Duke University AERO - Pitchfork

2024 IREC Spaceport America Cup 10,000 ft. SRAD

Duke PRATT SCHOOL of ENGINEERING

25

Duke AERO

We are AERO, Duke's aerospace engineering group dedicated to building high-powered competition rockets and exploring relevant propulsive/control methods. Duke AERO has flown four rockets, one an experimental two stage rocket and three previously at Spaceport America Cup 2018, 2022, and 2023. Six years ago the team was rebranded as a rocketry team by only four members. Now we are proud to report 40 active members Duke AERO aims to promote a safe environment for students interested in aerospace and engineering to learn and bring their passions to real projects, filling a crucial role on a campus without many outlets for technical aerospace development.

Fig. 1 *Team Photo at SAC 2023*

Objective and Overview

Pitchfork was designed and built by Duke AERO over the course of the 2023-24 academic year. The rocket is designed to compete in the Spaceport America Cup 10,000 ft. SRAD propulsion category. The goal of Pitchfork is to reach an apogee of 10,000 ft AGL, while allowing for 2 - 3U CubeSat to be ejected and recovered on descent. Duke AERO prides ourself on manufacturing almost all parts of the rocket in house. This includes the composite airframe and interior parts. This is the first time the team is flying with an SRAD motor and parachutes. Duke AERO's air brake system returns for the second time in a lighter, more compact iteration. It will deploy drag blades to slow the rocket on ascent to reach a precise altitude. Pitchfork also features FINsight, an embedded fin strain measuring system, for the first time.

SRAD Solid Motor

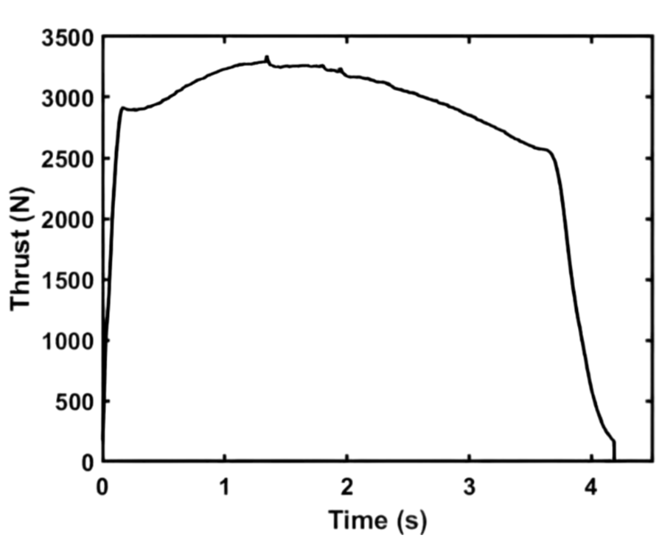

Fig. 2 *Thrust (N) vs Time (sec) for static hot fire*

Our N-class solid motor, nicknamed 'Marathon', will be the first SRAD motor flown by Duke AERO. It uses a standard 4 in internal diameter aluminum case with steel retaining rings, an isomolded graphite nozzle, and a phenolic insulation liner. It holds four ammonium perchlorate composite propellant (APCP) BATES grains using aluminum fuel with 87% solids loading. A hydrostatic test proves a FS of 1.5 and a static hot fire resulted in the thrust profile shown in Fig. 1. Key motor parameters are as follows

Kn = 217	Total Impulse = 11500 Ns
Avg Thrust = 2750N	Burn Time 4.18s

SRAD Parachutes & Guided Recovery Aerial Navigation (GRAN)

Pitchfork is the first Duke AERO rocket to fly with SRAD parachutes and a guided recovery system which will steer the rocket to a predetermined recovery location under drogue.

The main parachute 12 ft semi-ellipsoid with an aspect ratio of 0.707 and a drag coefficient of 1.6. There are 12 zero porosity ripstop gores joined with flat felled hem connections using Size E thread and a size 16 needle. This chute also utilizes a spill hole with effectively 1% of the canopy area and has 12 shroud lines. The drogue parachute uses the same manufacturing methods and materials as the main chute but boast a cruciform shape to promote horizontal capacity under guided recovery. Wind tunnel testing reports a drag coefficient of 0.52. It is a 6 ft parachute with a 3:1 arm ratio. There are 8 shroud lines for each corner.

The guided recovery system is pulled out of the forward section with drogue deployment. GRAN is controlled by the Eris Gamma SRAD flight computer which calculates current heading and location from the onboard magnetometer and GPS and relies upon a modified proportional controller to calculates a target heading. 2 dynamic lines have 8 in of reeling capacity.

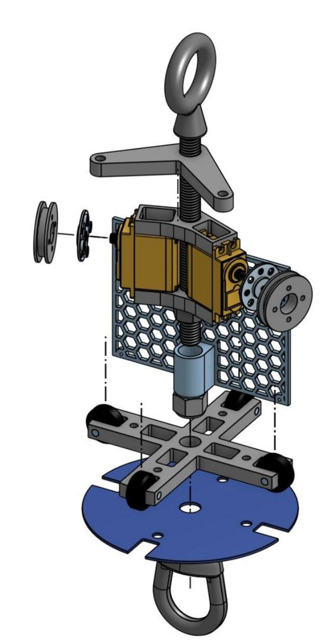

Fig. 3 *GRAN exploded view housing not pictured*

Airframe

The airframe is constructed in house from prepreg 2x2 twill carbon fiber (200 gsm and 430 gsm) and fibreglass (305 gsm). The fins are a sandwich composite of a G-10 core and 2 layers of 45 degree alternating 200 gsm, 2x2 twill, carbon fiber weave. Three fins are epoxied to the power tube supported by forged carbon fiber fin mounts under a 2 layer tip to tip layup. The nose cone was constructed using fiberglass sleeves on a 3D printed pattern.

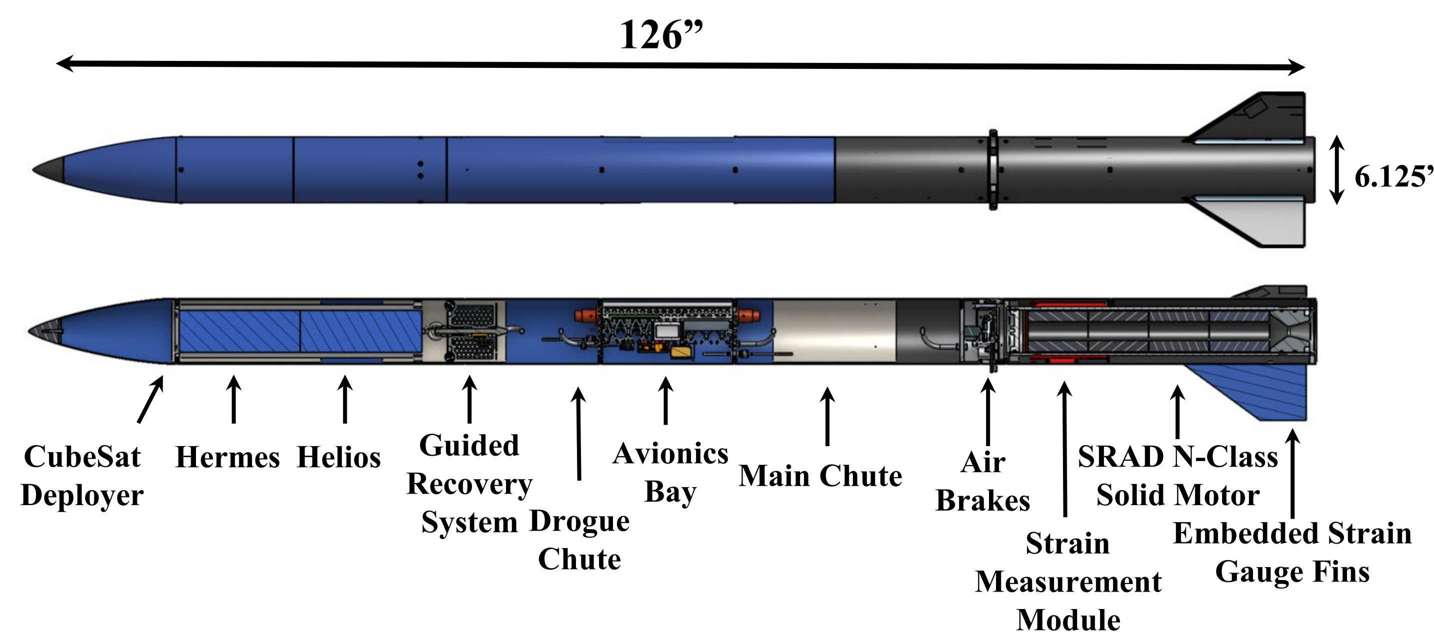

Fig. 4 *External and internal view of Pitchfork with labels and principle dimensions*

Strain-Sensing Fins - FINSight

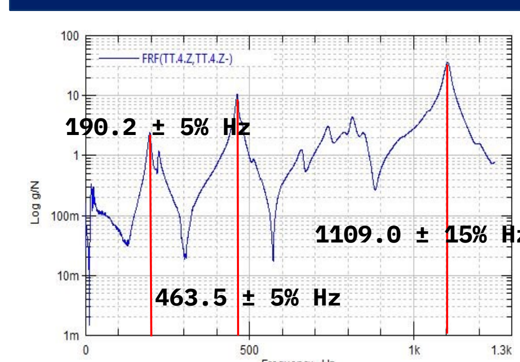

Fig. 5 *Hammer Impact Test Results*

Pitchfork contains the first iteration of FINsight, a system which embeds strain gauge PCNs into each fin and has a electronics unit in the power section which collects and stores fin strain data for post processing.

A hammer impact test on a past fin set with similar shape and composition provided natural frequency and mode shapes. This allowed the team to construct an Ansys model for modal analysis of *Pitchfork's* fins. Four strain gauges were strategically placed on the PCB to obtain deflection from the first, second, and third frequency modes.

These PCBs were placed on one side of a G-10/carbon fiber sandwich composite such that the PCB is distanced from the center of the fin for greater deflection . For symmetry a identical fiberglass plate was laid into the opposite side of the fin. The fins use an external mounting system but the PCB wires are threaded through the airframe to the Strain Measurement System (SMM). The SMM contains a Wheatstone bridges and analog to digital converters. Data is stored on a Teensy 4.1 flash chip.

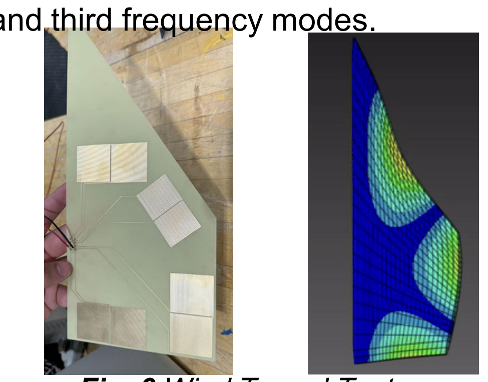

Fig. 6 *Wind Tunnel Test*

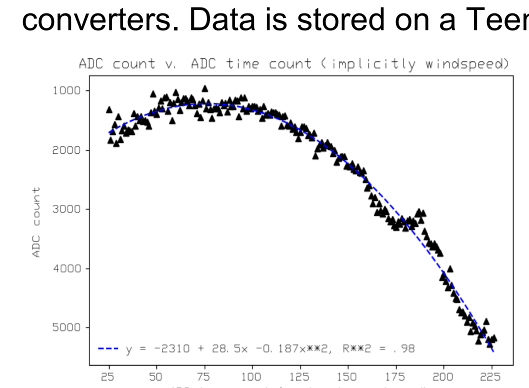

Fig. 7 *Wind Tunnel Test*

A series of ground test were performed on FINsight.

- 3-point bending test on sample specimens revealed a linear relationship between load and deformation, with the slope being gauge factor.
- Wind tunnel test with the fin set at an angle of attack of 30° confirms measured voltage varies with square of airspeed.
- A heat test revealed measured voltage has a nonlinear relationship with temperature loading. Data can be used for calibration.

Variable Drag Airbrake System (VDAS)

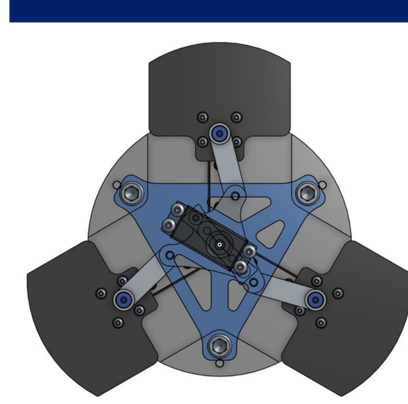

Fig. 8 *Air Brake Top View*

This is the second iteration of the Variable Drag Air Brake System, VDAS, which enables high precision apogee targeting. Three forged carbon drag blades can extend linearly during coast. Power and control are provided by the flight computer, Eris in the av bay , which employs a simplified version of model predictive control. By creating a simulation of flight profiles for varying airbrake activity throughout flight a matrix flight plans was stored on board. In flight the integrated IMU and the Ellipse 2-N provide velocity, altitude, and angle data for Eris to take in and interpolate for the optimal flight plan to reach 10,000 ft. The two systems are connected via a wire with a magnetic connector designed to separate at main deployment.

Concept of Operations (CONOPS)

Ignition - initiated by signal sent to motor ignitor, concludes once consistent burn is achieved from SRAD solid motor

Liftoff - begins with positive (vertical) non-zero vehicle velocity, concludes at rail clearance

Powered Ascent - begins once vehicle clears launch rail, concludes after motor burnout (approx. t=4.185s)

Coasting Ascent - begins following motor burnout, concludes at apogee (approx t=27.6s), authorized airbrake deployment area

Descent Under Drogue - begins with drogue parachute deployment (resulting from airframe separation) after apogee, concludes with the triggering of the second deployment event. Active guided recovery. Includes CubeSat Deployment at apogee and split at 2500 AGL

Descent Under Main - begins with the unfurling of the main parachute at 750 ft AGL, concludes at vehicle touchdown

Recovery - begins once vehicle has impacted the ground, concludes once team has identified, safed, recovered all associated components

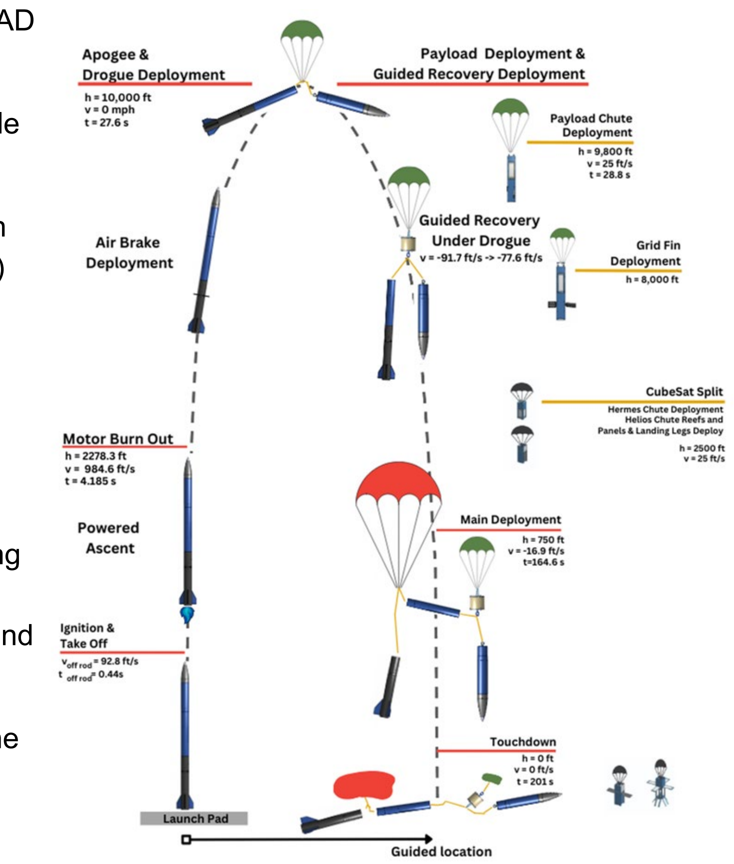

Fig. 9 *Flight CONOPS*

Hermes & Helios - 6U CubeSat

The deployer is gravity activated and releases the payload as one 6U CubeSat unit. The CubeSat descends under one chute with role stabilization until 2500 ft AGL when the payload splits into Hermes and Helios. Hermes deploys its own 4ft parachute, continues grid fin roll stabilization and live video feed. Helios will deploy solar panels and landing legs. It also reefs its parachute to match the descent rate of Hermes until touchdown.

Hermes

1U - Parachute

1U - Grid Fins

1U - Live Video

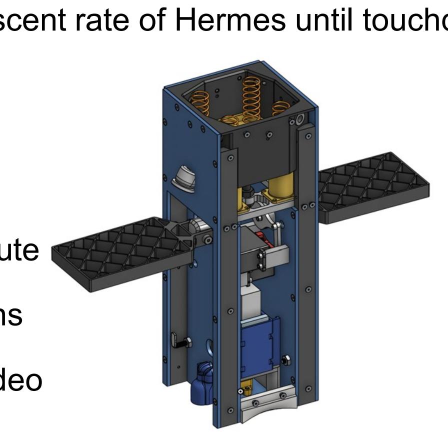

Fig. 10a *Hermes*

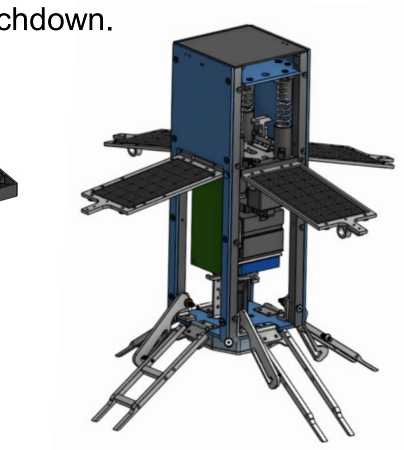

Fig. 10b *Helios*

Helios

1U - Reefed Parachute

1U - Solar Panels/Landing Legs

1U - 6U Splitter

Lessons Learned

- Technical team leads need to have autonomy beyond the exec team
- Systems engineers need to be considered throughout the project
- Knowledge transfer is essential early in the onboarding process
- Documentation is key during the research and development process
- Factors of safety should be applied to budgets and schedules as well

Support

Duke Pratt School of Engineering, Composite Factory, Composites Fibreworks, SBG Systems, SKB Cases, Ansys, Gene Haas Foundation, Protospace MFG, Kennametal, Duke Stores, Cadence, Centroid, SolidWorks, onshape