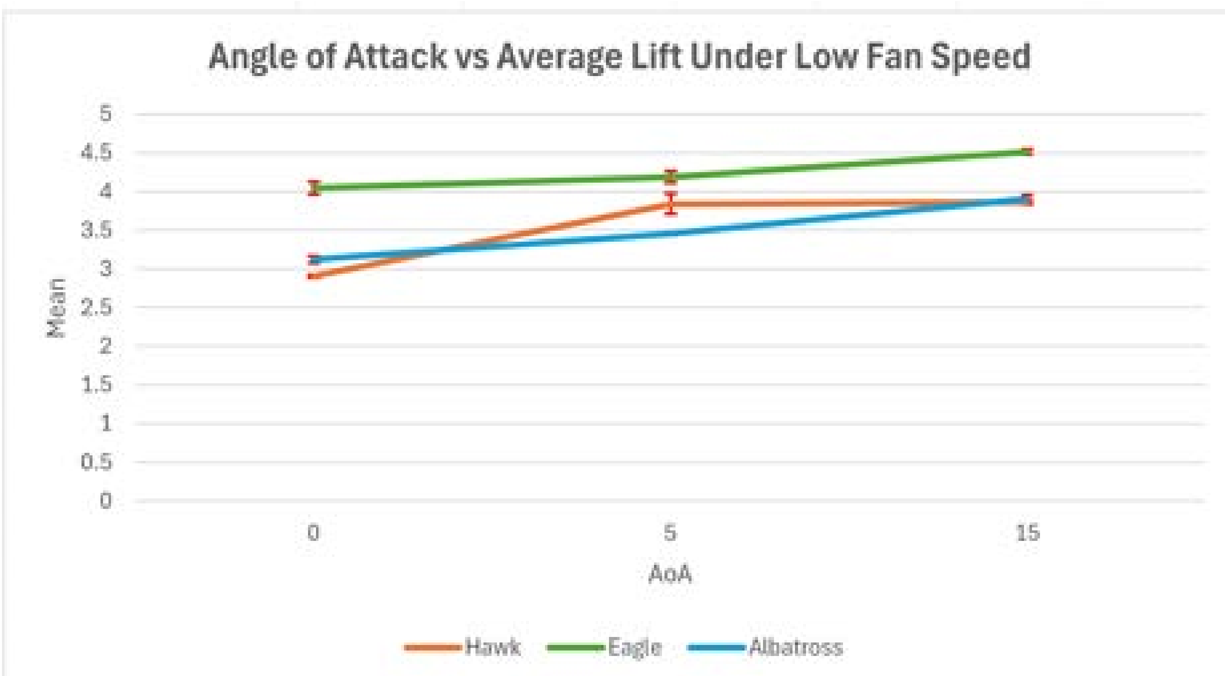

Figure 7. Lift vs. angle of attack for hawk, eagle, and albatross wings under low fan speed. Data points represent mean lift, and error bars indicate ±1 standard deviation from five repeated trials.

Results Analysis: Medium Fan Speed

At medium fan speed, lift values increased for all wings. The eagle remained the strongest performer (5.3–5.9 g), while the hawk displayed a marked improvement (3.8–5.0 g), becoming competitive with the eagle at higher AoAs. The albatross stayed lower in absolute lift (4.0–4.8 g), though consistent and stable.

Table 3. Mean lift (g) ± standard deviation for Hawk, Eagle, and Albatross wings at 0°, 5°, and 15° angles of attack under medium fan speed.

Wing Type	Fan Speed	AoA (°)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean Lift (g) ± SD
Hawk	Medium	0	3.78	3.77	3.75	3.81	3.73	3.8 ± 0.03 g
Hawk	Medium	5	4.99	4.92	4.93	4.97	4.88	4.9 ± 0.04 g
Hawk	Medium	15	4.99	4.96	5.01	4.97	4.95	5.0 ± 0.02 g
Eagle	Medium	0	5.27	5.3	5.22	5.08	5.38	5.3 ± 0.11 g
Eagle	Medium	5	5.56	5.69	5.62	5.53	5.6	5.6 ± 0.06 g
Eagle	Medium	15	5.81	5.99	5.86	5.87	5.93	5.9 ± 0.07 g
Albatross	Medium	0	4.01	3.99	3.94	3.98	3.92	4.0 ± 0.04 g
Albatross	Medium	5	4.32	4.35	4.39	4.33	4.41	4.4 ± 0.04 g
Albatross	Medium	15	4.87	4.83	4.46	4.95	4.84	4.8 ± 0.19 g

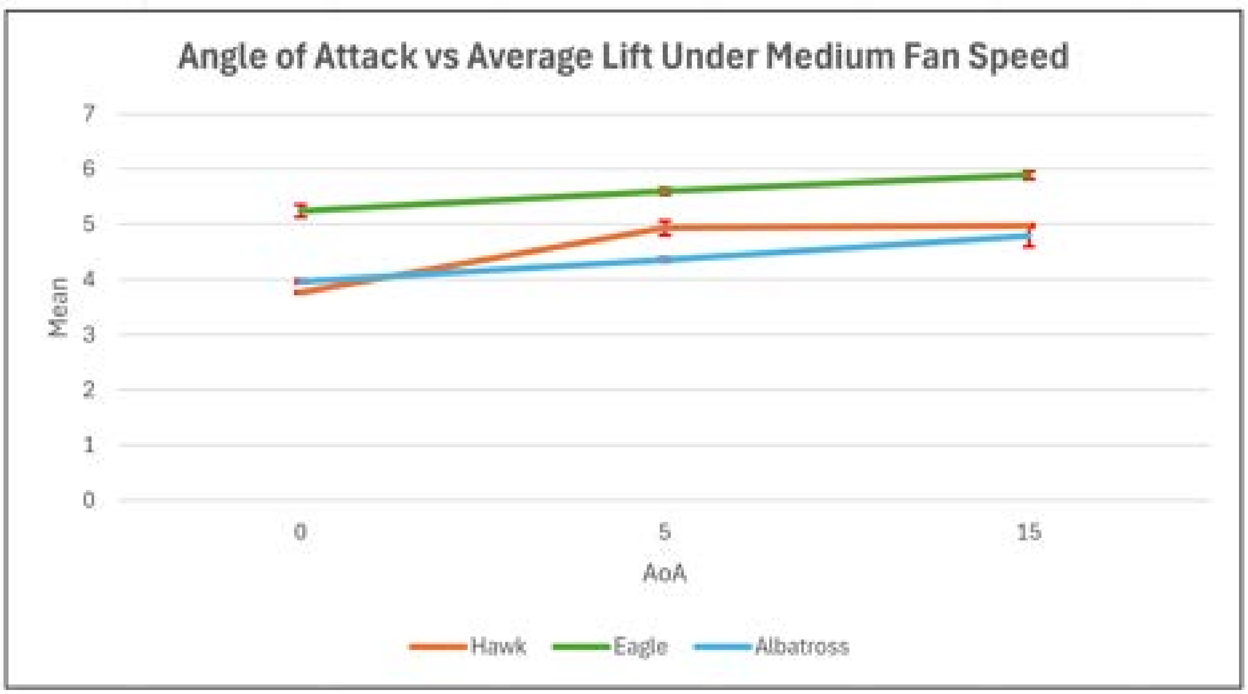

Figure 8. Lift vs. angle of attack (AoA) for Hawk, Eagle, and Albatross wings under medium fan speed. Data points represent mean lift, and error bars indicate ±1 standard deviation from five repeated trials.

Results Analysis: High Fan Speed

At high fan speed, all wings achieved their maximum lift. The eagle again produced the highest lift (6.3 g at 0°, maintaining ~6.2 g at 15°). The hawk generated slightly lower lift (4.9–5.6 g), but its performance at 15° AoA closely approached the eagle's. The albatross continued to produce lower lift values (4.3–5.2 g), but its lift increased steadily with AoA.

Table 4. Mean lift (g) ± standard deviation for Hawk, Eagle, and Albatross wings at 0°, 5°, and 15° angles of attack under high fan speed.

Wing Type	Fan Speed	AoA (°)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean Lift (g) ± SD
Hawk	High	0	4.9	4.91	4.88	4.97	4.9	4.9 ± 0.03 g
Hawk	High	5	5.62	5.68	5.59	5.63	5.65	5.6 ± 0.03 g
Hawk	High	15	5.48	5.52	5.46	5.59	5.53	5.5 ± 0.05 g
Eagle	High	0	6.62	6.64	6.61	6.59	6.83	6.7 ± 0.10 g
Eagle	High	5	6.32	6.4	6.28	6.56	6.34	6.4 ± 0.11 g
Eagle	High	15	6.2	6.21	6.22	6.27	6.19	6.2 ± 0.03 g
Albatross	High	0	4.32	4.29	4.28	4.31	4.33	4.3 ± 0.02 g
Albatross	High	5	5.1	5.05	5.07	5.12	5.13	5.1 ± 0.03 g
Albatross	High	15	5.13	5.17	5.25	5.19	5.15	5.2 ± 0.05 g

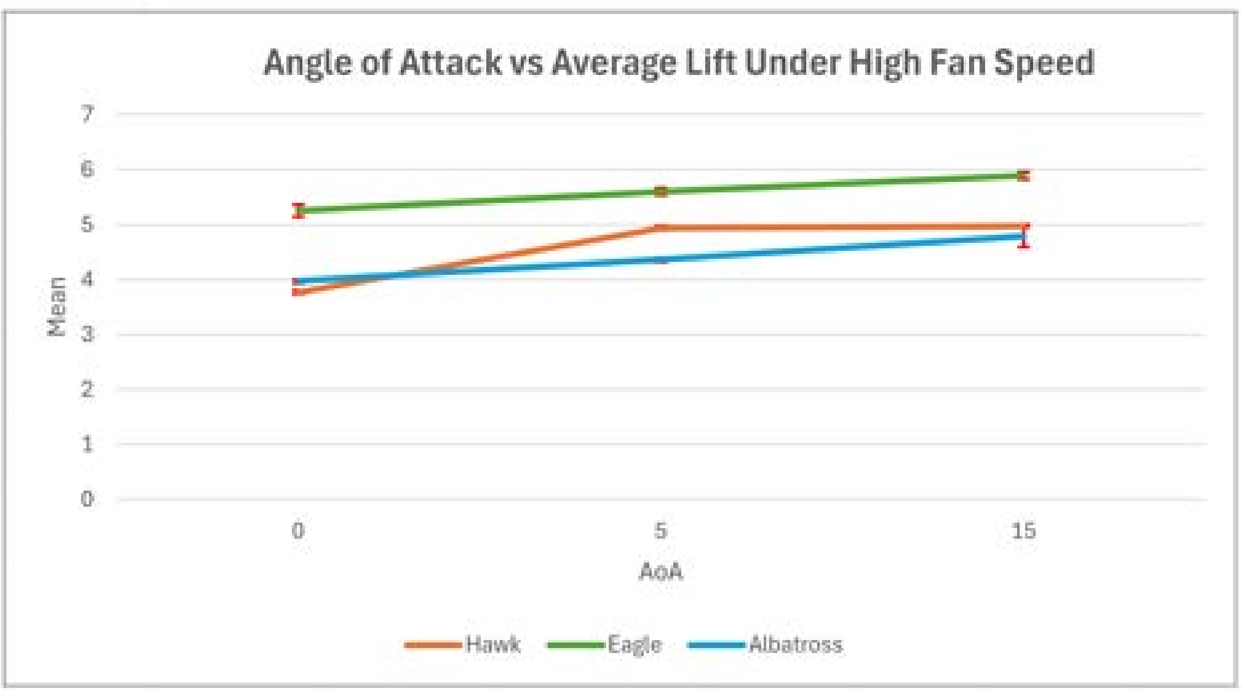

Figure 9. Lift vs. angle of attack (AoA) for Hawk, Eagle, and Albatross wings under high fan speed. Data points represent mean lift, and error bars indicate ±1 standard deviation from five repeated trials.

Across all fan speeds, the eagle wing consistently produced the highest lift, maintaining stable performance with relatively low variability. The hawk wing showed a strong response to increasing angle of attack, starting with lower lift at 0° but started to match the results from the eagle trials at higher angles, especially under medium and high fan speeds. In contrast, the albatross wing consistently generated the lowest lift values, though it demonstrated steady and predictable increases with angle of attack, reflecting its adaptation for efficient gliding rather than maximum lift. Overall, the eagle excelled in absolute lift, the hawk displayed strong AoA sensitivity and adaptability, and the albatross prioritized aerodynamic efficiency over peak lift output.

Drag Testing -

Table 5. Mean drag (g) for Hawk, Eagle, and Albatross wings across three fan speeds (Low, Medium, High). Each mean is based on five repeated trials.

Wing Type	Fan Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Hawk	Low	1.08	1.04	1.86	1.91	1.03	1.384
Eagle	Low	6.25	6.12	6.15	6.17	6.2	6.178
Albatross	Low	0.29	0.13	0.34	0.39	0.22	0.274
Hawk	Medium	2.49	2.36	2.39	2.42	2.43	2.418
Eagle	Medium	6.64	6.7	6.39	6.62	6.6	6.59
Albatross	Medium	1.29	1.32	1.38	1.3	1.33	1.324
Hawk	High	3.01	3.02	3.12	2.99	3.09	3.046
Eagle	High	8.73	8.42	8.57	8.53	8.62	8.574
Albatross	High	2.84	2.77	2.78	3.08	2.85	2.864

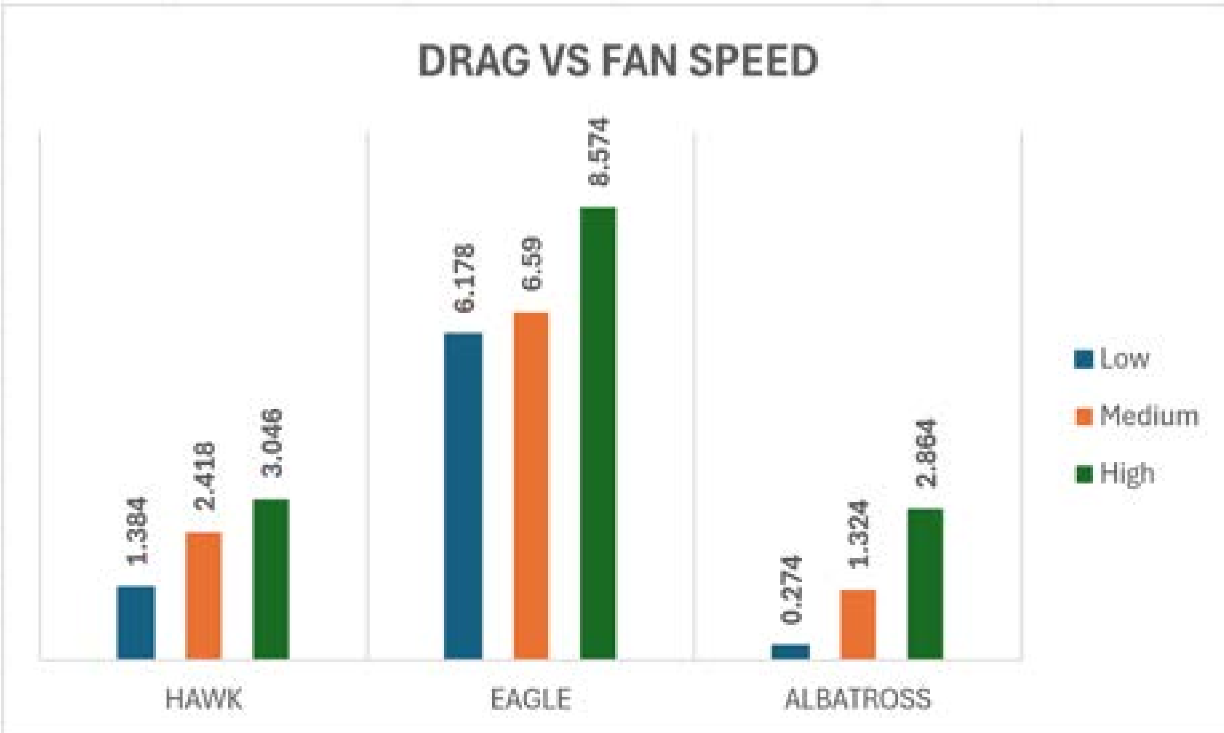

Figure 10. Drag vs. fan speed for Hawk, Eagle, and Albatross wings.

Drag increased with fan speed for all three wing types, but the magnitude varied significantly across designs. The eagle wing produced the highest drag values at every fan speed, ranging from 6.2 g at low speed to 8.6 g at high speed, consistent with its broad surface area and strong lift generation.[13] The hawk wing showed moderate drag, increasing from 1.4 g at low speed to 3.0 g at high speed, reflecting its balance between lift production and maneuverability.[3] The albatross wing consistently generated the lowest drag, with values ranging from only 0.3 g at low speed to 2.9 g at high speed, highlighting its efficiency-oriented design for long-distance gliding.[35]

Overall, the eagle sacrificed efficiency for maximum lift, producing the highest drag; the hawk demonstrated a balanced performance with moderate drag levels; and the albatross achieved the lowest drag, aligning with its evolutionary adaptation for sustained soaring with minimal energy loss.[35]

Across all tests, clear differences were observed in the aerodynamic performance of the three bird-inspired wings. The eagle wing consistently produced the highest lift at every fan speed and angle of attack, but this came with the trade-off of generating the highest drag values.[1] The hawk wing showed strong sensitivity to angle of attack, with lift increasing sharply as AoA rose, making its performance comparable to the eagle at higher speeds, though with moderate drag levels.[34] In contrast, the albatross wing produced the lowest lift overall but also maintained the lowest drag, reflecting its evolutionary specialization for long-distance gliding with energy efficiency rather than maximum lift.[35] Together, these results highlight the distinct aerodynamic strategies of each wing type: the eagle prioritizes power, the hawk balances lift and maneuverability, and the albatross emphasizes efficiency.[35]

Conclusion

The wind tunnel experiments clearly showed that wing shape has a major effect on aerodynamic performance.[15] Across all tests, the eagle wing generated the highest lift but also the most drag, while the albatross wing produced the least lift but was the most efficient with minimal drag.[35] The hawk wing performed in between these two extremes, showing that it can adapt to different angles of attack while maintaining a good balance between lift and drag.[3] These patterns match what is observed in nature: eagles are powerful soarers that rely on lift to carry heavy loads, hawks are agile and maneuverable hunters, and albatrosses are built for long-distance gliding with low energy use.[35]

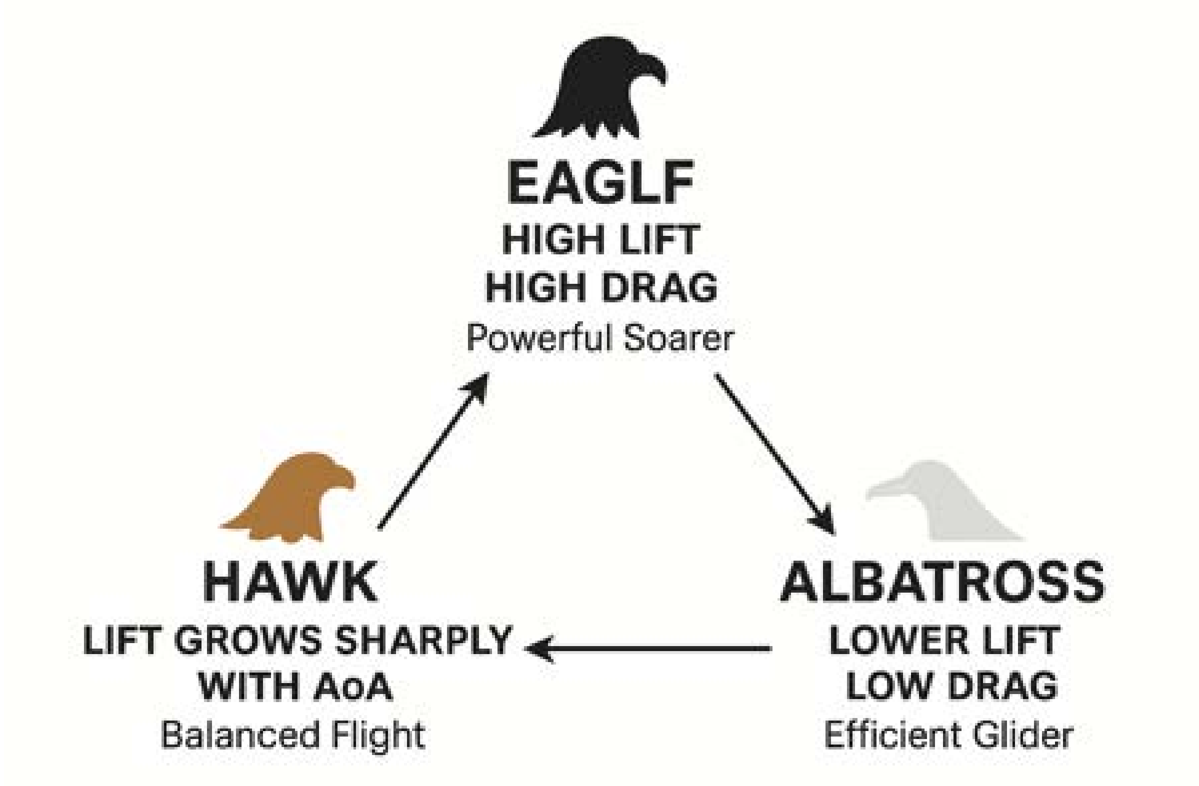

Figure 11. Summary of aerodynamic performance of bird-inspired wings.

These results highlight the aerodynamic trade-offs that exist between power and efficiency. Wings designed to maximize lift usually face higher drag, while wings that minimize drag often sacrifice some lift.[14] This is important for engineers studying biomimicry because it shows how natural wing designs can inspire aircraft or drone wings that are specialized for different tasks—powerful lift, agile maneuvering, or efficient gliding.[24]

One limitation of this experiment was that the exact airspeed inside the wind tunnel was not measured, which means lift and drag could only be compared between fan settings and not converted into standard aerodynamic coefficients.[1] The 3D-printed wings were also simplified versions of real bird wings and did not include features like flexible feathers or smooth surface textures, which could affect real flight performance.[35] In future experiments, adding an anemometer to record air velocity would allow more accurate calculations of lift and drag forces.[1] Using smoke or dye visualization for all three wings could also help show how airflow separates or stays attached during flight.[1] Future studies could test more wing shapes, materials, or even scaled airplane wings inspired by birds to see how small design changes improve efficiency.[45]

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