Team 103 Project Technical Report for the 2024 IREC

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The Tufts SEDS Rocketry Team ("Tufts Rocketry," "the Rocketry Team," or simply "the Team") is competing in the 10k COTS category of the 2024 IREC; this represents the Team's first ever entry. The rocket, known as the CubeSAT-Adorned Rocketry Masterpiece (CARM) is a six-inch-diameter, single-stage fiberglass rocket that will carry a prototype 2U CubeSAT to a target altitude of 10,000 feet, while testing the Team's custom Student Researched and Developed (SRAD) onboard flight computers. The intended CubeSAT payload was developed by the Tufts SEDS CubeSAT Team, in partnership with Tufts Rocketry. The payload originally aimed to test SRAD reaction wheels, gather motion and atmospheric data, and validate the chassis (primary structure) in a launch environment.

Throughout the project, the Team focused on designing a robust vehicle that would withstand the harsh New Mexico environment and provide a high tolerance for off-nominal flight conditions. To support this, the Team adopted a first-principles-based design approach: desired safety factors and the competition's technical requirements formed the foundation of all design decisions. The Team also set the ambitious goal of conducting three test flights before the competition, and have so far completed two, with a further one scheduled.

Both test flights saw the rocket recovered intact or with only minor damage. Crucially, the first and second test flights had an apogee prediction %error of 11.6% and 0.8%, respectively, compared to the flight simulations. As can be expected with such a complex project, technical difficulties with the SRAD flight computers have so far limited their scope, while several aspects of the project (including the payload) have suffered from long scheduling delays. Sadly, due to manufacturing, sourcing, and personnel issues, the CubeSAT payload's SRAD reaction wheels will not fly at the competition. The team is also prepared to replace the CubeSAT payload with an inert payload of the same mass and form factor if any payload problems arise. Despite all this, the successful test flight program means the Tufts SEDS Rocketry Team will compete in the 2024 IREC with a robust and capable vehicle.

I. Nomenclature

A_e = nozzle exit area
C_D = coefficient of drag
Cp = center of pressure
Cg = center of gravity
F_{thrust} = thrust force of motor
I = Impulse
m^* = mass flow rate
P_e = exit pressure
P_a = atmospheric pressure
t = time
v = vehicle velocity

v_e	=	propellant exit velocity
ρ	=	air density

II. Introduction

A. Academic program

The Tufts SEDS Rocketry Team is composed of undergraduate and graduate students from Tufts University in Medford, Massachusetts. Tufts University is a small liberal arts school that is best known for its International Relations program; however, it also boasts a capable School of Engineering (SoE). The Tufts SoE provides some direct financial support to the Team, as well as access to manufacturing laboratories and makerspaces. Although Tufts University does not offer any Aerospace program, the Tufts chapter of SEDS (Students for the Exploration and Development of Space) enables the existence of a thriving de-facto aerospace community. As a result, a large portion of Tufts Rocketry's members are currently studying mechanical engineering with a demonstrated interest in aerospace. Tufts University teaches a significant portion of the skills required for this project, but SEDS and specifically the Rocketry Team hold a variety of workshops to cover the knowledge gaps and ensure the Team is well-educated and well-prepared.

B. Stakeholders

The primary stakeholders in this project are the students who have worked tirelessly all year to bring the CARM project to fruition. For many, especially for subteam leads, this project is highly personal and a significant point of pride. It is also an excellent showcase of technical and engineering ability that the entire Rocketry Team is very proud of, and represents a significant step forwards from the Team's previous rocketry projects. The Team's Mentor and Flier of Record, Samuel Fineberg, has also been a kind, helpful, and encouraging advisor who has played a significant part in helping the Team succeed.

The larger Tufts University community is also an involved and important part of the project. A collection of professors, department chairs, and other faculty all provide support, advice, and technical resources for various parts of the project. These stakeholders generally operate within their narrow but deep fields of expertise, providing the Team with a wealth of knowledge and ideas. The Team's faculty advisors are among these; they provide helpful feedback at major design reviews and throughout the general design and assembly process. Additionally, the Tufts SoE is directly invested in the project's outcome and publicizes the Team's significant milestones. This extends the interest to the Tufts community at large, bolstering support and increasing excitement. A good deal of this support comes from the larger SEDS community, where students interested in tangentially related aerospace projects support their peers and friends working on the CARM project.

The Rocketry Team's external sponsors have a vested interest in the Team's success and in seeing individual members learn valuable engineering and project skills. The Team's talent pool is appealing to engineering companies, while team members who receive internships or jobs at said sponsor companies learn a great deal of highly applicable skills that they then bring back to the Team.

Finally, and most importantly, the friends and family of the Rocketry Team's members have provided enthusiastic emotional and financial support throughout the CARM project. This unwavering support has provided an important backstop for team members during intense and stressful periods (e.g. pre-launch "crunch time" preparations) pulled the project through difficult times and contributed greatly to the success of the CARM project.

C. Team structure

Although the Tufts SEDS Rocketry Team has two co-leads (Nico Moldovean and Bode Wildgrube), the specific leadership structure for the CARM program (shown in Fig. 1, below) includes only one Team Lead, to allow for Bode Wildgrube simultaneously leading the electrical subteam. The Team Lead is responsible for all systems engineering, high-level design, accounting, and parts procurement. Moreover, the Team Lead must understand and effectively communicate subsystem requirements to each individual subteam, as well as delegating any appropriate tasks. Each subteam lead is responsible for designing, developing, building, and integrating their respective subsystem. The body of subteam leads and Team Lead meet weekly outside of the general Rocketry Team meetings to discuss progress, address issues, and improve cross-subteam collaboration on key systems. This leadership body also maintains a robust communication channel to ensure the Team runs smoothly and efficiently. The specific subteams, as well as their respective responsibilities and deliverables, are listed below.

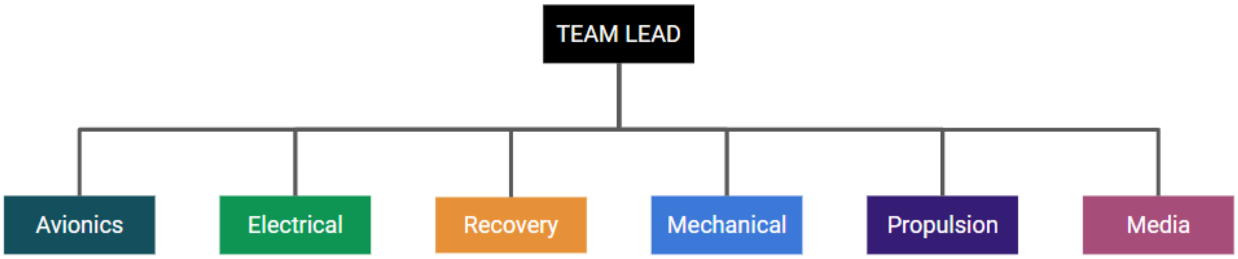


Fig. 1 Tufts SEDS Rocketry Team Leadership Structure

1. Avionics & Telemetry Subteam

The Avionics & Telemetry subteam receives and analyzes all telemetry from the vehicle during and after flight. In support of this, the subteam is responsible for programming the SRAD flight computers. These computers gather key data on the rocket's position (and derived values velocity and acceleration), atmospheric conditions, and vehicle health. The SRAD computers also control several of the onboard cameras and are responsible for transmitting all flight data to the ground station. In support of this, the Avionics & Telemetry subteam is also responsible for developing and programming a working ground station and information dashboard to track vehicle health and performance before, during, and after the flight.

2. Electrical Subteam

The Electrical subteam is tasked with designing, building, and integrating all circuits on the rocket. This includes the wiring and setup of the COTS flight computers, batteries, switches, and onboard cameras. Notably, the Electrical subteam works closely with the Avionics subteam to identify requirements for the SRAD flight computer, then completes the Printed Circuit Board (PCB) design. This is followed by soldering, wiring, and testing of all SRAD flight computer PCBs. It is the Electrical subteam's responsibility to deliver functional flight computer hardware that the Avionics & Telemetry subteam can then program. The Electrical subteam also works closely with the Recovery team to operate the COTS backup flight computers and provide wiring interfaces for ejection charge igniters.

3. Mechanical Subteam

The Mechanical subteam is responsible for the design, testing, and construction of the airframe and all internal mechanical components. Based on high-level design parameters determined by the Team Lead and competition requirements, the Mechanical subteam makes all the 3D Computer-Aided Design (CAD) models for the rocket, maintains version control of critical parts, calculates expected failure criteria, and simulates critical loads using Finite Element Analysis (FEA) software. The Mechanical subteam must ensure that the airframe can be properly integrated with all other subsystems, and particularly that the Electrical, Avionics & Telemetry, and Recovery subsystems are provided with secure mounts that minimize loading on key components. The waterjet cutter, manual lathe, CNC mill, and Bridgeport (manual) mill in Tufts University's Bray Laboratory are the Mechanical subteam's most-used manufacturing tools.

4. Media Subteam

The Media subteam is responsible for providing visual engineering data for performance analysis, as well as images and videos for promotion, outreach, and thorough visual documentation for the Team's own benefit. In support of this, the Media team is tasked with taking closeout photographs of key assemblies (e.g. the avionics bay, the motor assembly, and the fin assembly) that can be analyzed at a later date in case of failure. Slow-motion videos of ignition and liftoff, as well as onboard video footage that can be directly compared with flight telemetry for useful analysis, are also the Media subteam's responsibility.

5. Propulsion Subteam

The Propulsion subteam handles all operations concerning the rocket motors. Because the Team currently only flies COTS solid motors, the propulsion subteam does not conduct any motor development. However, key responsibilities include safely handling the motors at all times, inspecting the motors for damage, integrating motors prior to launch, and maintaining the motor casing hardware. Additionally, the propulsion team determines motor selection based on high-level desired flight parameters and works directly with the Mechanical team to ensure the motor can be mounted safely and securely inside the airframe.

6. Recovery Subteam

The Recovery subteam is tasked with returning the rocket to the ground safely and in good condition. In support of this, the Recovery subteam sews custom harnesses, folds and integrates parachutes and recovery gear prior to launch, handles and integrates all deployment energetics, and works with the Electrical subteam to ensure a proper setup for firing ejection charges is in place. The Recovery subteam also repairs and maintains all recovery gear to ensure

Note: The Rocketry Team also includes a small logistics team, which operates semi-independently of the leadership structure outlined in Fig. 1, and reduces the logistics load on the Team Lead and subteam leads. This logistics team was incorporated partway through the 2023-2024 academic year and has therefore not yet been fully integrated into the team rocket program. However, as the team continues to grow in subsequent years and logistical challenges increase both in scope and complexity, the logistics team will become fully integrated into the rocketry leadership structure.

D. Team Management Strategies

1. Personnel Management

The Team is primarily managed in a joint effort between the Team Lead and body of subteam leads described in the previous section. All subteam leads are equally positioned within the leadership board, while the Team Lead maintains additional veto power over measures that require a vote or over an individual subteam's design choices. However, in practice the team operates cohesively on a good-faith basis: for key decisions the parties involved will jointly choose the course of action that most closely supports the project's end goals and the health and happiness of Team members. The Team Lead's only additional management responsibility is to make driving decisions concerning team operations (e.g. choosing a target launch date, organizing a design review, or making high-level design choices), while delegating responsibilities to all subteams. During general meetings and separate subteam meetings, each subteam lead is responsible for overseeing their own members and ensuring their adherence to good design practices. Whenever possible, the Team Lead supplements this and routinely checks in with each subteam to ensure any safety, technical, or schedule issues are properly addressed.

2. Schedule and Project Management

In order to properly track and organize progress, the Team Lead consults project requirements and subteam leads to develop a feasible target schedule, and continually updates the schedule based on the team's current progress. During the Rocketry Team leadership body's weekly meetings, each subteam lead will give an update on their respective subteam's progress, key outstanding issues, and plans to mitigate those concerns. This allows the Team Lead to and other subteam leads to point out any mistakes and suggest improvements, while ensuring the subteam leads maintain clear weekly progress goals.

Check-in meetings with the Team's faculty advisors and mentor happen on an ad-hoc basis (when project problems or uncertainties arise), and during team design reviews. The faculty advisors maintain extremely minimal direct management over the team, but provide useful advice and direction when required. Faculty advisors also assist in forming a direct liaison between the Team and Tufts University.

3. Documentation and Revision Control

The Rocketry Team maintains a Google Drive folder (within the Tufts SEDS google drive) dedicated to the CARM project. This folder (which is shared with all team members) contains all the current information on the project that is not documented in official communications channels. The Google Drive allows subteams to maintain documentation in a central location accessible to the entire team, facilitating team operations and cross-subteam collaboration. Select access-controlled folders (which are still viewable by all members) hold important revision control information on OpenRocket flight simulations and other important documents. For CAD version control, the Team uses OnShape's built-in revision control to track changes and ensure changes are properly reviewed before parts are manufactured. Finally, select documentation is added to the public Tufts Rocketry Notion page, although this is currently a work in progress.

4. Financial Management

The team independently tracks their own inventory and finances; the controlling documents for this are viewable by all subteam leads, streamlining procurement processes and allowing efficient re-ordering of parts previously ordered. All purchases need to be approved by the Team Lead (or the Tufts SEDS Treasurer) and the Tufts Community Union (TCU) Treasury, and parts must be purchased with the oversight of the Campus Life Financial Office (CLFO). This ensures that the team follows sound business and spending practices which are crucial to maintaining the financial health of a costly and complicated project.

5. Part and Process Control

For all manufactured parts, and manufacturing processes that require a specific technique (e.g. fiberglass preparation), the appropriate subteam lead will ensure adherence to the intended design, tolerances, quality, and procedures. Team Lead (functioning as a de facto Safety Lead) will also provide their approval. Once a part is manufactured and inspected, it is clearly labeled with either the part information and key dimensions, or with the words "NOT FOR FLIGHT" in the case it is deemed unsafe or otherwise inadequate. For subassemblies that contain multiples of certain parts (e.g. the four fins in the fin assembly), each separate part is labeled with its relative position within the assembly. Any parts that incorporate any symmetry or pseudo-symmetry about the X-Y plane are labeled with Z+ and Z- on their top and bottom surfaces, respectively.

Specifically for assembly and integration processes, the Team Lead and subteam leads continually ensure that processes are strictly adhered to and any deviations are recorded. For procedures under development, the members responsible for developing the procedure will document it and refine it until a set procedure can be finalized. Given the scale of the CARM project and the wide variety of manufacturing techniques involved, many of which were more new to the Team, development work is ongoing on many of these procedures. Once fully defined, a procedure will be officially documented in the shared Google Drive folder and must be adhered to by all members.

III. Systems Architecture Overview

The CubeSAT-Adorned Rocketry Masterpiece (CARM) is a six-inch-diameter, single-stage fiberglass rocket that employs a dual-separation, dual deploy architecture. The primary goals are to carry a prototype 2U CubeSAT to 10,000 feet, while testing the Rocketry Team's custom SRAD onboard flight computers.

The six-inch architecture is the smallest diameter that allows for the payload to maintain a CubeSAT form factor, in order to allow for an inert "dummy" payload to be launched as a backup option. Based on estimated vehicle masses and performance metrics, the team chose 98 mm as the motor diameter for the IREC, maintaining the option to launch lower-altitude test flights on smaller 76 mm motors with the help of a COTS motor adapter. Fiberglass was the material of choice for the airframe due to its durability, strength-to-weight characteristics, RF transparency, and frequent use in other large high-power model rockets. Throughout the CARM project, the Team focused on using SRAD parts wherever possible to improve performance and increase student involvement. However, the base composites for the airframe were all sourced from commercial vendors because the Team does not currently possess the requisite composite manufacturing capabilities. Therefore, standard COTS fiberglass airframe components were used to lay out the preliminary vehicle mass and dimensional constraints.

The Team decided to choose a simple, reliable, and robust design, at the expense of space or launch mass efficiency. The justification for this was two-fold: first, as the Team's first ever entry into the IREC, a simple and reliable design was understood to significantly increase the Team's chances of success. Secondly, significant priority was given to designing for aggressive, off-nominal flight profiles, especially high temperatures, deploy speeds, and landing speeds. This design priority was chosen to lessen the impact of any off-nominal flights, and create a vehicle that is very thoroughly designed. The result is that certain components (e.g the airframe bulkhead assemblies and the fin can) are heavier than intended, but the additional security buffer provided was deemed to be more valuable than the marginal performance gains.

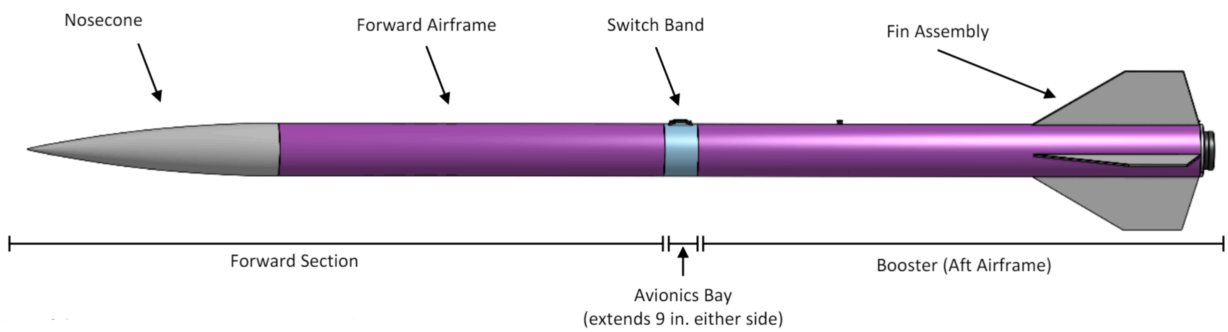


Fig 2. Fully Assembled CARM Vehicle

The integrated vehicle is shown in full in Fig. 2, with Fig. 3 showing a cutaway to highlight the internal systems. The motor mounts in the aft airframe, or "booster" section, and is fastened in place by a COTS motor retainer mounted to the booster thrust plate. The drogue parachute sits in the booster section just below the avionics bay, and deploys at apogee. The avionics bay houses all the flight computers, electronics, batteries, the majority of the sensors, and the three external onboard cameras. The deployment energetics are mounted to the bulkheads at each end of the avionics bay. The bottom compartment of the forward airframe houses the main parachute and harness assembly. Separated from the main parachute compartment by a bulkhead, the payload sits just above, mounted in a cylindrical payload adapter. Both the intended CubeSAT payload and the backup dummy mass occupy a 2U volume, allowing them to be easily and quickly interchanged. Finally, the nosecone houses an independent GPS tracker system to aid in rocket recovery. Although the nosecone does not deploy during flight, it can easily be removed to switch out the GPS system batteries and to integrate the payload.

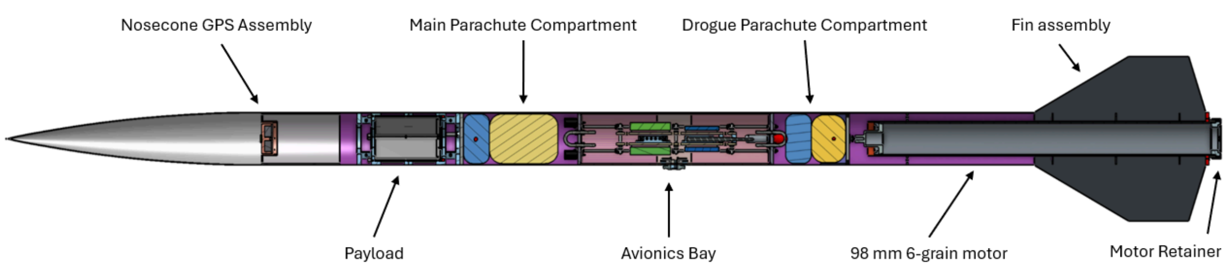


Fig 3. Cutaway View of CARM Internal Components

This overall mission architecture also prioritizes simplicity of integration and recovery. Although the two separation events slightly increase airframe complexity, the recovery configuration for each is significantly simpler, decreasing the chances of the harness tangling. In terms of the airframe proper, each section is short enough to be comfortably carried by one person or transported in a passenger vehicle, facilitating transport and integration operations. However, the relatively cramped parachute compartments result from these architecture-level design choices, and increase the importance of careful pre-flight parachute folding and harness reefing.

A. Propulsion Subsystems

The main propulsion system for the CARM project is a 98 mm diameter COTS solid motor. The motor which the Team intends to fly at the 2024 IREC is the Cesaroni Technologies Incorporated (CTI) N2600. Once the propellant and inert motor components are loaded into the motor casing, the casing can be slid into the booster's motor mount tube until the lip of the thrust ring is resting against the COTS RA98 Aeropak adapter. This adapter is bolted directly to the thrust plate, which in turn communicates the thrust loads directly into the airframe walls.

During very early design and simulation iterations, the 98 mm motor architecture was chosen because there were no 75 mm diameter motors with sufficient impulse to be able to carry the rocket to its target altitude of 10,000 feet. To choose a specific motor for the IREC, the Team simulated several motors in the initially assumed impulse range, and continually updated those simulations as the design and construction progressed. Once more concrete and accurate masses could be determined, the Team originally chose the CTI N2200, which was simulated to bring the rocket to within 1% of the target apogee. However, this particular motor could not be sourced in time for the competition, so the Team was forced to reevaluate and choose another motor. The Team analyzed motors of the same diameter and similar impulse from both Aerotech and CTI. However, none of the motors lined up exactly with the desired flight profile, and the Team was forced to choose between a motor that was expected to overshoot apogee by 10%, or one that the simulation indicated would undershoot apogee by 5%. For the motor which was expected to overshoot, the Team considered altering the vehicle properties to improve the apogee estimate. Active aerodynamic components were not an option, due to the vehicle's simple architecture and the Team's limited time; passive aerodynamic components were deemed too complicated to accurately simulate and properly test in time for the competition. Hence, the Team decided to accept the slight performance hit and chose the CTI N2600. Although unclear, there was some hope that the Spaceport America launch site's initial altitude of 4,600 feet would slightly improve the performance of the motor compared to the simulation. This is because all organizations that certify model rocket motors in the United States must comply with the National Fire Protection Authority document NFPA 1125, which states that motor testing must be "done at, or corrected to, sea level and a temperature of 20∘C (68∘F) [1]. The motor's thrust is determined by the equation (1), where

$$F_{Thrust} = m^{*} \bullet v_e + (P_e - P_a) * A_e . \quad (1)$$

F_{thrust} is the force exerted by the motor; m^* is the mass flow rate, v_e is the exit velocity of the combustion products, P_e and P_a are exit and atmospheric pressures, respectively, and A_e is the area of the nozzle exit plane. Given that the mass flow rate and exit velocities are intrinsic to the motor, and the area of the nozzle exit does not change, the only quantities that change are the pressure differences between the exit and atmospheric pressures. The higher altitude and increased temperature at the Spaceport America launch site should therefore cause a higher change in pressure and an increased thrust compared to the sea level thrust curve. The OpenRocket simulation documentation appears to ignore this discrepancy, which theoretically should result in a slightly higher motor thrust, and therefore higher impulse, based on the simple equation

$$I = F_{thrust} \bullet \Delta t, \quad (2)$$

where I is impulse and Δt is the motor burn time. This would correlate to a slightly higher apogee. To achieve a quantitative analysis, an existing thrust curve could be adjusted based on equation (1) and reasonable launch condition estimates and then re-simulated; however, time constraints prevented this and a qualitative analysis was deemed sufficient for the Team's purposes.

Notably, the N2600 motor incorporates a titanium sponge into the propellant, making it a "sparky" motor. To account for this, additional elements were added to the pre-launch and pad preparation procedures to ensure the removal of dry brush and debris which could easily be ignited on launch.

The thrust plate interface was originally designed to handle a 5,600N thrust load with a safety factor of 1.5, resulting in a maximum allowable load of 8,400N. The thrust design value was chosen to increase flexibility of motor choice, since the thrust plate was designed early on, before the exact motor was selected. The safety factor was chosen based on the standard adopted by the team for the majority of components, and in this case allows room for motor overperformance, material defects, manufacturing errors, and FEA simulation discrepancies when compared to real-world loading scenarios. However, this increased flexibility and capability comes at a weight penalty for the overall part. The positive motor retention mechanism (epoxy between the thrust plate and the airframe) was incorporated directly into the thrust plate to reduce the total number of components. The alternative option of a forward-end retention would have also required more space inside the booster, which was already extremely limited.

Finally, as mentioned previously, the 98 mm motor mount tube architecture allows the option to fly a 75 mm motor using a COTS motor adaptor. Given the Team's location near Boston, Massachusetts, far from launch sites with very high ceilings, the option to use 75 mm motors allows for increased test flight flexibility, and practice flights at lower altitudes and speeds until the Team has enough confidence to attempt competition-scale flights.

B. Aero-Structures Subsystems

All external airframe components, besides the aluminum nose cone tip, are entirely made from fiberglass. The nose cone, forward and aft airframes, motor mount tube, switch band, and avionics bay are all constructed from COTS G12 fiberglass tubing. G12 tubing consists of glass filament wound into a tube at a variety of angles to provide strength in multiple directions. The fin assembly, which includes the four fins, centering rings, and alignment ring, is made from COTS ⅛" G10 fiberglass sheets, which are cut both manually and via waterjet cutter. These fiberglass composites have many desirable material properties, including stiffness, compressive strength, and relatively low weight. They are also easy to modify with common workshop tools and serve as an excellent base for additional external fiberglass layups.

Robust design and construction of the fin assembly is a critical component of ensuring a successful launch. To achieve this, 0.5 in. epoxy fillets were applied along the length of each fin. A 5-layer tip-to-tip layup was also performed. This layup, applied in an alternating 0°- 45° - 0° orientation to minimize unwanted anisotropy, features four layers of 7.5 oz fiberglass and one layer of 2 oz fiberglass. The layup was applied with Fibreglast System 2000, which exhibits excellent thermal and mechanical characteristics. Fin flutter is a key parameter that must be evaluated. The factor of safety can be approximated with knowledge of the geometry, material properties, and anticipated maximum speed. Given the 0.125 inch thick fiberglass fins, a 0.05 inch-thick layup, and the expected maximum velocity of 908 feet per second, the factor of safety is approximately 3. This number is difficult to calculate exactly, due to the anisotropy of the fiberglass-layup-filet combination. The high fin flutter velocity safety factor is a by-product of the robust fin assembly design, chosen to maximize chances of surviving a hard landing. This provides an additional weight and therefore performance penalty, but the higher chance at recovery success was deemed well worth it.

The fin assembly is mounted to an SRAD thrust plate manually turned and milled from 6061-T6 aluminum. The thrust plate communicates the motor thrust directly into the airframe walls. It is secured inside the aft airframe via 2.5-inch-tall grooved and roughed bosses (each measuring 0.05 inches deep) that provide ample area for adhesion via high-strength epoxy. As mentioned previously, the thrust plate was designed to a maximum load of 5,600N with a safety factor of 1.5, and the design was validated with FEA. Due to the eventual choice of a lower-power motor, and the resulting high safety factor (2.8, specifically), physical load testing was deemed unnecessary.

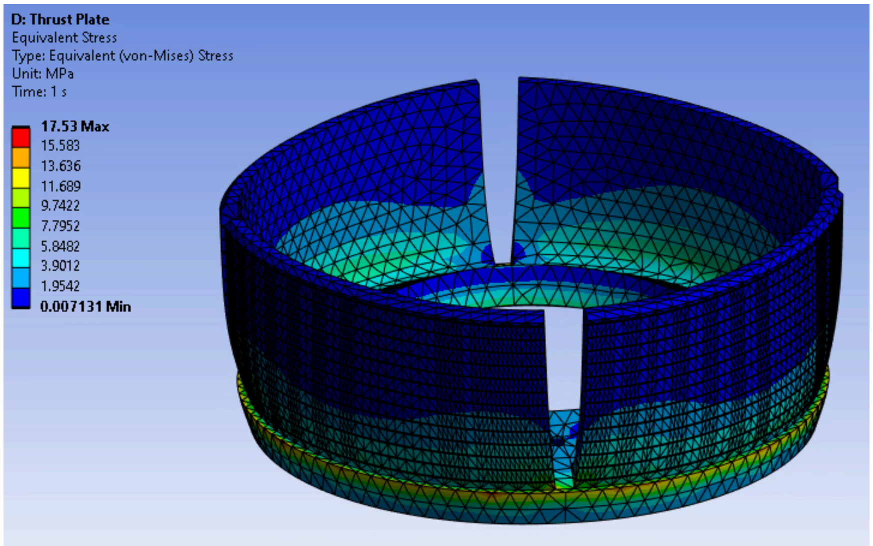


Fig. 4 Finite Element Analysis of Thrust Plate

The thrust plate must be capable of withstanding the force of chute deployment while retaining the spent motor inside the airframe.The thrust plate can withstand a scenario of a 8G chute deployment, with the force applied directly along the length of the aft airframe, with a factor of safety of approximately 2.1. This slightly higher safety factor was chosen to eliminate any problems with adhesion between the aluminum thrust plate and fiberglass airframe, since the total coverage area of the epoxy could not be properly verified (i.e. in the case small voids formed and reduced the connection area).

Aluminum bulkheads are used to partition the airframe, attach recovery hardware, and provide secure mounting points for the rail button and payload. There are five bulkheads throughout the vehicle: the aft airframe bulkhead above the motor, the two avionics bay bulkheads at either end of the avionics bay, the forward airframe bulkhead beneath the payload, and the payload bulkhead. These bulkheads are made of ⅜" aluminum 6061-T6 due to its strength, affordability, light weight, and workability. The avionics bay bulkheads are machined using a CNC mill, to incorporate more complicated geometry associated with the mounting of the CO_2 deployment system. All other bulkheads are machined using a waterjet cutter to improve manufacturing efficiency and allow for quick iteration if required. The aft, forward, and payload bulkheads are affixed to the main airframe via eight #6 screws while the avionics bay bulkheads are fixed to the avionics bay via nuts and four ¼"-20 steel all-threads that run the length of the avionics bay. To prevent tear-out of the bulkheads during parachute deployment, a bulkhead stop ring (a 3"section of G12 fiberglass coupler tube) was epoxied on the parachute side of each bulkhead; this also improves the forward airframe bulkhead's ability to safely withstand the payload weight under high acceleration loads, since the loads will travel through the bulkhead stop ring instead of only through the airframe attachment screws. With the exception of the payload bulkhead (which must simply retain the mass of the payload), each bulkhead has been evaluated to withstand a load of 1075 pounds through a U-bolt mounted at the center of the plate. Due to the relatively complex geometry, this was done via finite element analysis (FEA) in Ansys Mechanical. To ensure maximum accuracy, a mesh convergence study was conducted for each part.

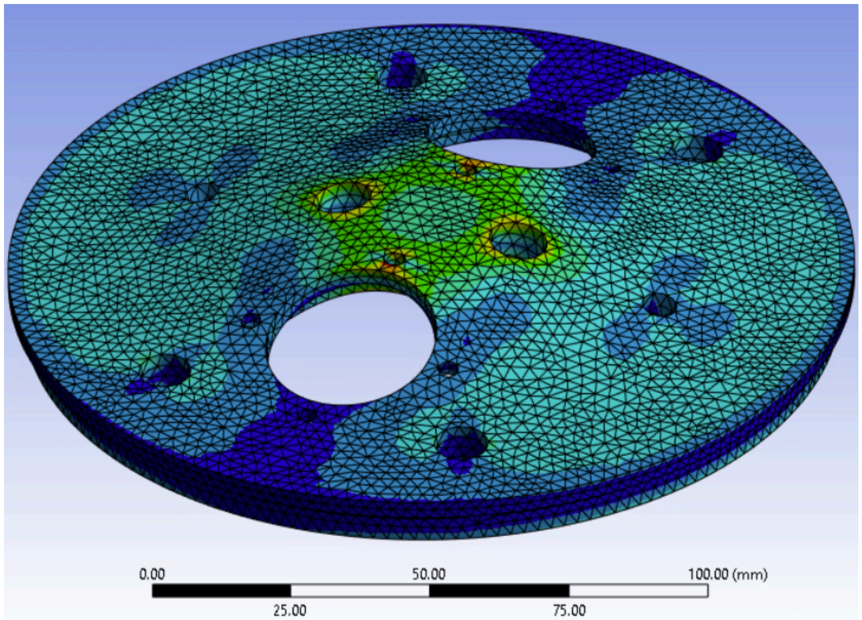


Fig. 5 Finite Element Analysis of Avionics Bay Bulkhead

The avionics bay is a critical subcomponent of the airframe, as it contains much of the electronics vital to the mission's success. Besides the rigorous FEA assessment of the bulkheads and the choice of robust G12 fiberglass already discussed, much care has been taken in the design of the avionics bay to reduce risk of failure. Lock nuts have been implemented to maintain positions of components, and rubber washers are used to reduce vibrations where possible. The electronics are all mounted to thick ¼" sheets of plywood that are reinforced with custom aluminum braces that mount to the steel all-threads that run the length of the avionics bay. The batteries are kept in dedicated enclosures with high-infill 3D prints that are oriented to minimize delamination risks and are capable of withstanding many times the weight of the battery packs.

The payload is secured via a 3D-printed ABS adapter sandwiched between the forward airframe and payload bulkheads. This ABS adapter has been tested on an Instron 68-TM50 in compression to withstand the mass of itself and the payload during chute deployment without signs of failure. Further analysis with Ansys FEA tools corroborates this assessment.

C. Recovery Subsystems

The recovery scheme for this rocket is a rather simple dual deploy method. A 36 inch ballistic drogue parachute will deploy at apogee and a 96 inch iris ultra main parachute will deploy at 1200 feet. Both parachutes are COTS, hemispherical nylon chutes. Each harness is a 11/16" tubular nylon harness connected to U-bolt in a bulkhead or to a swivel link on the chute with a quick link. The main separation will occur between the avionics bay and the forward airframe, the drogue separation will occur between the aft airframe and the avionics bay. The harnesses closest to the avionics bay are the shortest to ensure the harnesses become fully taut and pull the parachutes out of the airframe. The harnesses attaching the parachutes to the forward and aft airframe are longer to prevent collision with the chutes or the avionics bay. The harness lengths and connection points are as follows:

- Forward to main - 40 feet
- Main to avionics bay - 10 feet
- Avionics bay to drogue - 12 feet
- Drogue to Aft airframe - 35 feet

This concept of operations is outlined in the diagram in **Fig. 7** below.

The calculations for the sizing of the chutes used equations (3) listed below where m is the mass of the entire system, ρ is the air density, Cd is the drag coefficient of the parachutes, and v is the descent velocity after deployment.

$$Diameter\ of\ Chute\ =\ \sqrt{\frac{8mg}{\rho(Cd)(v^2)\pi}} \tag{3}$$

To carry out these calculations, the descent velocity under drogue was projected to be 118.1 ft/s and 29.52 ft/s under main. This resulted in a calculation of about a 38-inch drogue and 85-inch main for which the closest sized COTS chutes were purchased. Out of an abundance of caution the drogue chute is a ballistic mach II parachute made from bulletproof nylon and rated for deployment at near supersonic speeds. This chute has a much lower drag coefficient than a lighter iris ultra, thus has a larger diameter than would have been necessary with that alternative. However, the increase in size significantly decreases the risk of the drogue chute shredding if deployed prematurely or with a high descent velocity. This risk was analyzed through shock load calculations using equation (4) below.

$$F\ =\ (\tfrac{1}{2}\rho v^2)(SC_D)_{sd}\,C_k \tag{4}$$

The max shock force of the ejection is directly proportional to the air density (ρ), velocity at ejection (v), drag area of filled parachute $(SC_c)_{sd}$, and opening shock factor C_k. This calculation is conducted as a risk assessment therefore the opening shock factor was set to 1.5 as this was the max probable C_k this system will experience. For the drogue, the max shock force under the condition that the ejection occurs at a decent speed of 278 ft/s is 570 lbf. This is sufficient to say that all of the connection points will be able to withstand a worse case deployment of the drogue. The connection hardware such as quick links, swivel links, and U-bolts are at least rated up to 2,000lbf shock force. The recovery harnesses are rated to withstand up to 3000 lbf shock force. Loops at the end of each harness for connection points were made by sewing 6 inches of the harness into itself in a pattern creating 3 X's of stitching as well as many rows of stitches running vertically and horizontally across this connection. This connection point was tested using an instron machine to withstand at least 1,300 lbs continuous force.

This tubular nylon was chosen for harnesses to mitigate the risk of the body tube zippering and to be able to create stronger connection points. As most options for kevlar harnesses have a smaller diameter than any nylon option, choosing kevlar would pose a risk of zippering the body tube. This was observed after our first test flight when the nylon harness had been worn down due to collision with the edge of the airframe during descent, but the airframe was unharmed. However with such force against the airframe if the diameter of the harness was smaller some damage could have come to the edge of the airframe. This error brings into question the use of nylon over kevlar. While nylon is not as strong or tolerant to heat as kevlar, it is strong enough to withstand the worst case ejection forces, thus the tradeoff of risking damage to the airframe for excessive strength is unnecessary. The last consideration with nylon vs kevlar was the heat tolerance. This is an issue when considering the high temperatures the interior of the rocket will reach from motor burn and black powder combustion. However, the parachute compartments will be shielded from the direct heat from the motor burn by aluminum bulkheads. Lastly, to mitigate the risk of heat damage to the nylon harnesses the primary energy for the both drogue and main ejection is compressed gas. However, the backup energetic will be black powder in both events so the harnesses that are attached to the bulkhead housing the energetics will be covered in a Nomex cord protector and all of the harnesses and chutes will be guarded from the potential black powder combustion by a kevlar cloth.

The primary energetic for both events will use a COTS Raptor CO2 deployment system. The motivation for using compressed cas as the primary energetic was to mitigate the risk of damaging the harnesses as well as to ensure deployment at a lower air density. As we are deploying the drogue at an altitude where the air density is significantly lower than that of sea level. This poses only a slight risk in the ability to fully ignite the black powder charge, especially with FFFFg black powder. However, the pressure seal in the black powder well that sets off the raptor system will be more reliable at a lower air pressure.

To calculate the masses of energetics needed for separation of both the main and drogue compartments the ideal gas law ($PV\ =\ nRT$) was used such that n is the mass of black powder. The mass of the CO2 was calculated by scaling the mass of the black powder by 5. These calculations predicted 5.51g black powder for the main and 2.46g for drogue. These calculations were then ground tested with 4 4-40 nylon shear pins on the drogue and 6 on the main. The number of shear pins were calculated based on force applied by the energetic during the separation of each compartment and the break force of each 4-40 nylon shear pin. These calculations resulted in an estimated 2 shear pins for the drogue and 5 for the main. Each of these were upsized to ensure there would be no pre-emptive separations of the airframe as there was an added concern of the difference in mass between the aft and forward airframes that would cause a larger inertial difference than these calculations would account for. The masses of the energetics were also upsized in order to ensure upsizing the number of shear pins would not be an issue in separation.

The ground testing resulted in a successful separation of both preliminary calculations of black powder and shear pins for drogue and main. We upsized both masses to 3g and 6g for drogue and main respectively. The black powder masses were tested as the primary energetic in the first flight test which resulted in a successful dual deploy with the main deployment at 700 ft with an apogee at 3,600ft. In this flight test the backup charges were chosen to be 0.5g more than the primary, thus 3.5g for backup drogue energetic and 6.5g for backup main. From these results the CO2 masses were calculated to be 12g and 30g for drogue and main respectively. However, there were no available CO2 canisters below 23g that would fit in the raptor system. As a result, the ground testing for the CO2 was carried out on 23g of CO2 for the drogue with an increase to 6 shear pins to account for the excess strength of the blast and to minimize opening shock force. The main also upsized and was tested on 35g with 6 shear pins. This ground testing went well with the drogue separation less powerful than was anticipated, resulting in a decrease back to 4 shear pins.

Thus, for the final flight the primary energetics will be 23g CO2 on drogue, 35g CO2 on main with 4 and 6 4-40 nylon shear pins respectively. The backup energetics will be 3.5g black powder and 6.5g black powder. The separation of the main will occur at 1,200 feet subject to change due to wind and other conditions at the launch site.

D. Payload Subsystems

The rocket payload consists of a 2U CubeSAT, equipped with several sensors, secured within the ABS adapter. The Tufts SEDS CubeSAT Team (a separate entity from the Rocketry Team) consists of Power, Mechanical, and Software subteams. Furthermore, there are additional subteams such as Attitude Determination and Control Systems, although these are not relevant to the SpacePort America Cup collaboration with rocketry and thus will not be covered.

The Power subteam is responsible for the design, manufacturing, and testing of the electrical portion of the CubeSAT. The array of sensors being flown include: one Adafruit 9-DOF Accel/Mag/Gyro+Temp Breakout Board, one Adafruit LPS35HW Water Resistant Pressure Sensor, and one SparkFun Humidity Sensor Breakout. These are all interfacing with a Teensey microcontroller development system compatible with Arduino Software & Libraries.

The Mechanical subteam is responsible for the design, simulation, manufacturing, and testing of the mechanical components of the CubeSat, including the in-house design and machining of the chassis. The side panels of the chassis were cut from 1/16 inch steel sheet metal using a waterjet. The corner and lid pieces were cut the same way using 1/32 inch aluminum 6061 sheet metal the same way, using metal bending for the edges, to eliminate the high monetary and time costs imposed by mill machining. The chassis was then assembled with 6mm M2.5 machine screws and lock nuts. A modal analysis for the empty external structure was completed using a solid face design to simplify the mesh, employing SolidWorks and Ansys license. The first frequency is 252.93 Hz, which is over the expected frequency during launch. The Mechanical subteam also tested the compression strength of the ABS adapter, which withstanded 490 N of force without any signs of failure.

The Software subteam's main responsibilities in terms of the engineering process for this payload was the embedded systems programming to support the electrical components selected and leveraged by the Power subteam. This involves programming the Teensy using the Arduino environments to control and manage the various electronic components. This required writing code to communicate with these sensors and gather data.

E. Electronic and Avionics Subsystems

The avionics of CARM consist of two COTS flight computers and two SRAD flight computers. The two COTS devices are RRC3s, where one is the primary recovery device and the other is the backup. Each is set to deploy the drogue at apogee and the main at 800 feet. The SRAD flight computers, named the Scallion Pancakes, were built with the intention of being the primary flight computer to deploy the recovery devices. They are based around the Adafruit Feather M0 RFM95 LoRa (433 MHz), which is based around the ATSAMD21G18 ARM Cortex M0 processor. The main functions of Scallion Pancakes, in addition to deploying the recovery devices, include:

- Interfacing and collecting sensor data from breakout boards (breakout boards include the MCP9808 temperature sensor, BMP388, LSM9DS1 (IMU), and the Adafruit Ultimate GPS breakout board)
- Performing filtering techniques (e.g. complementary filtering, Kalman filtering) to reduce noise in sensor data
- Performing state detection to determine the relative stage of flight rocket is in (e.g powered flight phase, burnout phase, apogee phase, etc.) based on sensor data
- Writing flight data to external storage
- Transmitting compressed flight data to the ground station using custom transmission protocol
- Emitting buzzer sounds to signal rocket location and to verify whether or not the rocket has been armed

The Scallion Pancakes rely on several open-source Arduino (C++) libraries to interface with breakout boards and extract collected data. To ensure the accuracy of flight data crucial for state determination, sensor data undergoes a Two-Step Kalman filter process. This involves sensor fusion with barometric altitude, accelerometer readings across three axes, and gyroscope readings across three axes. The output provides essential elements for state determination: altitude, vertical velocity, and vertical acceleration. These parameters, coupled with temperature changes in the avionics bay, allow for the determination of distinct rocket flight phases. Moreover, based on the rocket's specific state, events triggering the deployment of either the drogue or main parachute are initiated. Additionally, the Scallion Pancakes will sport a 2.5 dBi spring antenna that will be connected to the Feather M0 LoRa module to downlink to the ground station.

Regarding telemetry, the ground station consists of an Adafruit Feather M0 LoRa connected to a 9 dBi Yagi antenna. The Feather M0 will also be connected to a laptop via serial to send the transmitted data from the rocket for parsing. The ground station is designed to interface with the flight computer for various functions, including:

- Displaying decompressed flight data in a user-friendly dashboard using the Dash Plotly framework
- Storing decompressed flight data to an external SQL-based database (InfluxData DB)
- Manually switching rocket states (switching from the Power On state to the Launch Ready state to monitor sensor readings and switching back from Launch Ready to Power On to conserve battery power)
- Switching operating frequencies from the range of 400 MHz to 450 MHz

IV. Mission Concept of Operations Overview

CARM uses a dual-separation, dual-deploy architecture. In keeping with this, the concept of operations is relatively streamlined. There is no defined state before the team begins to assemble the rocket–this is essentially the design and construction phase, and lasts nearly the entire academic year. The "Preflight" phase includes assembly, integration, and inspection; during this phase, all electronics are off, and nominal operation involves all components safely fitting together. This phase is not included in the CONOPS diagram (Fig. 7) for simplicity. The "Pad Operations" phase begins when the team finishes the preflight preparation checklist and begins to move the rocket to the pad. During this phase, the rocket is loaded on the launch rail, prepared for flight, and armed. Nominal operation of mechanical subsystems remains as intended; nominal operation of electrical subsystems require all flight computers to be on and recording. Although not required, the onboard cameras should also be on and recording at this point.

The "Launch" state begins when the pads are armed and the Launch team retreats to a safe distance (accomplished by the LCO, not the Team). During this phase, telemetry should be operating nominally, with the ground station receiving GPS coordinates from the rocket and other data. As soon as the rocket is cleared for flight, and the command is sent to the motor, nominal operation involves a full and rapid (<3s) ignition of the motor. The "Ascent" state begins once the rocket begins to move vertically (accomplished by the propulsion subsystem); during this phase, the motor should execute a smooth burn, and at motor burnout the entire rocket should remain fully assembled. Telemetry should continually transmis GPS position to the ground station. Once the rocket detects it has reached apogee, the onboard flight computers will fire the deployment charges to separate the booster section from the rest of the rocket and deploy the drogue parachute, bringing the mission into the "Drogue Deploy" phase (accomplished by the electronics and recovery subsystems). During this phase, the drogue should inflate and organize the stack as at falls; recovery harnesses should maintain their integrity; the payload and the spent motor casing should remain securely fixed in the rocket; the separate sections of the rocket should not hit each other while descending; and the electrical components should not be damaged so as to continue transmitting data and preparing to fire the Main parachute. Once the rocket drops below 1,200 feet, the onboard flight computers should command the firing of the main deploy charges, which will separate the forward airframe section from the avionics bay and pull out the main parachute. During this "main parachute" phase (accomplished by the electronics and recovery subsystems), the main and drogue parachutes and harnesses should not tangle; the mechanical integrity of the rocket should be maintained, similarly to the drogue deploy state; and the rocket should slow down to an acceptable speed prior to landing. As soon as the rocket hits the ground, it enters the final "recovery" state (accomplished by the mechanical and airframe subsystem): during this phase, the onboard computers reduce the frequency of transmission to save battery, although GPS coordinates and other data should still be transmitted to the ground station to aid the recovery team in finding the rocket. Additionally, the entire airframe should land in a ready-to-refly condition. A replenishment of energetics, folding of parachutes, and replacement of "quick-swap" parts like the nosecone, camera mount, or payload mount sections should allow the vehicle to be capable of reflight on the very same day.

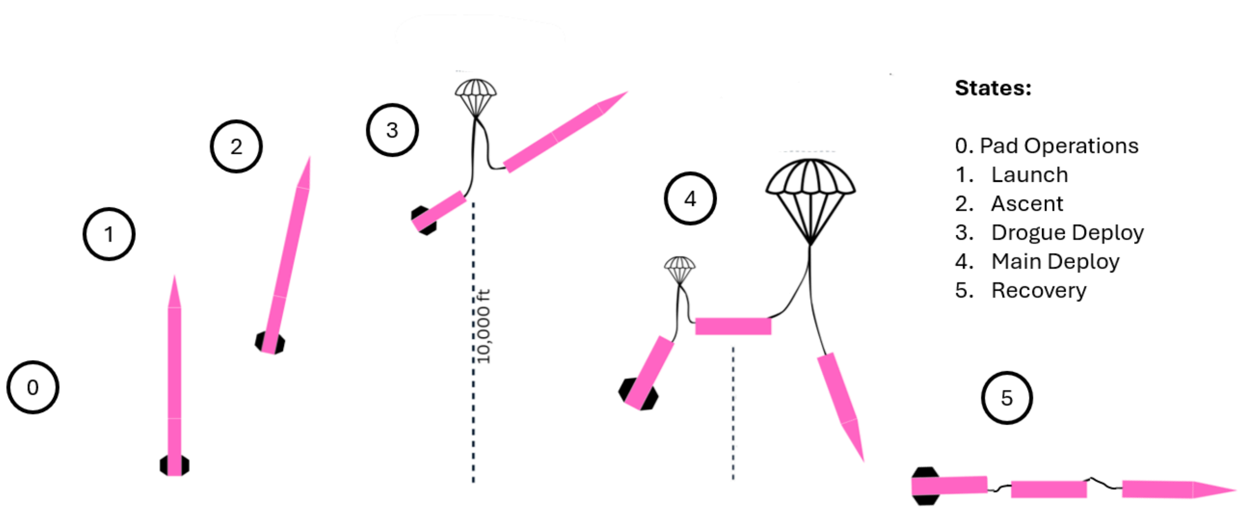


Fig. 7 CARM CONOPS Diagram

V. Conclusions and Lessons Learned

The CARM project is the Rocketry Team's most ambitious project to date, and the knowledge gained from it has matched the scope. Below are some of the many lessons learned, organized by subteam or category. The section below lists some specific learnings from certain subteams, but many of the conclusions can be applied to the entire team.

A. Avionics Subteam

The Avionics Subteam learned the importance of creating effective unit tests. Attempts to "break" the flight program (make it handle edge cases) and subsequently fix the issue to properly respond to them also vividly demonstrated the importance of these tests, and the robustness they can impart to the design.

However, the Avionics subteam failed to properly retain interested avionics members over the long term due to the steep learning curve. In response to this, the subteam learned to incrementally introduce material to avionics members as opposed to dumping the entirety of the subteam tasks onto them, which had overwhelmed them with information with no follow up. The subteam also learned that in projects of this scale and breadth, members get more value and feel more encouraged to participate when there are "active" tasks (doing actual coding, testing filters and hardware, etc.) as opposed to "passive" tasks (reading papers on implementation, gaining deep conceptually of dependent code libraries via stepping through the control flow, etc.). Although there are people that prefer one method over the other, the mistake of assigning these tasks to people who would not like them was made and played a part in poor member retention. Finally, the subteam failed to meet deadlines for when new features of the flight computer should have been rolled out, and in response learned how to set realistic milestones and divide large tasks into subproblems that can be solved iteratively.

B. Mechanical Subteam

The Mechanical subteam learned to scale and manage operations for a large team after some initial difficulties. The subteam provided valuable experience learning how to effectively subdivide and distribute important tasks; for example, fabrication and assembly was split into airframe, metalworking, and avionics bay teams during the spring semester. Although the subteam failed to meet several deadlines, in doing so they learned how to better predict the timeline of complex projects, and the result was a spring semester timeline that was much better adhered to than the one in the fall.

In an effort to accelerate knowledge transfer from the current senior mechanical team lead to rising underclassmen, new leadership was decided two months prior to the end of the spring semester. The leadership role also gained three sub-team leads: Theoretical, Airframe, and Metalworking. These four members were then invited to sit in on leadership meetings and directly encouraged to attend fabrication meetings more regularly. During these meetings, the new leadership learned critical management and technical skills. Over the summer, they will meet semi-regularly with the outgoing lead to discuss strategies for ensuring the continued success of the mechanical team.

C. Recovery

The recovery subteam learned how to adapt both on the spot and for long term concerns that arise late in the stages of development of the rocket. For example, during flight test 2 the concept of operations from flight test was identical except for the addition of a deploy bag for the main parachute. During the descent the main chute deployed and filled perfectly, however the aft airframe ended up flying over the main chute just after it filed and the harness between the aft and drogue chute got caught on the line attaching the deploy bag to the top of the main chute and dragged the main chute down. This caused a rather harsh landing, but much of the rocket was thankfully recovered unharmed.

From this experience the subteam learned to adapt to unexpected outcomes. This was not a risk that was payed out in the risk matrix nor was anyone entirely sure what happened until a thorough investigation of the footage was conducted. The team ended up mitigating the risk that was introduced by this experience by removing the deploy bag and reducing the harness length from the drogue to the avionics bay. For this and the first flight test this length had been 24'. However, by reducing this length it will force the correct stack ordering of the chutes and airframes in descent more effectively, thus the aft airframe will be situated farther from the main parachute which will be at the top of the stack.

D. Propulsion

Difficulties integrating the motor grains in the liner, and the liner in the motor casing, were encountered during motor assembly due to improper tolerancing on the manufacturer's part. These were resolved at great pain by carefully using a hammer and block setup to integrate the grains on the first and second test flights. Learning from this failure (exacerbated by the time pressure to integrate the motor, and the frustration at the motor integration not proceeding smoothly), all components of the motor were thoroughly and completely fit checked prior to assembly, and the motor liner was sanded down as needed to be able to fit in the casing for the third test flight. Additionally, on the first test flight, the team was unable to remove the motor from the case after firing; as a result, the team updated their casing preparation procedures and changed the lubricant used, to great success.

Appendix

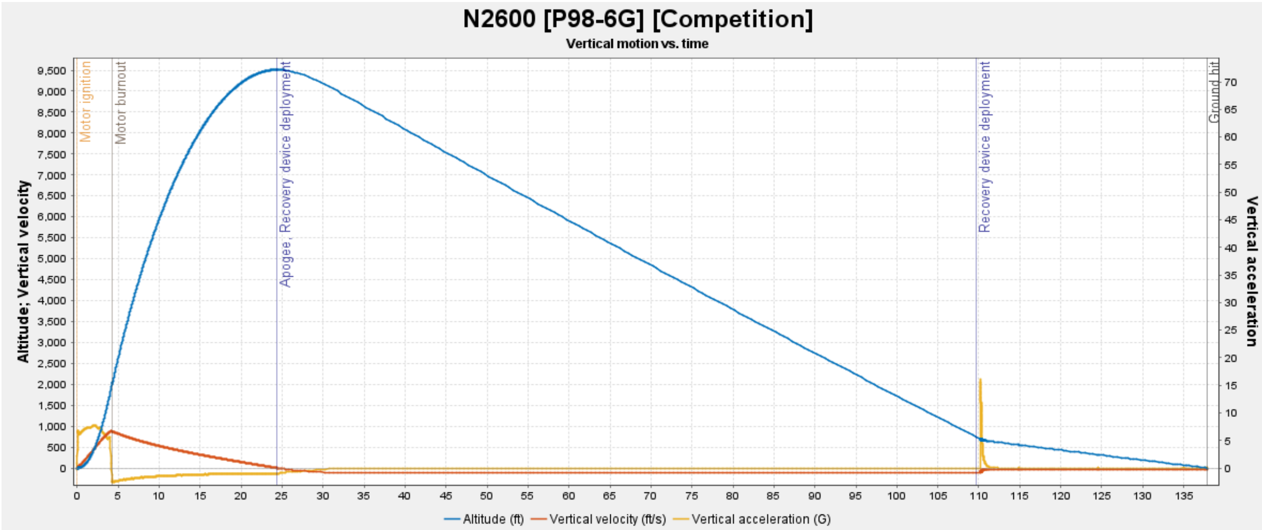
A. System Weights, Measures and Performance Data:

Basic Rocket Information
Stages: 1
Vehicle Length: 140 in
Airframe Diameter: 6.17 in
Number of fins: 4
Fin semi-span: 6.5 in
Fin tip chord: 7 in
Fin root chord: 20 in
Fin thickness: 0.175 in
Vehicle weight: 45.21 lbs
Propellant weight: 14.58 lbs
Empty motor case weight: 10.71 lbs
Payload weight: 8.8 lbs
Liftoff weight: 79.3 lbs
Center of pressure: 110 in
Center of gravity: 92.8 in

Propulsion Information
Motor type: COTS (Cesaroni 11077N2600-P)
Classification: N
Average thrust: 2,585.5 N
Total impulse: 11,077.3 Ns
Burn time: 4.3 s

Predicted flight data:
Launch rail length: 17 ft (total)
Liftoff thrust-to-weight ratio: 7.37
Rail departure velocity: 75.4 ft/s
Minimum static margin: 2.15
Maximum acceleration: 7.98 G
Maximum velocity: 908 ft/s
Fin flutter velocity: 5076 ft/s
Target apogee: 10,000 ft
Predicted apogee: 9,512 ft

Flight profile graph



Recovery Information
COTS Altimeter 1 & 2: MissileWorks RRC3
COTS Altimeter 2
Drogue primary deployment charge: 23g CO_2
Drogue backup deployment charge: 3g Black Powder
Drogue deployment altitude: 10,000 ft
Drogue descent rate: 127.4 ft/s
Main primary deployment charge: 35g CO_2
Main backup deployment charge: 6.5g Black Powder
Main deployment altitude: 1,200 ft
Main descent rate: 26.3 ft/s
Shock cords: custom 11/16" tubular nylon webbing, protected with kevlar in select spots
Mechanical links: Steel quick lengths (3,000 lb test); steel swivels (3,000 lb test)

B. Project Test Reports

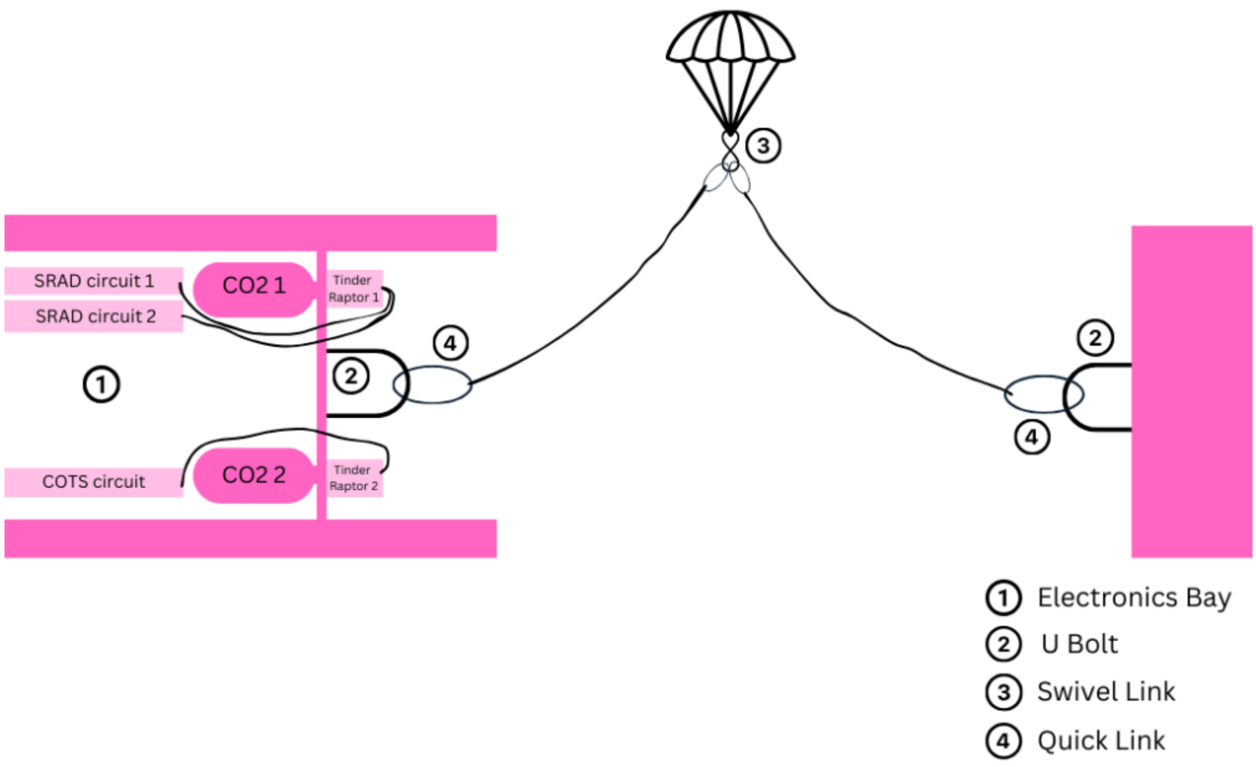
1. Recovery System Testing:

Black Powder Ground Tests: (Completed February 14th)

In February we conducted a ground test for black powder. We tested 2.46g and 5.51g of FFFF black powder for drogue and main respectively with 4 and 6 4-40 shear pins. These tests went very smoothly, successfully shearing all of the pins and ejecting the respective compartments a few feet.

CO2 Ground Tests: (Completed April 17th)

We conducted a ground test for the compressed CO2 energetic using the COTS raptor system from Apogee. We tested the drogue with 23g of CO2 with 6 4-40 shear pins and the drogue with 35g of CO2 with 6 4-40 shear pins on the main. We upsized the number of shear pins for the drogue because we calculated 15g of CO2 for the drogue but we were only able to attain a 23g canister that would fit with the CO2 system. So, to lessen opening shock load on the bulkheads we added shear pins. Both drogue and main tests went well, but the separation seemed relatively weak; we therefore plan on downsizing to four shear pins on drogue and 5 on main.



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3. SRAD Pressure Vessel Testing

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4. SRAD GPS Testing

The SRAD GPS module is based on the Adafruit Ultimate GPS breakout board (v3.1), utilizing the MTK3339 chipset. To test its functionality, the module was taken outdoors, and the GPS coordinates were monitored via the serial monitor to verify their alignment with the SRAD board's actual location. The GPS module was confirmed to be accurate when compared to the testing location indicated by Google Maps.

5. Payload Recovery System Testing

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C. Hazard Analysis

Team 103 **Tufts SEDS Rocketry Team**	**Project Name: CARM**	**5/10/2024**	**Hazard Analysis Matrix**	
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Explosion of solid-propellant rocket motor during launch with blast or flying debris causing injury ("Motor CATO")	Cracks in propellant grain; debonding between propellant grains and liner after assembly	Low; COTS motor from reliable manufacturer (CTI) that has been thoroughly tested and has well-documented assembly procedures. Some risk added by the team's reduced experience with 98 mm motors compared to 76 mm motors	Visually inspect all propellant grains for cracks, debonds, and gaps before and after assembly	Low
	Motor case unable to contain normal operating pressure due to defects		Inspect motor case and closures for damage during final assembly before launch	
	Motor end closures fail to hold due to improper O-ring installation		Familiarize the propulsion subteam with the specific motor assembly procedures, and maintain proper cleanliness of O-ring grooves	
	Gaps between propellant sections and/or nozzle		Assemble motor horizontally to prevent gaps forming because of gravity;	
	Chunk of propellant breakings off and plugging nozzle		Handle propellant grains carefully during installation to prevent cracks	
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Loss of stability	Very Low (two integrated flight tests have been conducted showing excellent stability)	Weigh all vehicle components prior to installation and ensure flight simulations are updated; ensure rocket is modeled to be stable	Very Low
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Flight computers fail to detect apogee	Low to Moderate (COTS altimeters are very reliable, but wiring could come loose, and energetics calculations could be incorrect)	Only essential personnel in launch team; ensure all members are at a safe distance from rocket during launch; thoroughly ground test all electronics and deployment systems	Low
	Energetics are insufficient to separate rocket sections			
Recovery system partially deploys, rocket or payload comes in contact with personnel	Energetics insufficient to separate rocket sections; parachutes get tangled	Low (Rocket is launched at 84 degrees, sending it far away from launch team and spectators)	Launch crew must remain behind barrier at least 500 ft from rocket at launch	
Recovery system deploys during assembly or prelaunch, causing injury	Energetics are not properly safed before arming	Low (careful wiring	Only essential personnel at launch site; only arm rocket once vertical; handle all energetics with extreme care	Low
Main parachute deploys at or near apogee, rocket or payload drifts to highway(s)	Flight computer failure, incorrect fire command	Moderate	Flight test deployment and recovery architecture	Low

Rocket does not ignite when command is given ("hang fire"), but does ignite when team approaches to troubleshoot	Improper igniter installation; less than ideal amount of pyrogen on igniter	Moderate	Wait for a period of 1 minute after when pads go cold before approaching the rocket; use large proven COTS igniters	Low
Rocket falls from launch rail during prelaunch preparations, causing injury	Rail button failure or rail button attachment failure	Low (rail buttons are mounted into secure airframe hard points)	Inspect rail buttons prior to rocket installation on rail	Low

D. Risk Assessment:

Team 103 Tufts SEDS Rocketry Team	**Project Name: CARM**	**5/10/2024**	**Risk Assessment**	
Risk & Possible Cause	**Mission Phase**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk to Mission Mitigation**
Schedule slip due to manufacturing or procurement delays	Pre-competition	High–ambitious project on tight schedule	Thoroughly analyze bulkheads with FEA; incorporate Bulkhead Stop Ring	Moderate
Test Flight failure	Pre-competition	Low chance of occurring, high impact → high risk	Load calculations and FEA to ensure adequate safety margin; use fasteners that will not come undone under vibration; ground testing	Low
Separation failure due to aerodynamic shear loads or friction	Ascent → Drogue deploy transition	Moderate chance of occurring, high impact → high risk	Ensure very close tolerance fit between airframe sections and nosecone; ensure connecting surfaces are smooth; adequate safety margin on amount of energetics used	Moderate
Thrust plate falls off after boost phase	Ascent	Low chance of occurring, high impact → high risk	Ensure good bonding preparation; use small grooves and/or chemical etching to improve bonding; pull test	Low
Payload attachment fails	Ascent, drogue deploy, main deploy	Low chance of occurring, high impact → high risk	FEA and testing on payload and attachment mechanism to ensure good connection with airframe; ensure connection between nosecone and forward airframe can sustain the added impact	Low
Rail button attachment fails	Pad operations	Low chance of occurring, high impact → high risk	Connect rail buttons to hard points inside the rocket, test and do FEA to ensure solid connection	Low
Rocket lands outside of acceptable landing speed	Recovery	Low chance of occurring, high impact → high risk	Ensure Booster and airframe are adequately reinforced to sustain impact; fin geometry minimizes impact loads	Low
Rocket veers off trajectory during ascent phase	Ascent	Low chance of occurring, high impact → high risk	Properly and empirically measure center of gravity to accurately predict stability; maintain stability margin >1.5 body calibers; do not launch in excessive winds; conduct test flight campaign	Low
Av Bay closure failure resulting in electronics damage	Preflight preparations	Low chance of occurring, high impact → high risk	Robust, evidence-backed construction and careful assembly/integration of avionics bay	Low

Incorrect deployment firing during any phase BESIDES just before drogue or main deploy–sensors mistakenly detect state change	Pad operations, Launch, Recovery	Moderate chance of occurring, high impact → very high risk	Extensively test state changes, use backup COTS computer	Moderate
Loss of telemetry connection (due to range or obstructions)	Launch, Ascent, Drogue deploy, Main deploy, Recovery	Moderate chance of occurring, moderate impact → moderate risk	Conduct range testing, Increase gain on antenna as needed; attempt to maintain obstruction-free path to rocket	Low to Moderate
Sensors fail or output incorrect data	Launch, Ascent, Drogue deploy, Main deploy, Recovery	Moderate chance of occurring, moderate impact → moderate risk	Test readouts pre-launch, use ground data to ensure they are working, recalibrate sensors	Low
Wires burn out/lose connection on SRAD flight computer PCB during flight	Launch, Ascent, Drogue deploy, Main deploy, Recovery	Moderate chance of occurring, moderate impact → moderate risk	Extensively test deployment, Calculate Trace diameter; conduct flight tests and flight-like tests	Low to Moderate
Batteries runs out of power	Launch, Ascent, Drogue deploy, Main deploy, Recovery	Moderate chance of occurring, high impact → very high risk	Use backup batteries, incorporate battery indicator light, choose batteries with long life	Low to Moderate
Kalman Filters don't filter properly and provide incorrect apogee and main deployment altitude readings	Ascent, Drogue deploy, Main deploy	Low chance of occurring, moderate impact → high risk	Test filters on raw dummy data, conduct passive test flights	Moderate
Deployment system failure	Drogue deploy, main deploy	Moderate chance of occurring, high impact → very high risk	Increase redundancy (2 backup COTS computers), perform quantitative deployment analysis, perform ground deployment tests, validate during flight tests	Moderate
Drogue parachute tears/fails after deployment	Drogue deploy	Moderate chance of occurring, high impact → very high risk	Use ultra-high-speed drogue; use long shock cord length to maximize impact load time	Moderate
Main parachute tears during deployment	Main deploy	Moderate chance of occurring, moderate impact → high risk	Run simulations to ensure deployment speed is low enough to be safe; reinforce parachute if needed; remove sharp edges on inside of airframe	Low
Main parachute or harnesses burn	Drogue deploy, main deploy	Moderate chance of occurring, low impact → moderate risk	Cover in nomex blankets and cord protectors	Low
Tangling of chutes and harness	Drogue deploy; Main deploy	High chance of occurring, high impact → extremely high risk	*Investigate use of deployment bag, wrap loose band around harness for packing, test deployments on ground, analyze flight test behavior*	High

For CTI N2600: sparky motor ignites surrounding brush during ignition (launch phase)	Launch; beginning of Ascent phjase	Moderate to high (there is a lot of dry brush in the desert)	Clear launch pad area of dry brush; douse with water if needed. Ensure fire extinguisher is on hand.	Low

E. Assembly, Preflight, Launch, and Recovery Checklists

1. Assembly & Preflight Inspection Checklist

AVBAY Prep [Electronics, Avionics & Telemetry]

- ☐ Verify there is no foreign object debris (FOD) within the Avbay, that the sleds are not cracked, and that the hardware otherwise appears in good condition

- Check that all flight computers are safely fastened:
  - ☐ COTS 1
  - ☐ COTS 2
  - ☐ SRAD 1
  - ☐ SRAD 2

- Check that all wires for charges (NOT igniter leads) are correctly and safely installed (inside avbay)
  - ☐ COTS 1
  - ☐ COTS 2
  - ☐ SRAD 1
  - ☐ SRAD 2

- Connect batteries
  - ☐ COTS 1
  - ☐ COTS 2
  - ☐ SRAD 1
  - ☐ SRAD 2

- Calibrate barometer with local sea level air pressure readings
  - ☐ SRAD 1
  - ☐ SRAD 2

- Check that external storage (SD card) is formatted and can be read/written
  - ☐ SRAD 1
  - ☐ SRAD 2

- ☐ Install Runcam 2 in external mount
- ☐ Insert avionics stack into avbay and align switch mounts
- ☐ Align Z+ Avbay bulkhead

- Align switches with holes and test fit with key
  - ☐ COTS 1
  - ☐ COTS 2
  - ☐ SRAD 1
  - ☐ SRAD 2

- ☐ **TIGHTEN WING NUTS**
- ☐ Confirm proper alignment of Avbay bulkheads (no gaps, offsets, or angles)

- ☐ **AVBAY CLOSEOUT COMPLETE**

PARACHUTE Prep [Recovery]

- [ ] Check chutes and harnesses for tangles
- Attach and **TIGHTEN** short harnesses with quick links
  - [ ] 10’ to Fwd airframe bulkhead
  - [ ] 35’ to booster

- **LOOSELY** Attach quick links to bulkheads and parachutes
  - [ ] Main
  - [ ] Avbay Z+
  - [ ] Avbay Z-
  - [ ] Drogue

- [ ] Thread 10’ (drogue harness) through cord protector
- [ ] Thread 10’ (main harness) through cord protector
- [ ] Add kevlar sheet to 10’ (drogue harness)
- [ ] Add kevlar sheet to 10’ (main harness)
- [ ] Coil harnesses with painters tape

- Attach harnesses to quicklinks
  - [ ] 35’ to Z- end of av bay to drogue chute
  - [ ] 10’ from drogue chute to av bay
  - [ ] 40’ to Z+ end of avbay to Main chute
  - [ ] 10’ from main chute to avbay

TIGHTEN AND CHECK ALL QUICK LINKS

- [ ] Fwd Airframe Bulkhead
- [ ] Main chute
- [ ] Avbay Z+
- [ ] Avbay Z-
- [ ] Drogue chute
- [ ] Aft Airframe Bulkhead

- [ ] **ALL QUICK LINKS TIGHTENED**

DEPLOYMENT system prep [Recovery]

- **Verify all switches set to off**
  - [ ] COTS 1
  - [ ] COTS 2
  - [ ] SRAD 1
  - [ ] SRAD 2

- **Attach igniter leads to screw terminals**
  - [ ] COTS 1 to Main CO_2 (x2)
  - [ ] COTS 2 to Main BP Backup
  - [ ] COTS 1 to Drogue CO_2 (x2)
  - [ ] COTS 2 to Drogue Backup

Integrate Main Parachute Charges

- [ ] Integrate rapport system

- ☐ Load 35g CO_2 into primary (raptor system)
- ☐ Load 6g black powder to backup main well
- ☐ Stuff backup bp well with "dog barf" wadding
- ☐ Seal backup bp well with painter's tape
- ☐ Cover screw terminals with painter's tape

☐ **MAIN PARACHUTE CHARGES INTEGRATED**

Integrate Drogue Charges

- ☐ Integrate raptor system
- ☐ Load 23g CO_2 into primary (raptor system)
- ☐ Load 3g black powder to backup drogue well
- ☐ Stuff backup bp well with "dog barf" wadding
- ☐ Seal igniter inside backup BP well with painter's tape
- ☐ Cover screw terminals with painter's tape
- ☐ Cover screw terminals with painter's tape

☐ **DROGUE PARACHUTE CHARGES INTEGRATED**

AIRFRAME integration

- ☐ Payload battery connected
- ☐ Payload adapter assembled
- ☐ Check adapter screws
- ☐ Adapter aligned in forward airframe
- ☐ Adapter fastened to airframe (8 #6-32)
- ☐ Citrus bulkhead aligned in airframe
- ☐ Citrus bulkhead fastened to airframe (8 #6-32)

- ☐ **NOSECONE GPS batteries in ON position**
- ☐ Nosecone aligned in forward airframe
- ☐ 6 #6-32 screws installed and tightened

- ☐ Wrap kevlar around main chute and harness
- ☐ Main parachute and harnesses loaded into forward airframe
- ☐ Avbay loaded into forward airframe and aligned
- ☐ Install 6 shear pins on main compartment (Z+)

- ☐ Wrap kevlar around drogue chute and harness
- ☐ Drogue parachute and harnesses loaded into booster
- ☐ Install 4 shear pins on drogue compartment (Z-)

MOTOR integration

- ☐ Visual inspection: motor appears in excellent condition
- ☐ *[Pro75 ONLY] Attach and tighten adapter ring*
- ☐ Load motor
- ☐ **TIGHTEN RA98 CLOSURE RING**
- ☐ Verify nozzle protector is secure
- ☐ **MOTOR INTEGRATED**

Final Inspection Checklist

- ☐ Motor closure ring tightened
- ☐ Aft rail button fastened properly
- ☐ Forward rail button fastened properly
- ☐ Aft airframe bulkhead screws in place and tightened
- ☐ **Drogue parachute shear pins fastened (x4)**
- ☐ Switches are aligned
- ☐ Switch band is flush with booster
- ☐ Switch band is flush with forward airframe
- ☐ Small Runcam split camera hardware fastened
- ☐ Big Runcam 2 camera installed
- ☐ Big Runcam 2 cap fastened
- ☐ **Main parachute shear pins fastened (x6)**
- ☐ Forward airframe bulkhead screws in place and tightened
- ☐ Payload adapter attachment screws in place and tightened (x8)
- ☐ Citrus bulkhead screws in place and tightened (x8)
- ☐ **Nosecone attachment screws fastened (x6)**
- ☐ GPS attachment screws fastened (x6)

- ☐ **Clear to proceed to pad checklist**

2. Pad Checklist

Pad checklist [Launch operations, Electrical]

- ☐ Remove dry brush from area around pad
- ☐ Visually verify pad stability and integrity
- ☐ Lower launch rail

- ☐ Load aft rail button on launch rail
- ☐ Check forward rail button alignment and slide onto rail
- ☐ Ensure stop is in place below aft rail button

- ☐ **ROCKET IS VERTICAL**
- ☐ TAKE PHOTO WITH ROCKET

RECOVERY SYSTEM ARMING

- ☐ COTS 1: 5s beep, 10s pause, 3 short beeps
- ☐ COTS 2: 5s beep, 10s pause, 3 short beeps
- ☐ SRAD 1: 4 short beeps
- ☐ SRAD 2: 4 short beeps

- **Confirm GPS transmission with Telemetry team**
    - ☐ **Nosecone GPS**
    - ☐ **SRAD 1 GPS**

CAMERAS

- ☐ Pad GoPro 1 recording
- ☐ Pad GoPro 2 recording
- ☐ Distant GoPro recording
- ☐ Runcam 2 in Video Standby mode (solid blue light)
- ☐ **Runcam on video recording (slow flashing blue)**

INSTALL IGNITER

- ☐ Tap clips together, check for sparks
- ☐ Thread igniter through nozzle cap
- ☐ Install Igniter
- ☐ Secure cap in place
- ☐ Attach igniter leads to clips
- ☐ **CLEAR PAD**
- ☐ Check Continuity

- ☐ **Clear to proceed to Launch checklist**

3. Launch Checklist

Launch Checklist [Launch Operations]

- ☐ **Pad clear**
- ☐ **Sky clear**
- ☐ **Weather GO**
- **Poll Go for Launch**
    - ☐ **Visual tracking GO**
    - ☐ **Media team GO**
    - ☐ **Backup GPS tracking GO**
    - ☐ **Electronics & Telemetry GO**
- ☐ GO FOR LAUNCH

OFF-NOMINAL CASES:

Phase: PAD OPERATIONS

- **LACK OF CONTINUITY IN PAD PHASE**
    - Turn off Electronics via switch
        - [ ] COTS 1
        - [ ] COTS 2
        - [ ] SRAD 1
        - [ ] SRAD 2
        - [ ] Runcam 2

    - [ ] Remove rocket from pad
    - [ ] De-integrate booster, avionics bay, and forward airframe
    - [ ] Inspect avionics bay and then re-integrate following the nominal preflight checklist

---

Phase: LAUNCH OPERATIONS

- **IGNITER FAILURE**
    - [ ] Confirm pad is cold
    - [ ] Remove spent igniter

    - **Install backup igniter**
        - [ ] Tap clips together, check for sparks
        - [ ] Thread igniter through nozzle cap
        - [ ] Install Igniter
        - [ ] Secure cap in place
        - [ ] Attach igniter leads to clips
        - [ ] **CLEAR PAD**
        - [ ] Check Continuity
        - [ ] Proceed to nominal Launch Checklist

- **IN-FLIGHT FAILURE**

- [ ] Wait for rocket to land and range to clear
- [ ] Proceed to Off-Nominal Recovery Operations

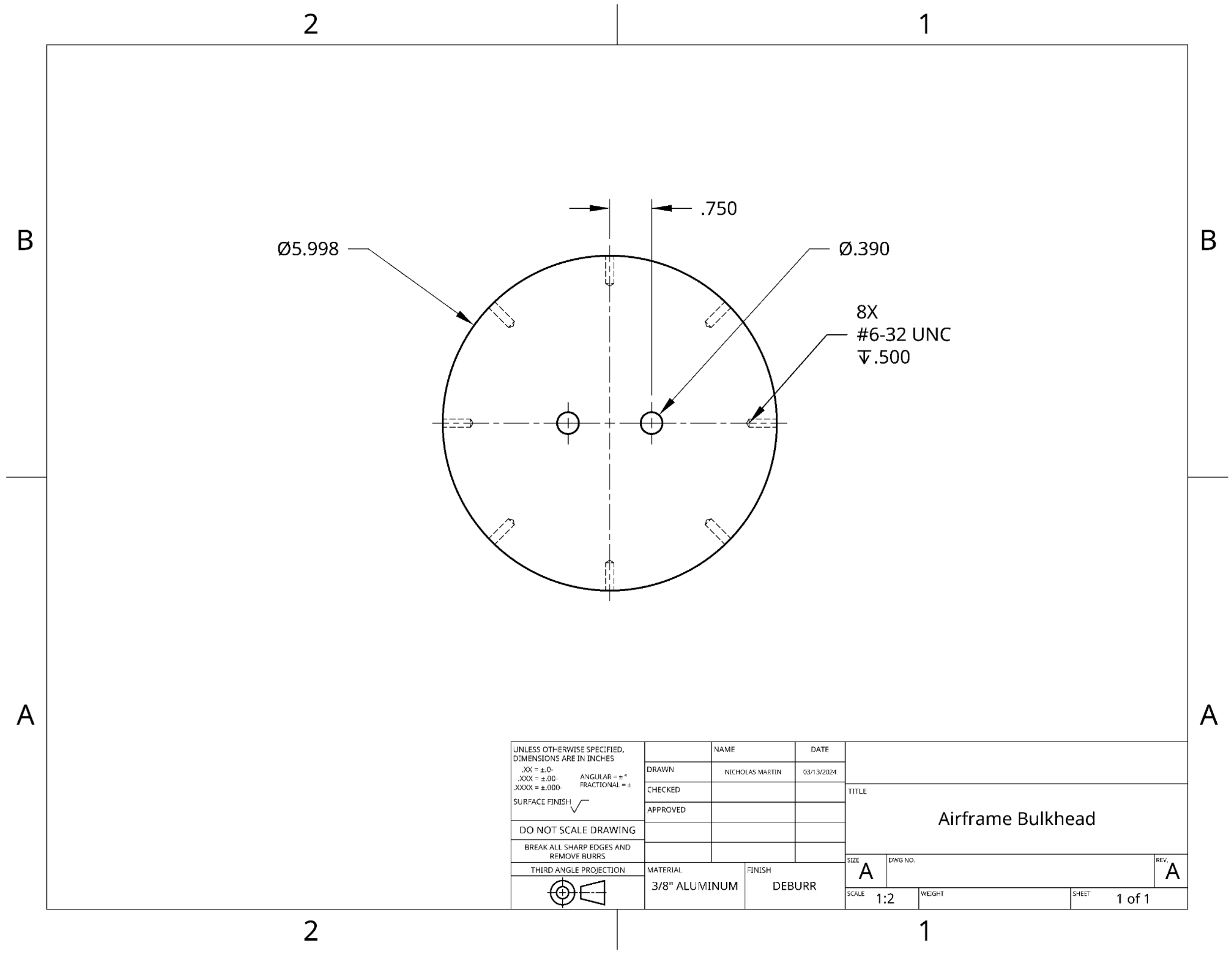
Phase: RECOVERY OPERATIONS

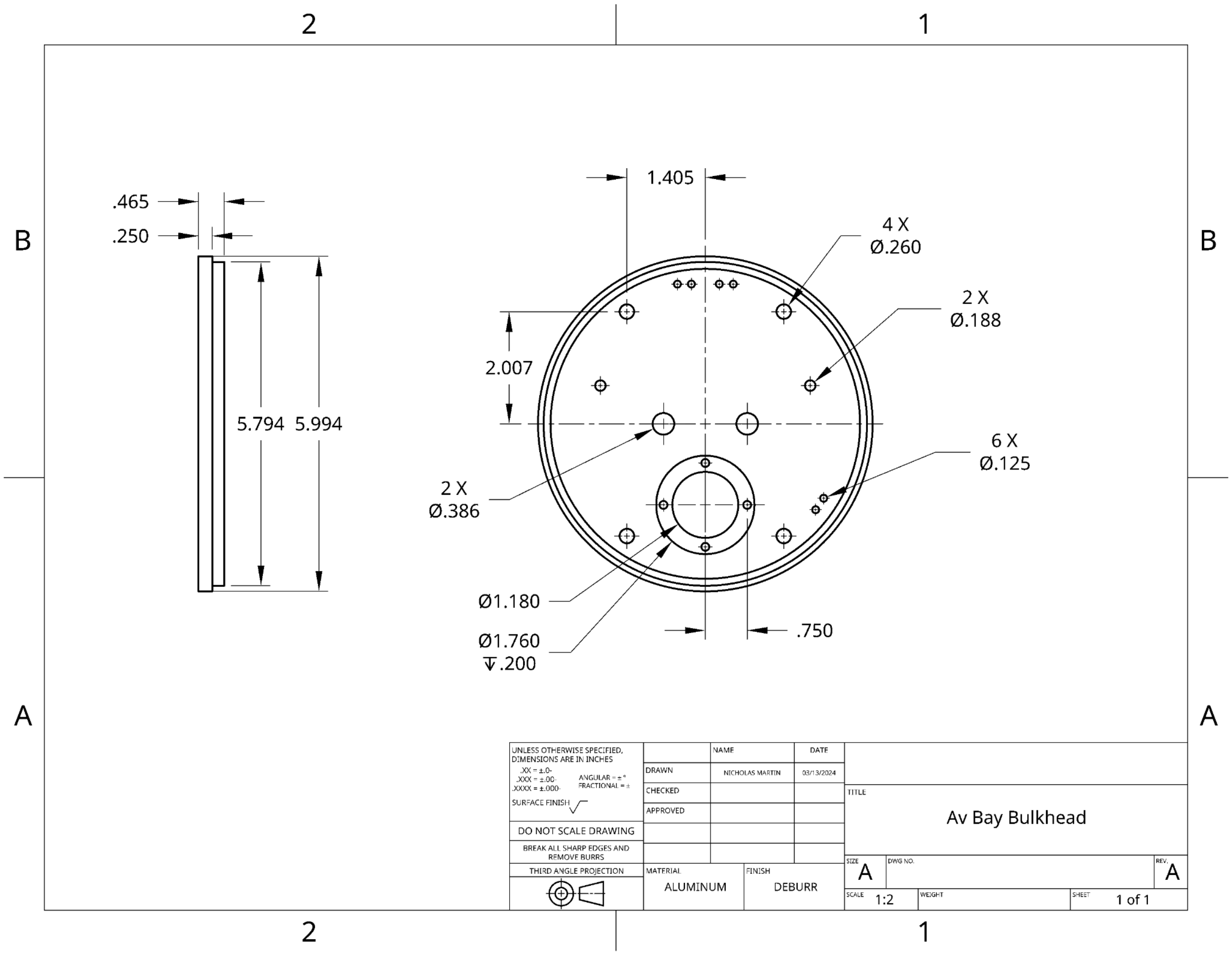
- **IF FIRES ARE PRESENT:**
  - [ ] Confirm members are at safe distance (10 ft minimum)
  - [ ] Extinguish with fire extinguisher
  - [ ] Confirm no

- **IF SWITCHES ARE INACCESSIBLE:**
  - **Cut wires to screw terminals for deploy charges**
    - [ ] COTS 1
    - [ ] COTS 2
    - [ ] SRAD 1
    - [ ] SRAD 2

- **IF ROCKET PARTS ARE MISSING:**
  - [ ] Establish search committee (ensure at least one member has a working communications device)
  - [ ] Begin searching along flight path

F. Engineering Drawings

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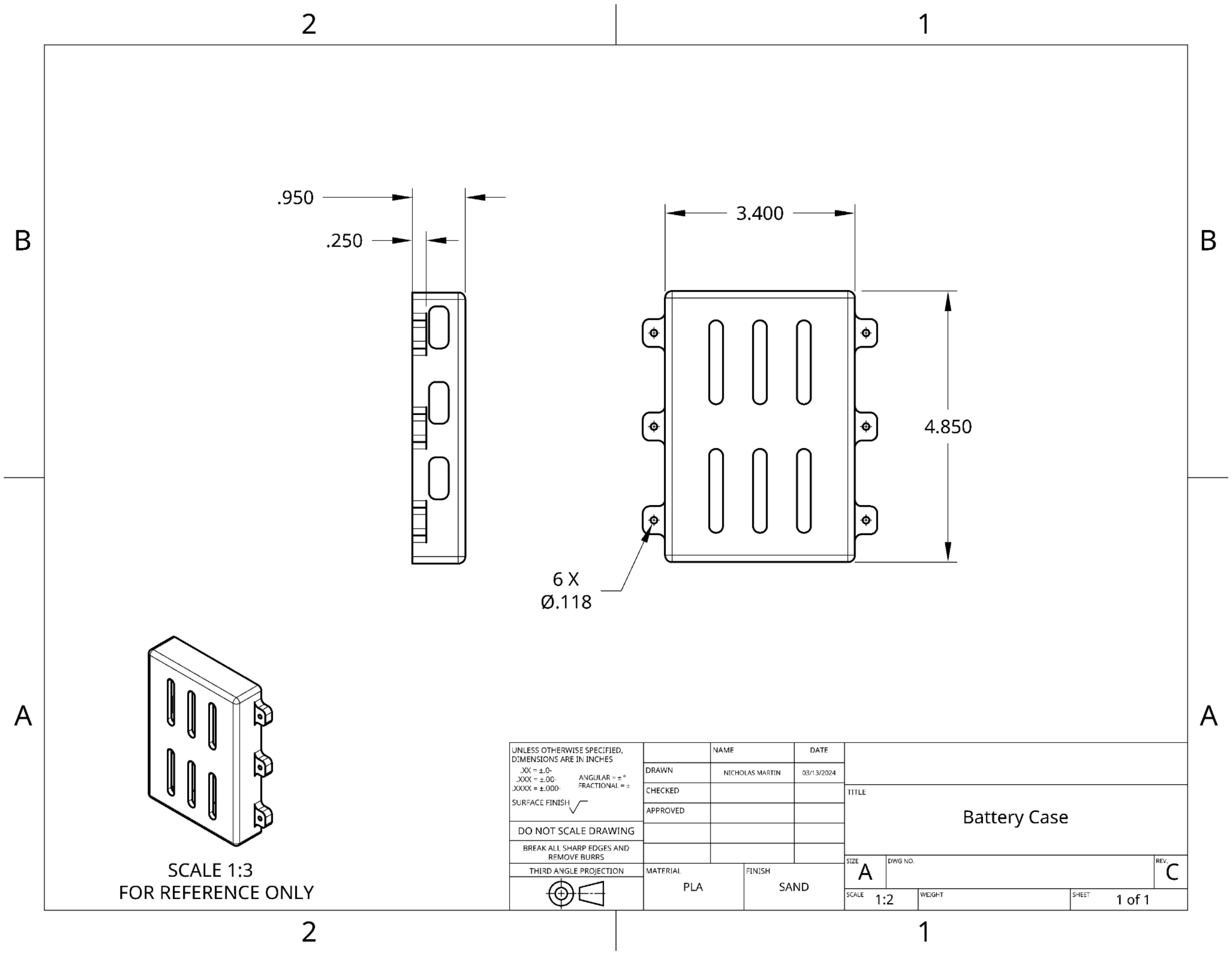
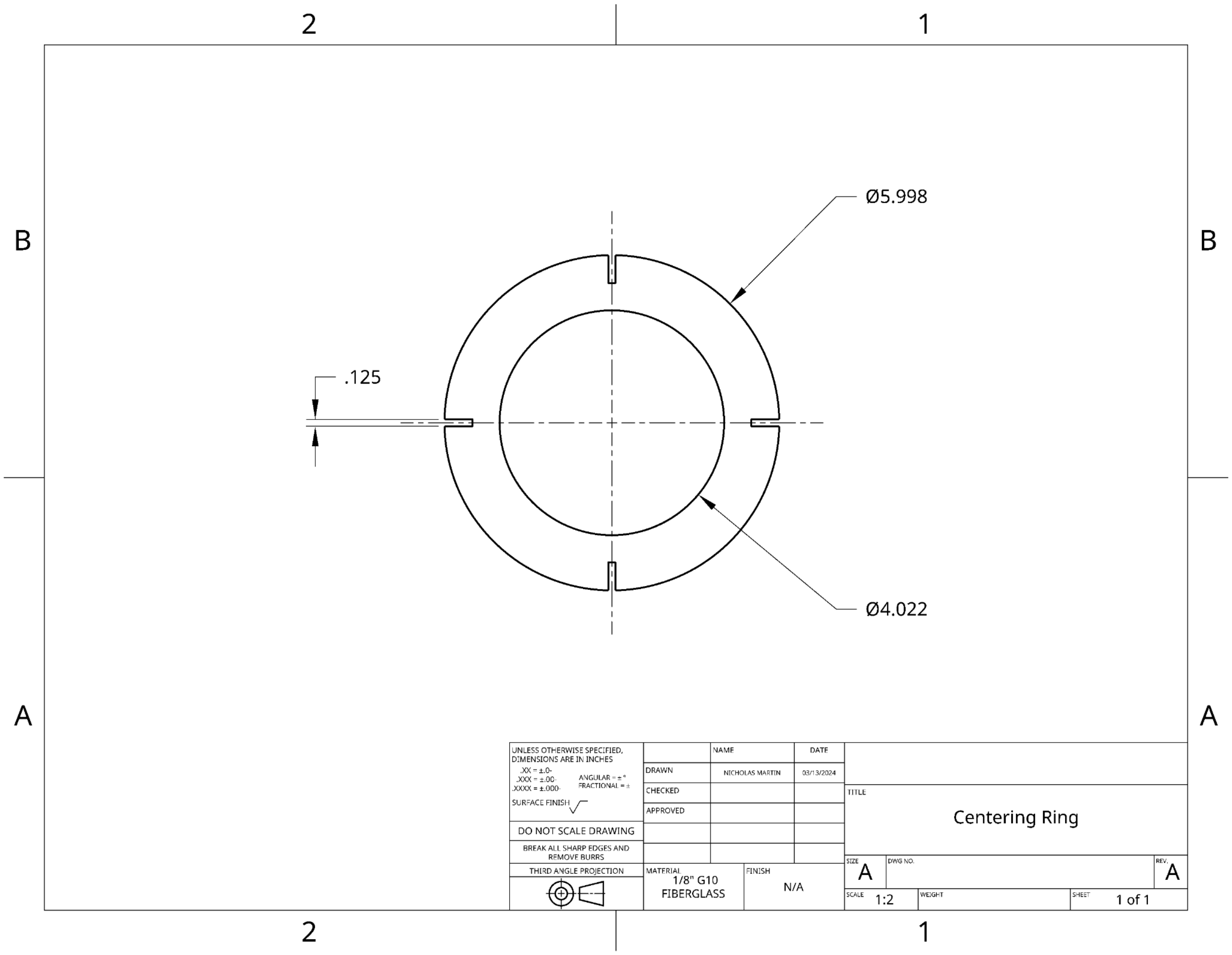
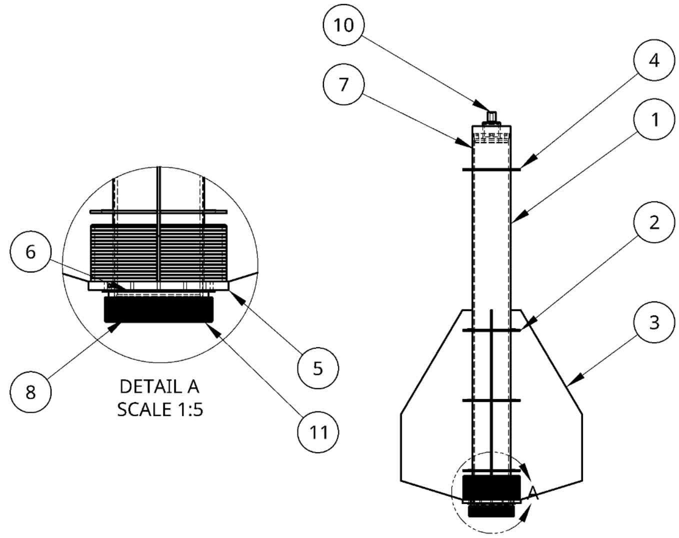
.250
5.794
5.994
1.405
4 X
Ø.260
2 X
Ø.188
2.007
6 X
Ø.125
2 X
Ø.386
Ø1.180
Ø1.760
⊽.200
.750
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
DRAWN
NICHOLAS MARTIN
03/13/2024
MATERIAL
ALUMINUM
FINISH
DEBURR
TITLE
Av Bay Bulkhead
SIZE
A
REV.
A
SCALE
1:2
SHEET
1 of 1

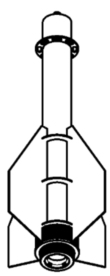

2
1
B
.950
.250
3.400
4.850
6 X
Ø.118
A
SCALE 1:3
FOR REFERENCE ONLY
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
03/13/2024
CHECKED
APPROVED
MATERIAL
PLA
FINISH
SAND
TITLE
Battery Case
SIZE
A
DWG NO.
REV.
C
SCALE
1:2
WEIGHT
SHEET
1 of 1


2
1
B
B
Ø5.998
.125
Ø4.022
A
A
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
03/13/2024
CHECKED
APPROVED
MATERIAL
1/8" G10 FIBERGLASS
FINISH
N/A
TITLE
Centering Ring
SIZE
A
DWG NO.
REV.
A
SCALE
1:2
WEIGHT
SHEET
1 of 1
2
1

Item	Quantity	Description
1	1	MOTOR MOUNT TUBE
2	3	CENTERING RING
3	4	FIN
4	1	ALIGNMENT RING
5	1	THRUST PLATE
6	1	98MM RETAINER
7	1	6G CASE
8	1	AFT RETAINING RING
9	1	FWD RETAINING RING
10	1	FWD CLOSURE
11	1	98MM RETAINER CAP



DETAIL A
SCALE 1:5



SCALE 1:16
FOR REFERENCE ONLY

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

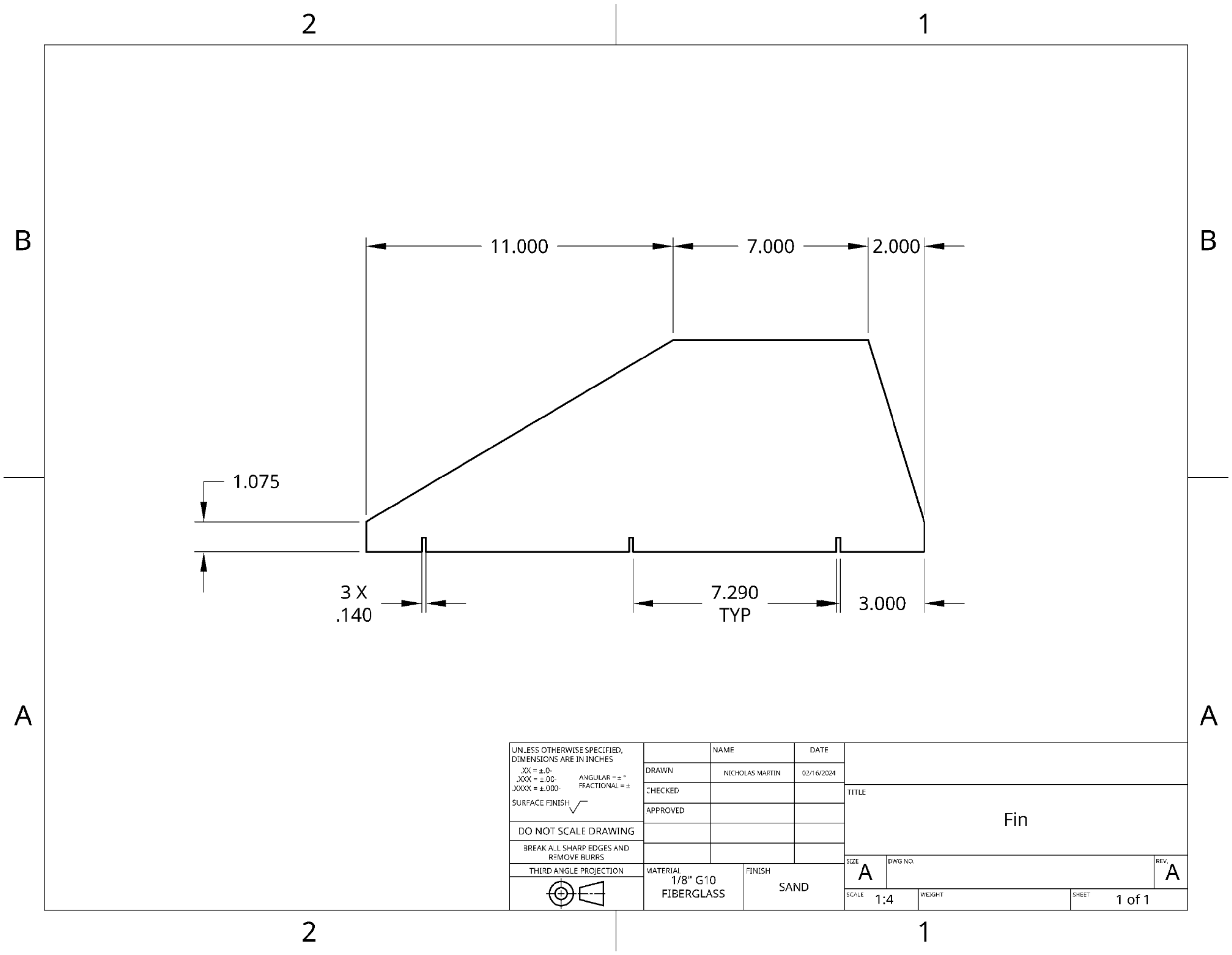
THIRD ANGLE PROJECTION

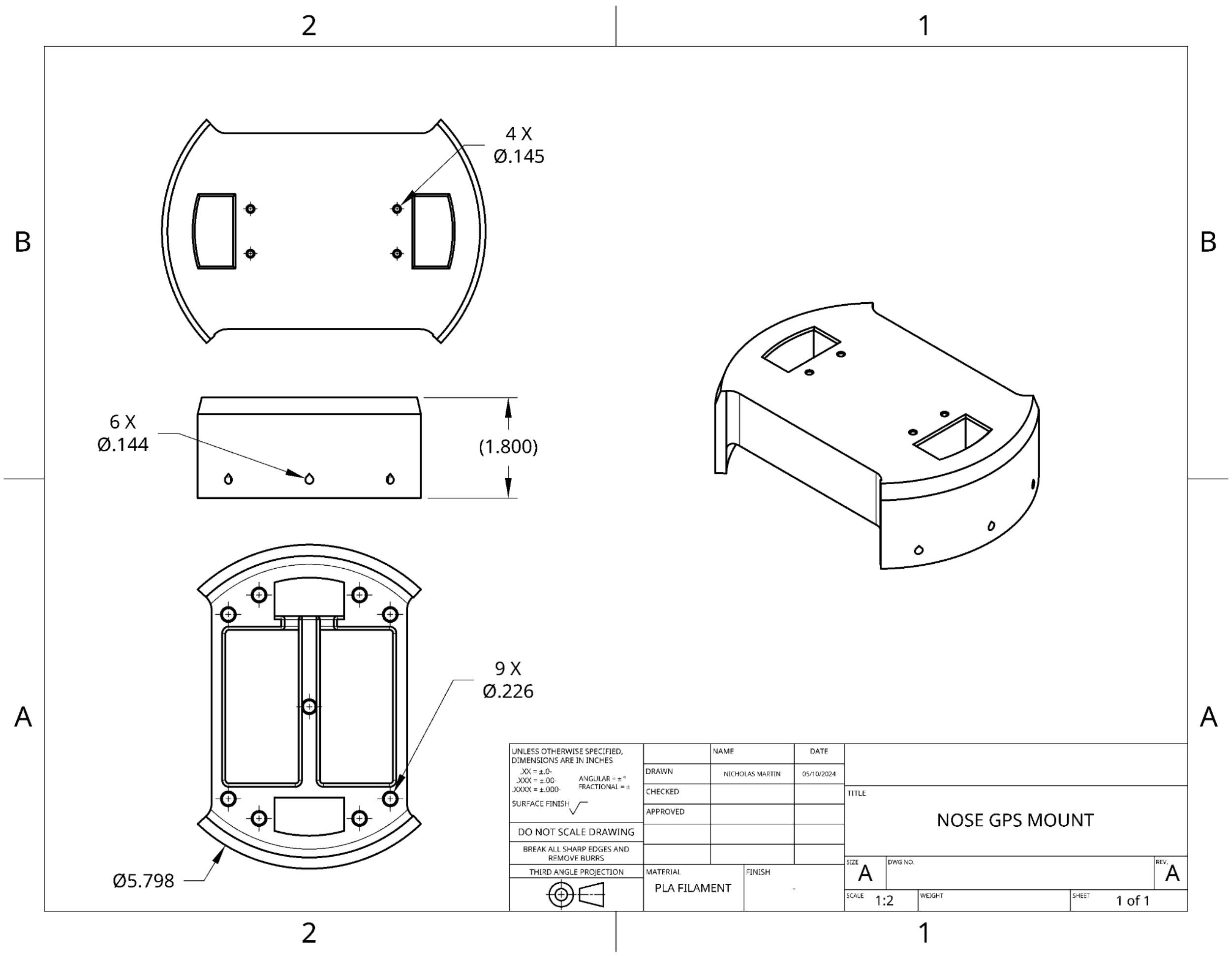
	NAME	DATE
DRAWN	NICHOLAS MARTIN	05/10/2024
CHECKED		
APPROVED		

MATERIAL: SEE BOM
FINISH: SEE BOM

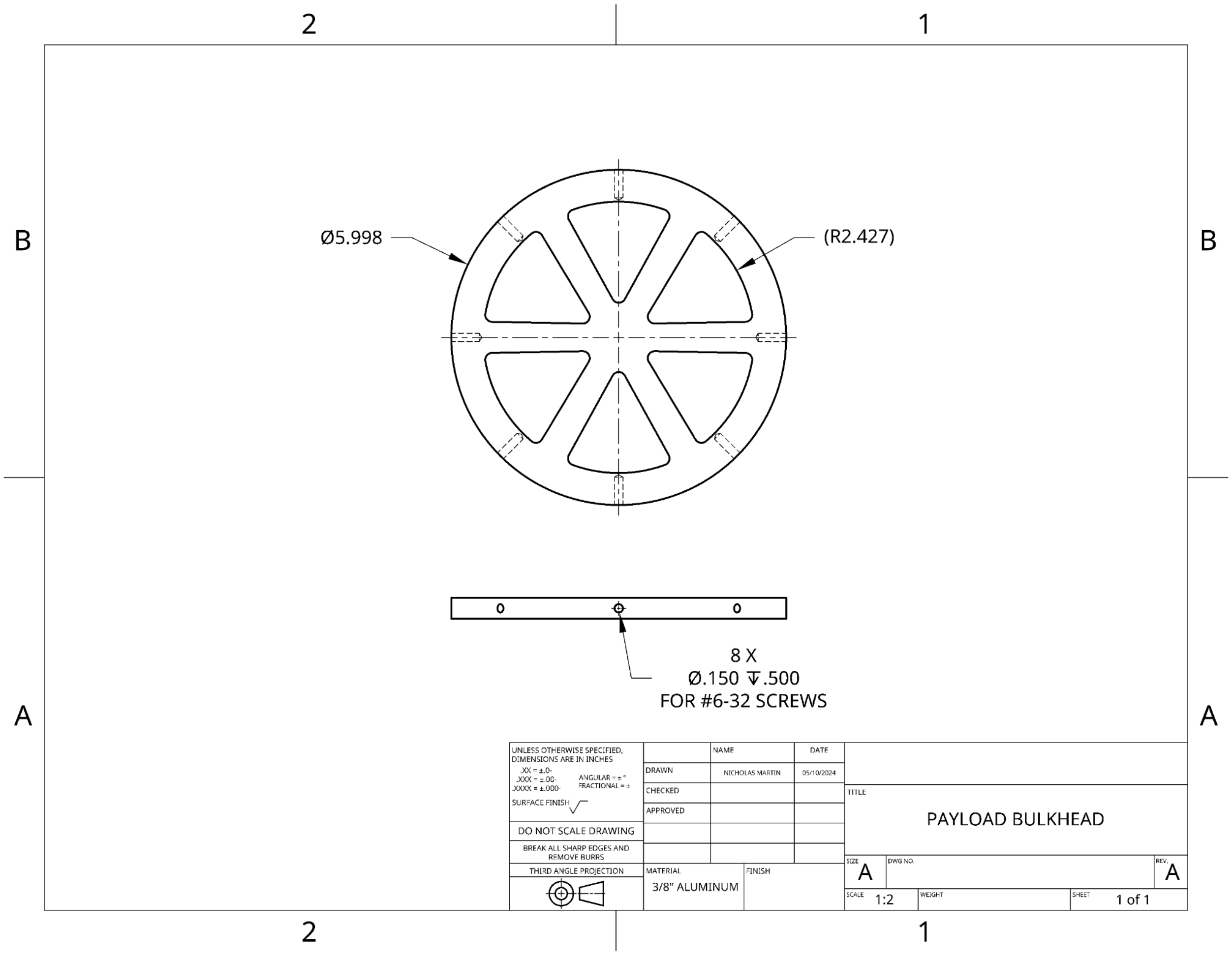
TITLE: FIN ASSEMBLY

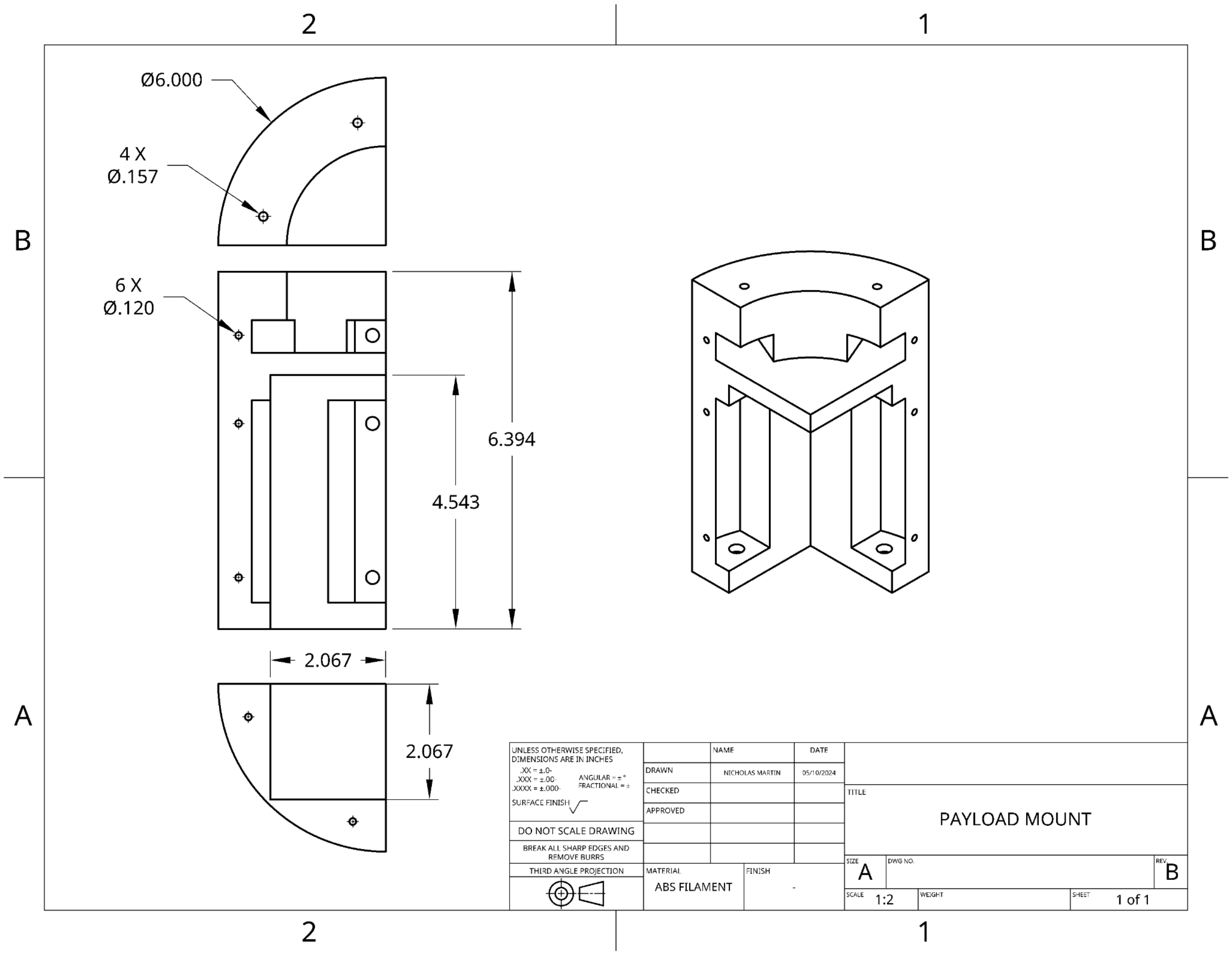
SIZE: A | DWG NO. | REV. A
SCALE: 1:12 | WEIGHT | SHEET: 1 of 1


2
1
B
B
11.000
7.000
2.000
1.075
3 X
.140
7.290
TYP
3.000
A
A
UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
02/16/2024
CHECKED
APPROVED
MATERIAL
1/8" G10
FIBERGLASS
FINISH
SAND
TITLE
Fin
SIZE
A
DWG NO.
REV.
A
SCALE
1:4
WEIGHT
SHEET
1 of 1
2
1

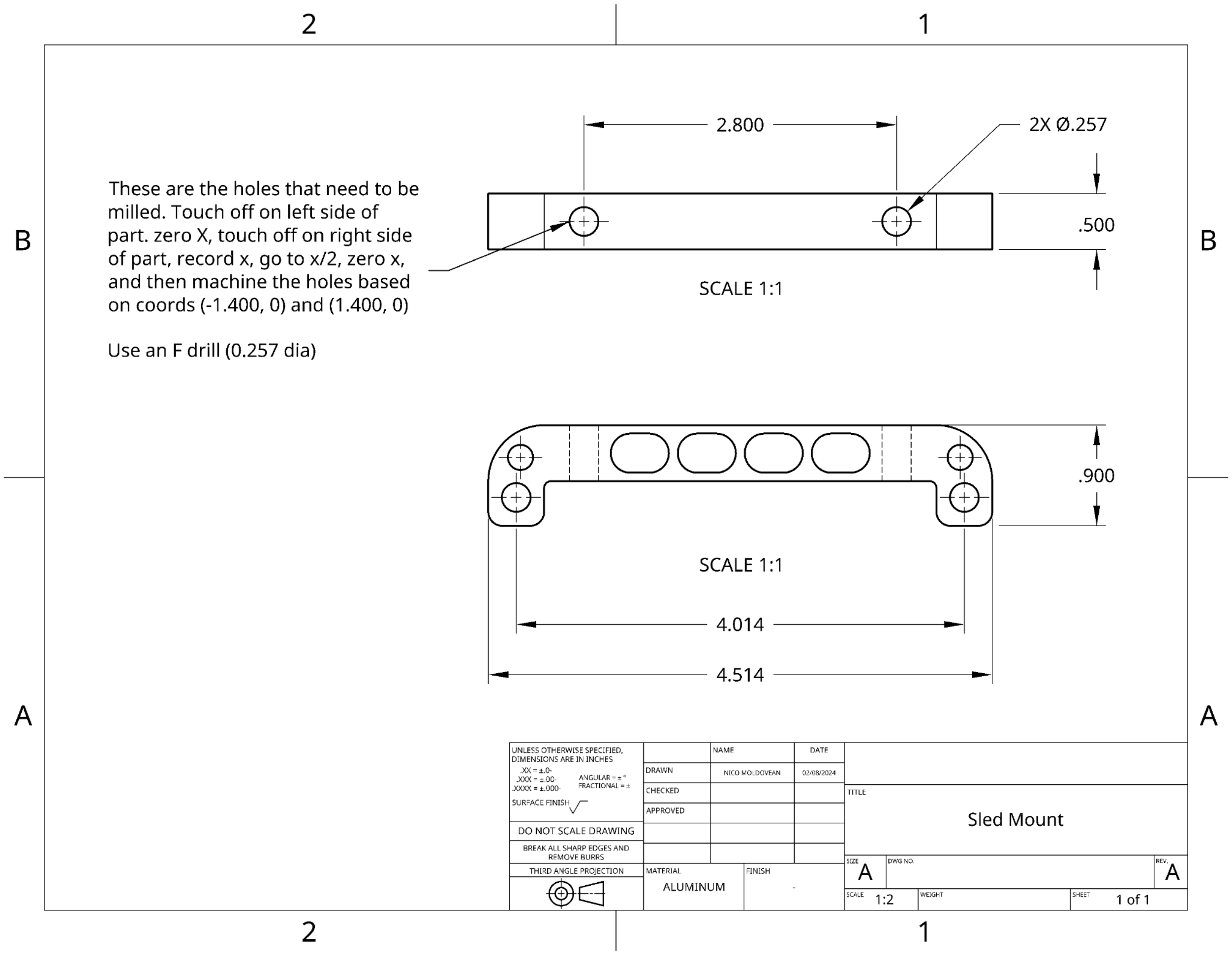


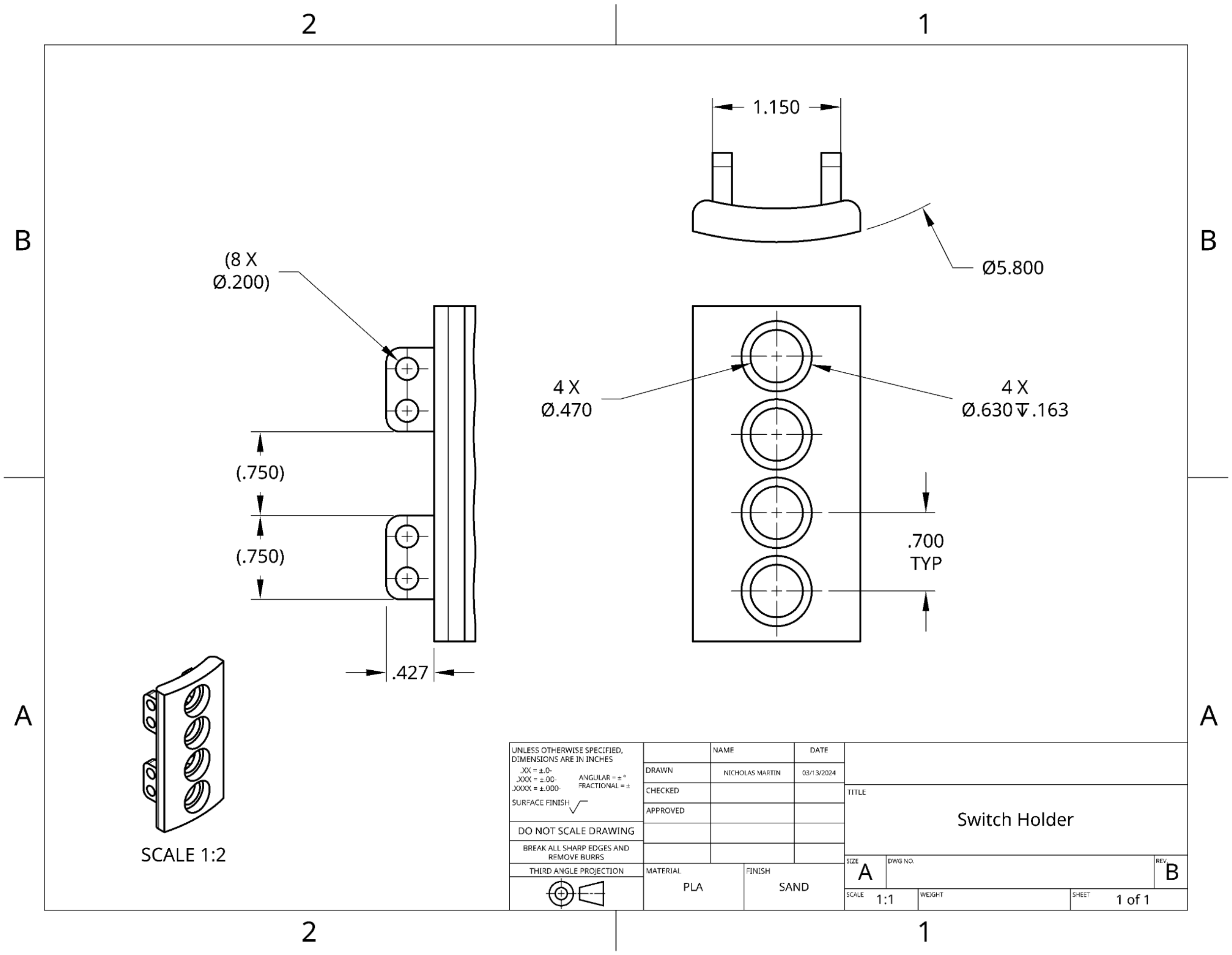
2
1
B
B
4 X
Ø.145
6 X
Ø.144
(1.800)
9 X
Ø.226
A
A
Ø5.798
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
05/10/2024
CHECKED
APPROVED
MATERIAL
PLA FILAMENT
FINISH
-
TITLE
NOSE GPS MOUNT
SIZE
A
DWG NO.
REV.
A
SCALE
1:2
WEIGHT
SHEET
1 of 1
2
1

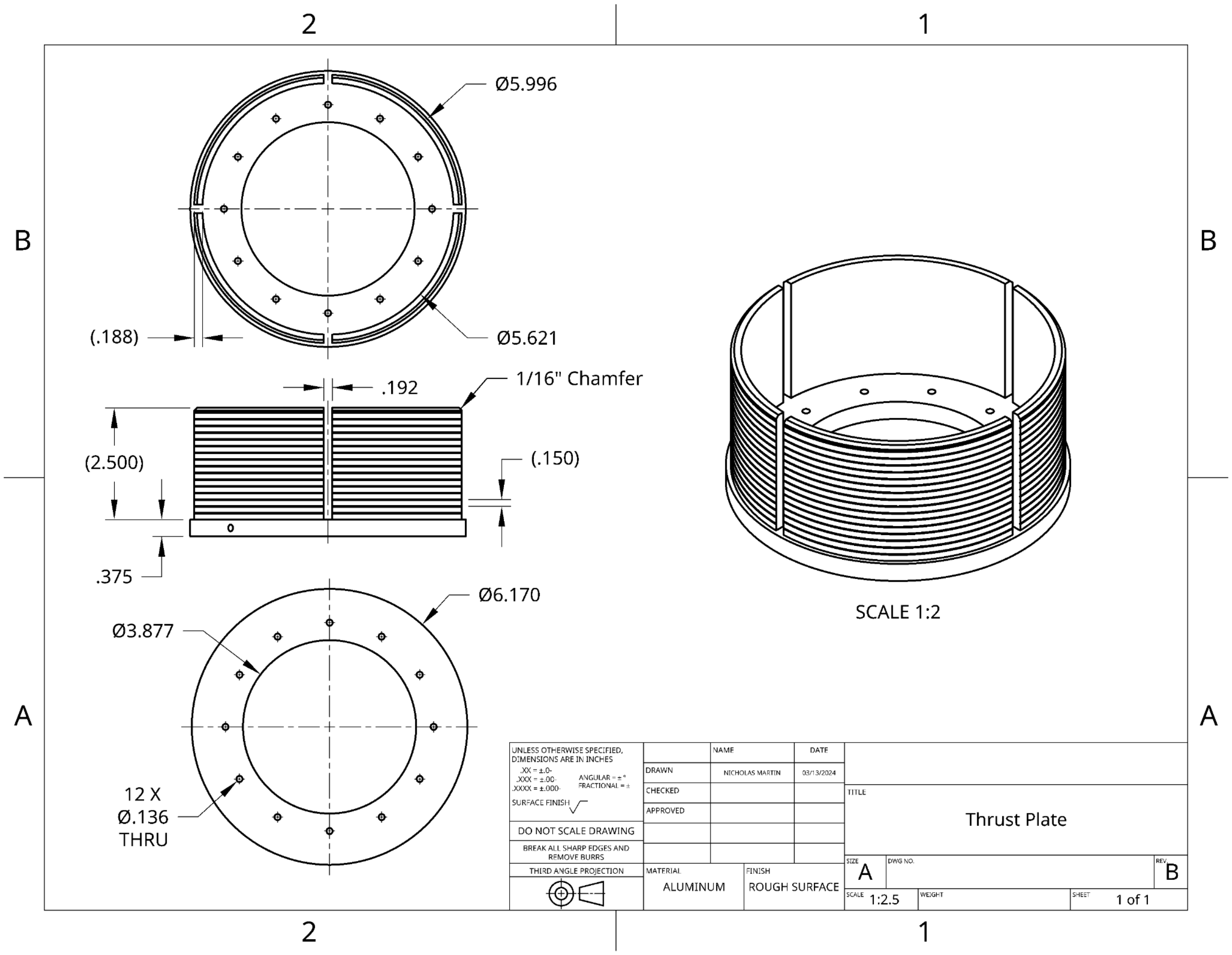

2
1
B
Ø5.998
(R2.427)
8 X
Ø.150 ↧.500
FOR #6-32 SCREWS
A
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
05/10/2024
CHECKED
APPROVED
MATERIAL
3/8" ALUMINUM
FINISH
TITLE
PAYLOAD BULKHEAD
SIZE
A
DWG NO.
REV.
A
SCALE
1:2
WEIGHT
SHEET
1 of 1



Ø6.000
4 X
Ø.157
6 X
Ø.120
6.394
4.543
2.067
2.067
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
05/10/2024
CHECKED
APPROVED
MATERIAL
ABS FILAMENT
FINISH
-
TITLE
PAYLOAD MOUNT
SIZE
A
DWG NO.
REV.
B
SCALE
1:2
WEIGHT
SHEET
1 of 1


2
1
2.800
2X Ø.257
These are the holes that need to be milled. Touch off on left side of part. zero X, touch off on right side of part, record x, go to x/2, zero x, and then machine the holes based on coords (-1.400, 0) and (1.400, 0)
Use an F drill (0.257 dia)
B
.500
B
SCALE 1:1
.900
SCALE 1:1
4.014
4.514
A
A
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICO MOLDOVEAN
02/08/2024
CHECKED
APPROVED
MATERIAL
ALUMINUM
FINISH
-
TITLE
Sled Mount
SIZE
A
DWG NO.
REV.
A
SCALE
1:2
WEIGHT
SHEET
1 of 1
2
1


1.150
Ø5.800
(8 X
Ø.200)
4 X
Ø.470
4 X
Ø.630 ↧ .163
(.750)
(.750)
.700
TYP
.427
SCALE 1:2
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
03/13/2024
CHECKED
APPROVED
MATERIAL
PLA
FINISH
SAND
TITLE
Switch Holder
SIZE
A
DWG NO.
REV.
B
SCALE
1:1
WEIGHT
SHEET
1 of 1


2
1
B
A
Ø5.996
Ø5.621
(.188)
.192
1/16" Chamfer
(2.500)
(.150)
.375
Ø6.170
Ø3.877
12 X
Ø.136
THRU
SCALE 1:2
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
NAME
DATE
DRAWN
NICHOLAS MARTIN
03/13/2024
CHECKED
APPROVED
MATERIAL
ALUMINUM
FINISH
ROUGH SURFACE
TITLE
Thrust Plate
SIZE
A
DWG NO.
REV.
B
SCALE
1:2.5
WEIGHT
SHEET
1 of 1

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