Duke University AERO - Blue Reaper

2023 IREC Spaceport America Cup 10,000 ft. COTS

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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 six rockets, one an experimental two stage rocket and two previously at Spaceport America Cup 2018 and 2022. Six years ago the team was rebranded as a rocketry team by only four members. Now we are proud to report 30 active members with an 80% growth in active membership over previous years, and that we represent an even more diverse set of majors and backgrounds than ever before.

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 *Duke AERO team members following spring test flight*

Objective and Overview

Blue Reaper was designed and built by Duke AERO over the course of the 2021-22 academic year. The rocket is designed to compete in the Spaceport America Cup 10,000 ft. COTS propulsion category. The goal of Blue Reaper is to reach an apogee of 10,000 ft AGL, while allowing for a 3U CubeSat to be ejected and recovered on descent. This rocket also features Duke AERO's first air brake system which will deploy petals as needed to slow the Blue Reaper's ascent after burn out and accurately reach the target apogee.

Blue Reaper utilizes a Aerotech M2500T-P motor. For the first time the carbon fiber and fiberglass airframe was made in-house using prepreg composites. Another new material innovation in Blue Reaper is forged carbon fiber which uses bulk molding compound (BMC) to retain strength while decreasing weight. The internal structural components and nose cone tip are also manufactured in-house from 6061 aluminum.

Fig. 2 *Blue Reaper's take off at the test flight*

Simulations & Testing

The propulsion team conducted flight simulations using the open-source software OpenRocket. OpenRocket allowed the team to test different motor and structural configurations.

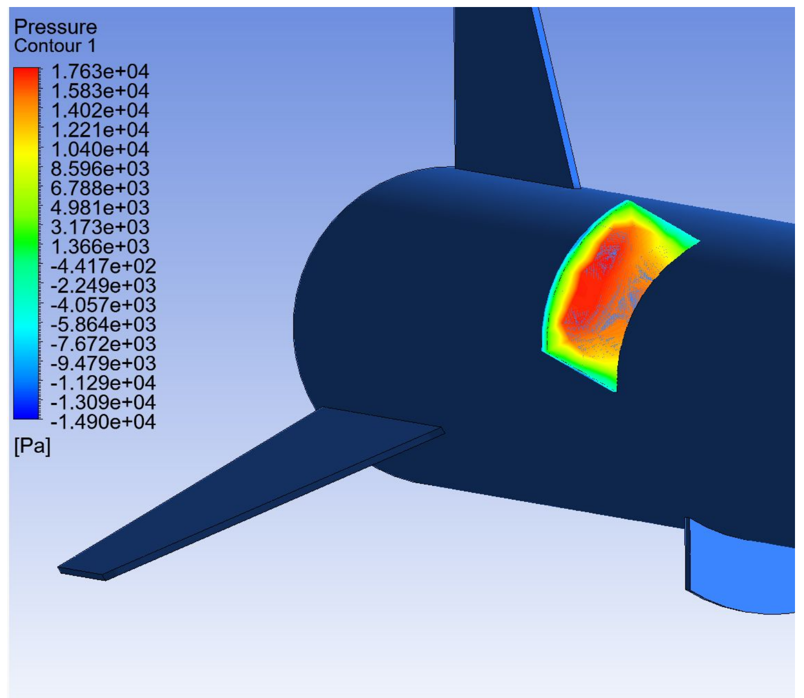

Fig. 5 *Ansys static pressure results on vehicle, part of mechanical and fluid simulations for development*

The theoretical strength of designed components were simulated using SolidWorks FEA and ANSYS Mechanical. The results from the FEA provides confidence in the designs due to the large factors of safety (all > 1.9). CFD was conducted using Ansys Fluent to evaluate the aerodynamic forces under varying levels of airbrake deployment in an array of flight conditions.

Various aspects of the avionics and recovery systems were tested on the ground through either manual ignition or simulating the pressure at the appropriate altitude.

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 a stair-step layup method in a custom high temperature fiberglass split mold.

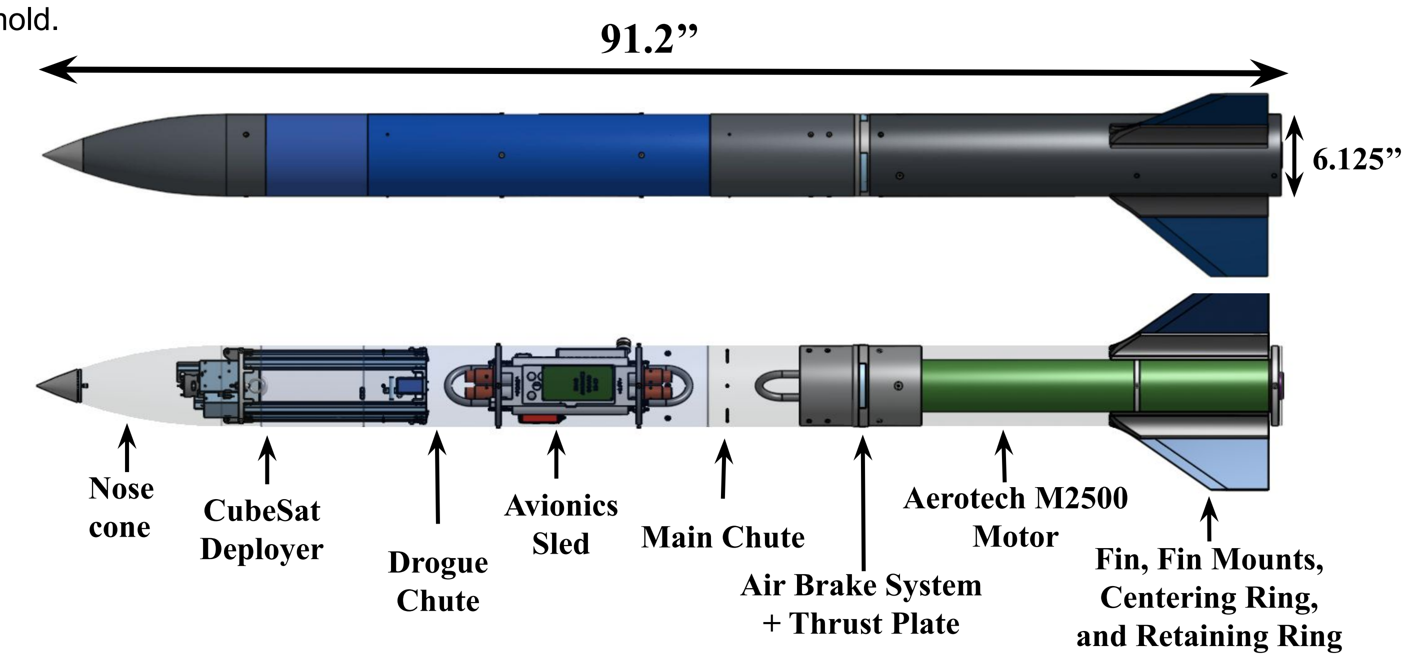

Fig. 4 *External and internal view of Blue Reaper with labels and principle dimensions*

Vehicle Systems

Payload Experiment - Nylon cord retains 3U CubeSat in deployer system until severed by a Tinder Rocketry Piranha Line Cutter at ejection altitude, 1200 ft. Custom PCB uses Stratologger pyro signals and its own altimeter to detect deployment altitude and initiate deployment to 775 High Power DC motor-and-belt driven rail system ejects Cubesat with an independent spring released 4ft parachute. CubeSat is equipped with a Featherweight GPS sending live telemetry

Recovery - Dual deployment system, with a 2 ft drogue chute forward of the avionics bay deployed at apogee, and a 14 ft main chute aft of the avionics systems deployed at 750 ft AGL

Avionics - The SRAD flight computer, Eris, and a redundant Altus Metrum Telemega will fly in the avionics bay. Both have complete separation event control and GPS redundancy. The Ellipse 2-D, an onboard INS with its own antenna, serves as a tertiary GPS source.

Separation Mechanism - Redundant 35 gram Peregrine (Tinder Rocketry) C02 charges will be used for both the drogue and main chute deployments.

Air Brakes - After burnout, a control algorithm on Eris with data from the integrated IMU and SBG Ellipse 2-D deploy three forged carbon air brake petals to add drag and reach target apogee.

Payload: CubeSat Deployer

The Payload is a versatile CubeSat deployer system, deploying up to 3U CubeSats at a given altitude. A test 3U CubeSat with "Seed-Spreading" functionality will be deployed in flight.

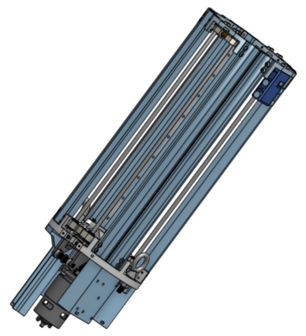

Fig. 3a *Deployer System*

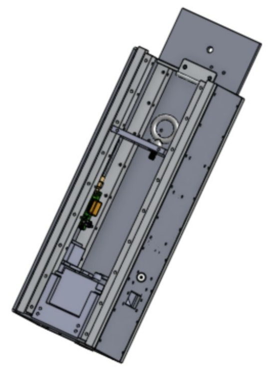

Fig. 3b *3U CubeSat Vehicle*

Deployer: utilizes a 14" long 775 motor-and-belt driven ejection system

Custom PCB: controls deployer system along with a StratologgerCF flight computer

Piranha Line Cutters (Tinder Rocketry): used for reliable restrainment/release during flight

CubeSat Recovery and Telemetry: 4' Rocketman Nylon Chute and Featherweight GPS

"Seed-Spread" mechanism: CubeSat will deploy seed-like particles on descent and capture onboard video footage, demonstrating the vast potential for deployable CubeSat payloads

In-house manufacturing: to emphasize learning and skill development for team members, all components were custom-designed in CAD and manufactured in-house using mills, lathes, waterjets, EDM, etc. (except for Protocase-sourced deployer rails)

Concept of Operations (CONOPS)

Ignition - initiated by signal sent to motor ignitor, concludes once consistent burn is achieved from COTS solid motor (M2500T-P)

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=3.36s)

Coasting Ascent - begins following motor burnout, concludes at apogee (approx t=26s), 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, includes CubeSat Deployment at 1200 ft AGL

Descent Under Main - begins with the unfurling of the main parachute at 700 ft AGL, concludes at vehicle touchdown, includes CubeSat seed scattering at 45 ft AGL

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

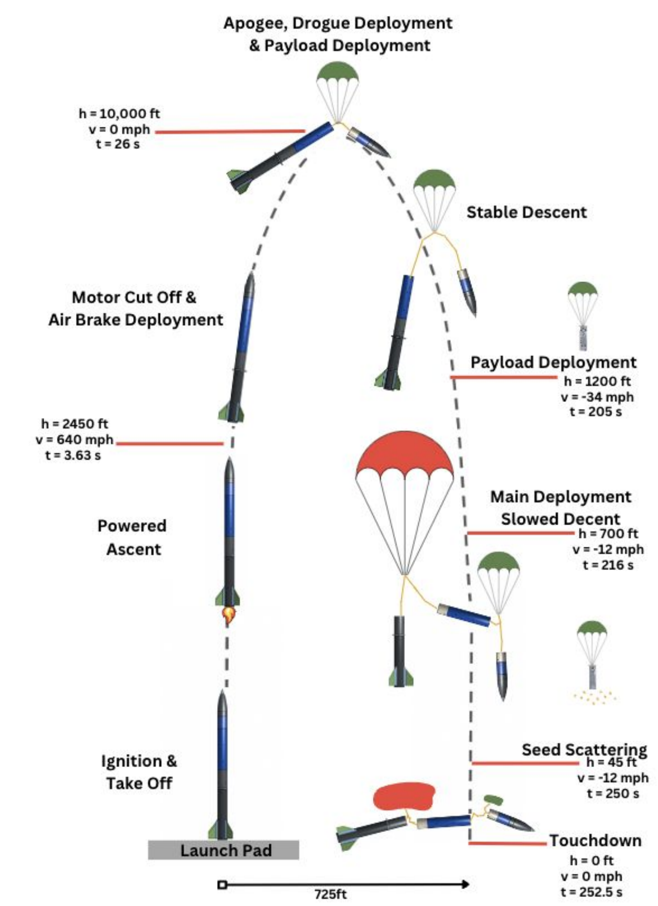

Fig. 6 *Flight CONOPS*

Air Brake

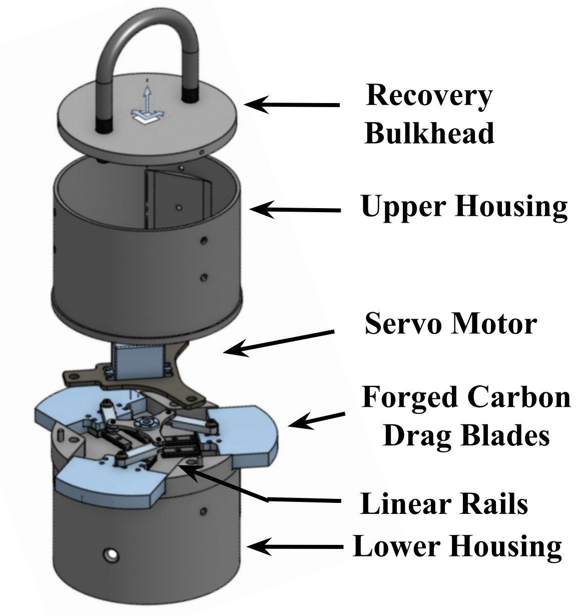

Fig. 7 *Air Brake Exploded View*

The Variable Drag Air Brake System, VDAS, was implemented this year to enable high precision apogee targeting. Three forged carbon drag blades can extend linearly during coasting apogee by a servo motor. Power and control are provided by the flight computer, Eris, housed in the avionics bay. The two systems are connected via a wire with a magnetic connector designed to separate at main deployment.

The control algorithm on Eris is 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-D provide velocity, altitude, and angle data for Eris to take in and interpolate for the optimal flight plan to reach 10,000 ft.

Lessons Learned

- Multi part mold optimization for even pressure distribution and part removal are essential for a uniformly distributed and saturated forged carbon fiber part.
- Debulking between layers of a prepreg composite layup aids in layer adhesion
- Deployable payload systems add significant R&D complexities but provide incredible scientific value
- Adapt designs for manufacturability early
- Communication within and between teams is crucial to success

Support

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