Falcon Inspired Robotic Glider with Multi-Joint Wing Morphing

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Introduction

Current variable-sweep aerial designs predominantly feature one-joint wing systems to increase diving speed, while addressing concerns regarding vibration management and mechanical durability. This project investigates whether integrating a bio-inspired wing design enhances aerodynamic properties. By drawing inspiration from the double-joint sweep wing morphology of the peregrine falcon, the effects on vibration and speed during diving were studied.

The purpose of this project is to test the following hypothesis:

A two-joint variable-sweeping wing system that folds its outer wings towards the body during flight will increase diving speed and reduce vibrations in comparison to fixed-wing and one-joint variable-sweep wing systems.

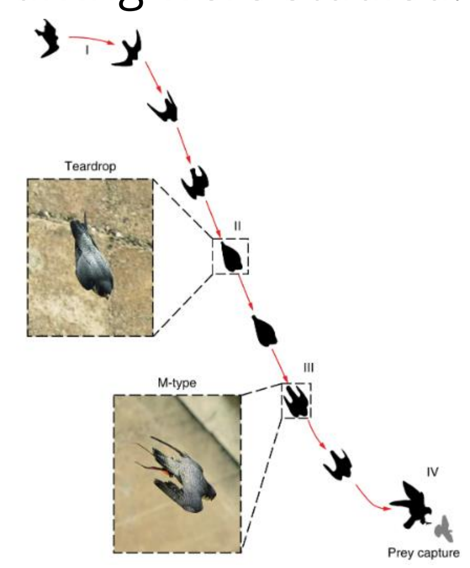


Fig. 1 Peregrine falcon diving wing configurations [1].

Robot Design and Fabrication

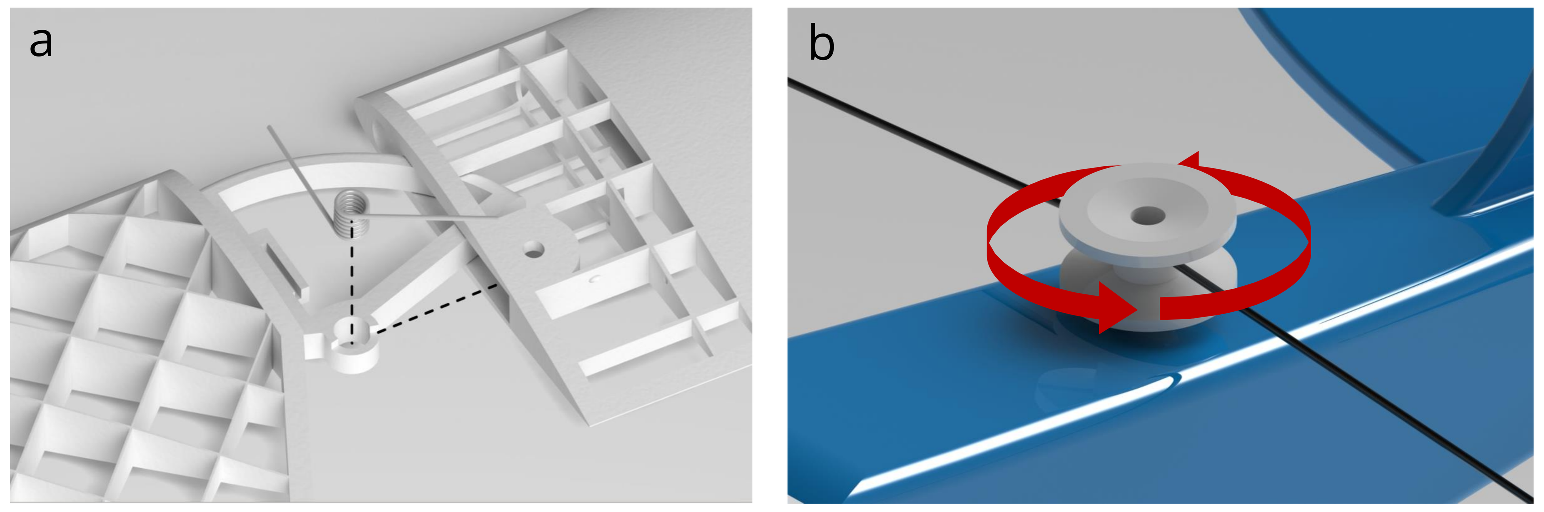
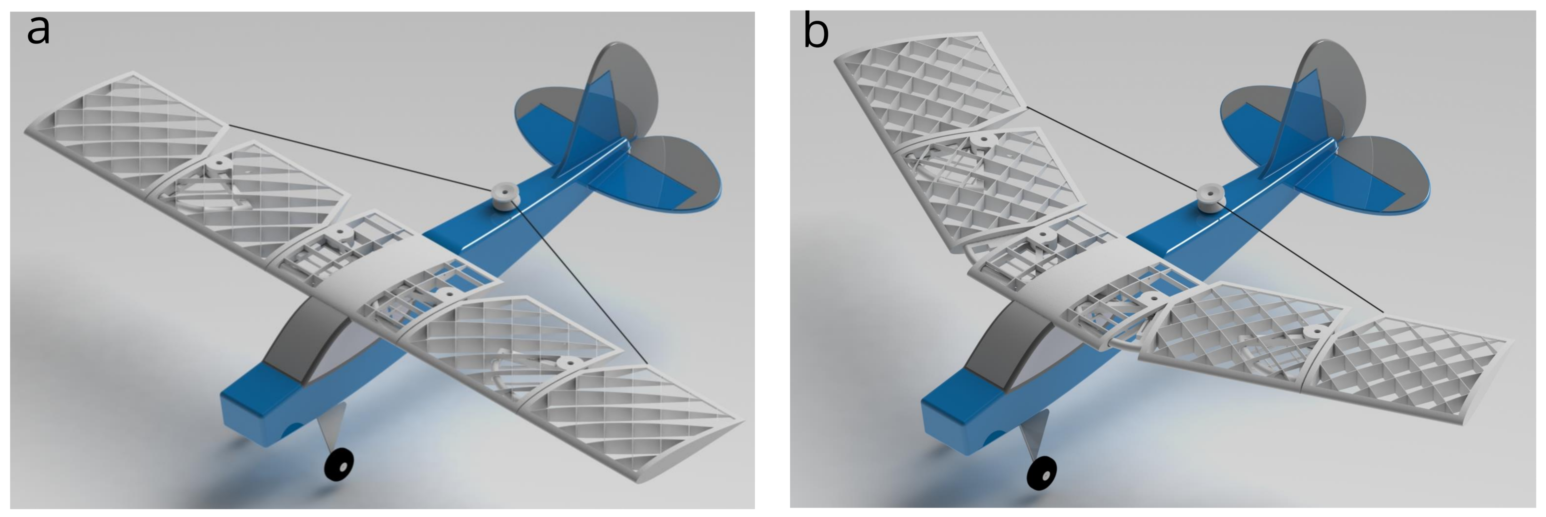


Fig. 2 Close-up views of a) wing joint mechanism using a torsional spring of 1.47 in.-lbs. torque and b) spool mechanism with rotational orientations.

- **Joint Mechanism:** Quarter-circle guide rails for rotational hinge motion, and torsion springs for retraction to fixed-wing position.
- **Spool Mechanism:** Continuous servo and pulley system that cycles the wings through the three morphing stages.



The two-joint wing system allows for zero joint, single joint, and double joint actuation to be achieved on a single aircraft. The glider isolates for the effects of the actuated wing joint on speed and vibrations. Testing different wing configurations on separate aircraft introduces the possibility of confounding variables.

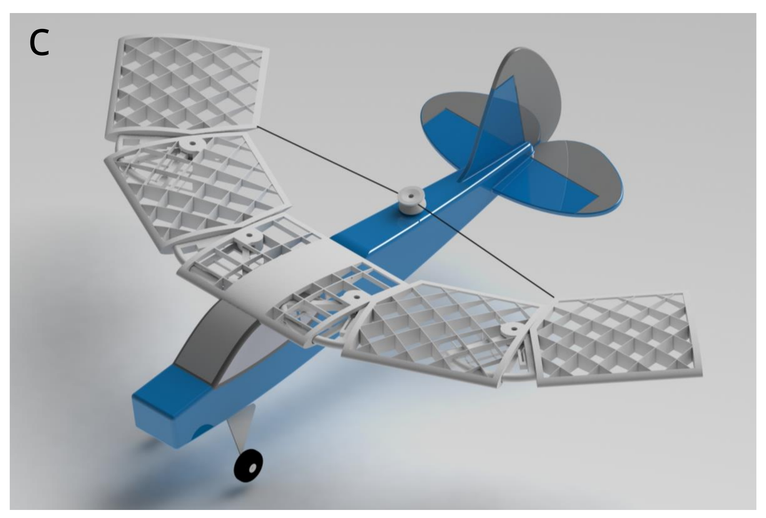


Fig. 3 CAD rendering of a) Zero Joint Actuation, b) Single Joint Actuation, and c) Double Joint Actuation.

Results: Velocities and Vibrations

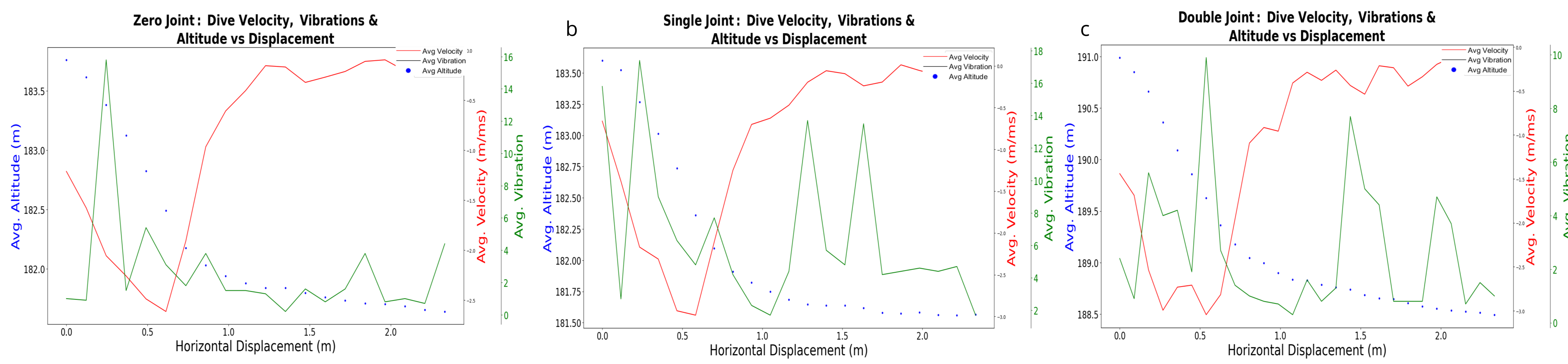


Fig. 4 Velocity and Vibration plots based off altitude sensor data for a) zero joint actuation b) single joint actuation c) double joint actuation.

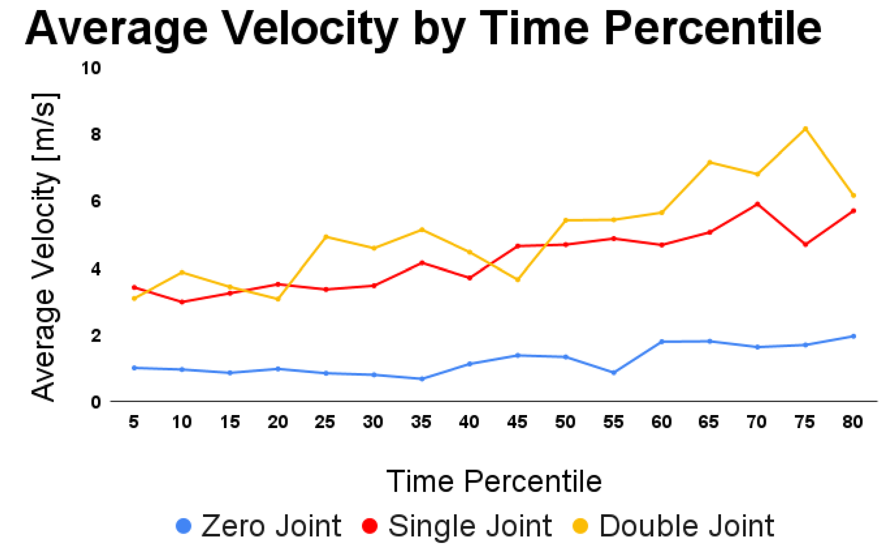


Fig. 7 The average velocities were calculated at the same time percentile to reduce the standard deviation of the velocities averaged over the entire diving duration.

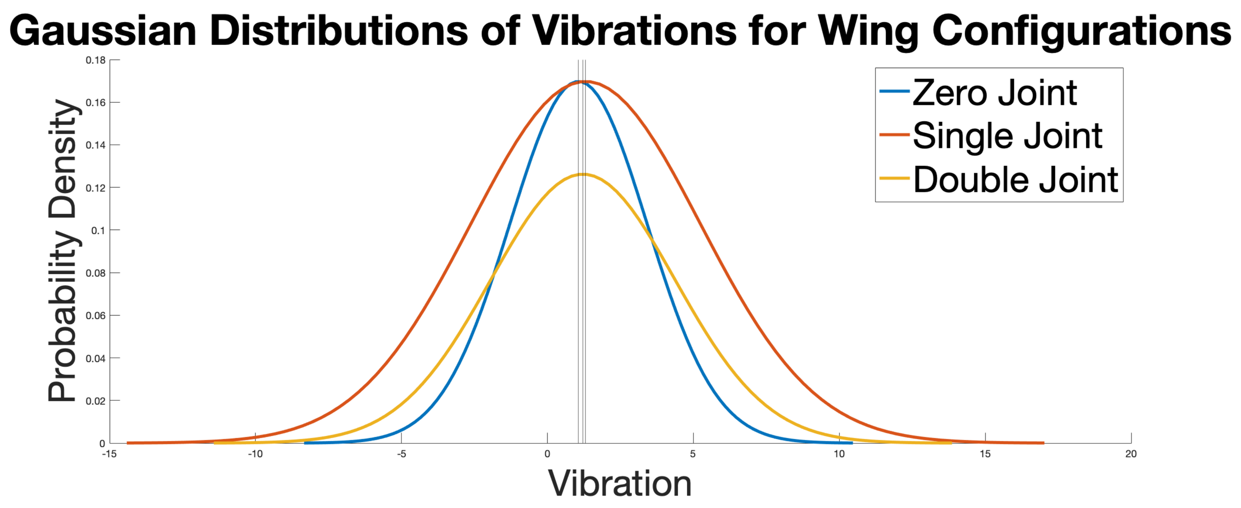


Fig. 5 Gaussian distributions of vibrations for all wing configurations. Distribution parameters were calculated from a sample size of 865.

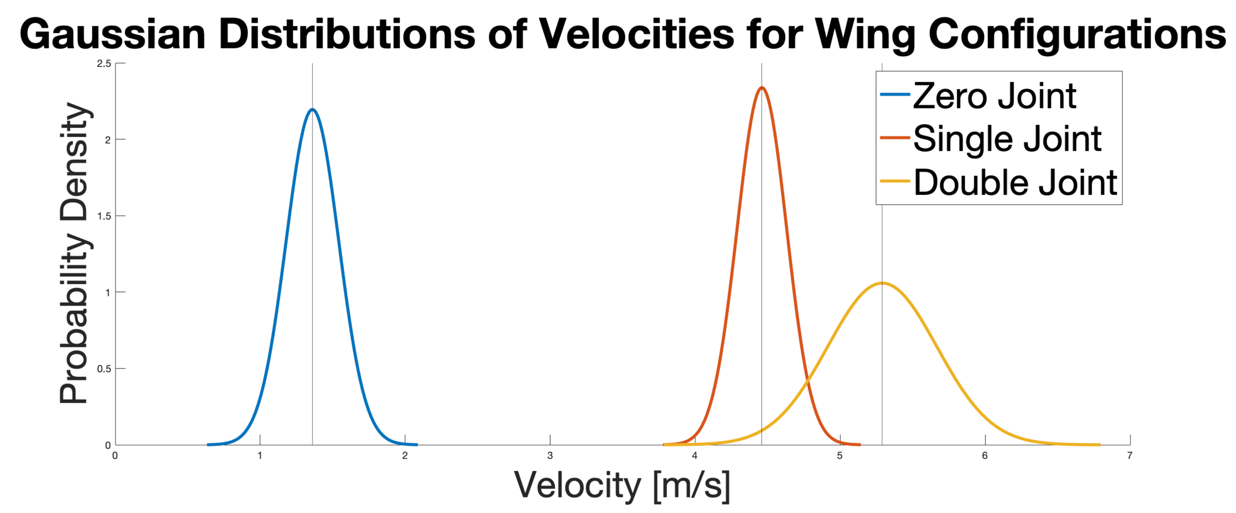


Fig. 6 Gaussian distributions of velocities for all wing configurations. Distribution parameters were calculated from a sample size of 5.

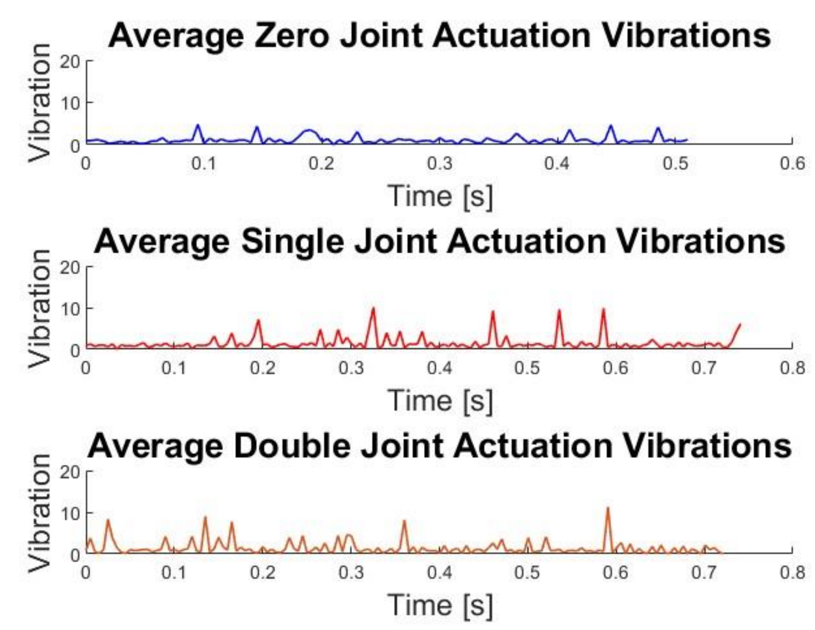


Fig. 8 Vibrations during diving were averaged across 5 trials of each configuration.

Table 1. Distribution Parameters and T-test for Wing Vibrations

Group	Mean	Standard Deviation	Group	p-value
Zero Joint Actuation (Z)	0.9548	1.9944	$\mu_D > \mu_Z$	0.0398
Single Joint Actuation (S)	1.3088	3.9298	$\mu_S > \mu_Z$	0.0183
Double Joint Actuation (D)	1.2162	3.1609	$\mu_D > \mu_S$	0.5893

Table 2. Distribution Parameters and T-Test for Velocities [mm/s]

Group	Mean	Standard Deviation	Group	p-value
Zero Joint Actuation (Z)	1.36	0.1097	$\mu_D > \mu$	5.974e-7
Single Joint Actuation (S)	4.46	0.1706	$\mu_S > \mu_Z$	1.549e-8
Double Joint Actuation (D)	5.29	0.3768	$\mu_D > \mu_S$	0.0049

Methods: Experimentation

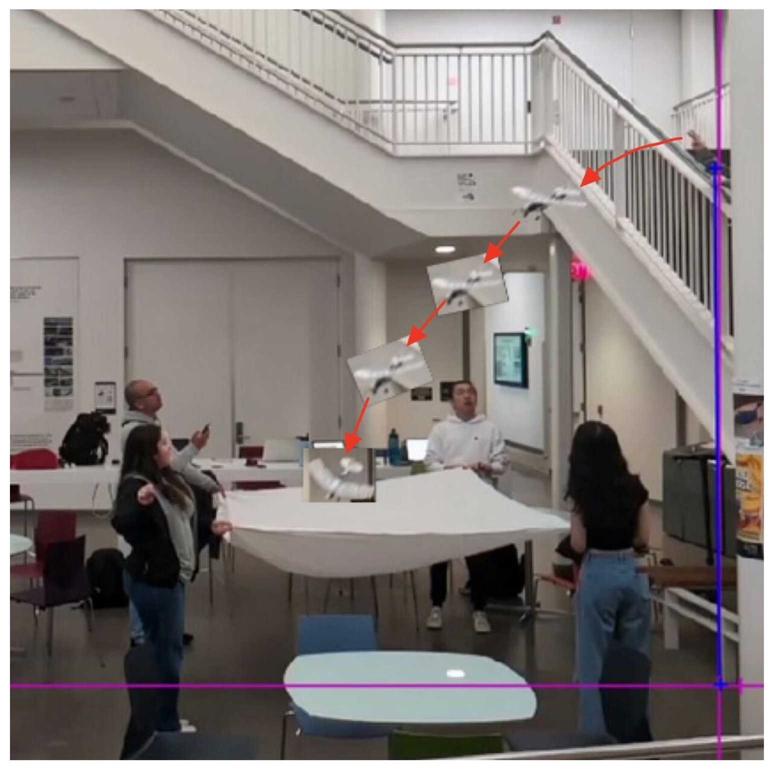


Fig. 9 Experimental setup visualized in Tracker software. Slow-motion video of trials were used to gain extra data points.

- **Gliding Test**: Launched glider at fixed height (130.5 in) for each wing configuration across 5 trials. 15 trials were accomplished in total. Wing configuration was changed using a FS90 servo.
- **Data Collection**: Stored 4 seconds of piezo vibration sensor and altimeter data into a microSD card using an Arduino Nano.
- **Motion Capture**: Employed Tracker Video Analysis and Modeling Tool software for positional data to derive velocity.
- **Data Analysis**: Utilized Excel, Python, and MATLAB for data processing. Matched video flight time stamps to altimeter data for extracting diving duration.

Fig. 10 Fully assembled and functional prototype.

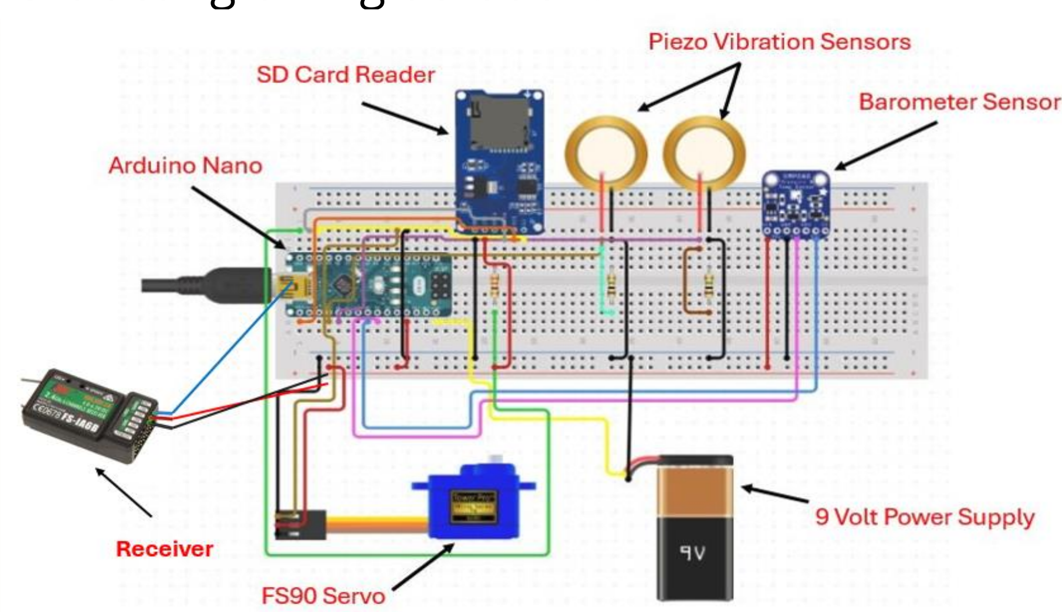


Fig. 11 Electronics schematics onboard the glider.

Conclusions

The results of the one-tailed unpaired t-test suggest:

- **Vibrations: Double-joint = Single-joint > Zero-joint**
  - There is no statistically significant difference between variable-sweep wings, but both variable-sweep wings have higher average vibrations than fixed wings.
- **Speed: Double-joint > Single-joint > Zero-joint**
  - Double-joint wings achieve higher average velocities than both single- and zero-joint wings.

With this bio-inspired approach, the glider opens new avenues of research in unmanned aerial vehicle (UAV) designs, potentially offering improvements in flight stability, fuel efficiency, and operational flexibility.

Future Work

Improve Upon Data Processing:

- Add IMU for dive angle tracking
- Add GPS module for 3D visualization
- Collect data from multiple heights & entry velocities

Acknowledgments

References

[1] E. R. Gowree, C. Jagadeesh, E. Talboys, C. Lagemann, and C. Brücker, "Vortices enable the complex aerobatics of peregrine falcons," *Communications Biology*, vol. 1, no. 1, pp. 1–7, Apr. 2018, doi: https://doi.org/10.1038/s42003-018-0029-3.