Development of Strain-Sensing Fins (FINsight)

June 18, 2024

DUKE AERO

Pitchfork contains three strain gauge integrated fins to capture in-flight fin strain (aerodynamic loading) data.

- Fins are inset with flex PCBs with custom strain gauges.
- Fins deform during flight, causing gauge resistance changes.
- Resistance changes are recorded via Wheatstone bridges.

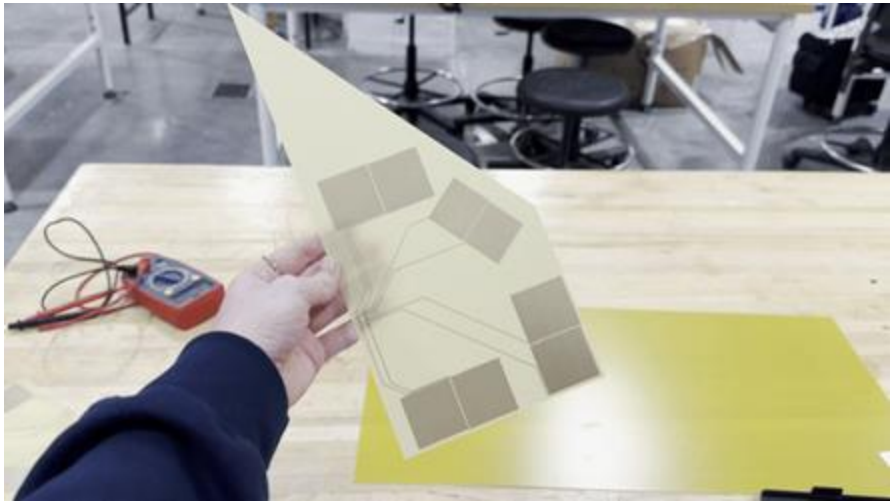

FIG 1. Integrated fin PCB

Why FINsight?

Fin strain data informs fin design decisions and simulations.

For example:

1. Uneven fin loading = Better fin mounting procedure necessary
2. Large flutter oscillations = Decrease mass or increase stiffness

Why custom strain gauges?

1. Easy to mount and integrate
2. No wire bumps or extrusions
3. Inexpensive with large surface area

Electronics and Circuit Diagram

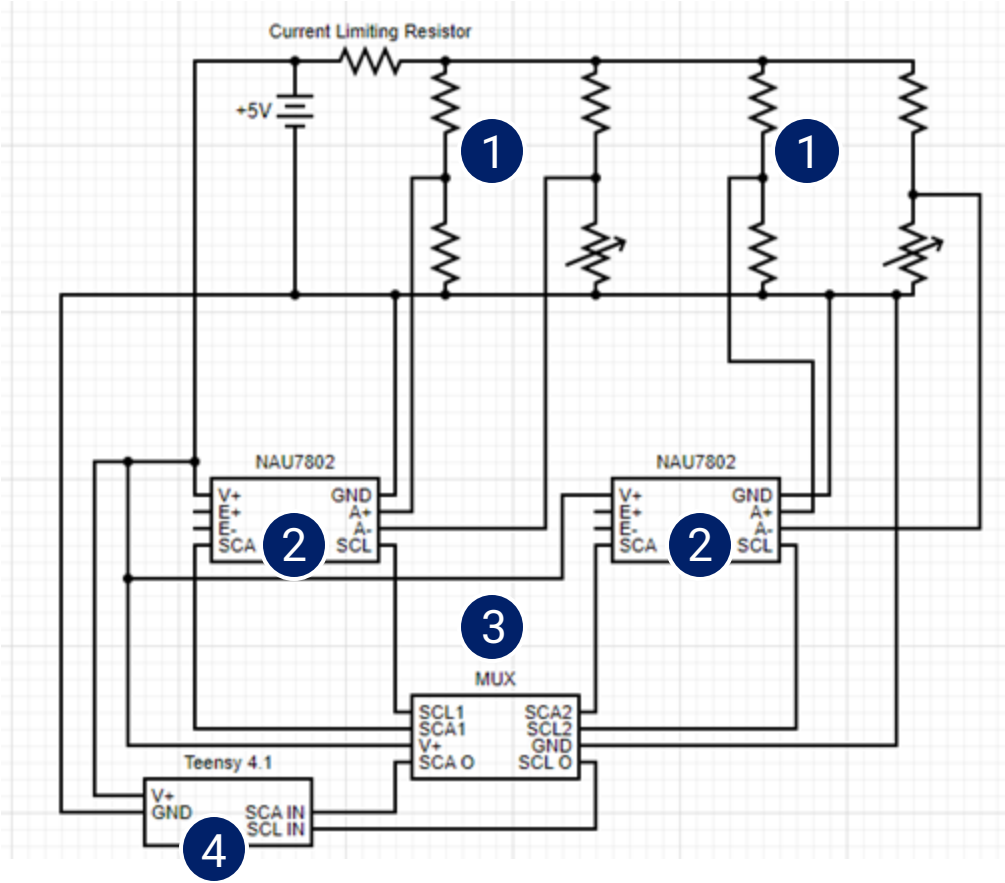

FIG 2. Example of a 2-gauge strain logger circuit

1. Resistance changes and unbalances the Wheatstone bridge

1. NAU7802 ADC converts voltage to digital signal

1. MUX TCA9548A transmits to Teensy 4.1 via I2C

1. Teensy records to flash memory

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What is modal analysis?

- Modal analysis is the study of how systems/objects vibrate.
- Experimental modal analysis is performed via impact testing.

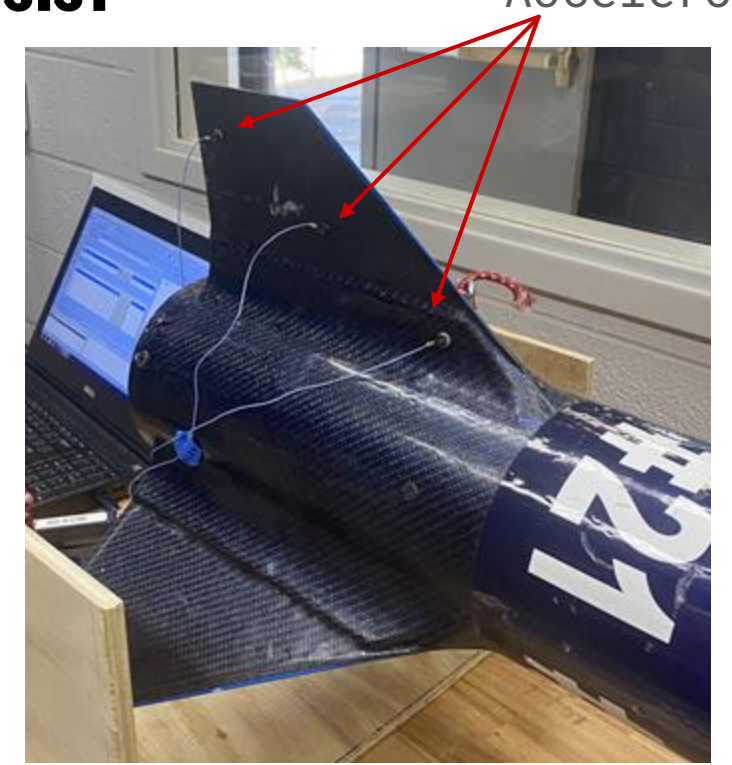


FIG 3. Duke AERO modal impact setup

FIG 4. A modal impact hammer

Optimal Placement of Strain Gauges

- Optimal placement is in areas of high curvature.
- Impact testing data and FEA modal study predicted frequencies/mode shapes.

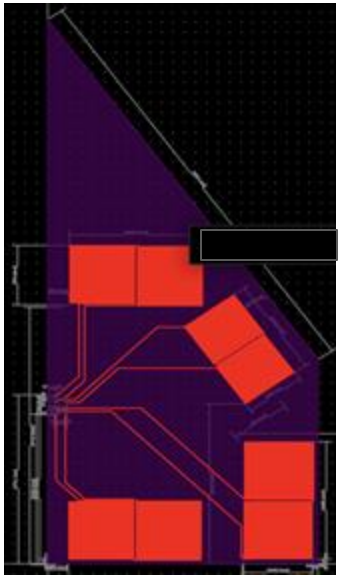


FIG 5. Fin PCB with optimal strain gauge placement

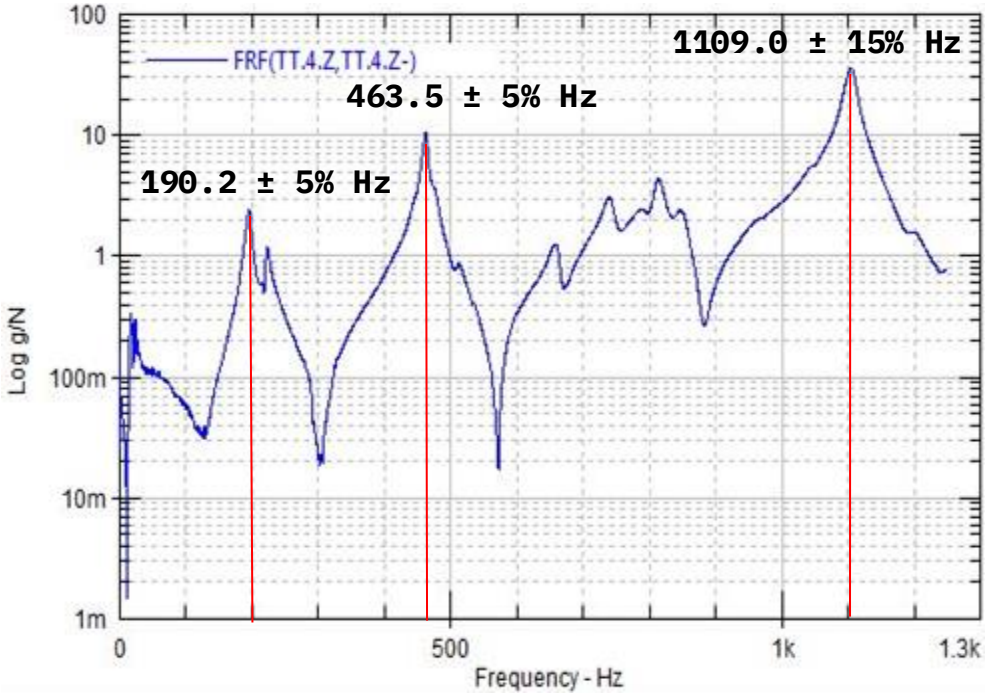
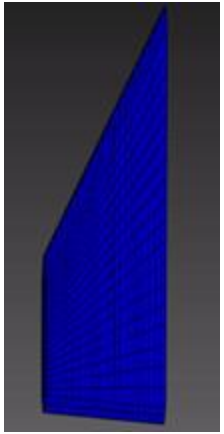
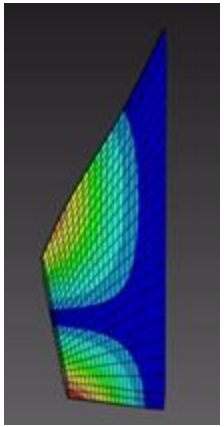
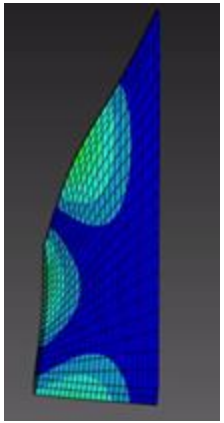
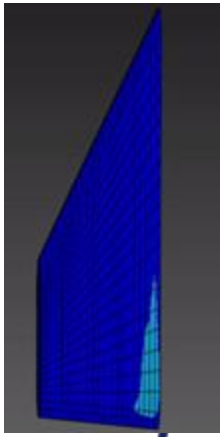


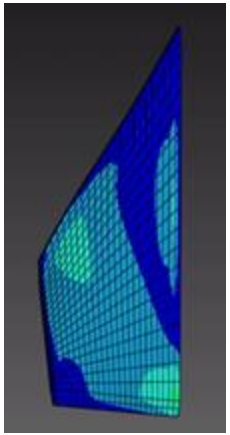
FIG 6. FRF results from modal impact test

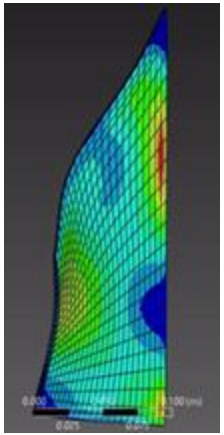

1st mode


2nd mode


3rd mode







Mode Shape Results

	Mode-1	Mode-2	Mode-3
Blue Reaper Modal	190 Hz	464 Hz	1109 Hz
Pitchfork FEA	287 Hz	641 Hz	1287 Hz

TABLE 1. *Blue Reaper* modal analysis results v. *Pitchfork* FEA in agreement with scaling laws

PCB Design Specifications

- 0.4 mm thick flex PCB
- 1.2 inch x 2.1 inch copper tracing strain gauges
- 0.127-mm-diameter wire
- UV-cured solder mask

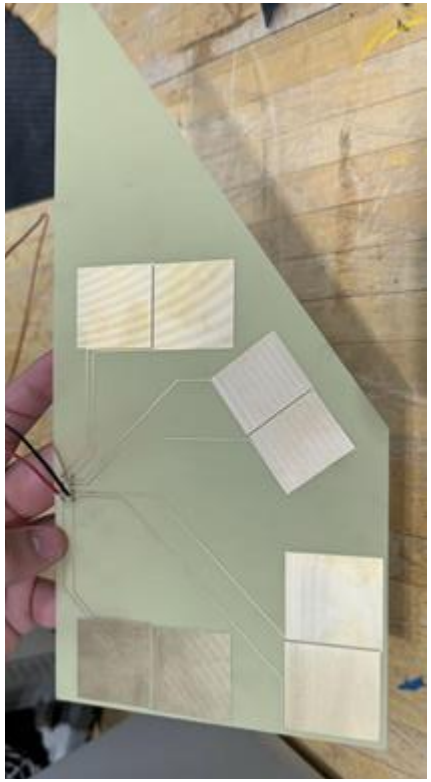


FIG 7. A PCB strain-gauge

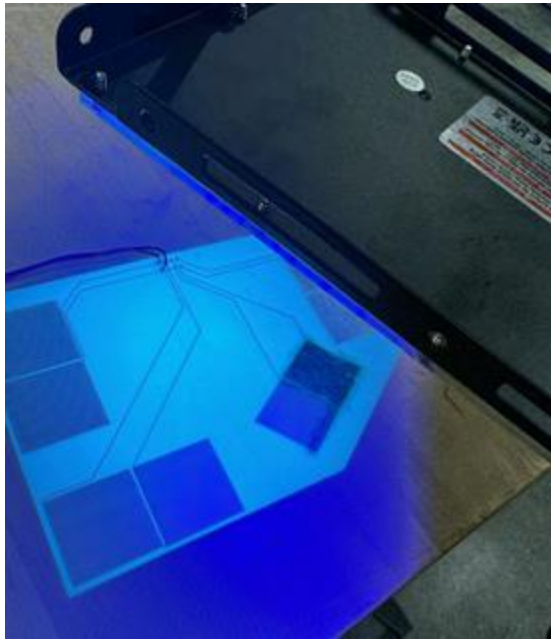


FIG 8. PCB strain-gauge undergoing treatment

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Manufacturing

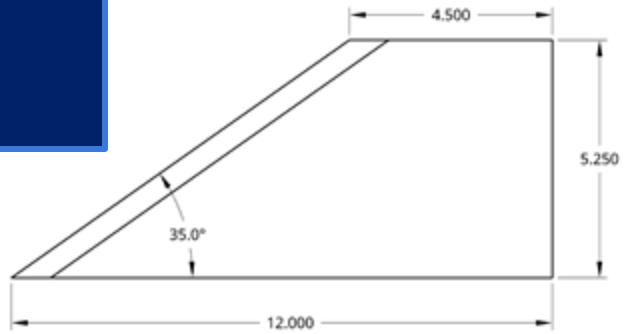

FIG 9. Fin dimensions

FIG 10. Fin layers

- Fiberglass / Carbon Fiber sandwich
- PCBs placed off center to detect more deflection
- Symmetric sandwich layup prevents torsion under loading
- Wires from PCB threaded through fin can

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Strain Measurement Module (SMM)

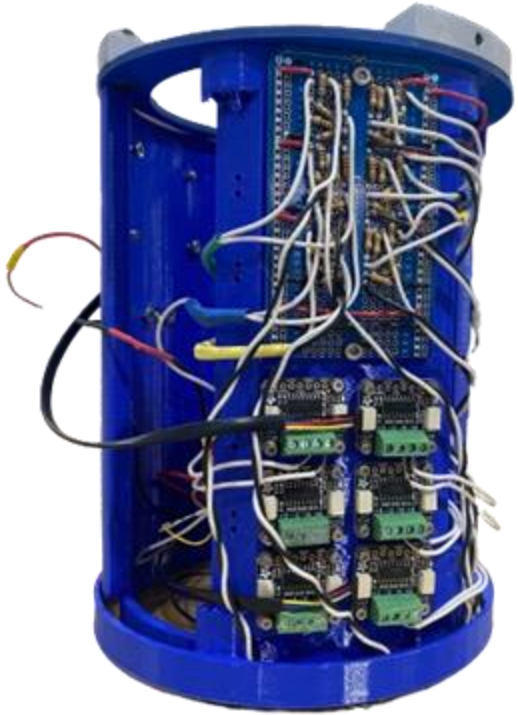

FIG 11. SMM with mounted electronics

- 3D-printed mounting bracket houses all circuitry in power section:
  - Wheatstone bridges
  - 24-bit ADCs
  - Teensy microcontroller with flash memory and mux
  - Two single cell lithium-ion batteries
- Fits all circuitry in 1” radial space between motor casing and body tube

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Static Load Testing

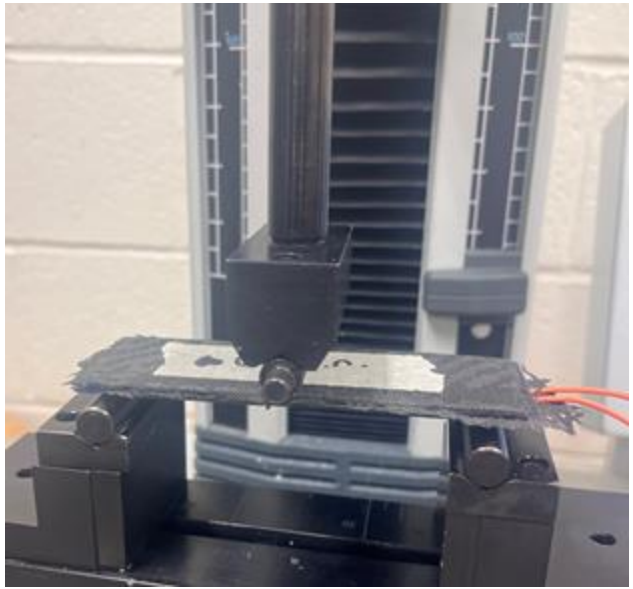

FIG 11. Test PCB mounted in extensometer

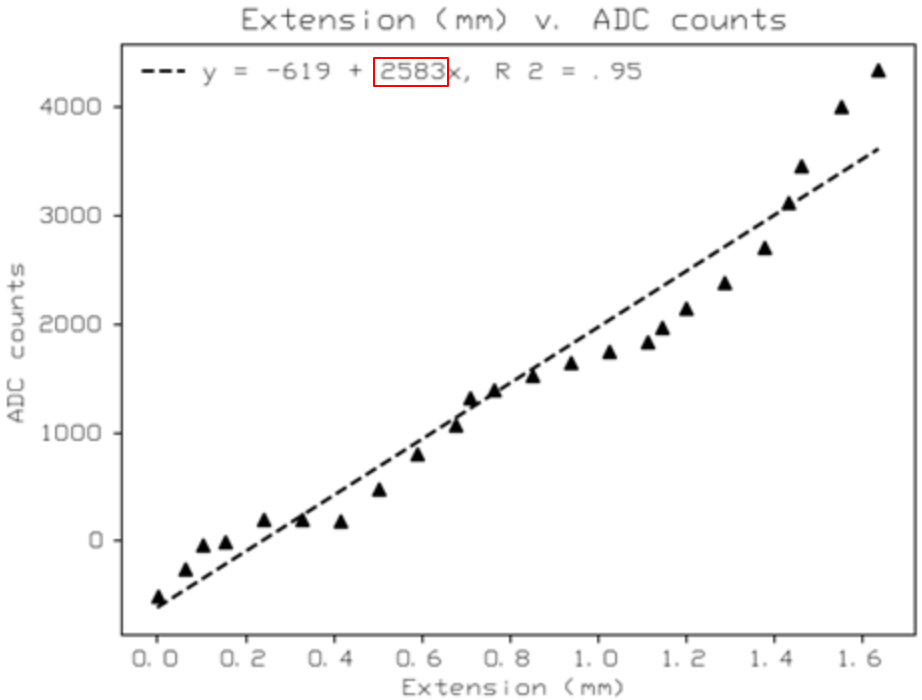

FIG 12. Example calibration data showing gauge's linear behavior

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Wind Tunnel Testing

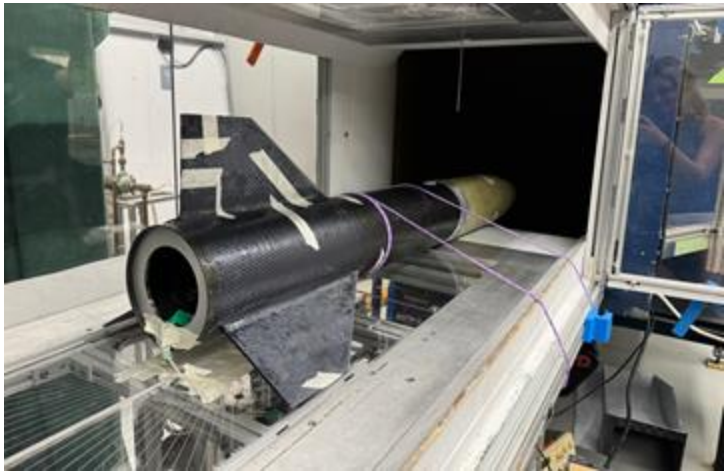

FIG 13. Pitchfork in the wind tunnel for strain testing

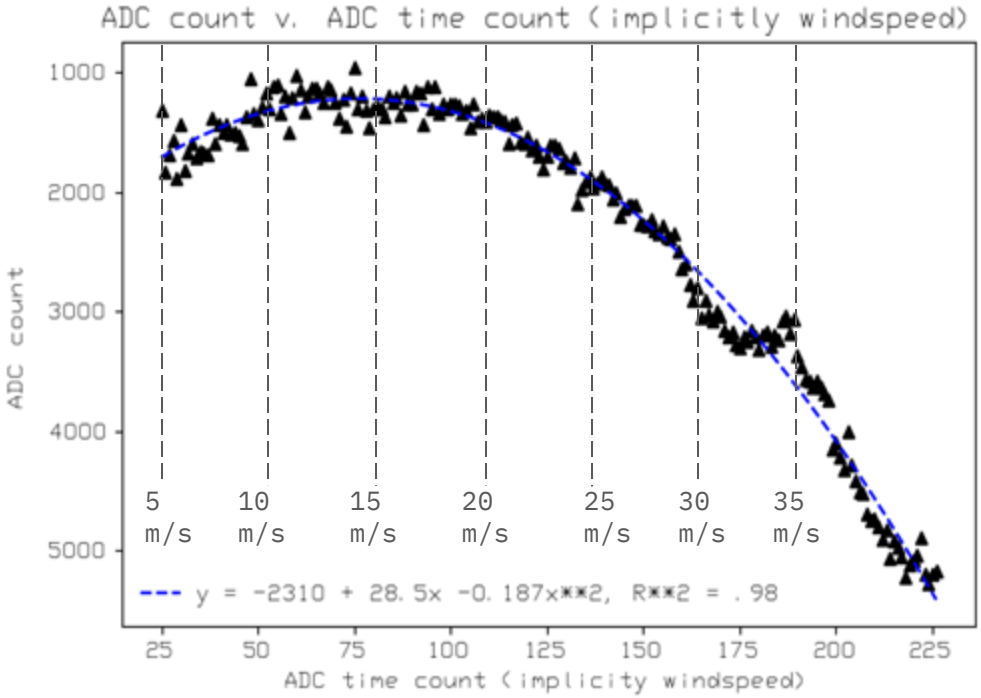

FIG 14. Windtunnel data indicating ADC voltage varies with the square of wind speed

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Thermal Testing

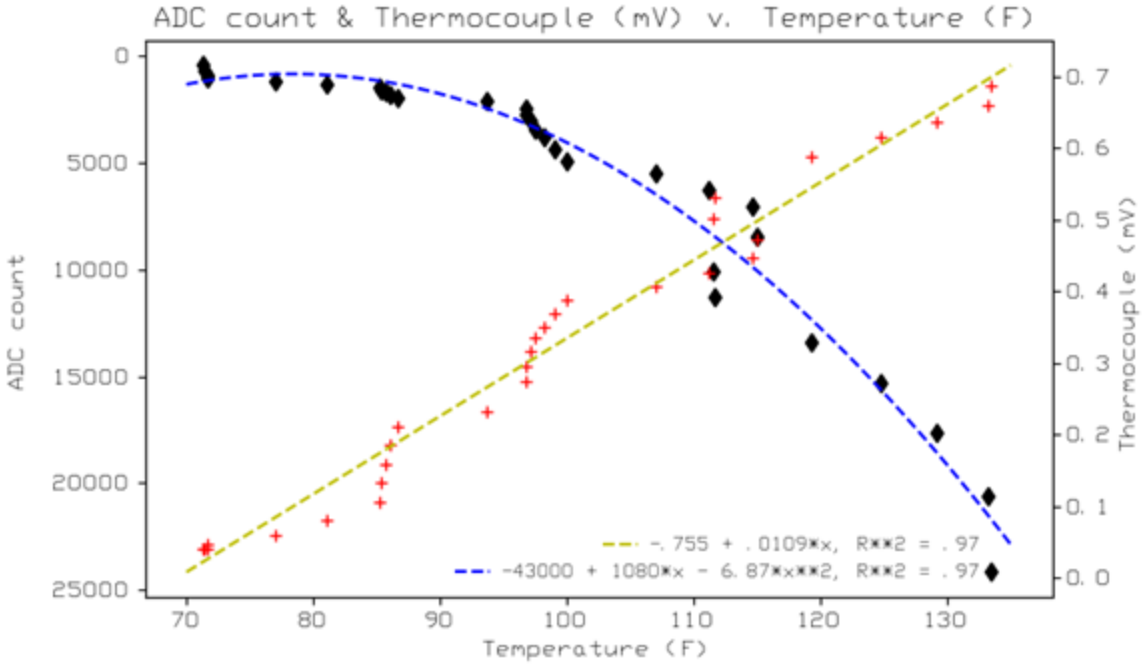

FIG 15. Thermal calibration curves for thermocouple (yellow)and strain gauges (blue)

FIG 16. Thermal calibration setup

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FINsight is calibrated, tested, and ready to collect in-flight data!

Future Improvements:

1. Improved calibration schemes
2. Thermal noise reduction
3. More sensitive strain gauge materials
4. Optimization of tracing patterns
5. Higher quality electrical components
6. Improved wire and component management

Currently creating software for data analysis, visualization, and optimization

FIG 17. A finished fin before mounting

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Does anyone have any questions?

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