Gust Interaction of Red- Tailed Hawks

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In recent years, unmanned aerial vehicles, or UAVs, have exploded in popularity. Governments and companies have utilized UAVs in military, commercial, and entertainment roles. Unfortunately, all UAVs possess a major drawback in the form of flight stability. Unmanned vehicles lose stability in the presence of sudden vertical gusts. To solve this issue, engineers have looked towards bio-inspired designs to resist gust instability. A leading design for this is a flapping-wing drone, modelling the flight of birds. To further advance bio- inspired design, research has been conducted to understand how flying birds respond to sudden gusts (Cheney et al. 2020) (Quinn et al. 2017). By better understanding both the response and the stimuli prompting the response, a robust, gust-resistant drone can be built.

In this project, our group observed the flight of a red-tailed hawk (Buteo jamaicensis) through an indoor flight arena, seen in Figure 1. Two Phantom VEO 640L and two Phantom VEO 4k 990L cameras were set up around the arena to obtain high speed footage of the flight. Six industrial fans of diameter twelve inches were placed in the middle of the flight path. The fans would be turned to a low or high setting depending on the desired gust to forward velocity ratio. The hawk would be flown through the tunnel, and the effect of gusts would be observed.

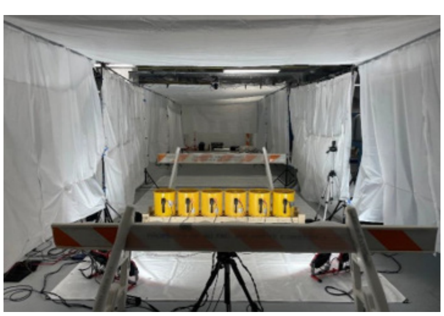

Fig. 1 Fully assembled indoor flight arena.

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Before any set of flights, the cameras would be calibrated for tracking using a checkerboard calibration technique (Theriault et al. 2014). After completion of a series of flights, the camera videos would be imported the DLTdv8 MATLAB application created by Dr. Hedrick (Hedrick 2008). Accurate 3-D point data was gathered for the wings, tail, and hawk body, as shown in Figure 2. The data was exported and manipulated using computer scripts to produce geometric variables such as roll angle, pitch angle, and yaw angle. A lower-order unsteady aerodynamic model was applied to these variables to produce lift coefficient values (Ignacio et al. 2022). Together with drag coefficient estimations, a linear dynamic model was created to estimate the expected change in height due to gust interaction. This model would provide information on the gust response effectiveness, and what aerodynamic forces would cause the observed response.

Fig. 2 Bird flight tracking using DLTdv8.

A general path track for wing and tail points can be seen in Figure 3. We observed a downwards pitch in both wings after crossing the fans. High gust ratio runs, where the gust speed to forward velocity ratio was greater than one, saw only slightly greater downward pitch than low gust ratio runs. After leaving the gust column, both run regimes saw a slight pitch back upwards.

Lift coefficient values were found for high gust ratio and low gust ratio runs. Due to the equation used, the lift coefficient starts at zero, when the wing first encounters the gust. The high gust regime sees a rapid increase in lift coefficient initially, before levelling out and increasing at a constant rate. After leaving the gust, the lift coefficient decreases rapidly.

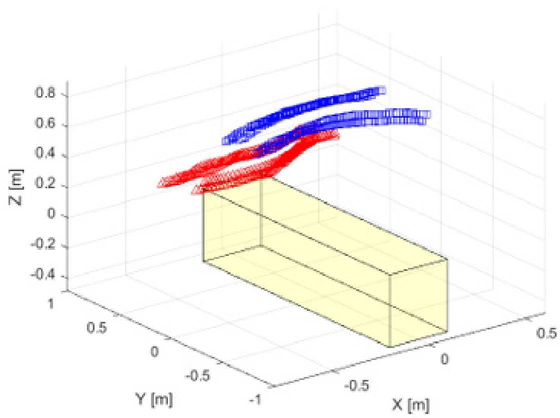

Fig. 3 Three-dimensional tracks of wing points and tail points over fans.

A linear model was created using the equations below (Josselson 1997). Together with the lift coefficients found previously and estimations of the drag coefficient of a bird's wing, expected height changes were calculated (Withers 1981).

$$\dot{u} = \frac{F_x}{m} + (rv - qu) \tag{1}$$

$$v = \frac{F_y}{m} + (pw - ur) \tag{2}$$

$$\dot{w} = \frac{F_z}{m} + (rv - qu) \tag{3}$$

The model assumed that only the aerodynamic forces over the wing were significant. The low gust ratio estimates possess somewhat large errors, but are still within realm of error given the lift and drag estimates used. The high gust ratio estimates are very far off, with relative errors greater than two hundred percent. Attempts were made to decrease error by assuming stall conditions; however, no manipulations of the aerodynamic forces decreased error significantly. A review of lift and drag force calculations was conducted to ensure the observed model response was not due to sub-par lift and drag estimations. Past investigations showed that the lift estimation scheme is sufficiently accurate for sine-squared gust patterns (Ignacio 2020). The fans used in this research produce a sine-squared gust pattern, making such substantial error unlikely (Swiney et al 2020).

The high gust ratio results suggests that there is some outside phenomenon the model is not taking into account. One possibility is tail response effects, which are not accounted for in this model. Future research will have to account for coupled wing and tail effects when examining gust responses.

Statement of Research Advisor

With the increasing rate of adoption of drones in civilian and military applications there is a need to design drones that are robust to aerodynamic perturbations such as gusts. In this study, a bio-inspired approach is adopted to investigate how a bird adapts to an adverse aerodynamic environment in a controlled manner. In the future, the plans are to design aerodynamic vehicles to include such bio-inspired gust mitigation techniques.

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References

[1] Cheney, J., Stevenson, J., Durston, N., Song, J., Usherwood, J., Bomphrey, R., Windsor, S., "Bird Wings Act as a Suspension System that Rejects Gusts," Proceedings of the Royal Society B, 287(1937), pp. 20201748, (2020).

[2] Hedrick, T., "Software Techniques for Two-and Three- Dimensional Kinematic Measurements of Biological and Biomimetic Systems," Bioinspiration and Biomechanics, 3(3), pp. 5123-5133, (2008).

[3] Ignacio, A., Babinsky, H., Biler, H., Sedky, G., Jones, A., "Effect of Transverse Gust Velocity Profiles," AIAA Journal, 58(12), pp. 5123-5133, (2020).

[4] Ignacio, A., Babinsky, H., "Mitigation of Airfoil Gust Loads Through Pitch," AIAA Journal, 60(9), pp.5273-5285,(2022).

[5] Josselson, R., "Derivation of the Equations of Mo-

tion," Introduction to 6-DOF Simulation of Air Vehicles, International Thomson Computer Press, Boston, pp.5-6, (1997).

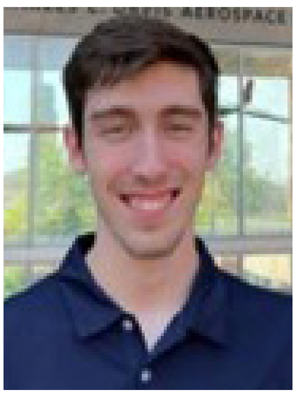
[6] Quinn, D., Watts, A., Nagle, A., Lentink, D., "A New Low- Turbulence Wind Tunnel for Animal and Small Vehicle Flight Experiments," Royal Society Open Science, 4(3), pp. 160960, (2017).

[7] Swiney, P., Wietstruk, M., Gosdin, L., Bellah, J., Raghav, V., "Preliminary Investigation of the Aerodynamic Response of a Red-tailed Hawk to a Vertical Gust," AIAA Scitech 2020 Forum, pp. 2001, (2020).

[8] Theriault, D., Fuller, N., Jackson, B., Bluhm, E., Evangelista, D., Wu, Z., Betke, M., Hedrick, T., "A Protocol and Calibration Method for Accurate Multi-Camera Field Videography," Journal of Experimental Biology, 217(11), pp. 1843-1848, (2014).

[9] Withers, P.C., "An Aerodynamic Analysis of Bird Wings as Fixed Airfoils," Journal of Experimental Biology, 90(1), pp.143-162,(1981).

Authors Biography



Colin Bamford is a senior-year student pursuing a B.S. degree in Aerospace Engineering. He assisted a research group with collecting data on a hawk's response to vertical gusts, and conducted a detailed analysis of the unsteady aerodynamics observed.

Jack Nix is a graduate student in aerospace engineering at Auburn University. He received a B.S. in Mechanical Engineering and Aerospace Engineering from the University of Florida. Jack is current working on developing a dynamic simulation platform for simulation of novel flight models under normal flight and gust perturbations.

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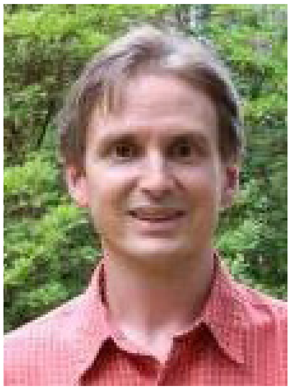

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