Design and Optimization of Carbon Fiber Composite Structures and Precision Apogee Control in Sounding Rockets

Team 147 Project Technical Report to the 2024 Spaceport America Cup

Demetra Kohart*
Virginia Tech, Blacksburg, Virginia, 24061

Dawsyn Schraiber†
Virginia Tech, Blacksburg, Virginia, 24061

Gabe Mills‡
Virginia Tech, Blacksburg, Virginia, 24061

Daniel Young§
Virginia Tech, Blacksburg, Virginia, 24061

Ben Anderson¶
Virginia Tech, Blacksburg, Virginia, 24061

Griffin Burd‖
Virginia Tech, Blacksburg, Virginia, 24061

Maxim Somov**
Virginia Tech, Blacksburg, Virginia, 24061

Xavier Burns††
Virginia Tech, Blacksburg, Virginia, 24061

Vanessa Bushell‡‡
Virginia Tech, Blacksburg, Virginia, 24061

For the 2024 Spaceport America Cup (SAC) hosted by the Experimental Sounding Rocketry Association (ESRA), Rocketry at Virginia Tech has designed and developed a sounding rocket for the 10,000 foot apogee, Commercial-Off-The-Shelf (COTS) propulsion category of the competition. Each year the team works to design a rocket to carry an 8.8 pound payload to exactly 10,000 ft. The configuration of this rocket includes a 3U form-factor, 8.8 lbs, Cubesat payload designed to provide GPS location and meteorological data; a Student Researched and Designed (SRAD) electronics bay; and a precision apogee control system named the Active Drag System (ADS). The airframe of the rocket is partially composed of SRAD carbon fiber composites including the body tubes, fins, and motor tube; all of these components are manufactured in-house. The rocket, named Inferno, performed two total test launches over the course of the academic year. Each Test Launch, held in Dalzell, SC, provided successful test flights of the rocket on an L2500 motor in preparation for competition.

*Chief Executive Officer, Aerospace and Ocean Engineering
†Vice Chief Executive Officer, Electrical and Computer Engineering
‡Chief Engineer, Electrical and Computer Engineering
§Aerostructures Lead, Aerospace and Ocean Engineering
¶Avionics Lead, Mechanical Engineering
‖Design Validation Lead, Aerospace and Ocean Engineering
**Recovery Lead, Aerospace and Ocean Engineering
††Payload Lead, Department of Geography
‡‡Treasurer, Industrial and Systems Engineering

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Nomenclature

ads	Active Drag System
AEDL	Advanced Engineering Design Lab
AGL	Above Ground Level
CFD	Computational Fluid Dynamics
COTS	Commercial off the shelf
ESRA	Experimental Sounding Rocketry Association
FEA	Finite Element Analysis
FEM	Finite Element Model
FOR	Flyer of Record
HPR	High Powered Rocketry
IMU	Internal Measurement Unit
IREC	Intercollegiate Rocket Engineering Competition
LCO	Launch Coordination officer
MEMS	microelectromechanical systems
NiMH	nickel–metal hydride
PWM	pulse width modulation
RSO	Range Safety Officer
SAC	Spaceport America Cup
SDL	Space Dynamics Laboratory
SISO	Single Input Single Output
SRAD	Student Research and Designed
STEM	Science Technology Engineering Mathematics
TRA	Tripoli Rocketry Association
TWR	thrust to weight ratio
UBEC	Universal Battery Eliminator Circuit

I. Introduction

A. Mission Statement

ROCKETRY at Virginia Tech is a student-led design team at Virginia Polytechnic Institute and State University in Blacksburg, Virginia. The team wishes to promote interest in high-powered rocketry and provide hands-on engineering experience among students at Virginia Tech and members of the surrounding community. As a design team, a safe environment for rocketry enthusiasts of all backgrounds is provided to operate high-power rockets and practice engineering design principles. Each year the team works toward competing in the Spaceport America Cup (SAC), hosted by Experimental Sounding Rocketry Association (ESRA), as well as providing its members with resources to obtain their L1 high powered rocketry certification. This year, to compete in the $10,000$ ft apogee with Commercial off the shelf (COTS) propulsion category, Rocketry at Virginia Tech has challenged itself to reevaluate past projects and innovate upon them for this year's rocket. Projects include a Student Research and Designed (SRAD) active flight control and a weather sensor suite to provide data for future competitions. Throughout this report is more information on the team's projects, how they appeal to SAC Requirements, and how they help in the team's goals.

B. Team Structure

Rocketry at Virginia Tech is composed of 55 undergraduate students and two graduate students across all years and 11 different majors in and outside of Science Technology Engineering Mathematics (STEM). The team's organizational structure consists of a Chief Executive Officer, Chief Engineer, Vice Chief Executive Officer, Safety Officer, Treasurer, eight Lead Engineers, and two L1 Certification Managers with some overlapped leadership.

Each subteam is responsible for a specific vehicle subsystem, and the lead engineer ensures that each subteam fulfills required tasks in pursuit of their project goals, all while adhering to SAC guidelines. In addition, the Chief Engineer and Chief Executive officer work to validate all systems conform to requirements as outlined by Intercollegiate Rocket Engineering Competition (IREC) rules and requirements, integration of the rocket can be done smoothly, and the team is being provided with a safe and educational engineering experience. They both schedule team rocket and safety inspections as well as team wide design reviews. The Vice Chief Executive Officer and Safety officer work to assist the Chief Engineer and Chief Executive officer in administrative tasks, lab safety and training tasks,and any oversight of team members as deemed necessary. Finally, the team's L1 Certification Managers aid the general team members in acquiring their L1 High Powered Rocketry (HPR) Certifications via hosting build and information sessions. Figure 1 presents the breakdown of team leadership in tandem with recognizing the faculty advisors who have mentored and supported Rocketry at Virginia Tech in pursuit of our mission.

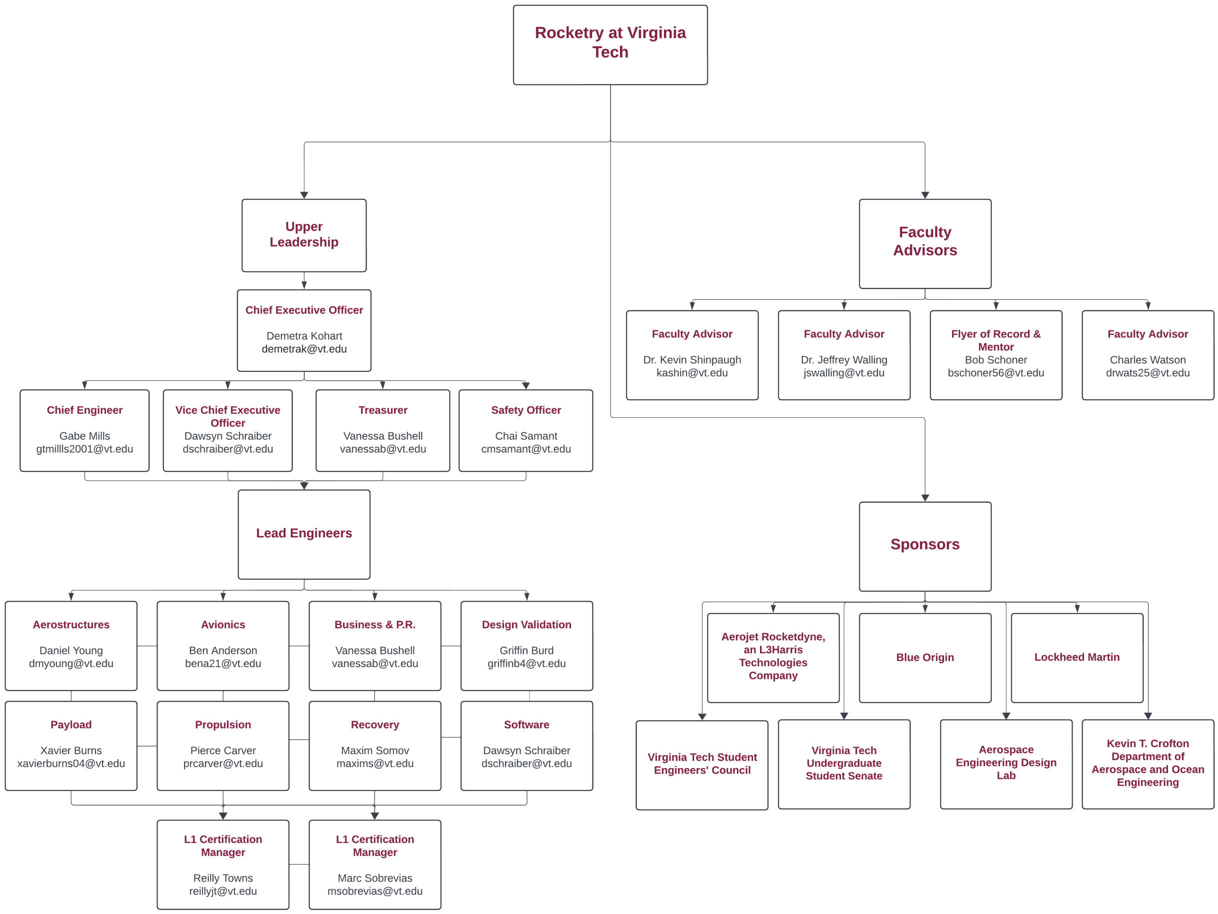

Fig. 1 Rocketry at Virginia Tech 2023-2024 Team Structure.

C. Mentors and Stakeholders

The team's mentor and Flyer of Record (FOR) is Bob Schoner, a Level 3 certified Tripoli Rocketry Association (TRA) member, prefect for the TRA prefecture #143 in Christiansburg, VA and head of the local New River Valley Rocketry association. Bob Schoner attended the team's first and second test launch in Dalzell, SC and provides Range Safety Officer (RSO) support to the team at certification launches in Kentland Farms, near Blacksburg VA.

Rocketry at Virginia Tech's first faculty advisor, Dr. Kevin Shinpaugh, is a collegiate professor of the Kevin T. Crofton Department of Aerospace and Ocean Engineering who works with a variety of university design teams including NASA SLVT, NASA Robotic Mining Competition, RASC-AL RoboOps, RockSat-X, Gobble Rockets, and other design teams. He is a Level 2 certified TRA member. Dr. Shinpaugh provides additional support at team certification launches as the Launch Coordination officer (LCO) as well as hosts team Undergraduate Research meetings for bi-weekly updates and consistent feedback on how to improve.

Rocketry at Virginia Tech's second faculty advisor, Dr. Jeffrey Walling, is a collegiate professor of the Bradley Department of Electrical and Computer Engineering. He provides support in the form of weekly Undergraduate Research meetings with a focus on electrical and computer subsystems on the rocket.

The team received financial support from a variety of sponsors. Corporate sponsors include Aerojet Rocketdyne, an L3 Harris Technologies Company, Blue Origin,and Lockheed Martin. Other support was provided by the Virginia Tech Student Engineers' Council, the Undergraduate Student Senate, the Virginia Tech Advanced Engineering Design Lab (AEDL), and the Kevin T. Crofton Department of Aerospace and Ocean Engineering. Rocketry at Virginia Tech was able to manufacture the team's 2024 launch vehicle through the use of the AEDL, a lab space owned and operated by the Kevin T. Crofton Department of Aerospace and Ocean Engineering, and its equipment. Lastly, the team received mentoring regarding current and past projects from its extensive alumni network now employed at various companies like Lockheed Martin, SpaceX, Norththrop Grumman, Aerojet Rocketdyne, TORC Robotics, and others.

II. Mission Concept of Operations Overview

An overview of the launch vehicle concept of operations is shown in Figure 2. Once the pre-flight checklist is completed and the RSO allows the team to continue to the pads, the rocket will begin its arming sequence. After all personnel are ensured to be a safe distance from the vehicle, ignition will occur. The motor will provide thrust until burn-out at approximately 2600 ft Above Ground Level (AGL). This begins the coast phase of the ascent. Once the coast phase begins, on-board telemetry systems will verify motor burnout via a timer that began at the start of acceleration corroborated with current negative acceleration values. It is from this time onward, during the coast phase, that the ads will deploy and retract as needed to get the rocket as close to $10,000$ ft as possible until apogee, and retract again at the start of descent. Should it be determined by the system that the rocket will not reach $10,000$ ft, then the system will not deploy.

At apogee, the vehicle will begin the recovery sequence. At approximately $T_{apogee} = 25\ s$, the on board recovery system will eject the drogue parachute. The rocket will then descend at approximately 82 ft/s. At 900 ft, the rocket will undergo its second recovery event with the main parachute's ejection from the upper body tube and nose cone. The rocket will descend at approximately 17 ft/s, and land at around 185 $seconds$ after launch. During the duration of the flight, the Payload subsystem will transmit GPS coordinates to a ground station. Both recovery events will be armed with additional backup black powder charges for redundancy; this is further detailed in the Recovery section.

Once the vehicle has touched down, on-board GPS on will continue to broadcast landing zone coordinates back to a ground-station. The launch operations team will proceed to recover the vehicle once it is deemed safe to do so. Following this, on-board data including in-flight footage will be off-boarded from the vehicle and the team will debrief on the flight.

A flowchart of the mission's Concept of Operations (CONOPS) can be seen below in Figure 2 with more detail regarding the order to events during the launch vehicle's flight. Greater detail about each phase of flight can be found in the vehicle subsystems' respective sections.

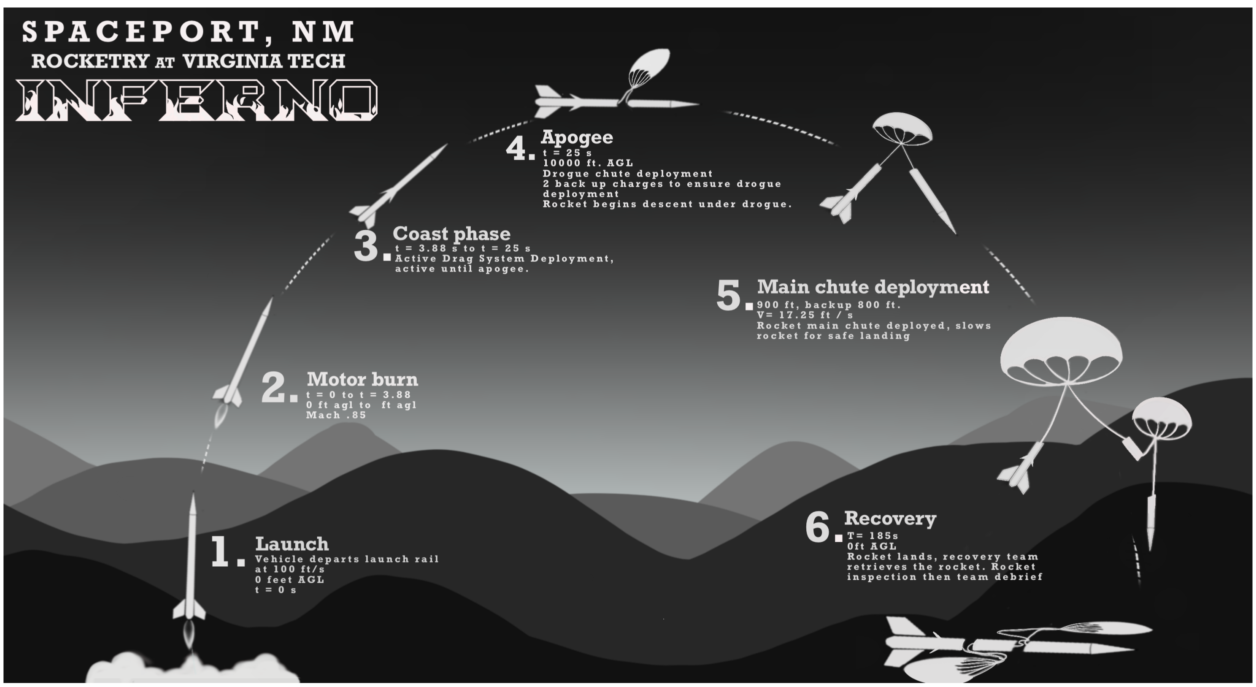

Fig. 2 Concept of operations graphic

III. System Architecture

A. Overview

B. Vehicle Trajectory and Flight Characteristics

Table 1 Mass Breakdown of the 2023-2024 Launch Vehicle

Subteam	System	Mass (g)
Structures	Nosecone	1,400
Structures	Internal Structure	5,279
Structures	Aeroshell	3,914
Structures	Fins	353
Avionics	Active Drag System	957
Avionics	Electronics Bay	1,315
Recovery	Chutes + Hardware	2,169
Payload	3U CubeSat	3,900
Propulsion	Casing Hardware	3,353
Propulsion	Propellant	4,711
Liftoff		27,351
Burnout		22,640

Table 2 Predicted flight data of the 2023-2024 launch vehicle.

Characteristic	Value	Unit
Liftoff thrust to weight ratio (TWR)	9.3	N/A
Off-Rail Velocity	103	ft/s
Liftoff Stability	1.88	N/A
Burnout Stability	3.13	N/A
Burnout Mach	0.89	N/A
Maximum Velocity	1,024	ft/s
Maximum Acceleration	10.1	g
Uncorrected Apogee	10,672 ft	ft
Corrected Apogee	10,000	ft

Table 3 Simulation atmospheric data for Las Cruces, New Mexico based on historical data in the month of June.

Characteristic	Value	Unit
Atmospheric Pressure	1.03	atm
Temperature	35	$^\circ C$
Elevation Angles	5	$^\circ$

C. Propulsion Subsystems

Rocketry at Virginia Tech's 2024 launch vehicle is a COTS solid motor-powered launch vehicle measuring 135 $inches$ in length with a body diameter of 6.17 $inches$. The vehicle structure is designed to carry propulsion, avionics, recovery, payload, and telemetry subsystems to an apogee of 10,000 ft AGL.

The vehicle's airframe is designed to allow for some limited replacement of vehicle sections both for modularity and flexibility of design in case of damage. This has allowed for multiple thrust structure sections to have been developed and tested over the 2024 design period.

In its current configuration, Rocketry at Virginia Tech's 2024 launch vehicle is designed to fly on an AeroTech M2500[2] constrained by the motor casing in the thrust structure. The thrust structure is fully composed of SRAD carbon fiber components and includes the motor tube, fins, centering rings, tailcone, and a bulkhead. It provides motor retention and transfers thrust loads into the airframe during flight. The vehicle's aerostructure is made of an SRAD carbon fiber body tube and tailcone, a COTS fiberglass body tube, COTS fiberglass couplers, and a COTS 5.5 : 1 Von Karman nose cone. The team uses a mixture of COTS fiberglass plates and SRAD carbon fiber plates for the centering rings and/or bulkheads used throughout the vehicle.

The avionics bay provides space for the primary electronics stack, ads, and flap attachment for the structure. The ads is placed as far aft in the vehicle as possible to reduce the destabilizing effect of control surface deployment into the free stream; it is located just above the fins on top of the thrust structure bulkhead. Flap deployment is expected to shift center of pressure closer to the center of mass, decreasing overall stability margin, but as this will be occurring post motor burn, the center of gravity will have shifted considerably further so as to not cause risk of an unstable flight. The electronics stack contains a Raspberry Pi Pico for ads control, a high-torque servo motor, a geared rack and pinion stack for servo actuation, altimeters, an Internal Measurement Unit (IMU), and associated batteries.

The aft bay contains the drogue chute, shock cord, Kevlar chute protectors, dog barf insulation material for flame protection, and redundant ejection charges. The forward bay contains the main chute, shock chord and redundant ejection charges. By placing the relatively heavy payload up in the nose cone as opposed to the upper airframe, vehicle stability is increased by roughly 0.37 calibers. The electronics bay and payload also contain electronics for redundant GPS tracking.

The vehicle is estimated to have a mass of 60.3 lb at liftoff; this decreases to 50.11 lb by burnout and chute deployment due to loss of propellant mass. The system-level breakdown of masses is given in Table 1 based upon real measurements of as-built systems.

Two tools were used to evaluate trajectories and flight characteristics: OpenRocket and RASAero II. Since the vehicle will travel into the transonic region by max-q, RASAero is used to supplement results from OpenRocket due to its lesser accuracy in the supersonic regime.

All models were run at local atmospheric pressures of 1.03 bar and temperatures of 35°C according to historical weather data for Las Cruces, NM in June. Simulated launch elevation angles are 84 ± 1° in accordance with IREC Requirement 10.1. At liftoff, the vehicle has a TWR of 9.3 based on the M2500's average thrust of 2500.0 N and a liftoff mass of 60.3 lb. Assuming a 4.88 m (17.0 ft) launch rail is provided by ESRA at Spaceport America, the vehicle will have an off-the-rail velocity of 103 ft/s. Stability margin is computed in dimensionless calibers by the following equation:

where C_p and C_g are the distances from the tip of the vehicle to its center of pressure and center of mass, respectively, and $D_{airframe}$ is the vehicle's body diameter. Based on this, the vehicle has a stability margin of 1.88 calibers when leaving the launch rail, rising to 3.13 as the center of mass shifts forward by 0.19 m during flight. This stability range, in addition to the estimated off-the-rail velocity, satisfies the stability requirements (10.2, 10.3, and 10.4) outlined by IREC.

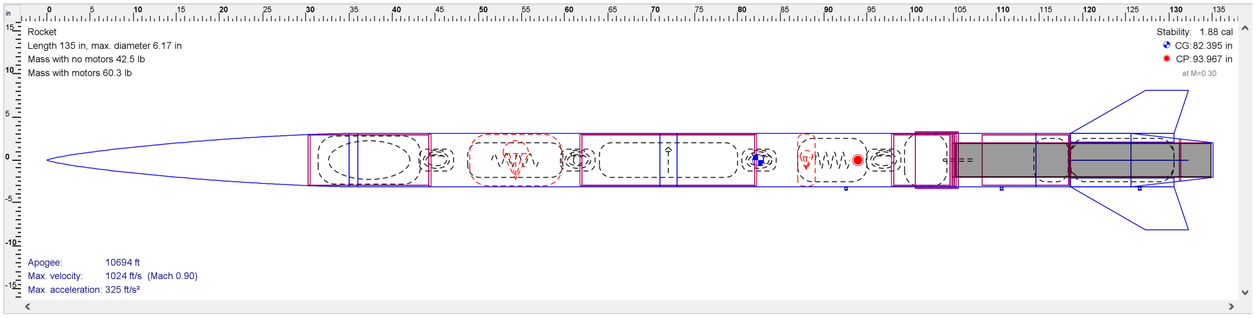

Fig. 3 Model of rocket in Open Rocket

Based on the average of the three models' uncorrected (by ads deployment) apogee predictions, the vehicle is expected to achieve an apogee of $10,822\ ft$ AGL in $0\ mph$ winds and $10,526\ ft$ AGL in the extreme case of $20\ mph$ winds. The tendency of the vehicle to overshoot the target apogee is intended to ensure the vehicle is capable of breaking $10,000\ ft$ with the remaining altitude to be scrubbed off by ads deployment. All models estimate a maximum velocity of $1024 ft/s$ or Mach 0.89. A Mach number and altitude plot for an uncorrected, median, 10 mph wind flight profile are given in Figure 4.

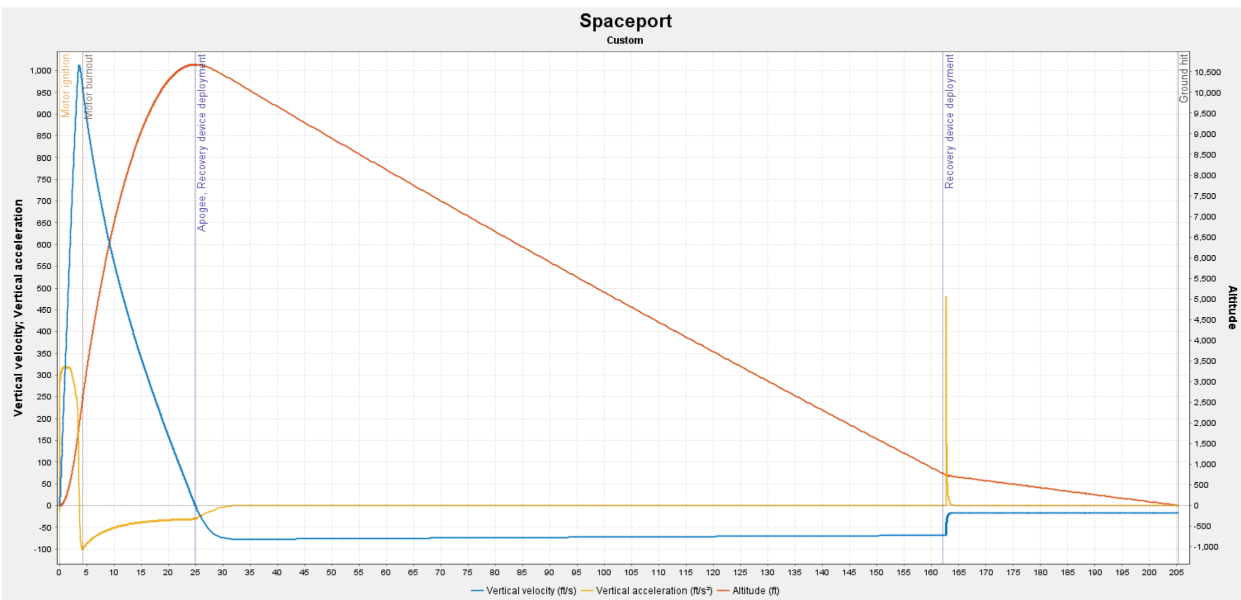

Fig. 4 Altitude Plot for 10 mph Flight Profile

D. Aero-structure Subsystems

The Aerostructures subteam is responsible for the design, analysis, manufacturing, and testing of the launch vehicle. Additionally, the subteam collaborates with avionics, payload, and recovery subteams to integrate their respective subsystems into a unified launch system. The subteam's goals include manufacturing precise components for ease of integration, analyzing and testing all load bearing components, and ensuring that the full launch vehicle can be assembled in a timely manner using only basic hand tools.

1. Vehicle architecture

The launch vehicle accommodates all subsystems necessary for flight and is designed to meet all of the required integration requirements for each subsystem. The rocket's overall length is 135 in and it has an outer diameter of 6.17 in. The rocket is able to use any 98mm Aerotech motor casing, but it was designed to fit an Aerotech 98/10260. A general layout of the launch vehicle can be seen in Figure 5.

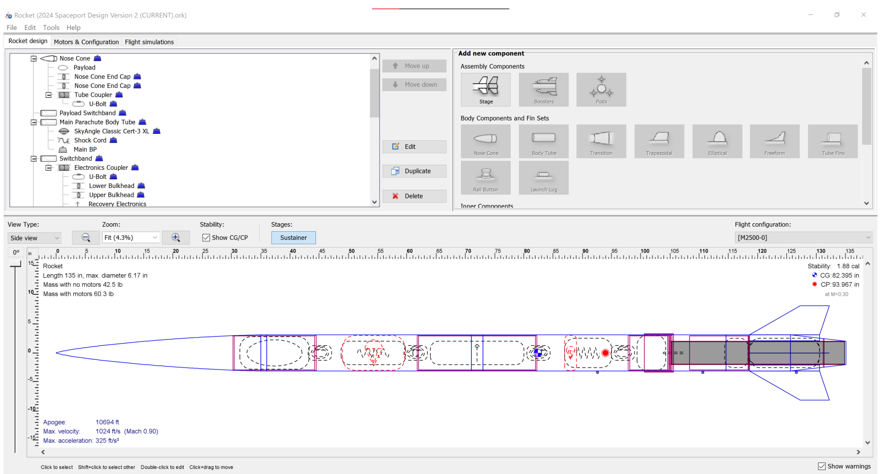

Fig. 5 OpenRocket flight simulation

The fin can and/or thrust structure are both built to house the Aerotech 98/10240 motor casing as well as mount the four composite fins that will have a more detailed description in the Fins subsection. The motor is placed inside of an SRAD carbon fiber motor tube made using a wet layup process on a 4-inch diameter aluminum mandrel tube. The mandrel tube is first coated with a release agent and then layered with wax paper. The layup uses 2 layers of carbon fiber and held in place and hardened by West System epoxy resin. It is then left to rotate and dry over a heater. Once it is dry, the tube is sanded thoroughly to remove rough patches and subsequently coated with another layer of epoxy. Once that layer has dried, the body tube is removed from the mandrel tube using a mandrel press system. Three centering rings are attached to the motor tube to ensure alignment within the thrust structure. The motor tube is secured to the tailcone and motor casing via a centering ring and bulkhead epoxied at the base with another centering ring placed at the top of the fins.

In front of the motor casing is the ads bay which holds the ads. The bay is 6.5in in length. The ads is located in the aft-most location possible, this is again done to minimize the destabilizing effect of deploying control surfaces into the air-stream forward of the vehicle's initial center of pressure.

In front of the ads bay is the drogue chute bay which houses the drogue chute that aids in the recovery of the rocket. The drogue chute is deployed at apogee through a break in the body tube caused by ejection charges.

In front of the drogue chute bay is the electronics bay. Recovery electronics, altimeters, and tracking electronics are located inside. The Recovery section will go further into detail about the exact components found inside the electronics bay. The electronics bay serves as a coupler between the two body tubes, and it is capped off on each end with fiberglass bulkheads. This helps prevent pressure through the ejection charges to escape and prevent the body-tubes from separating. The nosecone has a 1 in switch band around it, as well as a coupler which extends 8 in into the body tube and 5 in into the nosecone.

Above the electronics bay is the main parachute bay. The main parachute is stored here until the nosecone is ejected (i.e. the main parachute is deployed at 800 ft). The nosecone secures the payload section and the body tubes. The

Table 4 Rocket Mass Breakdown

Part	Mass (lb)
Nose Cone	3.09
Payload Section	11.4
Upper Body Tube	7.74
Electronics Bay	6.91
Lower Body Tube	6.22
Active Drag System	3.56
Thrust Structure	3.57
Motor	17.78
Total	60.25

nosecone is composed of fiberglass and is Von Karman-shaped. A shoulder is extended outside the nosecone that allows it to be coupled with the body-tubes. The shoulder is extended 8 in into the body tube, which satisfies the requirements that all couplers extend at least one body tube diameter. Furthermore, a third recovery bulkhead shall be placed into the nosecone. The dry mass of the vehicle is 43.43 lb. The mass will be broken down further in 4.

Table 5 Design Safety Factors

Driving Failure	Mode	Design Safety Factor
Strength	Yield	1.50
Stability	Flutter	1.50

The motor used is an Aerotech M-2500T with a maximum thrust of 834 lbs. The thrust structure is designed to withstand 1124 lbs to meet the requirements of design by having a safety factor of 2 or greater. The design safety factors used for analyzing yield strength and flutter stability failure are listed in Table 5

Peak thrust is the primary load considered for designing the thrust structure. Based upon the design of the thrust structure, the thrust load is transferred up the motor tube and through the forward bulkhead. To validate the design of the structure a Finite Element Model (FEM) of the thrust structure was generated by the Design Validation subteam using Ansys. The thrust load was applied to the aft end of the motor tube and the model was fixed at the forward end of the body tube. This is a conservative set of loads and boundary conditions as the actual force transmitted through the structure would be a function of vehicle acceleration and therefore instantaneous vehicle mass. The model was run using a liner elastic solver, and it produced the stress contour plots shown in Figure 6. The results of this analysis are summarized in Table 6 which shows positive margins for all structural members in the thrust structure.

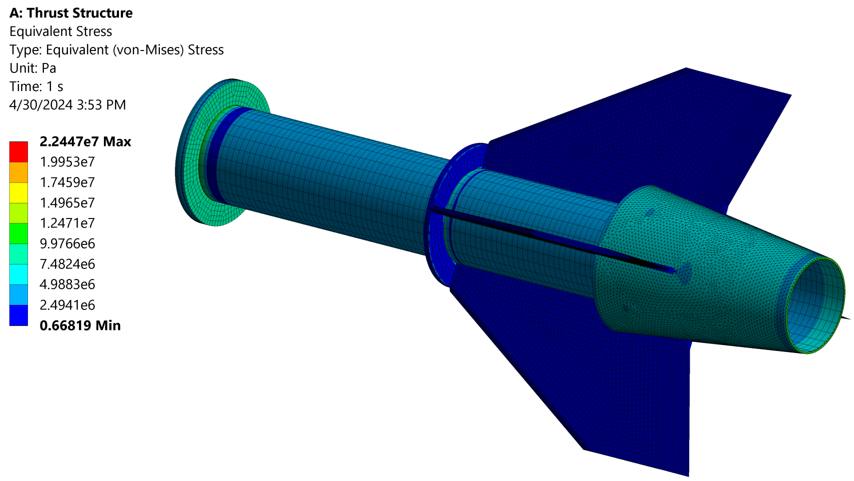

Fig. 6 Thrust Structure Von-Mises Stress Contour.

Table 6 Stress margins of thrust structure components under maximum thrust load.

Load Case	**Component**	**Stress Output (Pa)** σ_{max}	**Factor of Safety** FSy	**Allowables (Pa)** Fty	**Margins** MSy
Max Thrust	Body Tubes	12,723,000	1.5	311,000,000	15.30
	Boat Tail	17,014,000	1.5	311,000,000	11.19
	Motor Tube	13,034,000	1.5	311,000,000	14.91
	Fins	1,072,400	1.5	97,000,000	59.30
	Bulkhead	22,447,000	1.5	200,000,000	4.94
	Centering Rings	10,070,000	1.5	200,000,000	12.24

2. Airframe

The airframe structure of the launch vehicle is made out of SRAD carbon fiber epoxy reinforced body tubes and COTS fiberglass tubes. The body tubes hold the vehicle's internal structure and subsystems. The carbon fiber used for the body tubes was donated to the team in previous years and was selected for the body tubes because it has a high strength to weight ratio.

The carbon fiber body tubes are made using a wet layup process on a 6-inch diameter aluminum mandrel tube. The mandrel tube is first coated with a release agent and then layered with wax paper. The layup uses 3 layers of carbon fiber and is held in place and hardened by West System epoxy resin. The layup is then left to rotate and dry over a heater. Once it is dry, the tube is sanded thoroughly to remove any rough patches and then coated with another layer of epoxy. This ensures that the tube is aerodynamic and can be easily integrated into the rocket without any gaps or edges. Once that layer has dried, the body tube is removed from the mandrel tube using a mandrel press system. Shear pins are used to join the body tubes at the separation points. Rivets are used at the nose cone connection and the base of the body tube connection.

3. Fins

The fins are made up of a Nomex honeycomb core sandwiched between two layers of carbon fiber soaked in epoxy resin. The fin manufacturing process begins by laying a sheet of Mylar on a granite slab and spreading a small amount of epoxy on top of the Mylar. A layer of carbon fiber is laid over top and completely coated with epoxy to ensure that no air bubbles are formed. Nomex is then placed on the carbon fiber sheet and covered by another flat granite sheet. Once the first layer has set, the layup is flipped over and replicated on the other side. After the completed layup is dried, an angle grinder fitted with a cutoff wheel is used to trim and clean up the edges of the layup so it fits within the water-jet.

Using a CNC water-jet, two fins are cut out of each layup. After the general shape of the fin is cut out, they can be fitted with leading and trailing edge pieces. These pieces are 3D printed and sanded smooth to ensure a seamless transition between the fins and the edge piece. The entire surface of the fin is roughed up using sandpaper to aid in adhesion to the next carbon fiber layer.

Next, another sheet of carbon fiber is cut and vacuum sealed onto the fin around its leading edge. Using this process allows for the leading and trailing edge to be secured to the fin and create one seamless piece that has no bubbles or creases. To begin the vacuum sealing process, a layer of absorbent fabric is laid flat on the work surface and a layer of non-adhesive, porous Mylar is placed atop. The Mylar is used in order to ensure that nothing is able to stick to the layup, and the fabric is the outermost layer used to absorb any leftover epoxy. Epoxy is rubbed into the carbon fiber on both sides of the fin. The fin with the wet carbon fiber wrapped around it is folded into the two fabric layers.

Fin flutter is a critical failure mode that must be considered for launch vehicle fins. The high dynamic loads caused by the aerodynamic forces during launch can cause the fins to shear off the airframe. For the fins on this vehicle, Nomex is sandwiched between the carbon fiber layers to limit bending and reduce weight. Testing data collected in April 2023, shown in Figure 7, was used to estimate the effective elastic modulus of the fin material. It can be seen that the three tested samples yielded very similar stress-strain curves. As a note, the current fin construction consists of an additional layer of carbon fiber on the leading and trailing edges of the fins which will increase the elastic modulus and strength of the fins compared to the shown curves.

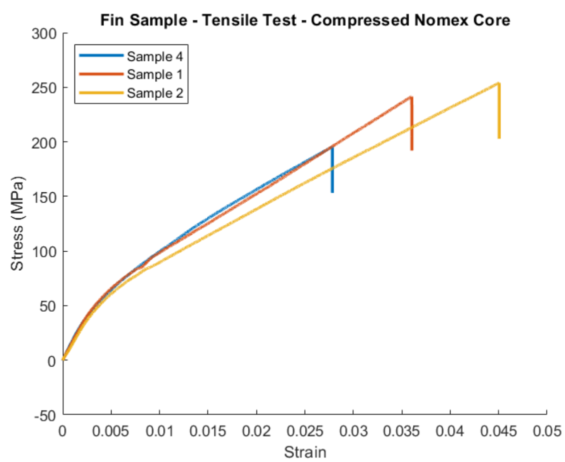

Fig. 7 Stress-strain curves of the 3 fin samples tested in April 2023.

Using the lowest slope result for the most conservative estimate, the E_{eff} of the fin material was determined to be 1.8 GPa. This does, however, assume the Nomex is included in the cross-sectional area which on its own provides negligible stiffness and strength. From there, the G_{eff} was calculated using Equation 1 including an assumed Poisson's ratio of 0.3.

$$G_{eff} = \frac{E_{eff}}{2(1+\nu)} \tag{1}$$

Equation 2 calculates the flutter velocity of the fins based on the known geometry and material properties of the fins as well as the estimated atmospheric properties during flight [3].

$$V_f = a\sqrt{\frac{G_{eff}}{\frac{1.337AR^2P(\lambda+1)}{2(AR+2)(\frac{t}{c})^3}}} \tag{2}$$

With the known geometry and G_{eff} of the fins as well as the estimated flight conditions, the V_f was determined to be M1.37. With a maximum expected Mach number of 0.9, this gives us a MS for flutter stability of +0.02. This margin was calculated using a design FS of 1.5 per Spaceport requirement 8.2.2.

E. Recovery subsystems

1. Electronics Bay

Using previous years' electronics bays as a foundation, the team developed a new modular structure that will serve as an electronics "sled." CAD software was used to develop the fully custom design. Four threaded rods are equally spaced 1.25 *in* across with bi-symmetric symmetry. The electronics bay slides along these threaded rods and is secured with washers and nuts at both ends. In terms of materials, the electronics bay is fully 3D printed using ABS plastic at a 20% infill. Brass threaded inserts are used at every screw hole and vary between M2.5 and M3 depending upon the required hole sizes. The threaded inserts were heat set into the structure to provide optimal adhesion while reducing material damage. Individual mounts were then created for each of the installed electronics.

As a redundancy measure to increase recovery reliability and comply with Spaceport requirements (Section 6.10), two altimeter units (EasyMini and Blue Raven, further detailed below) are integrated here. Similar to previous designs, the major driving factors in developing a modular electronics bay are weight reduction and easier integration. The electronics bay structure has a hollow center with mounting points for battery restraints as well as wiring channels for cables. This configuration allows the batteries to be easily replaced, recharged, or tested without need for complete disassembly. This is especially important when in the Spaceport America desert environment where the rocket may be sitting idle on the pad for extended periods of time. For securing individual electronics, mounts are designed for each component based off of their respective PCB footprint and are then screwed into place on the structure. Where necessary, such as at points of attachment and screw inserts, electronics mounts and battery modules are reinforced with epoxy. The modular spacing's on the electronics bay structure, which are 2 *in* across and 2 *in* height, increase available surface area where components can be mounted. This 2x2 custom form factor also allows the team to easily unscrew and unwire a mount to replace it with a different one if needed.

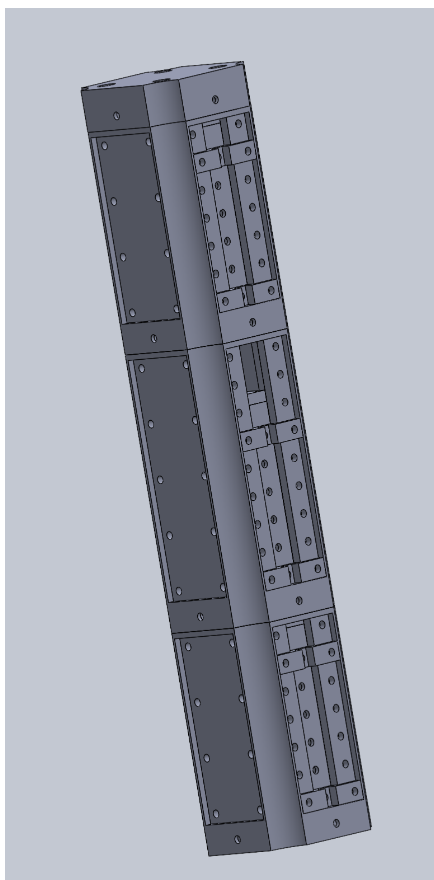

Fig. 8 Electronics bay in assembled configuration.

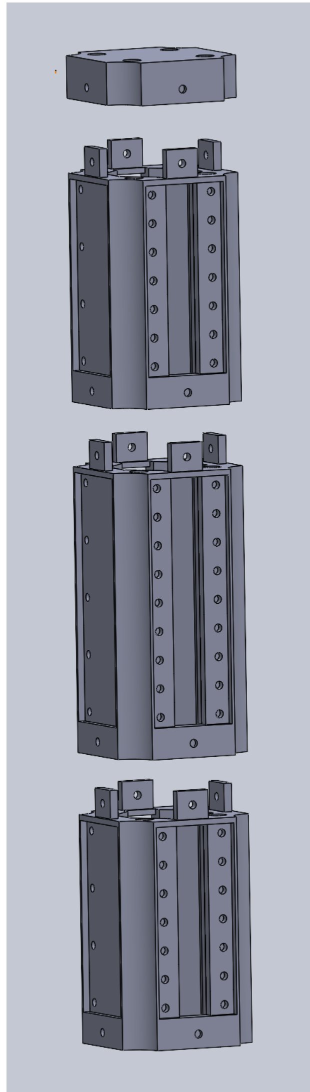

Fig. 9 Electronics bay in split configuration.

2. Recovery Electronics

The active recovery electronics consist of two barometric altimeters and a COTS GPS. The altimeters used are a Featherweight Blue Raven (primary) and an Altus Metrum EasyMini (secondary). The GPS used is a Featherweight GPS tracker, and it operates in the unregistered 900-915 MHz frequency band with the ability to change channels on the field to avoid interference between teams. Redundant GPS tracking is provided by the payload and is detailed in the Payload section.

The recovery altimeters are powered by combinations of 3.7v 3500 mAh 18650 Lithium-Ion battery cells. The combinations used are 2S (2 cells in series for a voltage of 7.4V and capacity of 3500 mAh, used on the EasyMini) and 2P (2 cells in parallel for a voltage of 3.7V and capacity of 7000 mAh, used on the Blue Raven and Featherweight GPS tracker). These battery packs hold a significantly higher capacity than common alkaline 9 volt batteries and even the previously used lithium-polymer batteries while retaining ideal operating voltages for the selected electronics. The high capacity of these batteries are selected to extend useful life in the field in the event of delays during launch operations. To prevent any failure, the altimeter power systems are completely isolated from each other and any other subsystems. The altimeter power connectors are connected to the boards with robust XT-60 connectors to prevent accidental disconnection during flight as well as wire strain or breakage at connection points. MissileWorks screw switches are used as arming switches to prevent unnecessary battery drain and allow all systems to be safely activated at the launch pad. The switches are mounted flush to the external switch band for easy access at the pad. The altimeters are then wired to multiple charge wells on both the top and bottom bulkhead(s). Hot glue is utilized in appropriate intervals to prevent the wires from becoming loose under vibration. This also reduces the stress the wires may experience during flight loads.

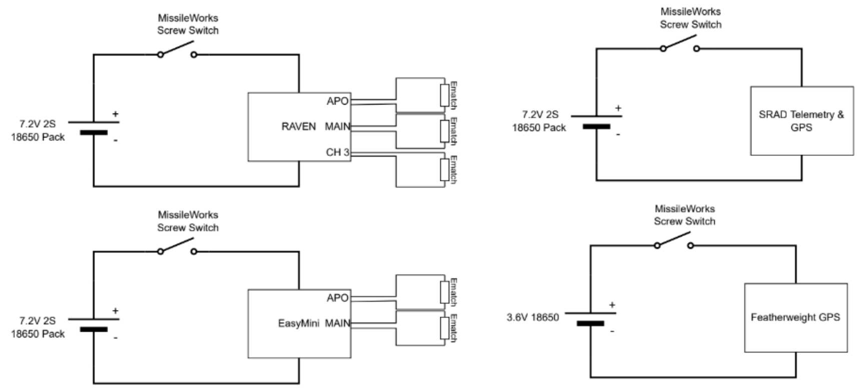

Fig. 10 Electronics bay wiring diagram.

3. Parachutes and Recovery Hardware

The main parachute used for our design is a SkyAngle Cert-3 XL. The drogue used is a Recon Recovery 30 in Parachute. This provides our rocket a descent rate of 82 ft/s under drogue and 17 ft/s under main. Apart from providing the ideal descent rates, these parachutes were selected based upon the strong over-the-crest shroud line construction (see image), weight, and packing size which were all factored into the structural design of the rocket. The main parachute fits into its bay without excessive friction or bunching to ensure an ideal deployment and recovery of the rocket. Baby powder is also utilized when packing the parachutes to reduce sticking and allow for a smoother parachute deployment. 18 in square Kevlar blankets are wrapped around the parachutes with "dog barf" (Fireproof Cellulose Insulation) placed atop as another precautionary measure to protect the parachutes from hot ejection gasses.

$\frac{3}{8}$ in tubular Kevlar shock cord is used to connect the parachutes attachment links to the bulkheads. The drogue parachute is attached to a shock cord length of 60 ft while the main parachute is attached to a shock cord length of 30 ft. This is done to prevent collisions between the body tubes following recovery events and to prevent the bulkheads from experiencing excess stress during ejection. Metal quick-links and barrel swivels are then used to secure the shock cord to the bulkheads. On the bulkheads, U-bolts are used as permanent mounting points to prevent the quick-link from slipping out during ejection. The use of quick-links, barrel swivels, and U-bolts helps minimize damage to the shock-cord and allows for easier integration of the recovery system.

Fig. 11 Skyangle Cert 3 used for recovery.[1]

4. Ejection System and Tests

Charge wells made of PVC pipe are mounted atop both the drogue and main bulkheads. The drogue bulkhead has 3 charge wells while the main bulkhead has 2. The drogue bulkhead charge wells hold the primary, first redundant, and second redundant black powder charges. The main bulkhead charge wells hold the primary and redundant black powder charges. The table below shows the charge well, deployment condition, and black powder concentration(s). Electronic-matches (e-match) are used to ignite the black powder via dedicated pyro channels. The e-matches are placed atop the black powder and packed tightly with "dog barf" to ensure downward propagation of the flame front; this increases the reliability of the black powder's burn completion. Multiple tests were also performed by the team to obtain the corresponding values (e.g. theoretical estimates (simulations), ground tests, and practice flights). The corresponding table is show below. 7

Table 7 Black Powder Ejection Charges

Charge Well	Ejection Condition	Black Powder [g]
1 (Drogue Bulkhead)	Primary Altimeter (Apogee, Barometric and IMU)	4.5
2 (Drogue Bulkhead)	Redundant Altimeter (Apogee + 1s, Barometric)	5.5
3 (Drogue Bulkhead)	Primary Altimeter (Apogee + 200 ft/s downward, Barometric)	6.5
1 (Main Bulkhead)	Primary Altimeter (800 ft)	5.5
2 (Main Bulkhead)	Redundant Altimeter (700 ft)	6.5

F. Payload Subsystems

The Payload subteam is responsible for designing a payload that contains a scientific experiment or technical demonstration for the Space Dynamics Laboratory (SDL) Payload Challenge. The goal for the team's 2024 Payload is to launch and recover a CubeSAT with live GPS, IMU data, barometric air pressure data, and battery voltage monitoring. With these sensors, we hope to collect data about our rocket trajectory, flight forces, and environmental conditions. In order for this to happen, the subteam is receiving telemetry by having the payload remain mounted in a RF-transparent, fiberglass section of the nose cone.

This year's 3U CubeSAT structure features four steel threaded rods running along each corner serving as the structural backbone. 3-D printed cubes also serve as the mounting points for the onboard systems. The payload is divided into two modular, 3D-printed cube substructures: one that houses a large nickel–metal hydride (NiMH) battery pack, and the other containing electronic sensors and telemetry equipment. Integration with the rocket is facilitated via fixed studs positioned at each end of the payload. Adjustment of the payload weight is achieved by adding aluminum plates with space for up to eight plates in total. Each plate weighs nearly 65 g; this allows for some fine-tuning of the weight within a 500 gram range with an approximate 65 g precision.

The first cube is a 3-D printed structure designed to house the NiMH battery pack that powers the entire system. This custom battery pack, configured as a 12S-1P setup, is composed of NiMH cells arranged in a 4x3x1 grid formation. These cylindrical cells are adhered together to form a rigid structure using a combination of superglue (cyanoacrylate), nickel strips bridging cells, and PVC heat shrink. Nickel strips are spot welded onto the battery terminals to establish the necessary electrical connections. The wire leads are soldered to nickel strips to connect to the VDD and GND terminal(s) of the battery pack. To maximize safety, the entire assembly is insulated using a combination of electrical tape and blue PVC heat shrink. Specifically, electrical tape is applied over all of the battery terminals with nickel strip connections to prevent any inadvertent short circuits in the event of a spot weld failure. Subsequently, PVC heat shrink is applied along each axis for additional electrical insulation and structural integrity.

The second cube consists of the sensor suite, which consists of four sensors and a radio modem interfaced with a BeagleBone Black single-board computer (SBC). The system's objective is for the SBC to gather sensor data whilst transmitting in real-time to a ground station for immediate processing and simultaneously saving a local copy to an onboard SD card. The first sensor is a GPS that captures satellite-based latitude, longitude, and altitude data. The second sensor is an IMU that records linear acceleration, rotational velocity, and temperature. The third sensor, a barometer, logs air pressure readings. The fourth sensor is dedicated to monitoring battery voltage. These sensor selections were made based upon their critical relevance to the success of the system and the analysis of our rocket's flight.

Another component of the payload is the Universal Battery Eliminator Circuit (UBEC) module. Positioned in series between the NiMH battery and the sensor suite is a 5 V, 3 A UBEC module tasked with converting the battery's nominal 14.4 V output to a usable 5 V output for the sensor suite. This module has been tested under load conditions to ensure its operational integrity with a measured current draw of less than 1 A. Its compact design allows for secure mounting on the first cube alongside the battery. Additionally, a screw switch is wired in series between the NiMH battery and the UBEC module; the screw switch is strategically placed for proper visibility outside the rocket to allow for ease in enabling and disabling the system.

To ensure the transmission of payload sensor data to our ground station, a RFD900x telemetry modem from RFDesign was implemented into the Payload. Upon system initialization, the modem automatically resets to its factory default settings; it is then reconfigured to transmit at a power level of 20 dB. Key default settings include a transmit frequency ranging between 915 MHz and 928 MHz, with the network ID set to 25 and node ID to 2.

G. Avionics Subsystems

The goal of the Avionics subteam is to improve upon the sophistication and capabilities of the rocket and to support team objectives. This year, in collaboration with the software and design validation subteams, the avionics subteam has designed the ads to assist with altitude control. The subteam designed, built, tested, and integrated this subsystem into the launch vehicle.

1. Active Drag System

The primary focus of our rocket design centers around a critical subsystem known as the ads, which constitutes the main air brake system. The ads is instrumental during the coast phase where it deploys flaps to reduce the rocket's total apogee to ensure specified altitude threshold of $10,000\ ft$, as mandated by the Spaceport America Cup category, is attained.

In the current iteration, the ads underwent a comprehensive redesign aimed at enhancing its effectiveness, durability, and modularity. The previous design featured outward-pushing fins capable of $50\ ft$ of altitude control. The redesign aims to be capable of $1,000\ ft$ of altitude control by using external flaps instead.

The redesigned ads incorporates carbon fiber flaps that are allowed freedom up to 20° from the vertical resting position they start and remain at until the coast phase. The flaps are mechanically and electronically controlled; this new iteration promises superior performance to provide the necessary drag to effectively achieve our altitude objectives.

The interior design of the flap features a mechanical locking mechanism to ensure that the flaps will not open in the boost phase; this is supplemented by the electronically controlled locking of the servo motor.

2. Design

Each flap contains a steel slot contained within several layers of carbon fiber. The slot has a thin channel approximately $1\ in$ long with a small hole at the top. A servo is used to actuate these flaps. We chose to design a rack and pinion system to connect the flaps to the servo. We created racks from aluminum with a water-jet to optimize the balance between strength and weight. Located at the end of each rack is a rod that slides into the slots on the interior of the flaps. The rods were designed with a ball at the end and are steel 3D-printed to ensure proper strength. The ball at the end slides into the hole at the top of the slot. The rest of the channel is thin and long enough that the end of the rod is not able to be forced out of the slot. This results in a mechanical locking mechanism as the ball cannot fall off the rod, and the ball rod cannot come out of the flap.

3. Testing

We conducted rigorous testing of the flaps to verify structural integrity and adequate surface area for generating the desired level of drag. This testing involved determining the optimal extension of the flaps and assessing the torque tolerance of our materials when subjected to servo manipulation. Utilizing Ansys for simulation, Computational Fluid Dynamics (CFD) analysis, andFinite Element Analysis (FEA) we refined our design parameters.

Upon fabrication of the prototype, in-person testing was conducted to evaluate the electronic control mechanism governing flap operation. This testing also verified the secure locking mechanisms, ensuring they remained steady until intentionally released. Through this comprehensive testing process, we validated both the functionality and reliability of the flap system.

A CFD model was generated in order to determine the aerodynamic characteristics of the launch vehicle under the influence of ads deployment. Since the algorithm utilizes C_D to determine the necessary ads deployment, five models were run at 0°, 5°, 10°, 15° and 20° flap deployments. A section of the rectangular prism domain used for the analysis is shown in Figure 12 below. Mesh refinement was used in locations that were expected to generate the most stagnation and turbulence. Areas such as the body tubes used a larger element size to reduce computation time. It was also important to ensure a large enough domain was utilized to fully capture the aerodynamic effects.

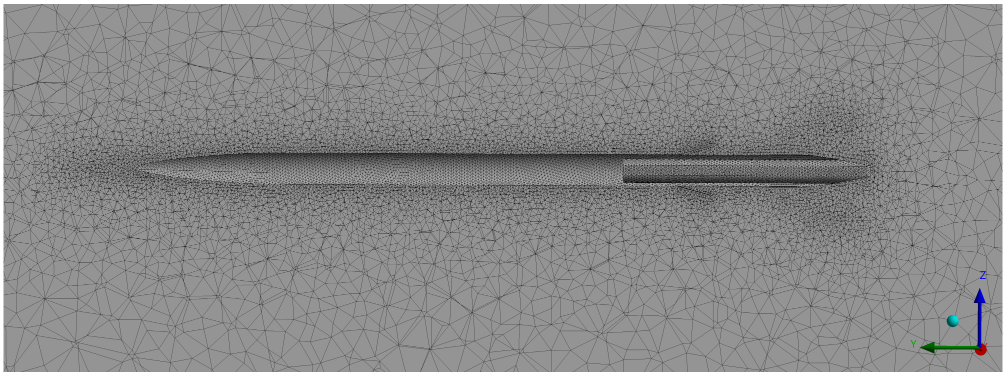

Fig. 12 Mesh of rocket and ADS used for calculation of drag force and C_D.

Simulations were conducted using pressure-based implicit methods via Ansys Fluent, with the assumption that the flows around the rocket will be similar to those of ideal gasses. Simulations were run until all converge criteria were met, or until the residuals plateaued at a small enough value that was still above the convergence limit, leading to $\pm 1N$ of possible error in results. Further mesh refinement and more computation resources, or longer simulation time, can potentially result in better convergence values, but the expected error of results is $\pm 1N$. Ultimately, the ads was found to be capable of roughly doubling the total drag of the rocket when fully deployed at high speeds. The results of the CFD study are summarized in Table 8.

Table 8 Coefficient of Drag at M0.8 Based upon ads Deployment

	ADS Deployment				
Velocity	**0°**	**5°**	**10°**	**15°**	**20°**
918	0.280	0.325	0.387	0.539	0.744

In addition to CFD, FEA was performed in the ADS to ensure the design met the structural requirements define by SAC. An Ansys FEM of a portion of the ads model was generated to decrease processing and computational time. Instead of using the full four flap system of the model, it was found to be most efficient to only generate one of the four flaps. With the push rod fixed in all degrees of freedom at the center, the model accurately models the system's deflection and stress resulting from drag forces. A drag force of 115 N per fin was used in the FEM as well as linear elastic material properties. It was important to refine the mesh in locations such as the push rod, guide rail, and screws as it required a higher level of accuracy. These areas were estimated to have the largest deformation and stress; therefore, the refined meshing ensured the highest accuracy of these locations. Bonded connection types were used at threaded locations with all other connections being of the friction-less type to yield the most conservative model stiffness. Figure 13 shows the mesh and stress contour of the analyzed maximum drag force case.

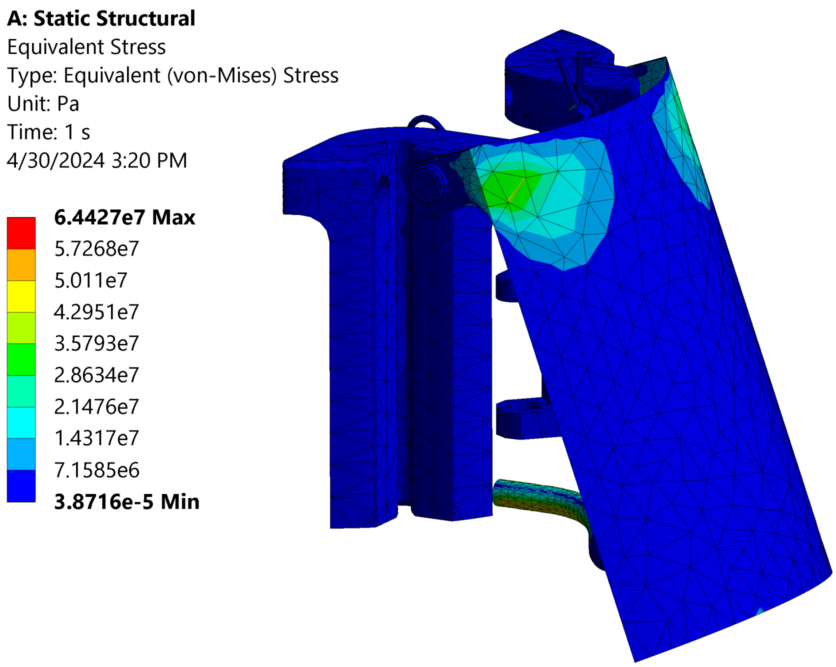

Fig. 13 ads Von-Mises Stress Contour.

Table 9 summarizes the margins of safety for the structural components. The design FS was applied to the load itself rather than the resulting stress to account for any non-linearities in the model stiffness. Since the system is expected to operate repeatedly during flight, it is important that MSy » 0 so the system does not permanently deform (yield) mid-flight. This occurrence could result in the mechanism locking up or result in the inability to deploy the desired amount.

Table 9 Stress margins of ads components under maximum drag force loading.

Load Case	Component	Stress Output (Pa)	Factor of Safety	Allowables (Pa)	Margins
		σ_{max}	FSy	Fty	MSy
Max Thrust	Flap	56,779,000	1.5	311,000,000	2.65
	Guide Rail	52,138,000	1.5	250,000,000	2.20
	Push Rod	41,035,000	1.5	250,000,000	3.06
	Pin	11,914,000	1.5	250,000,000	12.99
	Stand	3,774,100	1.5	32,840,000	4.80
	Base Plate	1,918,900	1.5	32,840,000	10.41

4. Electronics

A combination of sensors and electronics collaborate to actively control the drag model of a rocket by deploying fins, ultimately controlling the rocket's apogee. Sensors and the actuating servo connect to the microcontroller that serves as the flight computer for the ads.

The Raspberry Pi Pico was chosen as the primary microcontroller for its low cost, light weight, and excellent documentation. It features a 133 MHz, dual-core ARM Cortex-M0+ processor with 264 kB of internal static RAM. An external EEPROM flash storage module was also included to log flight data.

The team selected the Sincecam 50 kg, 8.4 V Low Profile Servo as the actuation mechanism for the ads fin

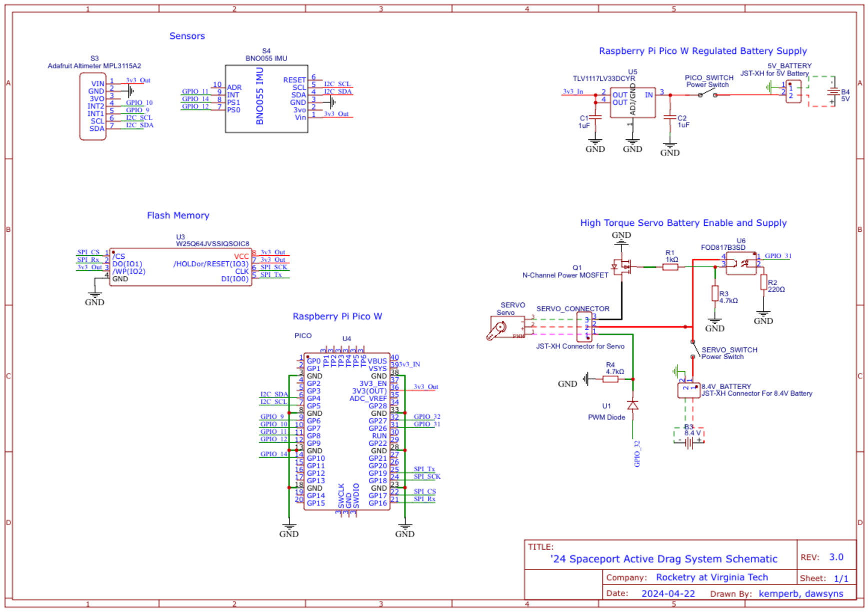

Fig. 14 Electronic Design Schematic for the ADS System

deployment. The servo features a 50 kg/cm torque and a 180° rotation angle making it ideal for use in applications requiring high torque and precise motion control. The servo has a pulse-width modulation (pulse width modulation (PWM)) input signal which is provided by the Raspberry Pi Pico through a diode to provide flow-back current protection. The servo is dynamically powered by a dedicated 2S 7.4 V Li-ion battery, as featured on the electronics bay, only during the flight. This is achieved through an N-Channel power transistor, driven via an optocoupler circuit controlled by the Pico, that acts as an electrical switch for the servo's power supply. The transistor is included to provide a stop against unnecessary battery drain. Both the microcontroller and the servo will not receive power until they are enabled via a MissileWorks screw switch.

The sensor suite consists of an Internal Measurement Unit (IMU) and a barometer. The team selected BNO055 as the IMU for the ads. The BNO055 sensor is a 9-axis sensor that measures acceleration, rotation, and magnetic fields. It provides data on the orientation and movement of the rocket. This data is used to determine the launch vehicle's zenith acceleration and attitude primarily during the flight, which is then used to determine the current coefficient of drag and other dynamical parameters for the launch vehicle. The BNO055 communicates with the microcontroller through the I2C protocol where the sensor acts as a "slave" device on the I2C bus on default hexadecimal address 0x28.

For the barometric altimeter, the team selected the MPL3115A2 digital barometric pressure and temperature sensor. The MPL3115A2 features a microelectromechanical systems (microelectromechanical systems (MEMS)) pressure and temperature sensor. The MPL3115A2 can operate in two different modes: altimeter mode and barometer mode. In altimeter mode, the sensor measures the sea-level altitude of the sensor based upon changes in air pressure. In barometer mode, the sensor measures the pressure of the surrounding air. The MPL3115A2 sensor measures pressure ranging from 20 to 110 kPa with an accuracy of 0.4 kPa and measures temperature ranging from $-40°$ C to $+85°$ C with an accuracy of 1° C. The MPL3115A2 sensor has the ability of outputting 20-bit pressure and temperature data through I2C protocol to the microcontroller along with the BNO055 sensor on the default address 0x61.

The microcontroller and peripherals are powered via a 2P 3.7 V Li-ion battery, like the ones found in the electronics bay, through a 3.3 V Low-Dropout (LDO) Voltage Regulator. Both batteries share a common ground with the microcontroller to ensure that the servo can be controlled via the PWM control signal.

5. Algorithm

Due to the nature of the Raspberry Pi Pico as a microcontroller, the project architecture has taken on an interrupt-based approach. The barometer sensor is initialized into 'altimeter mode' and an initial reading is taken to establish a base ground altitude. The sensor is then configured to set the interrupt pin high when it crosses 30 m above the base ground

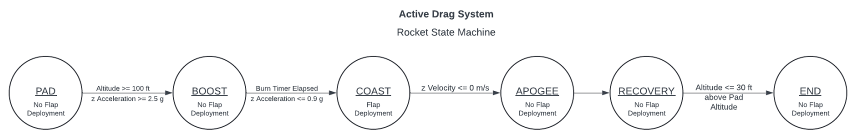

Fig. 15 ads State Diagram

altitude. The IMU is similarly initialized with an interrupt set to occur at 2 g. These are the events that are utilized to declare the beginning of a launch event. As they are interrupt-based, the microcontroller is free to allocate its resources to reading data and reacting rather than polling for the launch event to occur. In turn, an internal state machine is used to determine the different stages of the launch and the ads' functionality at each of those stages. The states consist of being on the pad at idle, boost (i.e. motor burn), coast, apogee, and recovery.

The initial launch events determine the point at which the state machine transitions from the idle state to the boost state. A hardware timer is then initialized and started for 110% of the simulated motor burn time. The end of this timer in addition to falling below the 0.9 g acceleration threshold marks the transition from the boost state to the coast state. The coast state transitions to the apogee state at the point where the velocity is determined to cross from positive to negative. The recovery state is marked in the immediate iteration following as the first recovery event occurs at and/or after apogee. A state machine update occurs at a frequency of 100 Hz (i.e. 100 times per second) via a hardware timer interrupt callback function. This state machine's functionality has been verified with camera footage and logged data at previous test launches.

The active drag system's behavior in each of these states except for the coast state is to log data and retract the ads flaps via the correct PWM configuration and subsequently disabling the servo's power supply as described in the electronics portion. The coast state is largely when the Active Drag System is active. A two state Kalman Filter based upon kinematics uses altitude read from the barometer sensor as the measurement and the z-axis component of the acceleration from the IMU as the control to obtain the climb rate.

The IMU contains an internal Kalman Filter and thereby provides valid control data. The current step drag coefficient is computed from the filtered altitude, the z-axis component of acceleration, and the fused climb rate. These measurements along with the current state are serialized and logged to the external flash chip for later inspection and analysis. The difference of the estimated optimal drag coefficient (e.g. to achieve $10,000\ ft$ apogee) and the current computed drag coefficient is given as the input for a Single Input Single Output (Single Input Single Output (SISO)) PID controller. A PID controller is used to adapt an interpolated curve correlating the simulated drag coefficient and percentage deployment of the ads. This percentage deployment is then translated to a proper pulse width to provide the servo's PWM input. In the coast state, if there is ever an error in reading sensor data or an attitude greater than 30° the flaps will be retracted accordingly.

IV. Conclusion

For the 2024 Spaceport America Cup in the 10k COTS category, Rocketry at Virginia Tech has designed and manufactured a launch vehicle that features a precision altitude control active drag system and a near fully SRAD carbon fiber composite airframe. In the process of designing one of the team's most innovative projects to date, Rocketry at Virginia Tech has aimed to improve on past iterations of subsystems as well as lay the groundwork for future team members to expand on these same subsystems and have a highly successful year at competition.

Throughout this year the team has improved on past projects, and has seen huge success in new manufacturing methods. The team's design and build process has become most reliable, and has allowed the team to produce lightweight rocket structures for this year's rocket. The Team has also seen massive success in subsystems like the ads which has proven itself to be better than even in this year's redesign. With the Teams continuing success the team brightly awaits competition with fresh hope for success.

Rocketry at Virginia Tech's 2023-2024 leadership team is the youngest it has ever been since the team's initial formation in 2015 and with that came a diligent effort not only to thoroughly understand previous design decisions but also to continue developing these projects for future generations on the team.

Going forward, the team seeks to continue improving our manufacturing, design, and analysis to do more than just build a high-powered rocket, but also to expose our members to industry standard engineering practices by providing them the opportunity to apply what they have learned in the classroom to one of Virginia Tech's most complex student researched and designed engineering projects.

Appendix A: System Requirements

S.5. PROPULSION SYSTEMS

S.5.1.1 A Commercial Off The Shelf (COTS) motor is defined as a motor which has been certified by the Canadian Association of Rocketry, Tripoli, or NAR, and appears on the then current combined Certified Rocket Motors List.

S.6. RECOVERY SYSTEMS AND AVIONICS

S.6.2. Batteries Contained in the Rocket

S.6.20.1. Lithium-Polymer (LiPo) batteries are not permitted due to fire hazard unless installed in the powered device by the manufacturer or recommended and supplied by the manufacturer.

S.6.20.3. NiMH (Nickel-Metal hydride) batteries are allowed in metal casing and any form factor.

S.6.20.5. Other Li-Ion batteries are permitted if packaged in a cylindrical metallic casing.

S.7. ACTIVE FLIGHT CONTROL SYSTEMS

S.7.1. Restricted Control Functionality

S.7.1.1. All launch vehicle active flight control systems shall be implemented strictly for pitch and/or roll stability augmentation, or for aerodynamic braking.

S.7.1.2. Under no circumstances will a launch vehicle entered in the SA Cup be actively guided towards a designated spatial target.

S.7.1.3. ESRA reserves the right to make additional requests for information and draft unique requirements depending on the team's specific design.

S.7.1.4. A neutral state is defined as one which does not apply any moments to the launch vehicle (e.g., aerodynamic surfaces trimmed or retracted, gas jets off, etc.).

S.7.2. Unnecessary for Stable Flight

S.7.2.1. Launch vehicles implementing active flight controls shall be naturally stable without those controls being implemented (e.g., the launch vehicle may be flown with the control actuator system (CAS) – including any control surfaces – either removed or rendered inert and mechanically neutral, without becoming unstable during ascent).

S.7.3. Designed to Fail Safe

S.7.3.1. Control actuator systems (CAS) shall default to a neutral state whenever either an abort signal is received for any reason, primary system power is lost, or the launch vehicle's attitude exceeds 30° from its launch elevation.

S.7.4. Boost Phase Dormancy

S.7.4.1. Control actuator systems (CAS) shall remain in a neutral state until one of the following conditions is met:

S.7.4.1.1. The launch vehicle's boost phase has ended (i.e., all propulsive stages have ceased producing thrust).

S.8. JOINTS IMPLEMENTING COUPLING TUBES

S.8.5.1. Airframe-to-coupler sliding joints intended to separate during a recovery event

S.8.5.1.1. Joints shall be designed such that the coupling tube extends no less than 1 body tube diameter (1 caliber) into the airframe section from which the coupler will separate during flight.

S.8.5.3. Joints not intended to separate during flight

S.8.5.3.1. Joints shall be designed such that the coupling tube extends into the mating component to the lesser of 1 body tube diameter (1 caliber) or the maximum depth possible by the design of the mating component.

S.8.5.3.2. Joints shall be affixed by mechanical fasteners and/or permanent adhesive.

S.8.5.4. Regardless of implementation (e.g., RADAX or other join types) airframe joints shall prevent bending.

S.10. LAUNCH AND ASCENT TRAJECTORY REQUIREMENTS

S.10.1. Launch Azimuth and Elevation

S.10.1.1. Launch vehicles shall nominally launch at an elevation angle of 84°±1° and a launch azimuth defined by competition officials at the IREC.

S.10.1.2. Range Safety Officers reserve the right to require certain vehicles' launch elevation be lower if possible flight safety issues are identified during pre-launch activities.

S.10.1.3. Competition officials may allow staged flights to launch at 87°+1

S.10.2. Launch Stability

S.10.2.1. A rail departure velocity of at least 30 m/s (100 ft/s) is required

S.10.2.2. Teams unable to meet 10.2.1 may use detailed analysis to prove stability is achieved at a lower rail departure velocity, preferably via flight testing. Alternatively, multiple computer simulations may be used, but must evaluate stability under a variety of launch conditions.

S.10.2.3. Departing the launch rail is defined as the instant at which the launch vehicle first becomes free to move about the pitch, yaw, or roll axis.

S.10.3. Ascent Stability

S.10.3.1 Launch vehicles shall maintain a dynamic stability margin of at least 1.5 body calibers, regardless of Cg movement and/or shifting center of pressure Cp location, from launch through the first recovery system deployment event.

S.10.4. Over-Stability

S.10.4.1 Launch vehicles shall not be "over-stable" during their ascent, defined as having a static stability margin >4 calibers or a dynamic stability margin during flight >6 calibers.

S.11. ESRA PROVIDED LAUNCH SUPPORT EQUIPMENT

S.11.1. ESRA-Provided Launch Rails

S.11.1.1 All teams competing in the solids (COTS or SRAD) categories shall use SA Cup supplied launch control systems.

S.11.1.2 ESRA shall provide launch rails measuring at least 5.2 m (17 ft) long, 1.5" x 1.5" (aka 1515) aluminum guide rails of the 80/20® type.

Appendix B: System Weights, Measures, and Performance Data

Table 10 Basic Rocket Information

Stages	1
Length	135"
Airframe Diameter	6.17"
Number of fins	4
Fin Semi-span	5"
Tip Chord	5"
Root Chord	12"
Fin Thickness	.25"
Vehicle Structure Weight	33.92 lb
Propellant Weight	10.39 lb
Motor Case Empty Weight	7.39 lb
Payload Weight	8.6 lb
Liftoff Weight	60.3 lb
Center of Pressure (from nose)	93.97"
Center of Gravity (from nose)	82.4"

Table 11 COTS Aerotech M2500T Characteristics

Characteristic	Quantity
Manufacturer	Aerotech
Designation	M2500T
Diameter	98mm
Length	29.57"
Total Weight	17.78 lb
Prop Weight	10.39 lb
Avg Thrust	2,500 N
Initial Thrust	2,578 N
Max. Thrust	3,711 N
Total Impulse	9,671 Ns
Burn Time	3.9 s
ISP	209 s
Motor Case	98/10240
Propellant	Blue Thunder

Table 12   COTS Altimeters and Specifications

Altimeter	Manufacturer	Model	Charges Controlled (See Parachute Table for sizing)	Scoring
Primary	Featherweight	Blue Raven	Drogue Primary, Drogue Failsafe, Main Primary	Scoring Primary
Backup	Altus Metrum	EasyMini	Drogue Backup, Main Backup	Scoring Backup

Table 13   COTS Parachutes and Specifications

Parachute Data	Type	Black Powder Charges (Primary, Backup)	Deployment Altitude (Primary, Backup)	Descent Rate
Drogue	Recon 30"	4.5g/5.5g/6.5g	Apogee / Apogee+1s / Apogee+200 ft/s	82 ft/s
Main	SkyAngle Cert-3 XL	5.5g/6.5g	900ft / 800ft	17 ft/s

Table 14   Shock Cord and Linkages

Shock Cord + POA Data	Type	Test Strength	Length	Supplier	Knots Used	POA Hardware
Drogue	3/8" tubular Kevlar	3,600 lb	60’	Wildman	Bowline	1/4" quick link + barrel swivel
Main	3/8" tubular Kevlar	3,600 lb	30’	Wildman	Bowline	1/4" quick link + barrel swivel

Appendix C: Project Test Reports

Recovery System Testing - Ejection Testing

Multiple ground tests were conducted to experimentally acquire minimum charge sizing for flight testing. Tests were conducted in "sagging" and "hogging" positions to simulate flight stress on the airframe coupler and separation points. Actual or simulated masses of all sub-components including parachutes, shock cords, and parachute protection were installed in the rocket for ejection testing to accurately represent flight characteristics.

Recovery System Testing -Ejection Testing Results

Testing determined minimum values of 3 grams for drogue separation and 4 grams for main separation. Shear pin configuration of 4 x 4-40 pins in the drogue parachute section and 8 x 4-40 pins in the main parachute section was also validated.

Charge selection for flight testing was completed using the ground test values as minimums. The primary charges were increased by 1.5 grams over the test value (4.5 grams for drogue primary and 5.5 grams for main primary) with the redundant charges being further increased. Charge sizing escalates in order of redundancy. Table 15 below includes final charge sizing information for all deployment events.

Table 15 Final Charge Sizing

Event	Primary	Secondary	Tertiary
Drogue	4.5g	5.5g	6.5g
Main	5.5g	6.5g	N/A

Flight Testing

Flight testing was used to further validate the vehicle design and onboard systems. Narratives of each test flight are included below and Table 16 shows a brief list of their purpose and results.

Table 16 Test Flights

FLIGHT	DATE	MOTOR	SYSTEMS TESTED	RESULT
1	11/18/23	L2500	Vehicle structure, recovery system	Success
2	2/24/24	L2500	Lithium-ion battery chemistry, partial ADS and payload	Success
3	4/20/24	M1939	Full Spaceport configuration, mass reduction, full ADS and payload	Weather scrub

Flight Testing - Test Launch 1

The first test flight was a simple test of the 2024 vehicle with only the recovery system installed. Boiler plate masses were used to represent ADS and payload. Lithium-polymer batteries from the previous competition year were used for recovery electronics. Vehicle performance and recovery were nominal.

Flight Testing - Test Launch 2

The second test flight incorporated active ADS and payload systems. One of the two recovery altimeters was switched to an 18650 lithium-ion battery pack for validation with the other remaining on the original lithium-polymer cell for redundancy. The flight primarily aimed to validate the ability of the ADS to inhibit flap deployment until after motor burn and test payload GPS transmission. To this end, the test was a success, with flap deployment occurring after burnout and accurate GPS coordinates received upon recovery. The recovery system experienced a minor anomaly, however, with the altimeter powered by the original lithium-polymer battery suffering a failure during flight, resulting in a late drogue event triggered by the second altimeter and some damage to the drogue parachute. The 18650 lithium-ion pack performed nominally and the vehicle recovered safely without further incident after main parachute deployment. Altimeter failure was diagnosed as being due to the type of lithium-polymer battery used, which was not rated for use with the altimeter. Full conversion to the now-validated 18650 lithium-ion chemistry for flight at SAC is expected to alleviate the issue.

Flight Testing - Test Launch 3

The third test flight was intended to be a full SAC configuration vehicle launched to 11,500 feet AGL on an M1939. The primary goal was to validate the entire competition functionality of the ADS and payload systems. The ADS was programmed to attempt to autonomously trim the vehicle to 10,000 feet AGL, which was chosen to provide a full stress-test of the algorithm, electronics, and mechanical systems. Mass reduction on the vehicle structure was to be validated and its effect on flight characteristics was to be analyzed. The weather on the day of the launch was marginal with high winds and low cloud cover, however, the vehicle was still integrated, assembled, and moved to the pad. After approximately 2 hours of waiting for a break in the cloud cover, the flight was scrubbed. Battery voltages were collected from the recovery electronics to add a qualitative assessment of idle performance to the existing battery calculations and previous flight test. Some minor flaws in hardware, integration steps, and the launch checklist were discovered and marked for remediation.

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Appendix D: Hazard Analysis

Hazard	Possible Causes	Risk of Mishap and Rationale	Mitigation Approach	Risk of Injury after Mitigation
Black powder	Mishandling of rocket before flight/poor arming procedures	Medium; Black powder charges pose a significant risk to personnel if mishandled. Poorly planned ejection tests also have the potential to damage flight vehicle.	Proper distancing from BP tests	Low
	Poor ground test procedures		Arm deployment electronics for flight on pad, not before	
			Utilize proper switches for electronics (screw switches or similar device)	
Li-ion battery burn/fire	Shorting battery terminals	Medium; Lithium-Ion batteries are used frequently, so they pose a significant risk to team personnel if mishandled	Instruct team members of correct handling of Li-ion batteries	Low
	Dropping/Cutting/Crushing batteries			
Falling rockets	Recovery system failure	High; Ballistic descent could have a catastrophic effect on the flight vehicle and poses an extreme risk to personnel and property.	Follow SRR guidelines to make recovery system as robust as possible	Low
	Public rocket launches		Instruct team members on proper launch day etiquette (point to descending rockets, give verbal warnings, etc.)	
Unstable flight; could cause unpredictable trajectory, endangering personnel	Improperly sized fins	Medium; Occurs if improper analysis and testing are done beforehand or if improperly integrated	Test fin assembly to point of yielding and/or failure	Low
	Loss of fins		Simulate fin flutter and size fins to avoid resonance	
	Rail button failure		Calculate maximum loading on rail buttons to ensure safety factor	
Motor failing to be restrained inside the vehicle; could cause unrestrained motor to fly towards people	Thrust plate failing/ yielding	High; Loading from thrust is hard to determine analytically in each component of the rocket, leading to some uncertainty in the factor of safety	FEA simulation to verify safety factor >2	Medium
	Bolts responsible for restraining thrust plate fail in shear		Compression testing the internal structure/ airframe assembly to yield/failure	
	Bearing stress on aluminum channels deforms holes			

Appendix E: Risk Assessment

Risk	Possible Causes	Risk of Mishap and Rationale	Mitigation Approach	Risk of Injury After Mitigation
GPS System malfunction	Loss of satellite connection	Medium; Consequences could include failure to locate rocket after landing which would mean a total loss of flight vehicle	Integrated and non-integrated test of GPS hardware to find and document limitations in range	Low
	Loss of power		Use shake table and pressure testing to ensure batteries and wiring are secure	
	Interrupted RF signal to ground station			
Altimeter malfunction	Loss of power	Medium; Consequences could include failure to deploy parachute which could cause ballistic descent, which can be catastrophic to the flight vehicle as well as dangerous to personnel	Follow all manufacturer guidelines on powering and static port sizing/placement	Low
	Poor static port hole placement/sizing		Use shake table and pressure testing to ensure batteries and wiring are secure	
Parachute/recovery harness tangling	Poor folding	Medium Risk; Parachute tangling could be dangerous to flight vehicle as higher descent rates mean higher probability of damage to the rocket upon landing. Higher descent rates also pose a risk to personnel.	Instruct all members on proper parachute folding	Low
	Ejection charge malfunction		Use ejection charge tests to ensure parachute is completely deployed from airframe	
Unstable flight; could cause unpredictable trajectory, endangering the launch vehicle	Improperly sized fins	Medium; Occurs if improper analysis and testing are done beforehand or if improperly integrated.	Test fin assembly to point of yielding and/or failure	Low
	Loss of fin(s)		Simulate fin flutter and size fins to avoid resonance	
	Rail button failure		Calculate maximum loading on rail buttons to ensure safety factor	
Motor failing to be restrained inside airframe	Thrust plate failure/yielding under normal load	High; Loading from thrust is hard to determine analytically in each component of the rocket, leading to some uncertainty in the factor of safety.	FEA Simulation to verify safety factor >2	Medium
	Bolts responsible for restraining thrust plate fail in shear		Compression testing the internal structure/airframe assembly to yield/failure	
Yielding of internal structure	Actual max stress greater than expected max stress	Medium; Occurs if improper analysis and testing are done beforehand or if improperly integrated.	Bulkheads prevent aluminum from buckling to the point of structural failure	Low
Premature drag separation	Pressure differential between chute bay and free stream	Low	Calculating the max pressure differential and required shear pins to prevent separation	Low
Errors in Active Drag System (ADS) structural analysis	Imperfect drag force load conditions used in simulations	Medium; Unsymmetric failure of ADS may result in instability during flight.	Determine there is a safety factor of at least 2 (TBR)	Low
	Internal Forces (i.e. friction, etc.) are ignored		Physical testing performed by Avionics subteam	

	Material properties do not align with the actual materials used in the system (especially non-isotropic materials)		Design ADS such that unsymmetric failure is unlikely	
Incorrect Stability Calculations	Component layout experiences significant changes	Medium; Pressure distributions on a rocket vary depending on angle of attack and trajectory. Simulations may not be able to account for these flight activities. Also, CG is likely to move as development progresses. This may result in unstable flight.	Results compared with Open Rocket and other softwares	Low
ADS structural failure	Inaccurate results determined from FEA simulations	Low; ADS will not deploy until after burnout (high altitude), so launch vehicle should be at a safe distance from personnel. Also, launch vehicle should be stable without ADS. A failure could result in unstable flight and difficulties with recovery.	Avionics will perform testing on the system	Low
	Flight Loads not properly implemented into simulations		Safety factor determined to be greater than 2	
Instability of the LV during ascent	ADS deployment failure	Medium; Personnel will be at a safe distance from the launch pad. Also, the likelihood of the LV heading towards people is relatively low	Personnel will be far from launch pad	Low
	Inaccurate stability caliper calculations		CFD will be performed to verify stability at all stages of ascent	
	Damage to fins or other external components		Stability caliper will be verified using multiple methods	
Li-ion batteries are damaged or shorted	Batteries are not properly handled	Medium; Damaged or shorted lithium batteries could combust and directly harm personnel or destroy other parts of the vehicle structure which could become harmful debris, posing a danger to personnel.	Training all team members in battery handling	Low
	Batteries are not properly mounted		Ensuring mounted power supplies and connections are secure	
	Batteries are not properly stored		Ensuring proper power regulation	
RF telemetry link is broken	Power failure with electronics	Medium; A failure to establish and hold an RF link would result in failure of the SRAD telemetry and GPS system and would result in losing all data is is not logged onboard the electronics and recovered. A GPS failure would also force complete reliance on the COTS GPS for recovery.	Perform telemetry range tests	Low
	RF equipment gets damaged		Test the efficacy of RF transparent sections of the rocket after the launch vehicle is fully assembled	
	The rocket structure blocks RF signals			
ADS structure or deployment fails during flight	ADS is not properly integrated	High; A collapsing ADS structure could produce damaging debris during flight. Additionally, uneven deployment of fins would produce uneven drag and could rapidly change the trajectory of the rocket.	Iteratively running integrated, simulated, and flight tests	Low
	ADS structure is weak		Ensuring proper algorithm safe guards	
	ADS is poorly manufactured		Rack and pinion design severely limits uneven deployability	

Appendix F: Assembly, Preflight, Launch, and Recovery Checklists

Launch Location: Spaceport, New Mexico **Launch Date:** June 19 2024

Flyer of Record: Bob Schoner

Pre-Flight Field Assembly

Avionics Checks

Action	Executor Initials	Witness Initials
☐ Insert motor and retain with forward bolt.		
☐ Check the battery voltages. Servo battery should be between 8.2-8.4v and PCB battery should be between 4.1-4.2v. If fail, see Emergency item 2.		
☐ Check ADS is secured. If fail, see Emergency item 3		
☐ Check that two nuts are securing the ADS on the threaded rods.		
☐ Plug in all wiring and make sure it is secure.		
☐ Slide the lower body tube onto the fin can and secure it in place with 6 rivets.		
☐Secure Rail guide in place		
☐ Attach all four ADS flaps onto the ADS structure using two small pins per flap, and make sure the rack pin is in the aluminum channel of the flap.		
☐ Secure the flap pins by inserting the lock pins into the end of the flap pin.		

Pre-Flight Field Assembly

Electronics Bay Checks

Action	Executor Initials	Witness Initials
☐ Check Battery voltages, must be 4.0 - 4.2 V GPS and Raven / 8.2 - 8.4 V EasyMini. If fail, charge or replace offending battery.		
☐ Tug test all wires. If fail, see Emergency item 1.		
☐ Photograph before continuing.		
☐ Check wire holes are properly sealed.		
☐ Photograph before continuing.		
☐ Ensure batteries are connected.		
☐ Ensure Featherweight GPS transmitter board switch is in ”On” position.		
☐ Photograph before continuing.		
☐ Secure Apogee wire to apogee charge		
☐ Secure Apogee +1 wire to secondary apogee charge		
☐ Secure Fail Safe wire to Fail Safe charge		
☐ Connect Primary, Secondary, and GPS switch pigtails.		
☐ Apply sealant to both bulkheads		
☐ Slide bulkhead/sled assembly into Electronics Bay coupler from the bottom.		
☐ Secure Main wire to P pigtail on upper bulkhead.		
☐ Secure Main 2 wire to S pigtail on upper bulkhead.		
☐ Secure upper bulkheads in place with nuts, metal washers, and rubber washers.		
☐ Check wire holes are secured. If fail, see Emergency item 3		
☐ Photograph before continuing		

Pre-Flight Field Assembly

Payload Checks

Action	Executor Initials	Witness Initials
☐ Check Battery voltage greater than 14.4 volts.		
☐ Weigh payload and photograph. Must be greater than 3.8kg. (3.9kg for this test launch)		
☐ Check Beaglebone and RFD modem are each securely fastened.		
☐ Check antenna is securely ziptied		
☐ Check pcb is securely fastened to beaglebone. check sensors securely screwed to pcb		
☐ Check battery connected to screw switch connected to ubec, connected to beaglebone		
☐ Check all payload nuts securely fastened and photograph		
☐ Insert 4 payload threaded rods into the bulkhead with the eyebolt.		
☐ Secure from both sides with nuts, washers, and rubber washers.		
☐ Slide payload coupler over payload/bulkhead assembly. Switch band should face away from eyebolt		
☐ Secure second bulkhead on opposite side with nuts, washers, and rubber washers.		
☐ Tighten all nuts into place, test for bulkhead security on threaded rods.		
☐ Insert payload/coupler assembly into the nose cone and secure with 6 rivets.		
☐ Turn on screw switch, wait for system to boot, and confirm transmission to ground station (ideally let run long enough to get GPS fix). Then turn off screw switch and make sure system stops transmitting		

Flight Integration

Avionics Checks

Action	Executor Initials	Witness Initials
☐ Apply sealant to aft Drogue Bulkhead		
☐ Insert aft drogue parachute (upper ADS) bulkhead.		
☐ Secure 4 metal washers, 4 rubber washers, and 4 lock nuts on ADS alignment rods, on top of bulkhead.		
☐ Tighten nuts evenly until snug.		

Electronics Bay Checks

Action	Executor Initials	Witness Initials
☐ Check Battery voltages, must be 4.0 - 4.2 V GPS and Raven / 8.2 - 8.4 V EasyMini. If fail, see Emergency item 3.		
☐ Attach ematches to screw terminals		
☐ Measure out apogee black powder charges. Primary charge 4.5g, backup 5.5g, fail safe 6.5g		
☐ Place charges into apogee wells on the lower bulkhead.		
☐ Pack charge wells with dog barf and wrap with blue tape		
☐ Measure out main black powder charges, primary 5.5g, backup 6.5g		
☐ Place drogue black powder charges in drogue wells on the lower bulkhead		
☐ Pack charge wells with dog barf and wrap with blue tape		
☐ Photograph before continuing		
☐ Insert Electronics Bay into main airframe and secure with 6 rivets.		

Payload

Action	Executor Initials	Witness Initials
☐ Turn on screw switch, wait for system to boot, and confirm transmission to ground station.		
☐Turn off screw switch and make sure system stops transmitting.		

Flight Integration

Fin Can Assembly

Action	Executor Initials	Witness Initials
☐ Fold drogue and add baby powder		
☐ Add baby powder to Chutes and surfaces		
☐ Attach recovery quick links to drogue shock cord, drogue chute, and chute protector		
☐ Attach long end of shock cord to ADS upper bulkhead		
☐ Attach middle quick link to drogue		
☐ Photograph before continuing		
☐ Cover drogue in chute protector		
☐ Insert drogue, chute protector, and shock cord into booster section with baby powder.		
☐ Add 2 cups of dog barf to booster section on top of parachute and shock cord		
☐ Connect quick links to main shock cord, main chute, and chute protector		
☐ Connect quick links to Electronics bay, and nose cone		
☐ Photograph before continuing		
☐ Fold Main chute with baby powder.		
☐ Cover Main with chute Protector		
☐ Add 2 cups of dog barf below chutes in the tube		
☐ Insert chute into upper body tube, Chute protector facing towards body of the tube, funneling shock cord with it		
☐ Photograph before continuing		
☐ Slide nose cone onto top of main airframe, secure with 8 shear pins. Use baby powder. If fail, see Emergency item 3.		
☐ Attach final quick link to lower electronics bay bulkhead		
☐ Connect upper rocket section (nose cone, main airframe, EB) on top of booster section. Add baby powder.		
☐ Secure with 4 shear pins. If fail, see Emergency item 3.		

Launch Pad Preparations

Action	Executor Initials	Witness Initials
☐ Check vehicle weight with OpenRocket values. If fail, see Emergency item 4		
☐ Mark vehicle CG and CP with Vinyl stickers		
☐ Record final off the rail velocities.		
☐ Notify RSO of preparation for inspection.		
☐ Assemble igniter and tape to the outside of the rocket.		
☐ Engage hand radios between launch crew and bystander crew if needed.		

CG$_{dry}$ ____________	**CG**$_{wet}$ ____________	**CP** ____________

Leadership Approval Signatures

By signing this document, you verify that to the extent of your knowledge this launch vehicle has been assembled and prepared following the exact steps of this checklist. Any deviation from the procedure in this document or any belief that this launch vehicle is unsafe or unprepared for flight should result in a refusal to sign. A missing signature from any of the following individuals will halt operations and the test flight will not proceed.

Approved:	______________________________
	Demetra Kohart
	Chief Executive Officer
Approved:	______________________________
	Gabe Mills
	Chief Engineer
Approved:	______________________________
	Dawsyn Schraiber
	Vice Chief Executive Officer
Approved:	______________________________
	Daniel Young
	Aerostructures Lead
Approved:	______________________________
	Ben Anderson
	Avionics Lead
Approved:	______________________________
	Bob Schoner
	Flyer of Record

Emergency Procedures

1. Failed tug test
    (a) Identify loose wires and connections
    (b) Locate where they are supposed to be attached
    (c) Solder wires where needed
    (d) Secure wires in place. Cover in electrical tape.
    (e) Tug test again.
    (f) If continued failure, scrub launch
2. Failed voltage checks
    (a) Identify failed battery
    (b) Charge the battery for 15 minutes
    (c) Check charge again
    (d) If charge increased continue charging until at required voltage
    (e) If charge has not changed then repeat 2x
    (f) IF continued failure to charge, scrub launch
3. Failed securing system
    (a) Identify a possible fix
    (b) Attempt general fix
    (c) If fix fails repeat with new fix
    (d) If repeated failure to secure a system, scrub launch
4. Update OpenRocket
    (a) Identify if numbers on open rocket are unacceptably different from measured
    (b) Identify if flight essential systems meet ESRA requirements
    (c) If not, scrub launch
    (d) If they do, continue checklist
5. Pad not disarmed
    (a) Disarm pad
    (b) Continue checklist
6. Altimeter won't arm
    (a) Disarm pad
    (b) Try 2 times to arm again
    (c) If continual failure lower rocket horizontal on pad
    (d) Remove rocket from launch rail
    (e) Briefly take rocket apart on ground at pad. If the problem is easy and quick fix, then attempt fix there
    (f) If the problem is complex or there is uncertainty bring rocket back to tables.
    (g) Inform RSO of situation and repair altimeter and bay as need.
    (h) Restart checklist at electronics bay Checks, and continue onwards
    (i) If repeated failure, scrub launch.

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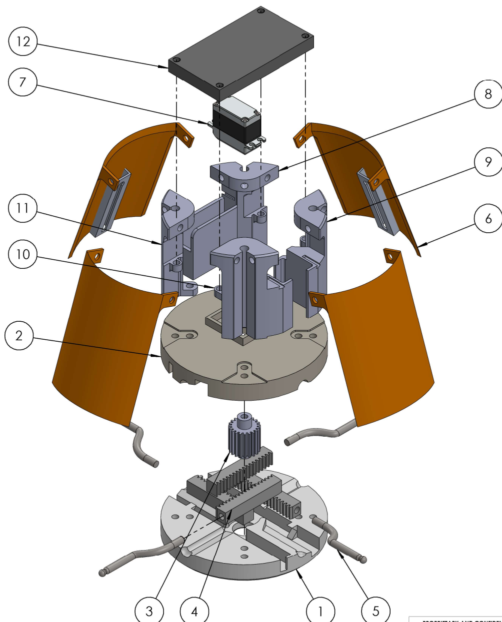
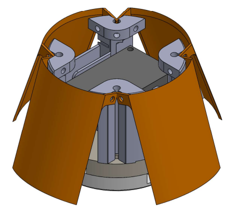
Appendix G: Engineering Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Lower Plate	ABS	1
2	Upper Plate	ABS	1
3	Double Gear	1020 Carbon Steel 1.0 in	1
4	Gear Rack	20 degree pressure angle, gear pitch 20, pitch height 0.45 in	4
5	Rack Pin	316L stainless steel	4
6	Flap (with Guide)	Carbon fiber and epoxy (stainless steel)	4
7	Servo Motor	Sincecam 8.4V servo motor	1
8	Column 1	ABS	1
9	Column 2	ABS, with Lithium Ion battery holder	1
10	Column 3	ABS, with Lithium Ion battery holder	1
11	Column 4	ABS	1
12	Electronics Placeholder	Placeholder for electronics block to show integration	1



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MFG APPR.		
Q.A.		

COMMENTS:
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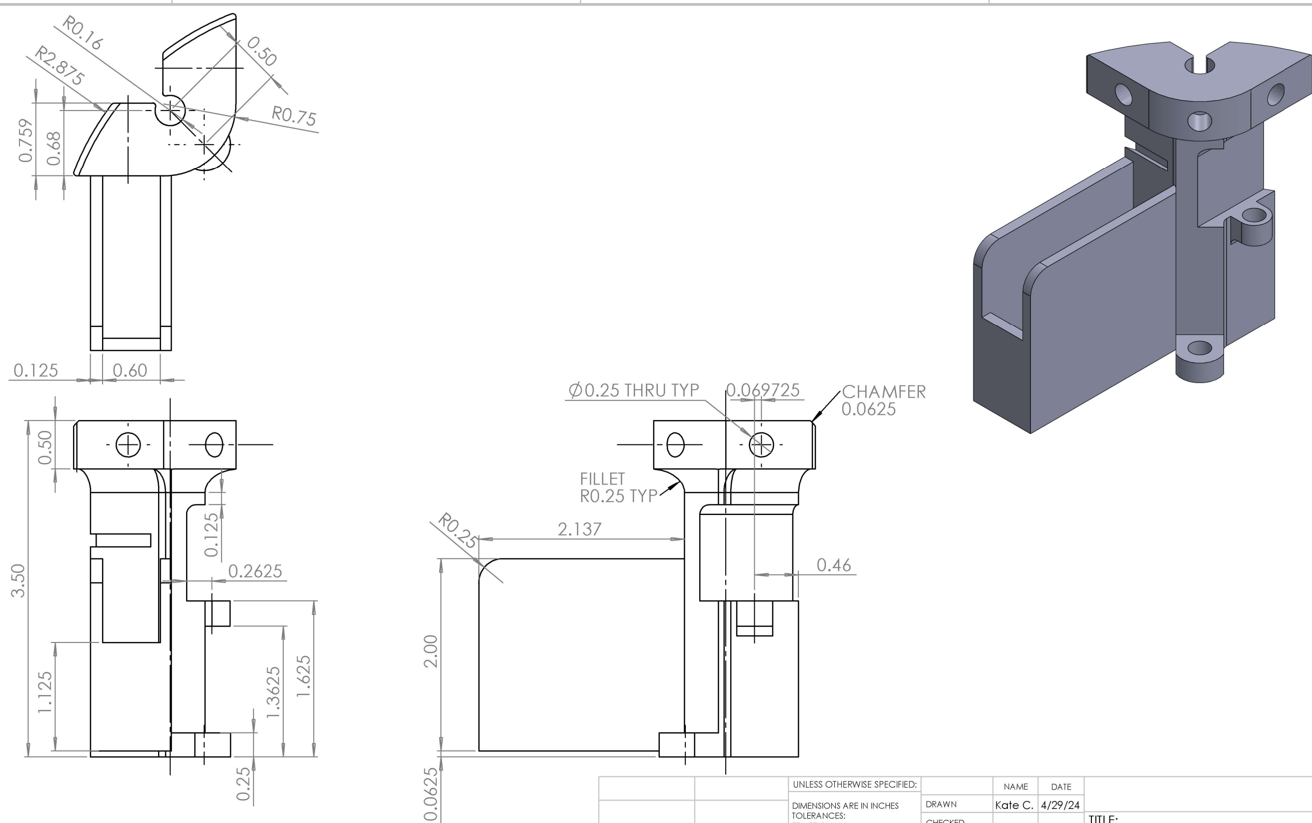

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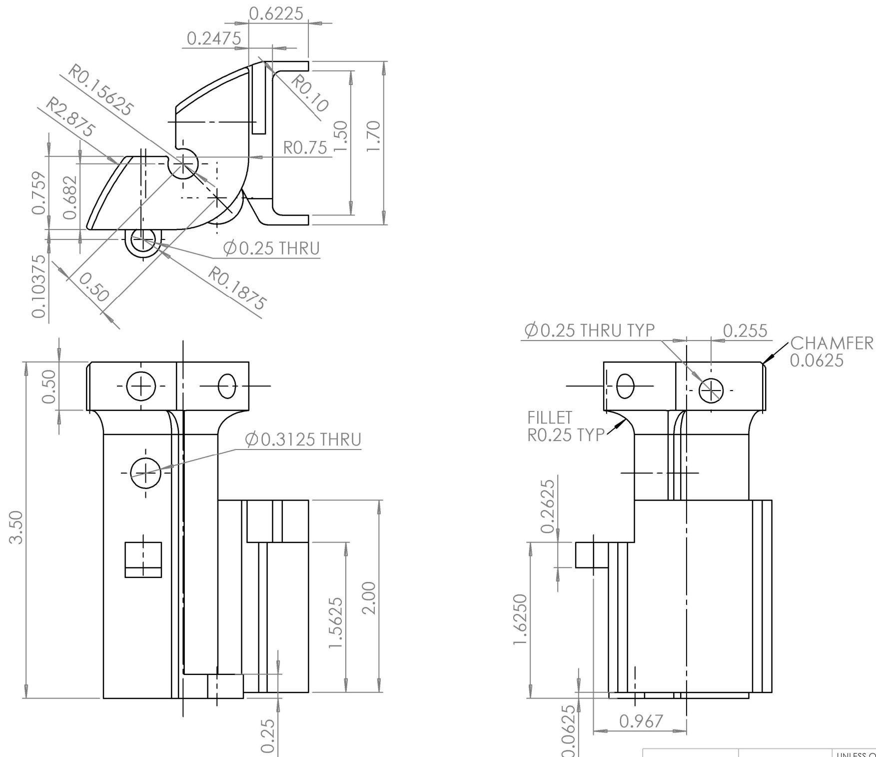

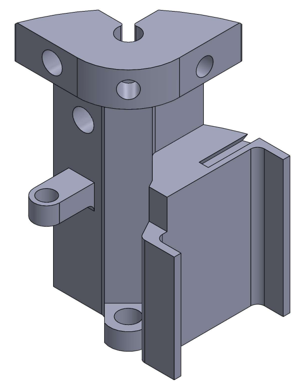

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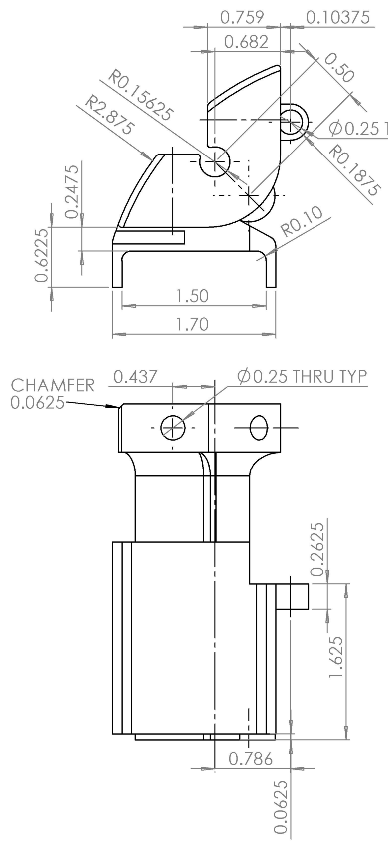

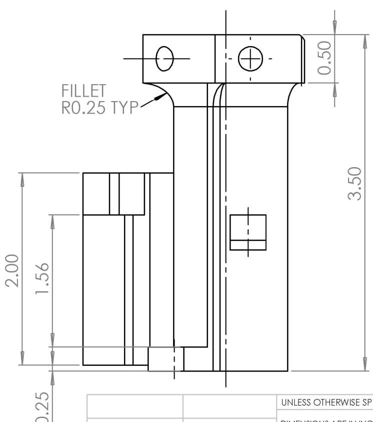

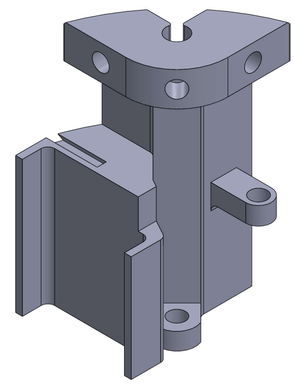

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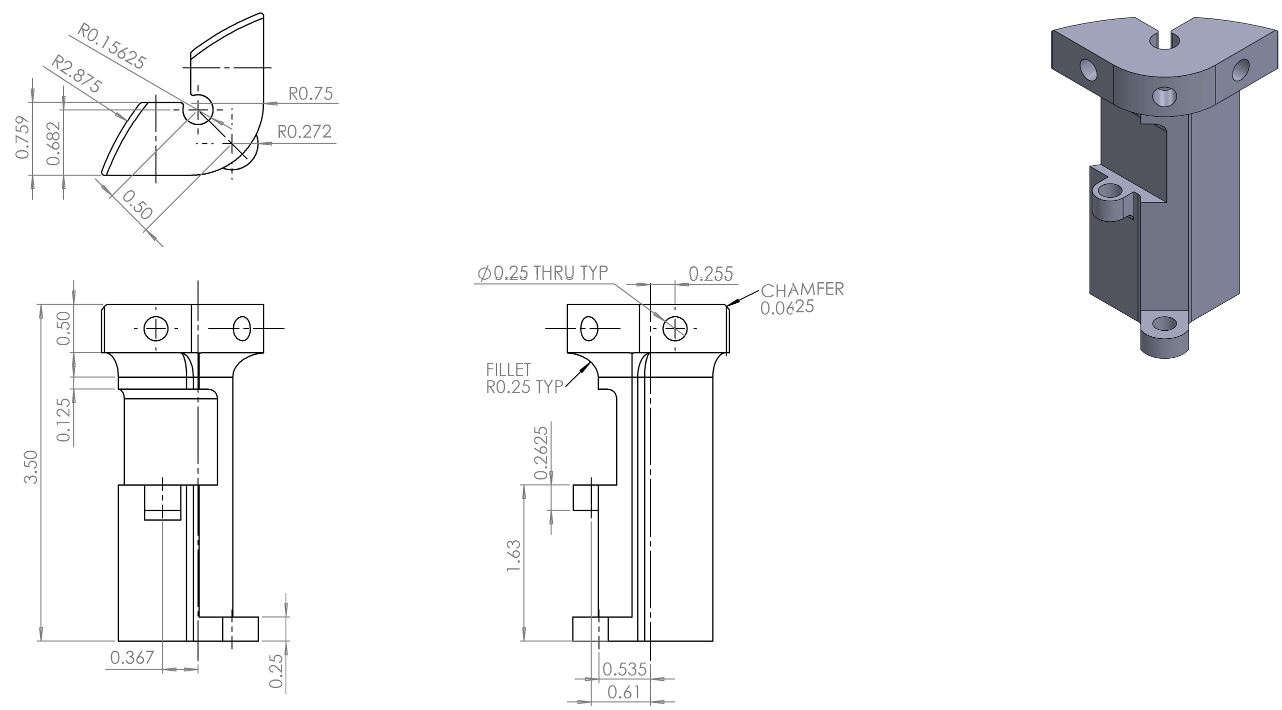

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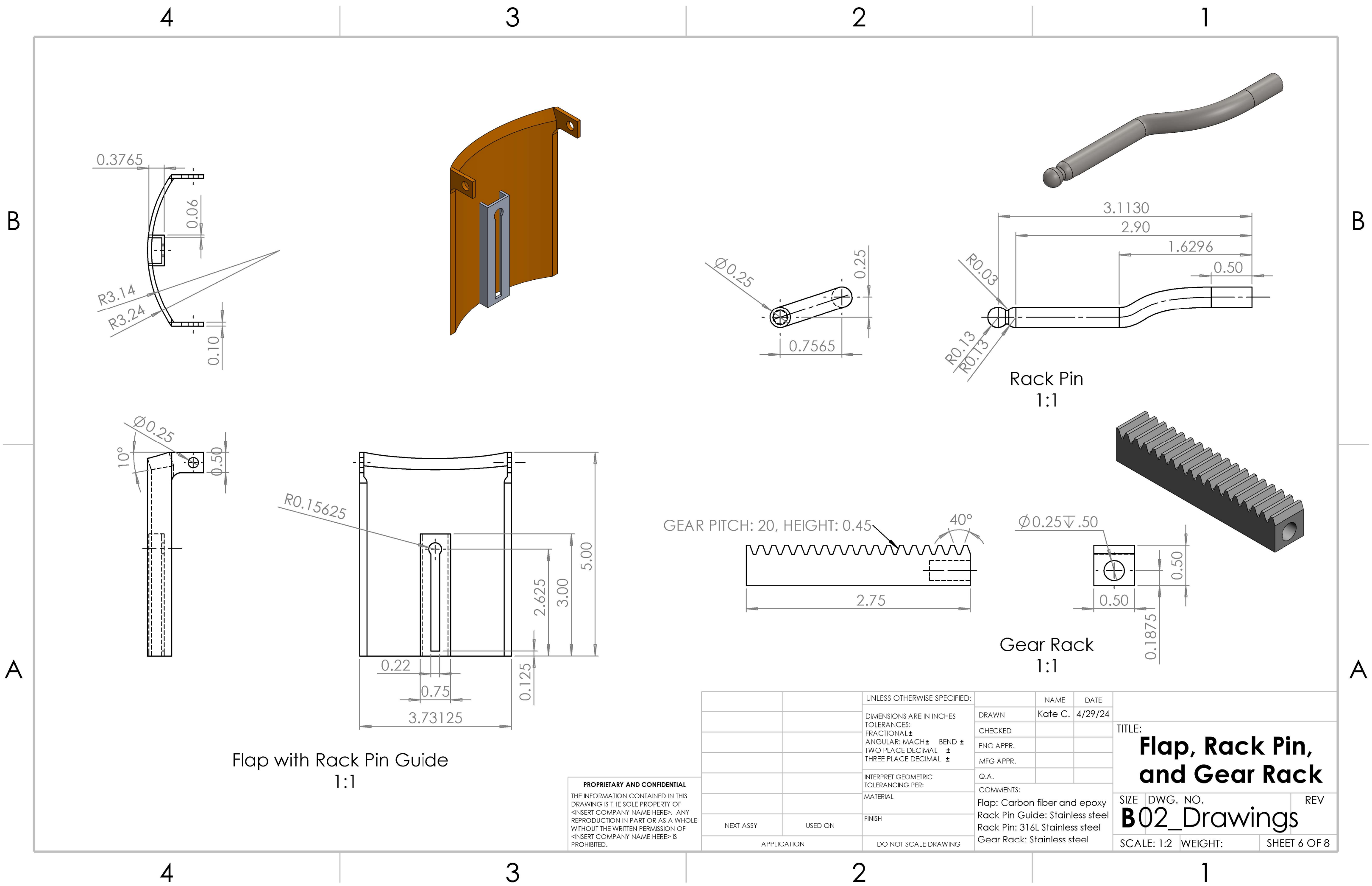
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5.00
3.00
2.625
0.125
0.22
0.75
3.73125
Flap with Rack Pin Guide
1:1
GEAR PITCH: 20, HEIGHT: 0.45
40°
2.75
Ø0.25↧.50
0.50
0.50
0.1875
Gear Rack
1:1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
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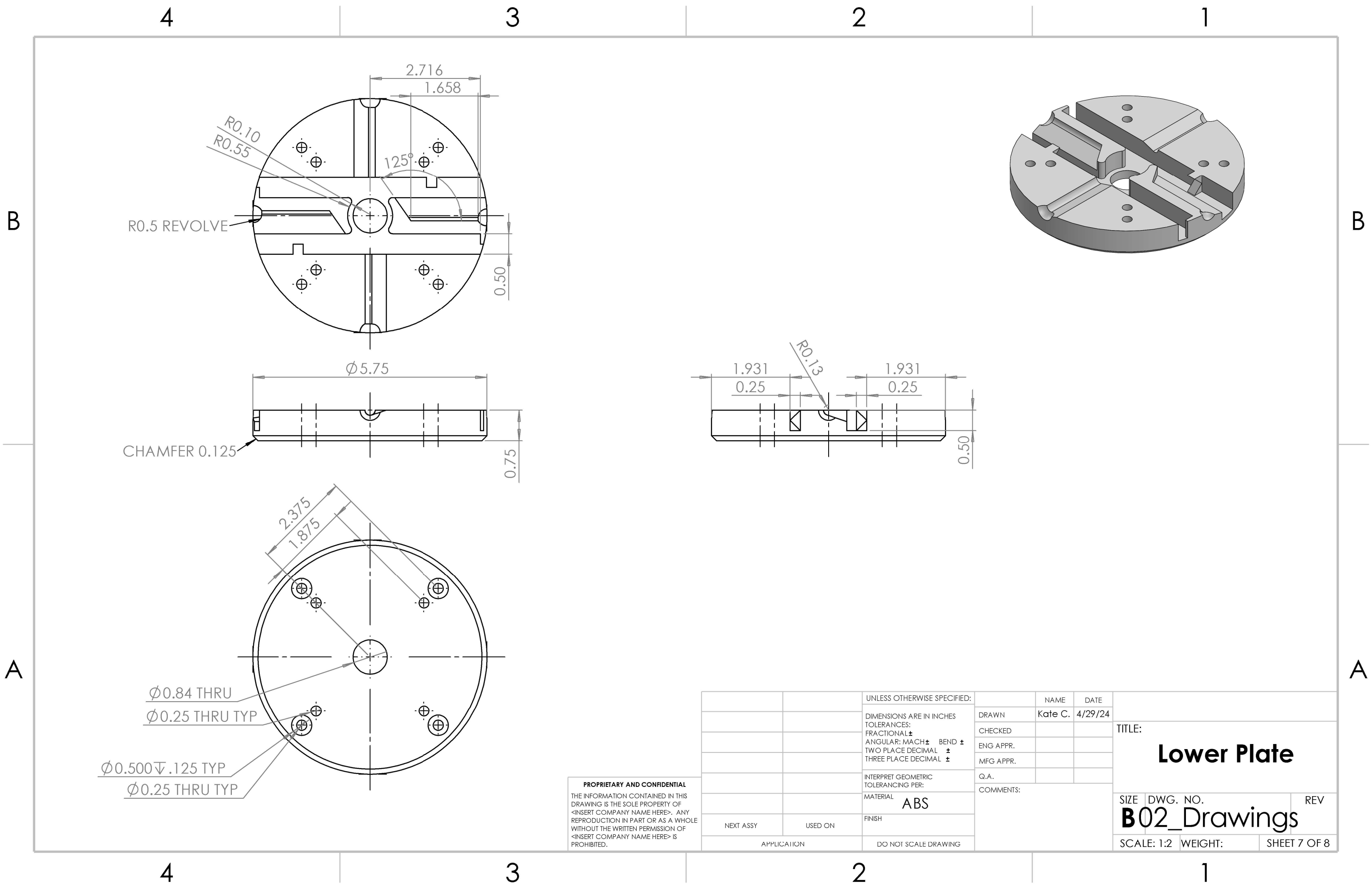
NAME
DATE
DRAWN
Kate C.
4/29/24
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Flap: Carbon fiber and epoxy
Rack Pin Guide: Stainless steel
Rack Pin: 316L Stainless steel
Gear Rack: Stainless steel
TITLE:
Flap, Rack Pin, and Gear Rack
SIZE
B
DWG. NO.
02_Drawings
REV
SCALE: 1:2
WEIGHT:
SHEET 6 OF 8


4
3
2
1
B
A
2.716
1.658
R0.10
R0.55
125°
R0.5 REVOLVE
0.50
Ø5.75
CHAMFER 0.125
0.75
1.931
0.25
R0.13
1.931
0.25
0.50
2.375
1.875
Ø0.84 THRU
Ø0.25 THRU TYP
Ø0.500 ↧ .125 TYP
Ø0.25 THRU TYP
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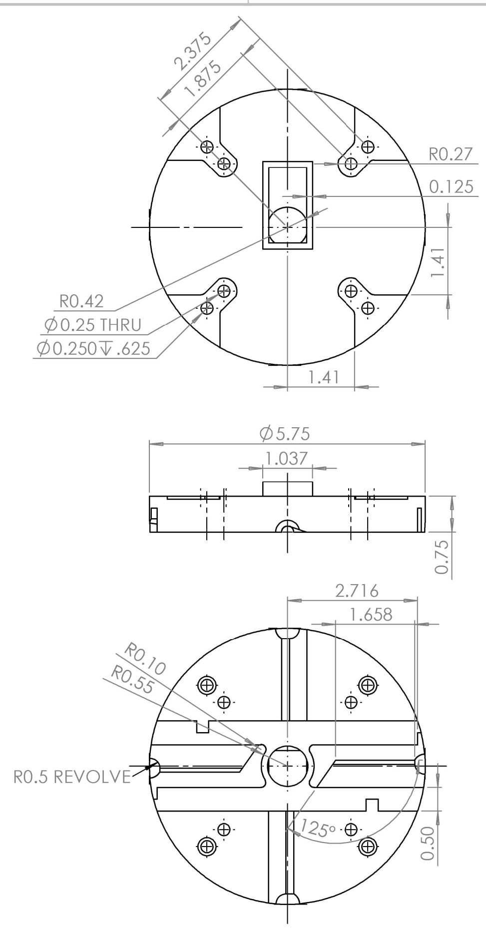
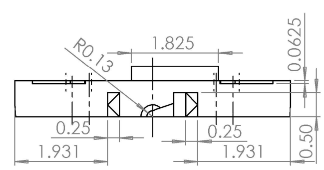
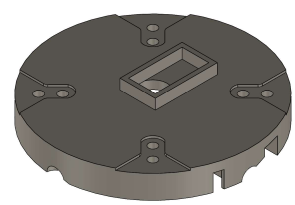
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ABS
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Kate C.
4/29/24
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Lower Plate
SIZE
DWG. NO.
REV
B
02_Drawings
SCALE: 1:2
WEIGHT:
SHEET 7 OF 8

4 3 2 1

B







B

A

A

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APPLICATION	

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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL ABS

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Kate C.	4/29/24
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

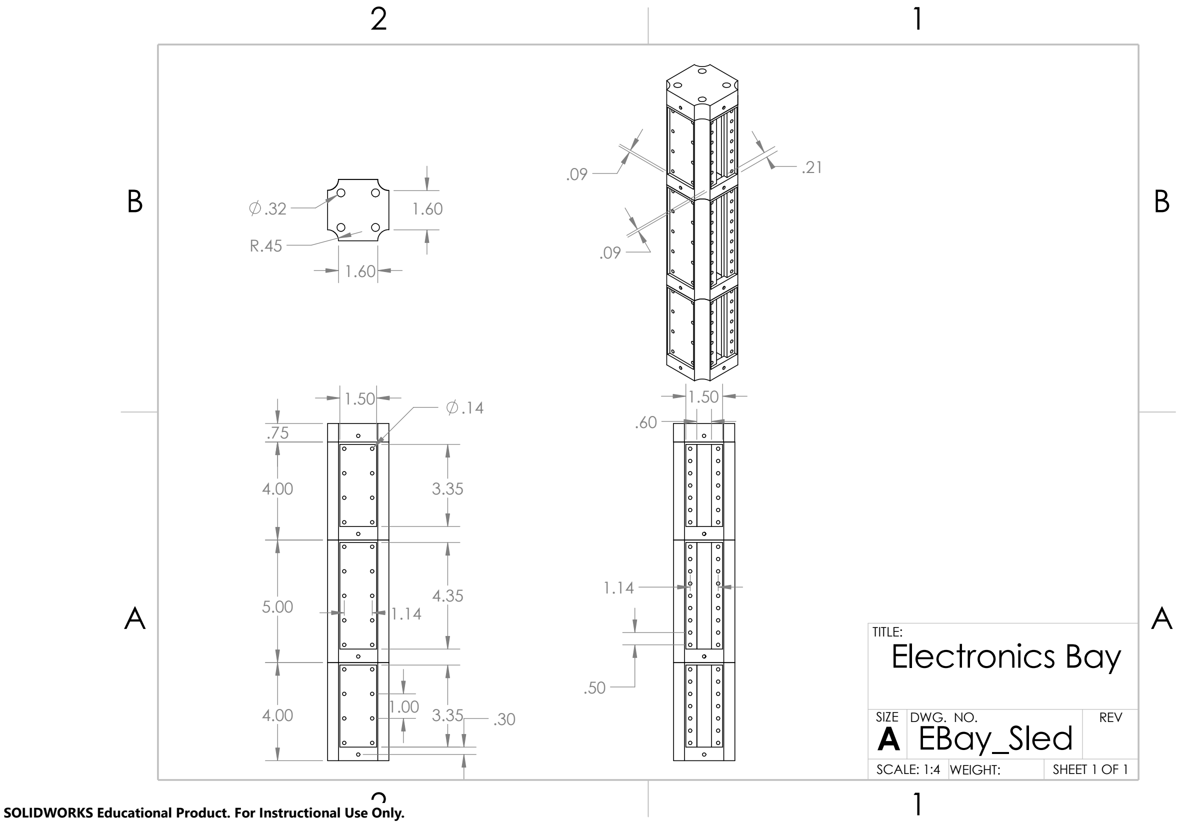
TITLE:

Upper Plate

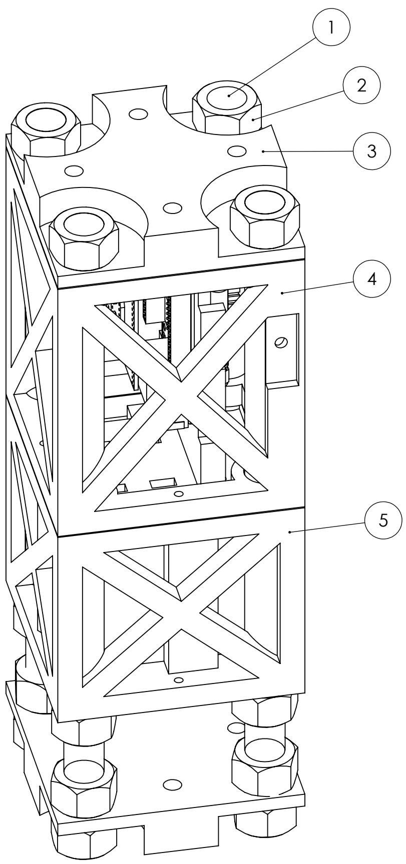
SIZE B DWG. NO. 02_Drawings REV

SCALE: 1:2 WEIGHT: SHEET 8 OF 8

4 3 2 1



TITLE:
Electronics Bay
SIZE A
DWG. NO. EBay_Sled
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
Ø.32
1.60
R.45
1.60
.09
.21
.09
1.50
Ø.14
.75
4.00
3.35
5.00
4.35
1.14
4.00
1.00
3.35
.30
1.50
.60
1.14
.50
SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO	PART	QTY.
1	5/8" Rod	4
2	5/8" Hex Nut	16
3	Endcap	2
4	Electronics Cube	1
5	Battery Cube	1

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

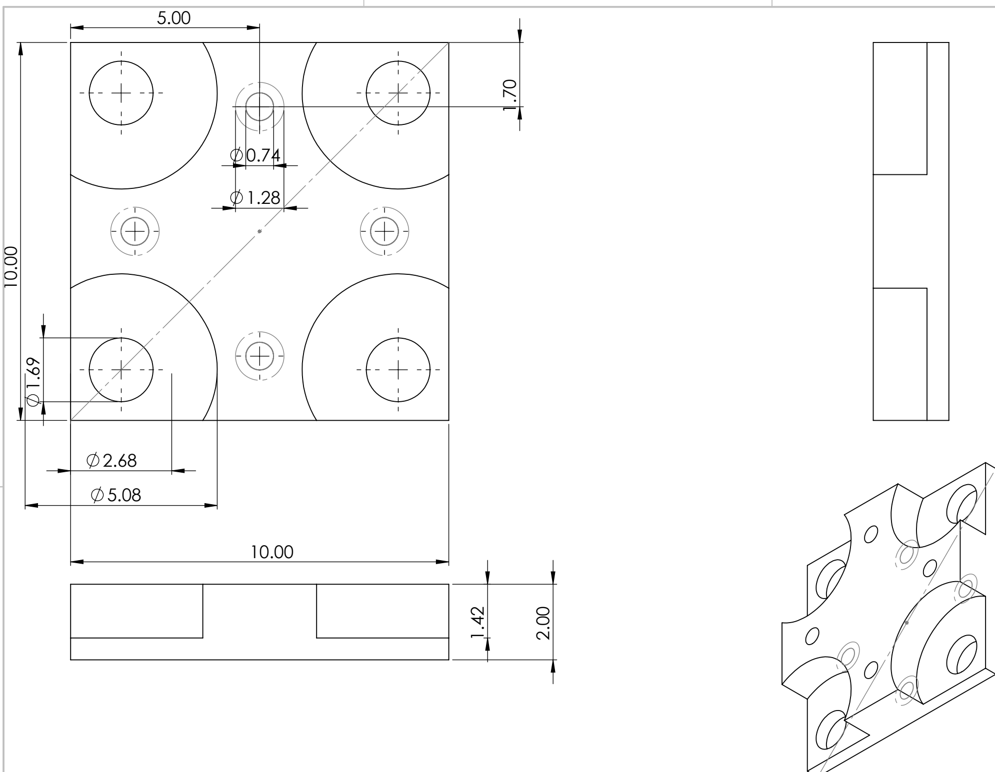
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE **B** DWG. NO. CubesatV1 REV

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH

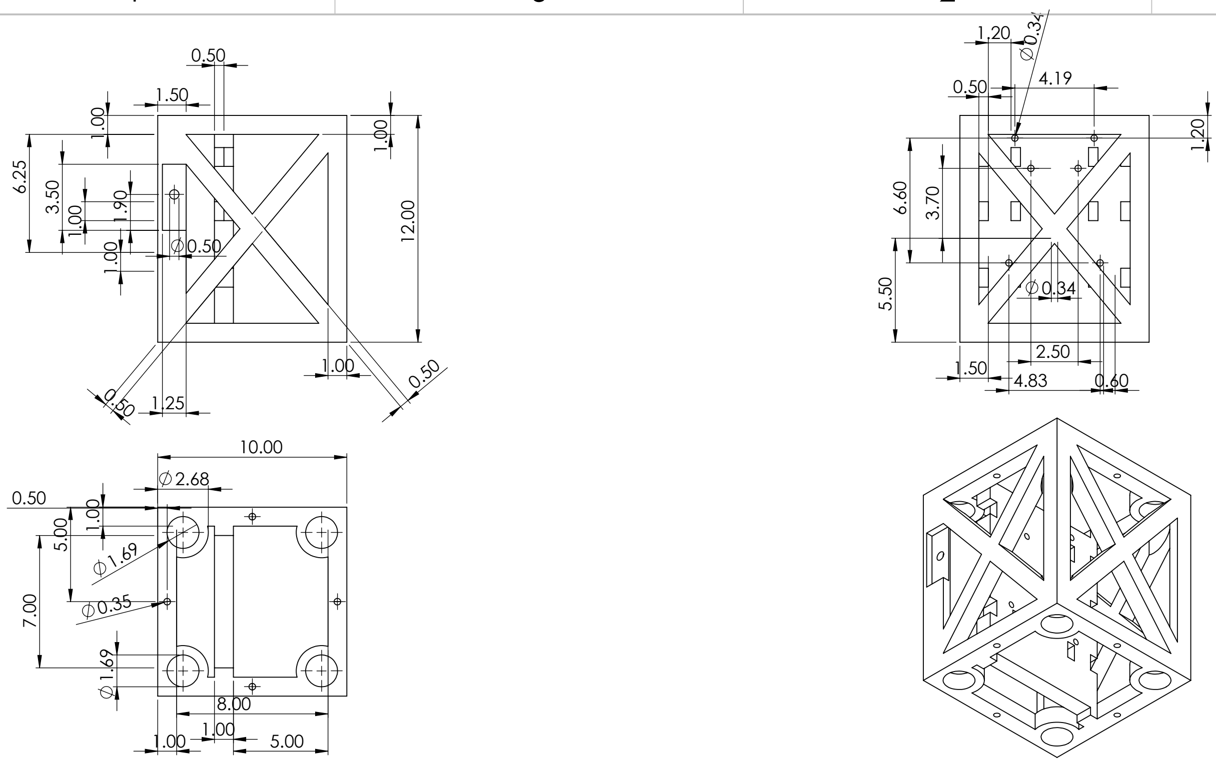
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

SIZE	DWG. NO.	REV
B	Endcap	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

4 3 2 1

B B



A A

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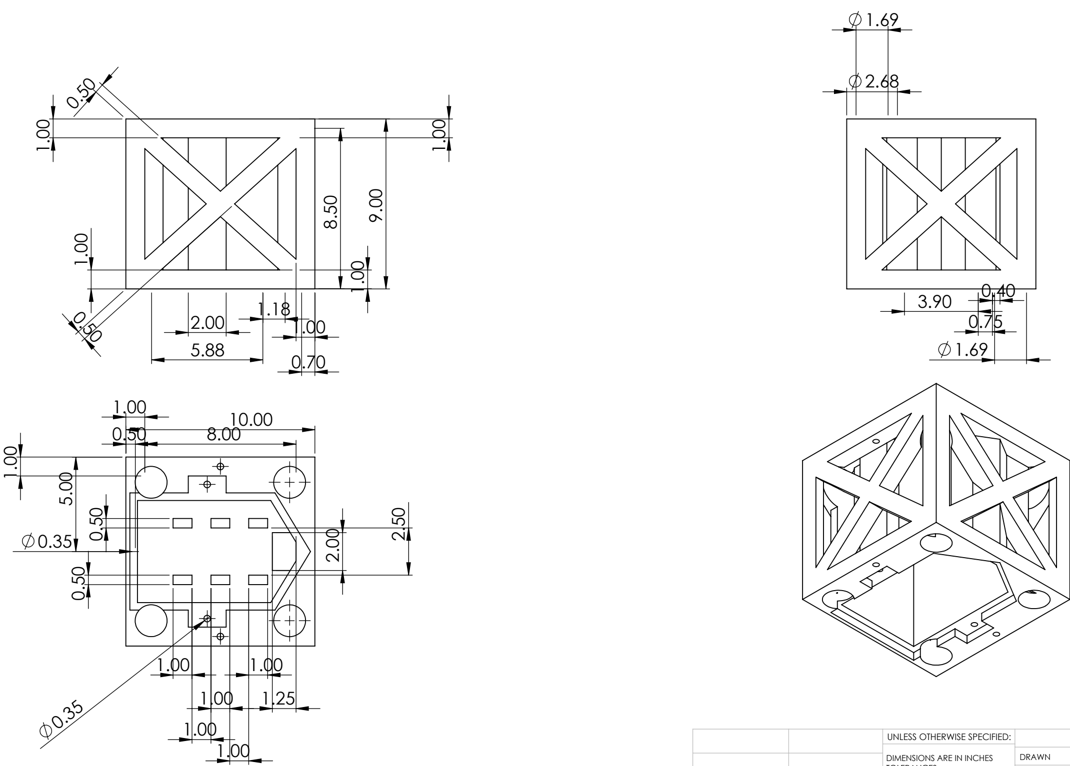
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE	DWG. NO.	REV
B	ElectronicsCube	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

4 3 2 1



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NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

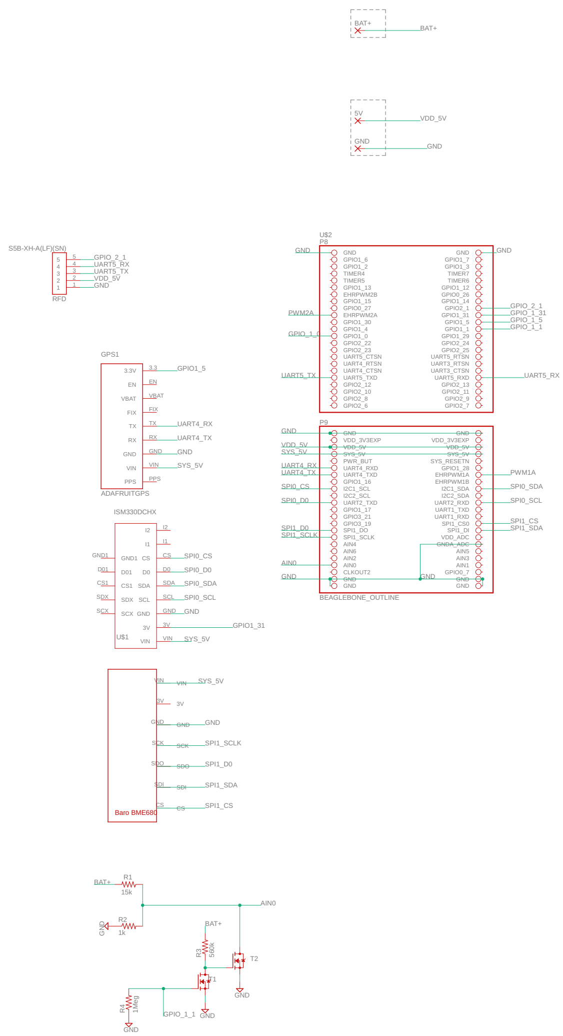
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	BatteryCube	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



References

[1] *"SkyAngle CERT-3 Series"*. URL: http://www.b2rocketry.com/.

[2] *AeroTech M2500T*. May 8, 2023. URL: https://www.thrustcurve.org/motors/AeroTech/M2500T/ (visited on 05/10/2021).

[3] Tim Van Milligan. "How to Calculate Fin Flutter Speed". In: *Apogee Components* (2011).