Iterating Innovation with CURE

Team 21 Project Technical Report for the 2024 IREC

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This abstract presents an overview of our project for the Spaceport America Cup 2024, wherein our team competes in the 10k COTS category with a launch vehicle designed for advanced particulate collection and analysis to monitor air quality. The defining characteristics of our launch vehicle include the Miniaturized Avionics for Rapid Testing, Handling, and Assessment (MARTHA) system, which supports low-cost deployment and reliable data acquisition crucial for ongoing advancements in flight computer technology. The vehicle construction features student-researched and developed (SRAD) body tubes, couplers, and structural reinforcements using carbon fiber plating. This year marks our first implementation of a dual bay deployment system and celebrates the success of our initial test flight, demonstrating significant improvements in design and functionality. Additionally, the payload incorporates a 360-degree camera array consisting of three cameras to capture comprehensive visual data during flight, serving a secondary mission of enhancing visual documentation. This report details the robust iterative design of our aero-structures subsystems as well as the effective and novel SRAD avionics system.

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I.Nomenclature

C_p = Pressure coefficient
Cx = Force coefficient in the *x* direction
Cy = Force coefficient in the *y* direction
c = Chord
kg = Kilogram
Fx = *X* component of the resultant pressure force acting on the vehicle
Fy = *Y* component of the resultant pressure force acting on the vehicle
h = Height
m = Meter
j = Waypoint index
K = trailing-edge (TE) nondimensional angular deflection rate
G = Gauss
° = Degree
dps = Degrees per second
°C = Degrees Celsius
°F = Degrees Fahrenheit
g = Gravitational acceleration
ft = Feet
in = Inch
s = Second
lbm = Pound-Mass
lbf = Pound-Force
N = Newton
oz = Ounce
V = Volts
A = Amps
Ns = Newton-Seconds
cal = Caliber
mAh = Milli-Amp Hour
mph = Miles per hour

II.Introduction

A. Clemson University

Clemson University is a public land grant research institution in Upstate South Carolina, centered between Charlotte, NC, and Atlanta, GA. With a student population of over 28,000 undergraduate and graduate students, Clemson hosts a diverse set of academic colleges, including the College of Engineering, Computing and Applied Sciences (CECAS); College of Science (COS); Wilbur O. and Ann Powers College of Business (COB); and more. "Clemson combines the benefits of a major research university with a strong commitment to undergraduate teaching and individual student success. Students, both undergraduate and graduate, have opportunities for unique educational experiences throughout South Carolina, as well as in other countries. Experiential learning is a valued component of the Clemson experience, and students are encouraged through Creative Inquiry, internships, and study abroad, to apply their learning beyond the classroom. Electronic delivery of courses and degree programs also provide a variety of learning opportunities. Clemson's extended campus includes teaching sites in Greenville, Greenwood, Anderson and Charleston, eight research campuses and extension centers in every county of South Carolina, as well as four international sites. The University is committed to exemplary teaching, research, and public service in the context of general education, student engagement and development, and continuing education. In all areas, the goal is to develop students' communication and critical-thinking skills, ethical judgment, global awareness, and scientific and technological knowledge" [5].

B. Clemson University Rocket Engineering

The Clemson University Rocket Engineering team, also known as CURE, is the primary source of aerospace involvement and education at Clemson University, as there is no formal discipline within aerospace. The CURE mission is to introduce the aerospace industry to Clemson University for all demographics, develop future leaders worldwide, and research cutting-edge technology. CURE is a delegated student organization (DSO) of Clemson University's CECAS, meaning we are direct representatives of CECAS and the University. To provide the outlet for Aerospace Engineering to the Clemson Student body, CURE participates in the annual Spaceport America Cup by designing, manufacturing, and launching a large team rocket fit for the 10k Commercial-Off-The-Shelf (COTS) Mission. Additionally, the CURE team incentivizes all members' personal certifications by hosting Level 1 (L1) and Level 2 (L2) high-power certification rocket build days and launches.

Our team is divided into the Administrative, Engineering, and Financial divisions. The delegation of these three divisions allows each team to focus directly on their role, leading to more efficient and productive work. The Administrative Division, led by the Vice President, oversees onboarding, certifications, and all safety precautions. The Engineering Division oversees all design, simulation, and manufacturing of the rocket and all electrical components, and the Chief Engineers of Mechanical and Electrical Systems oversee it. Lastly, the Financial Division oversees all budgeting, sponsorships, social media, and procurement for the team and is led by the Treasurer. The president then oversees the upper leadership team and the organization. The full, descriptive breakdown of the organization can be seen in Fig. 1 below.

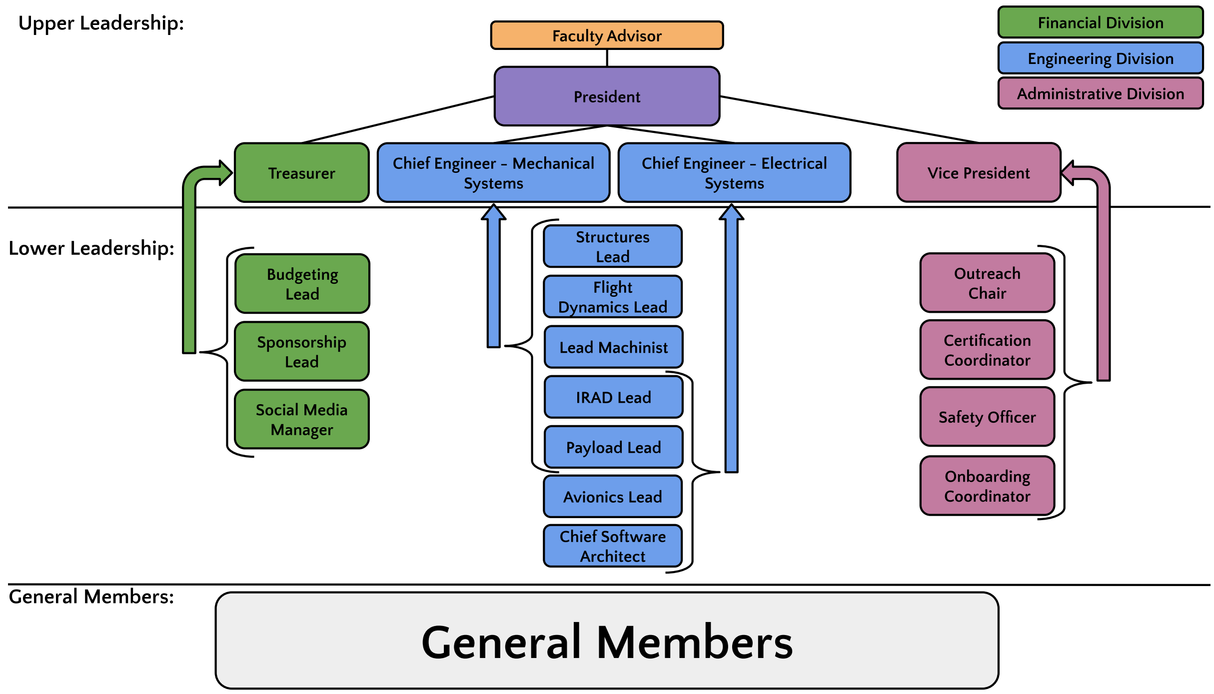

Fig. 1 Clemson University Rocket Engineering Organization Chart

1. *Avionics*

The Avionics Subteam provides dissimilarly redundant and independent COTS altimetry systems for dual-deploy parachute recovery. Additionally, Avionics develops dual redundant and independent COTS global positioning system (GPS) tracking systems to locate the vehicle over a range of multiple miles. These two systems encompass the electrical component of the vehicle's COTS recovery subsystem.

As discussed in Recovery Subsystems, the electrical components of the vehicle's COTS recovery subsystem control the entirety of both the primary and secondary altimetry and GPS recovery systems. Each system features independent power supplies, arming switches, energetics (if applicable), and sensors. No student-researched-and-developed (SRAD) electronic systems have any interaction with electrical components of the vehicle's COTS recovery subsystem.

One of Avionics' primary goals for this project was to design and develop an independent, reusable, and universal COTS electronics bay for both repeated use and greater system modularity for future team needs. We have split our dedicated electronics into COTS and SRAD bays. By decoupling the mounting of COTS and SRAD electronics, iterations to SRAD electronics during this (and future) development cycles will not require drastic modifications to COTS recovery systems. Additions and improvements to the COTS recovery systems will still be expected but will emanate from a template rather than a blank canvas each development cycle.

In addition to the electrical component vehicle's COTS recovery subsystem, Avionics is responsible for developing SRAD hardware and software to enhance data collection and control of passive internal systems within the vehicle to advance CURE's knowledge and understanding of rocketry. The broader goal of Avionics is to develop flight computer hardware and software to eventually control active systems, such as recovery and aerobraking, on more technically complex projects. Much development and testing, including numerous flight tests, is still needed to reach this milestone.

Avionics' current SRAD solution for passive data collection and flight computer testing is the Miniaturized Avionics for Rapid Testing, Handling, & Assessment (MARTHA) printed circuit board (PCB). This is CURE's second PCB since the COVID-19 pandemic and the first to feature a microcontroller (MCU). MARTHA collects nine degree-of-freedom (DoF) and altimetry data and stores the data on a Micro-SD card mounted on the rear of the board. MARTHA will fly on the vehicle, passively recording data during the flight for the team to analyze after the competition.

Avionics encompasses eleven members, with six members focused on software development and five focused on hardware development. The Subteam has two leads: one focused on hardware and one on software. Hardware development was split between work on MARTHA, the development of the electrical component of the COTS recovery subsystem, and the onboarding of three new hardware-focused members. These new members created their simplified version of MARTHA using an STM32 Nucleo board, a simple PCB, and various breakout boards.

Software development prioritized the establishment of core systems within the STM32 ecosystem, including data-collection, state-detection, and a unified team-wide architecture, as well as onboarding/upskilling two new software members. New members to the software team contributed to software that allowed for data collection by MARTHA during the team's test flight of the competition vehicle. Many team members contributed across the fence of hardware and software, with almost all new members contributing to both areas.

Avionics has worked with our Internal Research and Development (IRAD) Subteam to prepare SRAD avionics integration into the aerobraking design in the coming design cycles. This is emphasized on the software side as both groups maintain separate compatible code bases to maintain redundancy in software design while allowing for shared use of ideas, lessons learned, and resources as needed. Additionally, future integration of the MARTHA hardware platform, or any derivatives, into the active aerobraking system is a high priority.

2. *Business*

The Business Subteam of the Clemson University Rocket Engineering team consists of six dedicated members who handle a broad range of critical functions necessary for the team's operation and outreach. This Subteam is pivotal in managing the team's external communications and public relations by running all social media platforms. This involves curating content, engaging with followers, and promoting the team's achievements and events.

In addition to their digital presence, the Business Subteam is tasked with the creative and logistical aspects of designing and producing organization merchandise. This merchandise serves both to boost team spirit and to provide a source of funding through sales. Their responsibilities extend to collaboration with businesses and sponsors, forging partnerships essential for financial support and professional guidance.

Financially, this Subteam plays a crucial role in the team's sustainability. The business team is responsible for all procurement activities, ensuring the engineering teams have the necessary materials and equipment to build and test the rockets. Moreover, they create and manage the budgets for the entire team, allocating funds efficiently across various projects to maximize the team's capabilities and success.

3. *Flight Dynamics*

The Flight Dynamics Subteam works on the aerodynamic design of the flight vehicle and flight prediction. This Subteam oversees how long the rocket is, the nose cone shape and size, the fin design, and its overall stability in flight. OpenRocket and RASAero are the primary simulation methods for creating the rocket design [10][14]. Flight Dynamics also oversees motor selection through an iterative process of testing M and N class motors on OpenRocket using the prototype rocket profile and weight [10]. In addition to these duties, Flight Dynamics has also been attempting to manufacture custom nose cones this year using carbon fiber molds and 3D printing. This Subteam has eight active members.

This Subteam also uses simulation software to measure the performance of different aspects of the rocket. For predicting the vehicle's apogee, this Subteam primarily uses OpenRocket by creating a rocket model in the program to simulate how it would perform with different motors and at different locations, temperatures, and wind speeds.

Flight Dynamics Subteam also uses SolidWorks Flow Simulation to demonstrate pressure over the nose cone. This Subteam uses these simulations to determine any irregularities in the nose cone that would cause unwanted aerodynamic effects. This creates a dynamic process of testing various nose cones and comparing pressure values between them to find the ideal nose cone. With the simulations, this Subteam can graphically produce and distribute findings to other teams to create better communication within the overall team.

4. *Payload*

The Payload Subteam is responsible for the yearly design and production of the team's payload contribution to the SDL Payload Challenge. CURE's primary payload consists of a 3U, aluminum-framed CubeSat, which retains power cells for the payload and an additional camera section, a 1U sensor section, and an additional 1U space for stabilizing weight. Additionally, the Payload Subteam has developed 360-degree view camera systems for the team's past and current vehicles for the SAC Video challenge.

This Subteam is currently co-led with seven active members, including the two leads. The team is divided into a three-person electrical systems team and a four-person structures and design team to support the technical diversity in payload development. The electrical systems team focused on developing a program for in-flight sensor bay and camera operations. The program is primarily responsible for arming the sensors and recording data to a Micro-SD Card for post-recovery data analysis. Additionally, the team was responsible for manufacturing the wiring harness that formed the electrical connections between each component. The design team spent three months primarily working on 3D models of the Subteam's design using OnShape [9]. These models include the 3U CubeSat, the sensor bay insert, the camera covers, and the camera bay structure. The following four months were spent 3D-printing and iterating on camera covers and sensor bay prototypes and machining the aluminum structure of the 3U CubeSat and camera bay.

5. *Internal Research and Development*

The IRAD Subteam is responsible for an active aerodynamic braking system (Active Aero) designed to deploy flaps to slow down the rocket and to prevent overshooting a predicted apogee. The team consists of eight students, the Subteam lead, and seven handpicked students balanced between mechanical and electrical disciplines, with four students from each discipline in the Subteam. The active airbrake system's software and hardware components are being developed concurrently with the main team's rocket. This approach ensures compatibility and seamless integration when the final airbrake product is ready for flight. The IRAD team has also developed its own test vehicle to collect flight data and eventually test the airbrakes.

The software and electrical students focus on various aspects to perfect the functionality of the airbrakes and integration into the main team's codebase. One student's work involved establishing data collection from test flights, reading data output from sensors, and writing the data to an SD card during the flight. Sensors included an altimeter, an accelerometer, and a magnetometer. Flight data is essential for developing code to deploy the airbrakes, as code development can continue without requiring new flights to test changes. Another student worked on apogee prediction code and rocket flight dynamics, analyzing the flight data and finding the most optimal way to predict apogee accurately by motor burnout. Apogee prediction is essential to active aerodynamic braking, as the sooner the apogee is known, the more time the airbrakes have to change the vehicle's real-time flight path. A third student worked on sensor fusion and noise reduction, integrating data from sensors and interpolating data using an extended Kalman filter and an attitude and heading reference system to find the vehicle's behavior during flight. This cleaner data gives drastically more accurate results in apogee prediction, allowing the airbrakes to be more reliable and confident in flight. The fourth student worked on an experimental pitot tube to measure the forward speed of the rocket in flight, which can also refine the apogee prediction, as no other sensors can directly read the vehicle's velocity, a requirement in apogee prediction. Velocity is currently being calculated through the Kalman filter. Once the pitot tube is finished, it can be fused with accelerometers and altimeters in the Kalman filter to give highly accurate results.

The mechanical engineering aspect of the Active Aero project is driven by the efforts of four mechanical engineering students in designing, manufacturing, assembling, and launching the test vehicle that forms the backbone of the team's air braking system research. Their collective focus this year was on developing a robust, reusable hybrid test vehicle capable of enduring multiple flights and recoveries while facilitating rapid reloading, which is critical for financial sustainability and staying within budgetary constraints. The team emphasized structural integrity to ensure the vehicle could withstand numerous flights. It created a dependable platform for validating the Active Aero system's performance and ensuring its seamless future integration into the main team's competition rocket. With a successful launch and recovery of the test vehicle, the mechanical work in developing a test vehicle has laid a solid foundation for next year's endeavors by ensuring that the rocket provides the reuse needed to test and prove an air braking system's functionality accurately. This year, this Subteam's efforts have significantly contributed to developing an effective active aerodynamic system, enabling the project to achieve its primary objective of achieving effective in-flight apogee control and strengthening Clemson University's competitive edge in rocketry competitions.

6. *Structures*

The Structures Subteam is responsible for the design and manufacture of the overall airframe of the rocket, as well as taking on general manufacturing needs for Avionics and Payload. The Subteam oversees manufacturing composite body tubes and composite sheets for fins, bulkheads, and centering rings through in-house techniques developed over multiple years of testing. Members utilize certifications and skills with manual lathes, mills, waterjets, and laser cutters, using this experience to manufacture bulkheads, payload components, and testing apparatuses to validate load-bearing components.

The Structures Subteam has approximately fifteen active members and two co-leaders. Members across the organization have different levels of machine certifications at the Clemson Cook Engineering Laboratory: thirteen members with basic manufacturing certifications and ten with advanced manufacturing certifications. Since Structures has the most manufacturing experience, members work alongside the Avionics and Payload Sub teams to assist in designing and manufacturing internal structures. The sub-team members utilize 3-D modeling software such as OnShape and SolidWorks to design portions of the internal structure, such as COTS and SRAD housing [9][15]. They then print the designed parts and test the fit and their functionality, adjusting to the design of the internal structuring as needed. The 3D printing capabilities of the club are expanding as new printers are acquired, allowing the Subteam to prototype design concepts for feasibility and to test integration issues rapidly. Additionally, the Structures Subteam works with the Flight Dynamics Subteam to determine the vehicle airframe and fin lengths. Most Subteam members have hands-on experience manufacturing composite body tubes, and their knowledge of composites represents one of the club's most advanced areas of experience.

C. Budget Analysis

This section provides a thorough analysis of the budget for the CURE organization, detailing the financial allocation and management strategies employed throughout the project lifecycle. It outlines the total funds available, sources of funding, and a breakdown of expenditures across various categories such as materials, labor, testing, and administrative costs. This analysis aims to ensure transparency in financial operations and demonstrate how strategic budget allocation supports the project's goals and enhances our capability to deliver a successful vehicle design. Furthermore, the discussion includes a review of financial efficiencies and areas where cost savings were realized without compromising the quality or safety of the vehicle. This budget analysis reflects the current financial status and serves as a foundational tool for future fiscal planning and resource allocation within the team.

1. *Sources of Funding*

The CURE organization's financial resources are derived from various sources that support different facets of our project, ensuring comprehensive coverage of all necessary expenses. As a DSO, most of our funding comes from the Student Funding Board (SFB), which annually supports our rocket engineering activities' operational and material costs. This funding is crucial for maintaining the continuity of our projects each academic year. The CECAS also plays a significant role in our financial ecosystem. CECAS partially sponsors our travel to competitions and testing locations and funds the certification rocket initiative.

Our partnership with Science Applications International Corporation (SAIC) further enriches our funding landscape. SAIC sponsors our IRAD Subteam, which focuses on developing innovative technologies such as the ActiveAero airbrake system. This system is designed to enhance the precision and effectiveness of our rockets, representing a critical component of our research and development efforts.

In addition to financial contributions, our project benefits significantly from in-kind support. OnShape and Ansys provide free access to advanced engineering software, indispensable for our design and simulation tasks. Moreover, Chomarat supplies us with high-quality carbon fiber materials for constructing robust and efficient aerostructures. This combination of monetary support and material sponsorship enables our team to push the boundaries of academic and practical achievements in rocket engineering.

2. *Organization Budget*

The CURE team operates with an annual budget of $23,000.00, sourced primarily from the SFB and additional contributions from various sponsors. This funding supports the diverse needs of our team, ensuring each project phase is adequately financed while promoting an efficient and strategic allocation of resources.

The organization's budget is intricately structured to cover specific needs across multiple Subteams, each responsible for the vehicle's development. These categories include Avionics, Structures, Flight Dynamics, and more. Notably, the Travel category, which amounts to approximately $13,000.00, is fully sponsored by the CECAS, thus relieving the budget of significant travel expenses and allowing for more focused spending on technological and structural advancements. A detailed budget summary can be seen in Fig. 2 below.

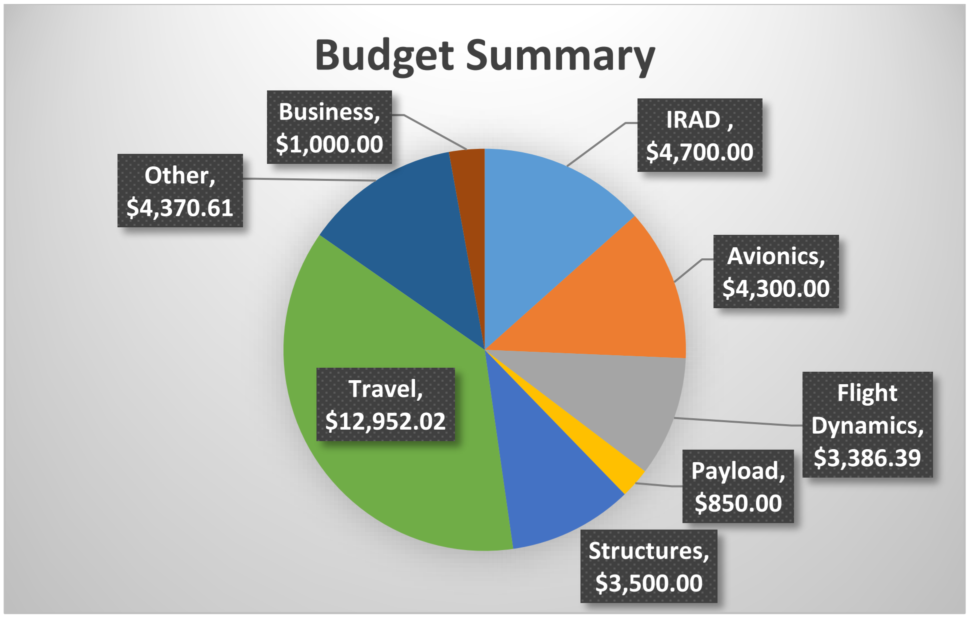

Fig. 2 Budget Breakdown of the CURE Organization

Before funds are distributed, each Subteam undergoes a rigorous budget request process, which includes a comprehensive project review and timeline, an itemized list of necessary materials, and a detailed rationale behind the requested budget and specific items. This process ensures that every dollar allocated aligns with our strategic goals and maximizes the potential for successful project outcomes.

3. *Procurement Analysis*

This year, the CURE organization has implemented a sophisticated procurement system using AirTable, enhancing our ability to track and manage expenditures with greater accuracy and transparency [2]. This system has allowed us to streamline our procurement processes, ensuring that all purchases are aligned with our project's needs and budget constraints. Our procurement strategy is divided into several major categories, as illustrated in the accompanying Fig. 3. These categories represent the various areas where funds are allocated, each supporting a specific aspect of the rocket engineering project, called buckets.

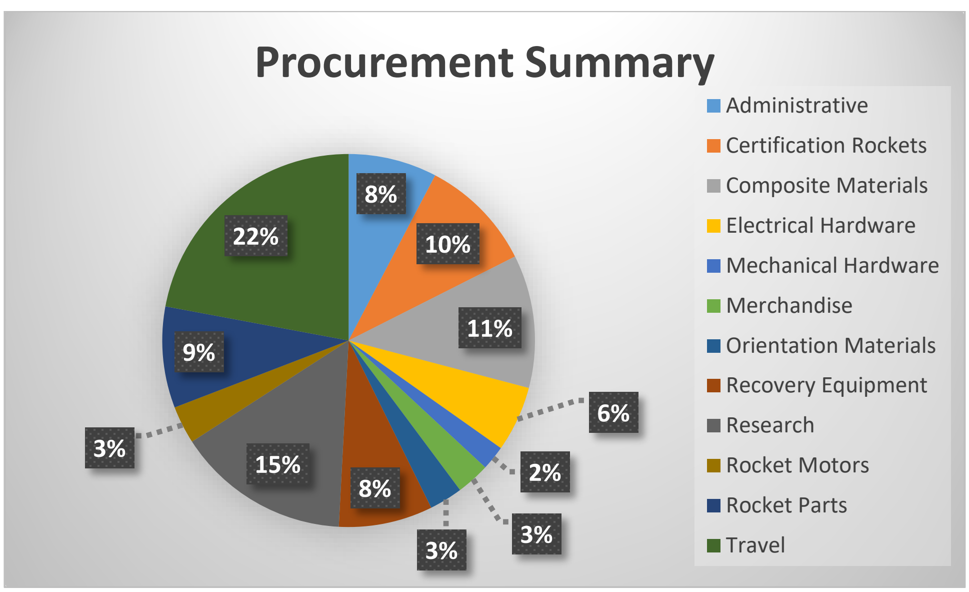

Fig. 3 Procurement Percentage by Bucket

The introduction of AirTable has facilitated a more nuanced approach to financial management, allowing us to monitor spending in real time and adjust procurement strategies swiftly [2]. This agility has been instrumental in identifying areas where cost savings can be realized without compromising the quality or safety of our rockets. For instance, bulk purchases of composite materials, hardware, and rocket motors have negotiated discounts. Fig. 2 details the percentage breakdown of expenditures across all procurement categories. This visual representation helps quickly assess which areas consume the most resources and where adjustments may be needed. For example, the significant investment in composite materials is justified by the need to manufacture a launch vehicle by hand physically. Meanwhile, the lower spending on merchandise and orientation materials reflects a balanced approach to non-essential expenditures.

Through this detailed procurement analysis, the CURE team ensures that every dollar spent is meticulously accounted for and strategically utilized, reinforcing our commitment to excellence and fiscal responsibility in all rocketry endeavors.

III.System Architecture Overview

The Clemson University Rocket Engineering organization's launch vehicle, "We'll 'C' What Happens," is one of the most novel designs for the University to date. While being one of the most technically advanced launch vehicles, "We'll 'C' What Happens" is also foundational for the club's future. One of the primary goals of this team is to create an iterative, modular design that can be improved upon each year, with this year's vehicle being the cornerstone of this effort. "We'll 'C' What Happens" can be seen in Fig. 4 below.

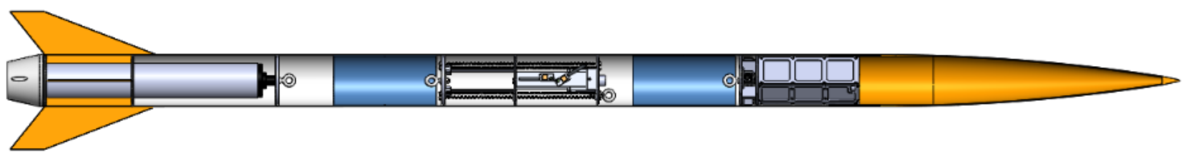

Fig. 4 Cutaway of Fully Integrated Launch Vehicle

The vehicle entered the 10k COTS competition with an AeroTech M2500T motor consisting of a motor section, avionics tube, payload tube, and nose cone. Most airframes are constructed of SRAD components, including composite body tubes and bulkheads, in-house machined payload components, and 3D printed carbon-reinforced nylon, which is proven durable and heat resistant. This design is flight-proven, having achieved a successful test launch with no damage, and represents an iteration of the largely successful design of last year's vehicle.

A. Propulsion Subsystems

The motor selection is critical to determining how much a rocket can weigh, how stable it will be during flight, and what apogee it can reach. It was determined that Clemson University's rocket would need to lift 58 *lbm* to an apogee of 10,000 *ft* for the competition. After analyzing thrust curve data for each of AeroTech's class N and M rocket motors, it was decided that a M2500T AeroTech[16] motor should be used. The team made this decision after considering prior experience and the rocket's stability off the pad. The team flew with the M2500T in the 2022 and 2023 SAC launches on rockets of similar geometry and weight as this year's design.

Furthermore, the thrust curve of the M2500T allows for the rocket to reach a velocity of 107 *ft/s* when it leaves the launch rail. The velocity off the launch rail is crucial for stability during launch. The motor also provides a near constant thrust of 2,700 *N* for the first three seconds of its burn time, reducing stresses that would have been increased by a more variable rocket thrust curve. The team's familiarity with the selected motor, as well as the stability and stress benefits, play a large role in increasing the team's chance of success at the SAC.

B. Aero-structures Subsystems

The design of this year's vehicle is an iteration of last year's design, with improvements made in the construction techniques and quality control of SRAD components. The vehicle has been validated through ejection testing and a successful test flight in which there was no structural or cosmetic damage. The airframe consists of a nosecone, payload tube, avionics tube, and motor tube.

1. Nose Cone

The nose cone is a COTS Wildman 31 *in* 5:1 Tangent Ogive, with an integrated fiber glass coupler extending into the payload tube one body caliber. The nose cone also includes a COTS machined aluminum tip with a shoulder extending into the nose cone and is secured with a threaded fastener and washer.

2. Body Tubes

The payload and avionics body tubes are constructed of SRAD hand-layup fiberglass, with West Systems 105 Epoxy Resin and 209 Extra Slow Hardener. Fiberglass was chosen for these sections for RF transparency. The body tubes are constructed using in-house techniques developed over multiple years, which involve wrapping a rigid blue tube mandrel with a layer of mylar, followed by a layer of woven peel ply. The layer of woven peel ply allows for an improved bond between the body tube and the epoxied bulkheads. The fiber weave is then incrementally wrapped from a single long sheet calculated to wrap around the mandrel three times for fiberglass and four times for carbon fiber, while the epoxy is thoroughly coated on each layer to ensure the result is a fully wetted-out composite material. Once the wrap is complete, a layer of woven peel ply is wrapped around the outside to improve the consistency of the outer surface finish. The result is an extremely strong body tube, able to withstand over 600 *lbf* of compressive longitudinal force.

2. Couplers

The couplers are made in a very similar way to the body tubes, except using a 3D printed mandrel sized such that the couplers may be made of four layers of carbon fiber, offering superior strength and durability over Blue Tube and COTS wound fiberglass couplers, which have buckled or been folded over upon landing in previous years. Unlike the body tubes, the couplers are only made with one layer of woven peel ply on the outer edge of the coupler to allow for a tighter fit within the body tube. This cut of the peel ply on the inner side of the coupler allows for an added layer of carbon fiber, thus increasing the strength and durability of the coupler. The couplers are secured to the airframe with West Systems epoxy for non-sliding joints and 6-32 shear pins[22] for sliding joints.

3. Bulkheads

The rocket has six main bulkheads: two carbon fiber ring bulkheads to secure the avionics bay and the boat tail, two centering rings to secure the motor assembly and index the fins radially, and one solid carbon fiber bulkhead for the forward motor retention. The carbon fiber bulkheads are made from 0.25 *in* thick COTS Dragon Plate[8] and 0.375 *in* thick SRAD hand lay-up and vacuum bagged carbon fiber sheet. Each layer of the twill weave was rotated 90 degrees, increasing the moment and radial strength to ensure the manufactured plate was sufficiently robust.

The bulkheads are water jetted out of the sheet and post-processed using drill presses and sandpaper to prepare the surface and holes for brass threaded inserts, which are epoxied into the bulkheads. The carbon fiber bulkheads are secured to the body tubes with West Systems epoxy, and fiber glass shavings are added for increased strength and viscosity.

4. Motor Tube

The motor tube consists of a carbon fiber body tube, with a minimum diameter carbon fiber inner body tube radially securing the motor. The fins are 0.25 *in* thick and have through-wall construction, being rigidly epoxied to the inner body tube with fillets and to the centering rings before being epoxied to the outer body tube with fillets.

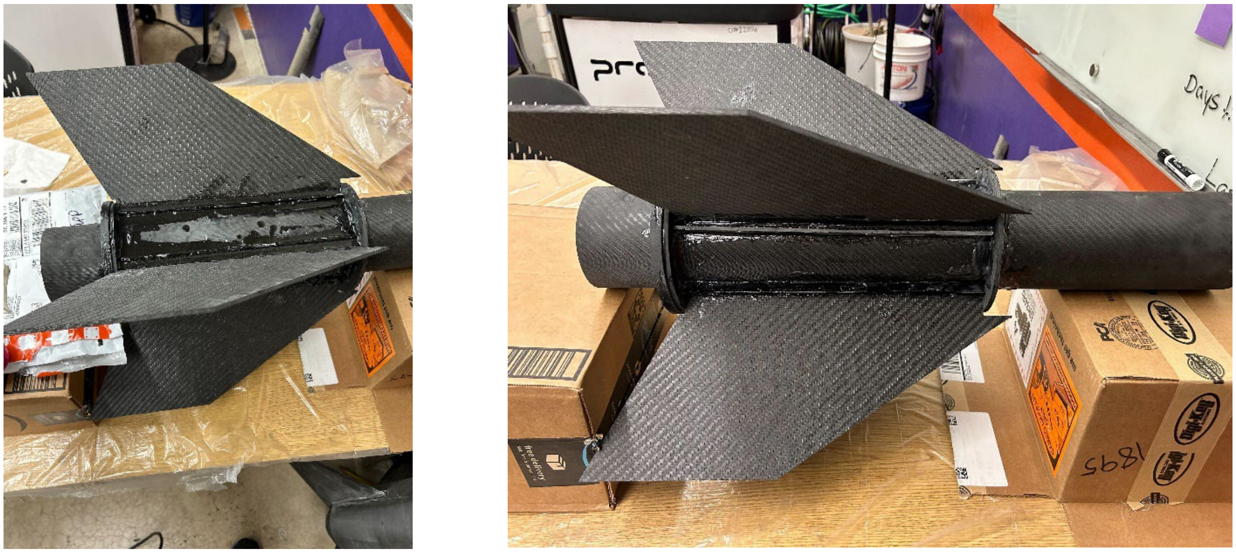

Fig. 5 Internal Assembly of Motor Tube

The fins include a tip-to-tip hand layup of two layers of carbon fiber. This decision was made to ensure the fins withstand the excessive landing forces that may damage fins without tip-to-tip reinforcement. Also, tip-to-tip reinforcement improves the airflow along the surface around the fins by making a more consistent transition from the fins to the body tube around the fin fillet.

Fig. 6 Completed Tip-to-Tip carbon fiber layup with layer of woven peel ply

The aft motor retention uses the machined shoulder threaded into the motor case, which fits tightly against the inner motor tube. The forward motor retention is a carbon fiber bulkhead epoxied to the body tube acting as a thrust plate, with a forged eyebolt[10] rated to 1300 *lbf* threaded tightly into the forward threaded hole on the motor case. The 3.77 *in* long boat tail is 3D printed from carbon fiber reinforced nylon and is screwed into the threaded inserts epoxied into the rear centering ring.

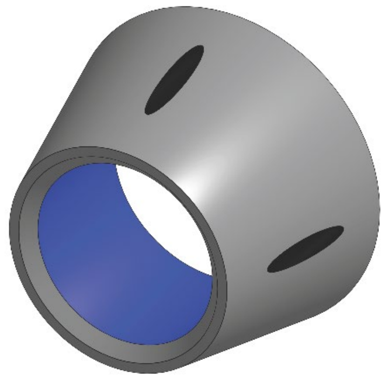

Fig. 7 Rendering of Boat Tail with Reliefs for Fasteners

C. Recovery Subsystems

The vehicle uses a dual-bay recovery system. The drogue parachute is stored in bay one, which lies above the motor and below the avionics airframe. The drogue[9] is a 48 *in* elliptical parachute manufactured by Fruity Chutes. This drogue chute has a 1.1 *oz* ripstop, 400 *lbf* braided nylon shroud lines, a 5/8 *in* nylon bridle, and a 1,500 *lbf* swivel. The main parachute is located in bay two, which lies above the avionics airframe and below the payload airframe. The main is a 120 *in* custom parachute manufactured by Fruity Chutes. This main chute has a 1.1 *oz* ripstop, 400 *lbf* braided nylon shroud lines, a 5/8 *in* nylon bridle, a 0.688 Webbing and a 3,000 *lbf* 316 stainless steel swivel[27]. 30 *ft* shock cords[23] are used for both bays. The shock cords are 9/16 *in* 3000 *lbf* nylon webbing. We use eye bolts to connect the shock cords to the airframe and quick links[20] and swivels to connect the shock cords to the eye bolts and parachutes. The eye bolts are 3/8 *in* 3-9/32 *in* coarse forged steel. The quick links are 3/8 *in* steel, rated for 2,640 *lbf*, and the swivels are rated at 3000 *lbf*.

Deployment for both bays is achieved with one 4-gram and one 4.5-gram of 4F black powder per bay, resulting in two redundant charges per bay for a total of four charges. A StratoLogger CF[26] triggers the primary charge in each bay, and an AIM[2] triggers the secondary charge. The StratoLogger fires the drogue charge at apogee and the main charge at 1000 *ft* AGL. The AIM fires two seconds after the StratoLogger for both charges. Both bays have fire blankets and cellulose packing material to prevent damage to the parachute caused by the black powder charges. Each charge is placed in an aluminum charge well and utilizes two e-matches wired in parallel to ensure proper ignition.

The COTS electronics wiring diagram for recovery systems is given in Fig. 8 COTS Electronics Wiring Diagram. As mentioned in Avionics, there are two COTS flight computers, a StratoLogger CF from PerfectFlite and an AIM USB from Entacore. The StratoLogger is a well-known flight computer for launches of this scale within the avionics industry. We chose the StratoLogger for the primary flight computer due to its low cost, reliability, and familiarity. Our team has flown using the StratoLogger as our primary flight computer multiple times. We chose the AIM as the secondary flight computer to add dissimilar redundancy to the recovery system and gain more experience with other flight computers.

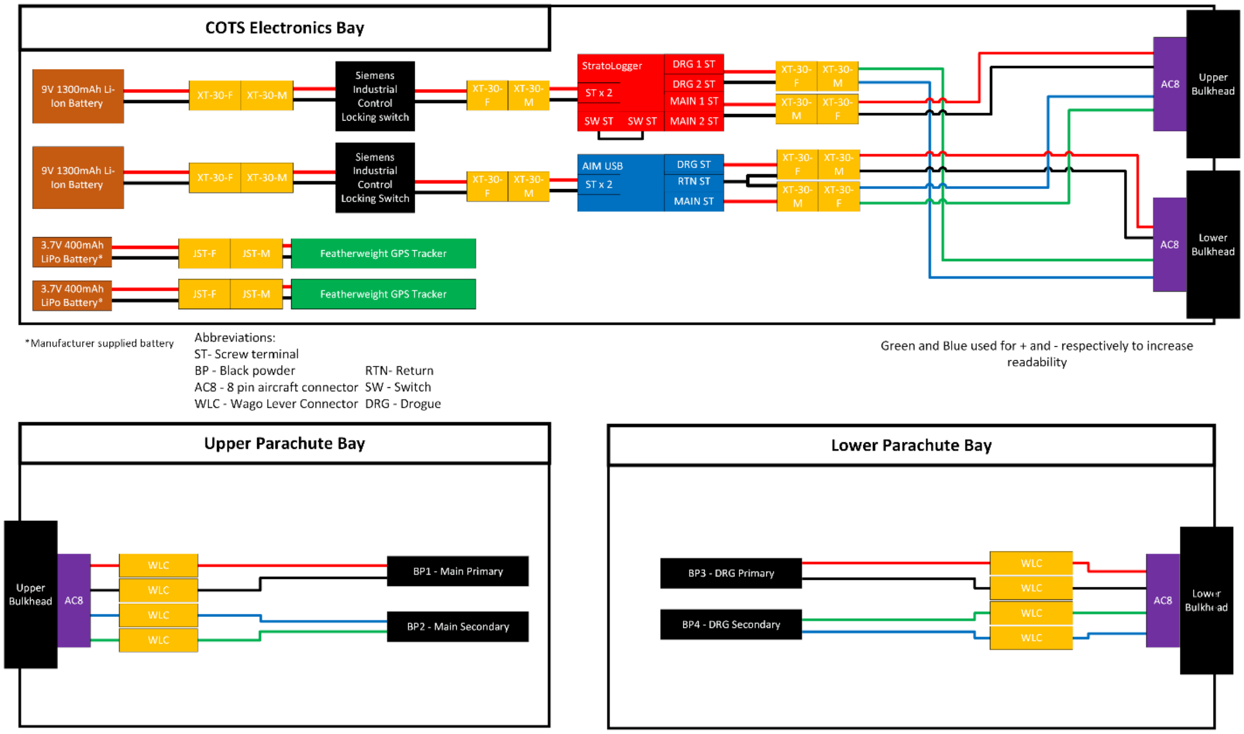

Fig. 8 COTS Electronics Wiring Diagram

Both flight computers are powered by separate, new 9 *V* Duracell batteries which have been proven to last more than six hours in launch detect mode and over twenty-four hours in the post-landing alert mode. Each flight computer is operated by a Siemens locking switch[24]. We chose these switches because of their durability, resistance to extreme temperatures, and 10 *A* continuous power rating. We have flown successful flights using these switches.

All wires on the bay are twisted pairs to prevent electromagnetic interference (EMI), run through bulkheads and organized using soldered, eight pin, aviation style connectors. We noticed that these connectors are sensitive to vibrations during the flight. To mitigate this effect and keep the connector in place, we used Loctite Threadlocker blue for its strength and ease of removal. Additionally, we use Loctite mounting putty on the bulkheads to fill in any gaps and screw holes to ensure that the entire system is airtight and to protect the electronics from the black powder charge. This system design adds modularity while maintaining a secure connection throughout the duration of the flight. To prevent misconnection, we configured the XT-30[29] connectors so that one cannot connect the drogue lines to the main charges and vice versa, as shown in Fig. 8.

We use a pair of Featherweight GPS trackers[13] paired with two Featherweight ground stations[12], each connected to its own phone, to allow for accurate, real-time tracking of our vehicle. We use the manufacturer supplied lithium polymer (LiPo) battery for these trackers, which can supply six hours of run time.

The COTS bay is held together by a 0.25 *in* carbon fiber Dragon Plate,[8] two fiberglass rails, and a smaller 3D printed bulkhead which connects the COTS bay to the SRAD bay. The rails, chosen due to their RF transparency and added strength, are held to the bulkheads with the aid of a mount on the carbon fiber bulkhead and L brackets on the connector bulkhead as shown in fig. 9.

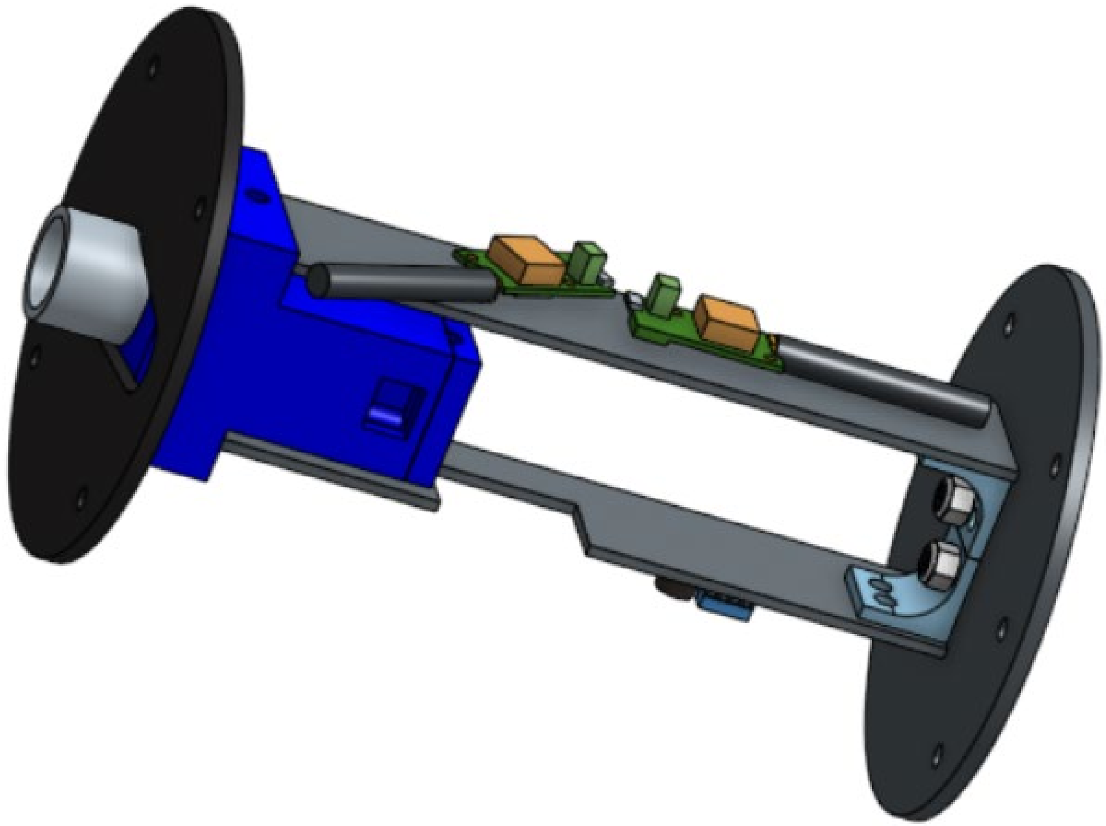

Fig. 9 COTS CAD Model

D. Payload Subsystems

The team aimed to simplify its approach to payload scope and design in its 2024 admission. Our vehicle's payload primarily hosts an aluminum 3U CubeSat containing sections for batteries, weight, and a sensor bay. A secondary payload of a three camera, 360-degree field of view camera section was also developed throughout the academic year.

Positioned at the bottom of the CubeSat, the sensor bay hosts a PMSA0031 air quality sensor[19] for air particulate size and count characterization before, during, and after flight, as well as an ADXL345 accelerometer[1] and BMP388 barometer[5] for self-contained flight state detection and relational flight data for the air quality sensor. These three components are managed by a Feather S3 development board[11]. The relevant data from the three sensors is recorded onto a microSD card at 8 *Hz* via a microSD breakout board. A 3D printed insert provides mounting points for each of the electrical hardware components while also acting as an internal duct for controlled airflow for the air quality sensor. The insert and sensors fit within the bottom 1U section of the 3U CubeSat. The sensor bay is powered by a single 18650 battery cell. This cell is held within the middle 1U section of the CubeSat alongside a 3s2p configuration of 18650 battery cells for powering the vehicle's camera section. The final, top 1U section is left empty and serves as room for emergency weight addition to help increase vehicle stability if the need arises during assembly.

The team has had various payload experiments and structures in previous years, each with bespoke mounting solutions. These different mounting solutions and complicated assembly processes often led to issues in both the time needed to develop these solutions and the problems with assembly right before launch. This year's payload Subteam focused on designing a more modular and faster-to-assemble system to reduce the time required to launch, learning from previous years' hardships. The payload team repurposed the 3U aluminum frame from the team's earlier OCULUS rocket's payload in part to reduce development time and cost.

This rocket's payload frame was chosen due to a variety of factors. Firstly, this payload frame was constructed entirely out of 1/4 *in* 6061-T6 aluminum plate and was flight-proven, having flown in the 2022 Spaceport America Cup. While the thick aluminum frame meant that the payload would be able to withstand the high accelerations of both launch and parachute deployment, the thickness of the aluminum allowed for components such as the sensor bay or ducts to be directly mounted to the frame at any arbitrary point by simply drilling and tapping holes in the plate. This also meant that the mount between the camera bay and the CubeSat frame could be reduced to a simple set of 3 bolts through a shared aluminum bulkhead. By re-using this flight proven superstructure, this year's payload team was able to greatly accelerate their development timeframe by giving more focus to designing the payload experiment and insert. The CubeSat frame and sensor bay insert are depicted in Fig. 10 below.

Fig. 90 SolidWorks render of CubeSat

The vehicle's camera section sits just beneath the 3U CubeSat payload. The three split 3 micro RunCams[21] sit between two, 1/4 *in* aluminum bulkheads. Three, 1/2 *in* aluminum spacers complete the frame of the camera section. Each camera is contained within a 3D printed PLA mount which also provides attachment points for each camera's control board. The bottom bulkhead is bolted to a carbon fiber bulkhead epoxied to the vehicle's airframe, serving as the main attachment point for the team's payload. The camera section is depicted in Fig. 11 below.

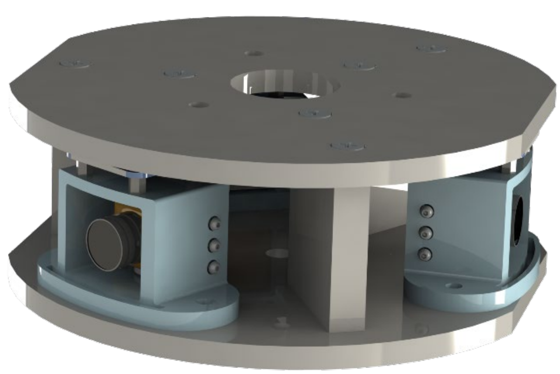

Fig. 11 SolidWorks render of payload camera section

The complete wiring diagram for the team's payload, including the sensor bay and camera section, is given in 11. The three cameras are powered by a 3s2p configuration of 18650 cells. A single 18650 cell powers the sensor bay. The various electrical hardware components of the sensor bay are controlled by the Feather S3 dev board. As it was the Subteam's first foray into a sensor-focused payload, the team prioritized familiar components, such as the Feather S3 and ADXL accelerometer, to complement the system.

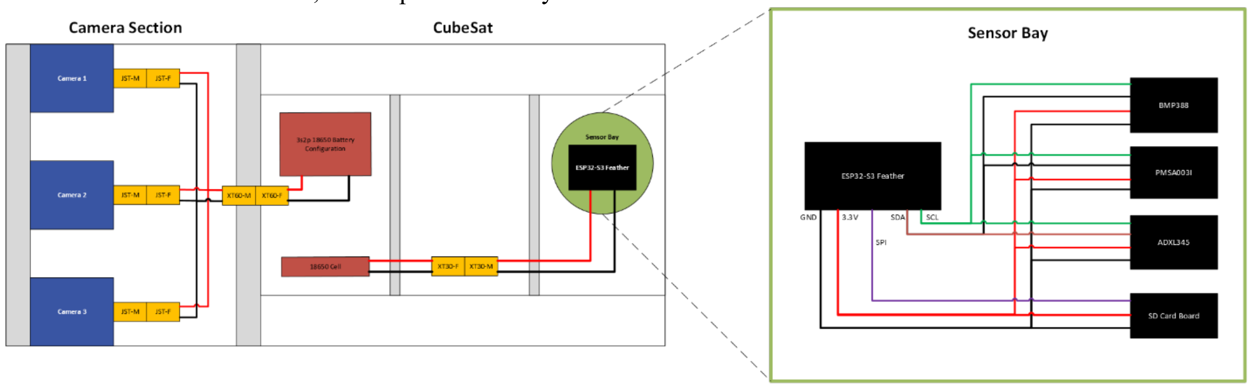

Fig. 102 Complete electric wiring diagrams of payload

Along with designing for an accelerated development timeframe, another major criterion for the Payload was ease of assembly. As previous payloads have had issues with being quickly assembled immediately before launch, the speed of assembly of this year's payload subsystem was a top priority. To achieve this, several features were built into the design of the payload. Firstly, previous payloads were often made in multiple parts that each needed to be installed into the vehicle separately, leading to long and complicated assembly procedures. To aid in this area, this payload was designed to fit into one single superstructure with the 3U CubeSat bolting directly to the structural camera section frame. This means that instead of each component being inserted and mounted into the airframe individually, the entire Camera Bay-Cubesat superstructure could instead be assembled as one piece and then installed into the airframe, greatly reducing lead time prior to launch. From dry runs performed in house and right before the test launch, the entire installation process from installing the batteries to securing the superstructure into the airframe took less than 4 minutes. Another benefit of this design paradigm was that the payload subassembly could be assembled off site prior to launch, further reducing assembly time and risks of broken or missing parts.

Secondly, one of the main assembly issues previous payloads encountered was the method of mounting the payload to the vehicle's airframe. Traditionally, this was achieved through screws that went through the outer skin of the airframe and into tapped holes on the round edges of aluminum bulkheads. This often led to issues with aligning the bulkheads with the airframe, manufacturing the tapped holed in the bulkheads, and transferring those holes to the airframe body. To remedy these issues, this year's payload instead rests on a carbon fiber shelf with a set of 3 vertical screws. These screws directly thread into a matching set of holes on the bottom of the camera section's frame. This greatly reduces the amount of time spent aligning the mounting holes with the payload subassembly as the CubeSat-Camera section assembly could be inserted through the top of the rocket and then rotated until the holes were aligned. By having the holes be vertical, this meant that these holes could be visually aligned when viewed from the bottom of the payload section and tightened by simply using a socket wrench with an extension.

While the thick aluminum frame meant that the payload would be able to withstand the high accelerations of both launch and parachute deployment, the thickness of the aluminum meant that hardware such as the sensor bay or ducts could be directly mounted to the frame at any arbitrary point by simply drilling and tapping holes in the plate. This not only allowed for greater design flexibility for both this year's experiment and future years. This also further simplified the assembly procedure by not requiring screws to have corresponding nuts which are notorious for being difficult to assemble in the tight confines of the vehicle's airframe.

The full payload system is flight proven, having been assembled, powered, and launched during the team's April test flight. From the test flight, the payload recorded its first particulate data during rocket flight. Fig. 13 shows the payload's recorded altitude versus time in flight, cropped to start just before motor ignition. According to payload, the recorded apogee was 8189 *ft* with an ascent time of approximately 24 seconds.

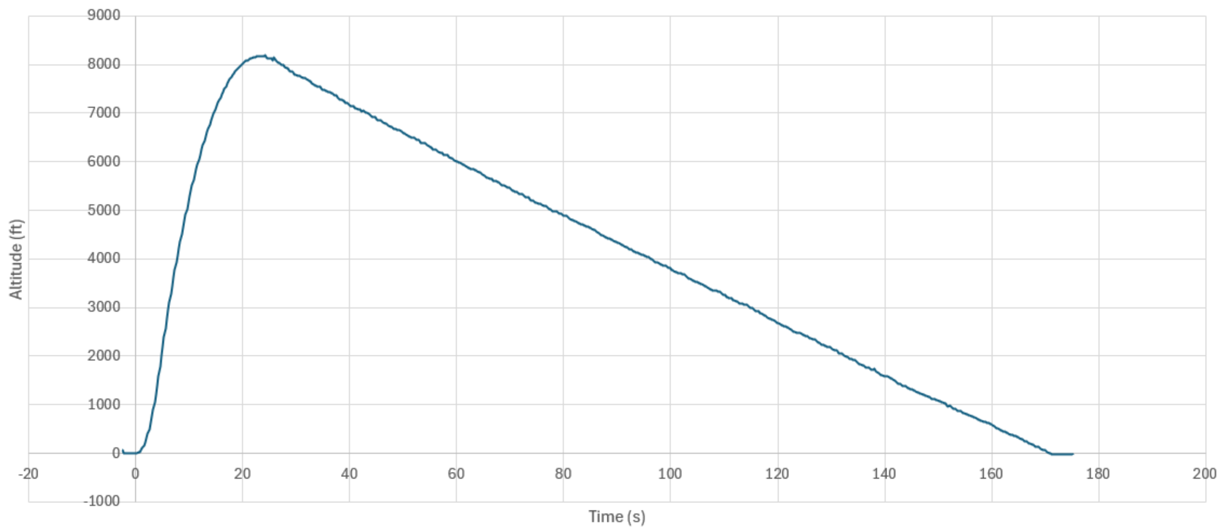

Fig. 13 Test flight altitude vs time according to Payload sensors

These measurements, while not perfect, largely agreed with Avionics' data indicating that our sensors are in good operation. The slightly higher position of the altimeter does not fully account for the discrepancy. Fig. 14 shows the measurements of the air quality sensor during the flight, showing results from different sizes of particles.

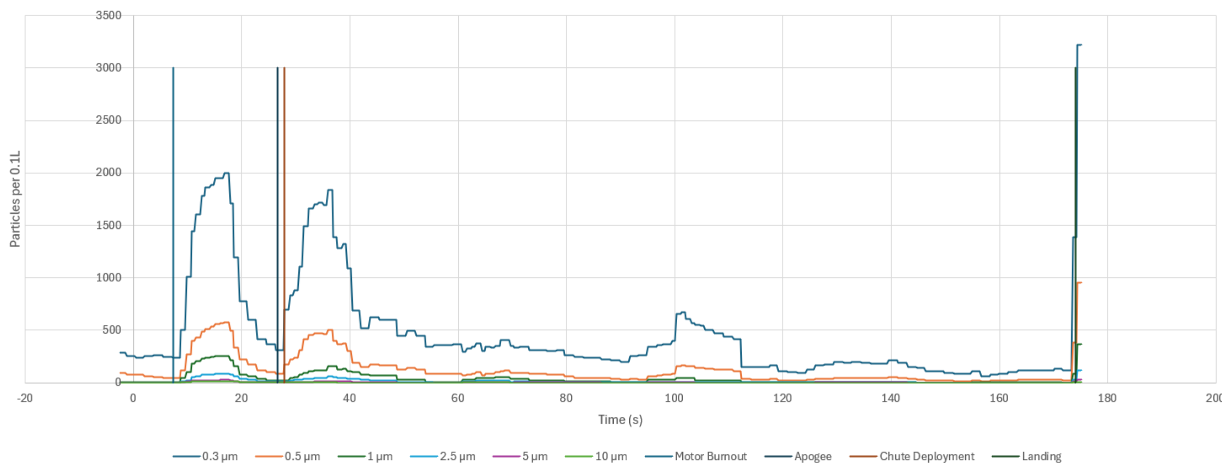

Fig. 11 Test flight particle count vs time from air quality sensor

This graph has various events during the flight marked off as well to show any potential correlation between flight events and particle readings. There appears to be a heavy correlation of particle count of all sizes with major milestones of the rocket's flight. Looking at the data from left to right, during motor burn the sensor detects a steady rate of particles. At motor burnout the number of particles detected spikes in all sizes of particles, likely due to a delayed response of higher flow rates during motor burn. However, this spike is not consistent, and as the rocket approaches apogee, the sensed particles decrease approaching the same numbers as seen before motor burnout. The next spike happens once the drogue parachute is deployed. It is speculated that the dog barf as well as other particles spread around from the ejection helped cause this increase alongside accelerated airflow as the rocket descended post-apogee and while the drogue was not in full effect. The curve of the data post-drogue deployment implies that the cause is unique when compared to the other spikes. The next spike at 100 *sec* is believed to be due to the main parachute ejection which also caused a dog barf and other particles to spread around rapidly. The failure of the main to open during the test flight resulted in little change to the vehicle's acceleration and likely explains the significantly shorter spike in particle count. The final spike which happens right at landing is speculated to be due to the particles that were stirred up as the rocket hit the ground and trees around it.

This flight test data has helped provide insight into how the sensor operates and, ultimately, helped verify the veracity of the team's payload. A noteworthy characteristic of the sensor is the apparent slight delay in response to changes in the air conditions around it. However, the magnitude of the data followed reasonable expectations for the changes in the air around the vehicle due to vehicle events, such as ejection charges firing, still seem to appear in the data as unique spikes.

E. Student Researched and Designed Avionics

In previous years, our team has used Raspberry Pi-based designs for SRAD avionics systems. These designs proved to be both cost-inefficient and bulky. Additionally, such designs were fragile and only supported limited features. We want to develop our own PCB-based designs this year and in future years. This is a new area for the team, which has only ever worked with PCBs before the COVID-19 pandemic. Our prototype is the MARTHA board, which will record 9 DoF IMU and altimetry data on our flight.

1. Design Philosophy & Requirements

As an emerging aspect of our team, communicating and understanding the design philosophy is crucial to providing context for current and future projects. We are confident that this area of our team will grow and develop to tackle novel challenges and enhance our understanding of rocketry. However, progress must be incremental, and attempts to complete large, complex projects without the requisite technical and financial capital will only result in cyclic failure. Starting small, using publicly accessible designs, and creating a platform for others to build from is crucial to long-term success. Secondly, as a smaller team, minimizing cost inefficiencies is essential to ensuring that the project is financially viable. Lastly, providing features that benefit and develop other aspects of the team gives enhanced purpose and meaning to the project.

A system like MARTHA emerged from a need for flight data to qualify and quantify changes to flight computer software. Additionally, through efforts within our team, we can launch over a dozen L1 and L2 certification flights each semester using certification kits. This represents a prime opportunity to collect subscale flight data. By designing a system small enough to fit within one of the standardized electronic sleds of these kits, we can enhance the development of future projects and build a comprehensive set of flight data for future testing. This reduction in scale makes designing, assembling, and integrating flight computers through this practice much easier and more economical than before. By focusing on implementing systems for data collection and filtering as well as state detection, we can provide a foundation from which others can build. This design philosophy will allow us to build better SRAD avionics affordably and incrementally with an emphasis on frequent flight testing and verification of systems.

2. Hardware Development

Development of the first MARTHA prototype spanned five months of planning and design, utilizing the KiCad 6.0 STM32 Electrical CAD (E-CAD) tutorial from respected hardware designer and YouTube creator Phil's Lab as the basis of the design [7] [11]. Phil's Lab provides comprehensive tutorials on many different topics, including the design of PCBs, providing a tutorial for how to navigate and utilize the E-CAD software, as well as best practices. Additionally, this would provide a proven basis for the design, limiting hardware issues to application specific sections of the design. While KiCad was chosen as the original E-CAD, we are heavily considering transitioning to Altium for future development due to its use in industry, possibility of cloud-based designs, and more thorough design reviews integrated within the toolchain. 3D renders of MARTHA can be found below. Notice, 3D models of some components were unavailable.

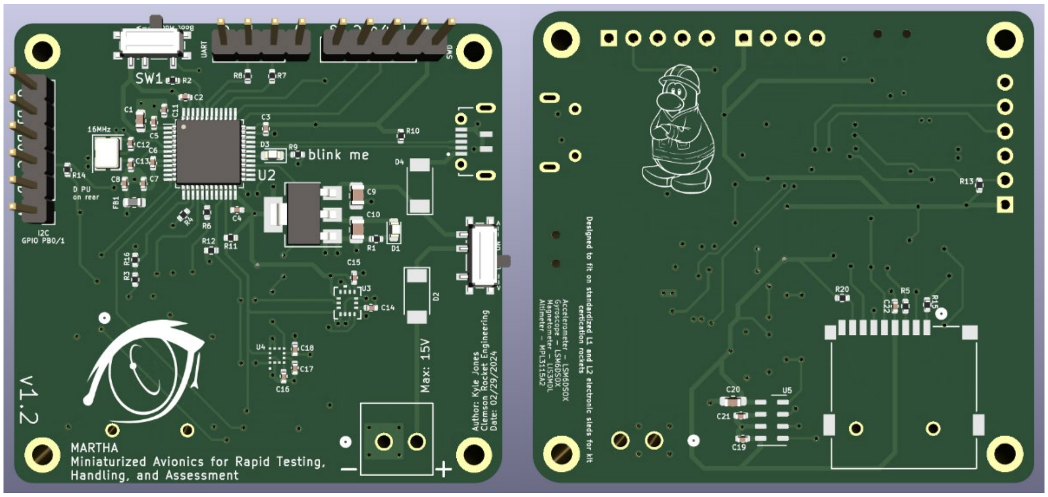

Fig. 1512 3D Render of MARTHA board

The Phil's Lab video for the KiCad 6.0 STM32 tutorial was used as the foundation of our design [12]. This design encompassed an STM32F103C8T6 MCU[25] with an AMS-1117 linear dropout regulator[3] (LDO) for power regulation, USB power and communication, as well as various header pinouts and miscellaneous circuitry. Using this design, all we needed in addition to the material discussed within the tutorial were the sensors and some method of data storage.

For our sensors, we decided to have a nine DoF IMU and an altimeter as opposed to a six DoF IMU and/or the option of an altimeter. The nine DoF IMU is comprised of a LSM6DSOX accelerometer and gyroscope as well as an LIS3MDL magnetometer. Although these sensors increase the cost of each board, a nine DoF IMU and altimeter represent the cornerstone for more advanced flight computer development. If we do not capture this data now, then using past data to qualify and test future systems with additional features will prove to be challenging at best case, and unfeasible at worst case. Therefore, we chose this design to balance the design requirements of creating a system for long-term use and meeting financial restrictions. Acceptable quality versions of these sensors can be found for a price point that was cost effective and are able to communicate over communication protocols such as Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I2C). Information on each sensor can be found in Table 1 MARTHA Sensors.

Table 1 MARTHA Sensors

Parameter	Sensor	7-bit I2C Address	Resolution	Minimum	Maximum
Acceleration	LSM6DSOX	0x6A	4.8828 x 10^{-6} *g*	-16.0 *g*	16.0 *g*
Rotation	LSM6DSOX	0x6A	0.061040 *dps*	-2000.0 *dps*	2000.0 *dps*
Magnetic Field	LIS3MDL	0x1E	4.8828 x 10^{-6} *G*	-16 *G*	16 *G*
Altitude	MPL3115A2	0x60	0.32808 *ft*	-2290.03 *ft*	38631.89 *ft*
Temperature	MPL3115A2	0x60	0.030500 *°C*	-40 *°C*	85.0 *°C*

The secondary design constraint is deciding how to store on-board data. This presents two design options: utilizing flash memory chips or Micro-SD cards. While flash memory chips were smaller and cheaper than Micro-SD cards, they did not possess nearly as much storage as a Micro-SD card. This proved to be the deciding factor as the lack of a state detection system meant that we could not throw away preflight data while sitting on the pad. With the possibility of delays, it could not be guaranteed that we would not run out of storage before the flight, as this was an issue faced in previous years. The excessive amount of storage will guarantee that we capture the flight data for this launch, allowing us to review and use it for future development. Additionally, we are testing preliminary state detection algorithms on this flight as discussed in *Software Development*. By developing reliable state detection algorithms, we can switch to flash storage of data for the future and only collect data strictly associated with the flight. This will reduce both costs and footprint.

The schematic below, Fig. 16, details the hardware design for MARTHA in the final working iteration of the board, revision 1.2. Power is input to the board through a pair of screw terminals for the power and ground connections of the battery. Passing through a diode, the voltage passes through a single-pole-double-throw (SPDT) switch to enable or disable the flow of power to the board and is then regulated to 3.3 *V* for the system power. The MCU, an STM32F103C8T6, is linked to each sensor over through the chip's second I2C bus. Fit with decoupling capacitors, each sensor communicates that new data is present through interrupt lines connected to the MCU's general-purpose-input/output (GPIO) pins. This is superior and more efficient than constantly checking for new data from each sensor through polling. Instead, interrupt triggers on each sensor prompt for data collection, ensuring that data is collected only when new data is present at each sensor. The header pins of MARTHA are the interface for the Serial Wire Debug (SWD) interface, a transmit receive pair for serial communication, the data and clock lines of a separate I2C bus, as well as two GPIO pins. Each of these header sets includes 3.3 *V* power as well as ground. Additionally, the header pin sets for serial communication feature zero Ohm resistors to allow for easy rewiring of the communication bus in the case of an accidental wiring from transmit to transmit, or receive to receive, which are common mistakes. USB -B Micro 2.0 can both power and communicate to the MCU for easy power solutions and advanced debugging for future use. The Micro-SD card uses SPI to write data for non-volatile storage. A pull-up resistor is placed on the chip select line of the SPI bus to ensure there are no accidental reads or writes of data too or from the card. Additionally, resistors are placed on each of the data and clock lines of the SPI bus, a common practice to prevent signal overshoot of bus signals at high frequencies.

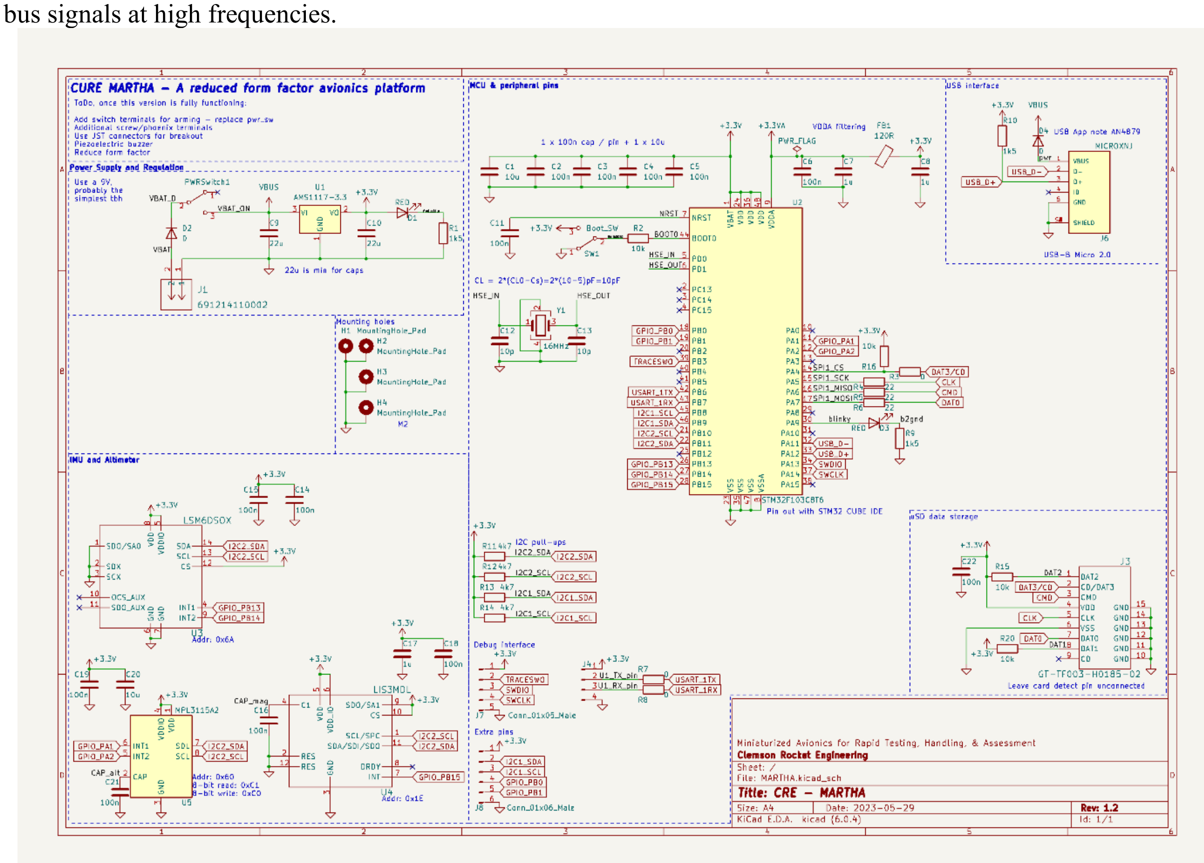

Fig. 1613 **MARTHA Schematic**

MARTHA is the first attempt at making a fully integrated custom PCB flight computer, so issues were inevitable. However, the only issues encountered for the prototype were improper wiring on the I2C bus for the altimeter and issues with the Micro-SD card. This was emblematic of our design choices, as using a proven design as the basis allowed us to focus on the innovative aspects of the design. If we had not taken this approach, design errors could have prevented basic functionality, which would slow development. MARTHA is now on its third iteration, only taking an additional three months to discern and fix any design flaws as discussed in the extended abstract.

3. Software Development

MARTHA's software was developed with a strategic focus on portability, speed, and reliability. As a team, we deploy software in multiple places other than MARTHA, such as in our active-aero and payload systems. Hence, writing portable software becomes critical to quick team-wide improvements. To this extent, we used PlatformIO as our primary development environment [13]. PlatformIO is built on an open-source ecosystem with extensive library management tools. Software written with PlatformIO can be built and then uploaded to various boards, such as the STM32 and ESP32 families. PlatformIO allows us to continue using the same software despite hardware changes.

Additionally, the improved portability pushes us to make reusable code. Nearly all flight computers solve fundamental problems: collecting data from sensors, processing and saving the data, and making state predictions. As a result, we put the code needed to solve those problems into a separate GitHub repository called "Avionics," which is referenced by all flight computers via GitHub's sub-repository feature [3]. Any updates to the "Avionics" repository will automatically be reflected on each repository that references it. That repository includes complete portable code for sensor data handling, writing to SD cards, data filtering, and predicting flight status. Because these modules are used across multiple systems, they are written in a generic manner that can be configured via constructors. Overall, we achieved portable code by using PlatformIO to give cross-platform support, implementing sub-repositories that solve common problems, and writing generic code that works across many launch conditions.

Besides portability, MARTHA's software prioritizes performance to address the rapidly changing environment of a rocket launch. As such, we aim for MARTHA's main processing loop to execute 100 times per second. That means MARTHA must collect data from each sensor, properly store it in buffers, save it to an SD card, and execute the state detection algorithm 100 times per second. To achieve this, we selected C++ for its high performance and fine-grained memory control, which is useful when working with MARTHA's limited RAM. One of our initial bottlenecks was writing data to the SD card as it was being done over serial in a human-readable format. To combat this, we switched to binary data encoding, along with the development of post-launch decoding scripts.

Additionally, we reduced the frequency at which some measurements are saved to prioritize others. For example, we reduced temperature to only be saved once per second. Our state detection system depends on a history of previous measurements to be accurate. We implemented a dual-circular array buffer system to provide the history without exhausting available memory. With circular arrays, you can set a fixed size, and the newest ones will always replace the oldest elements once the size is exceeded, enabling us to keep a rolling history of previous data. However, for state detection, each measurement in the array should have a constant time interval between them, hence the need for two circular arrays per measurement stream. The first is the read array, which receives all the raw data. The read array's buffer could be used for filtering and bulk-saving operations. The second array is the temporal array, which is given data only after a specific interval has passed since the last data point has been added. Because the interval between data points and the number of data points can be controlled in the temporal array, measurement windows that are useful for state detection are easily created. Temporal arrays are only used for state detection vital measurements such as acceleration and altitude to save memory. As a result, we achieve state detection with minimal memory overhead. Altogether, a high-performance system is necessary to deal with the rapidly changing launch environment, and we accomplished that by using C++, binary encoding, limiting certain save rates, and implementing circular arrays to keep constant high-frequency historical data without exhausting memory.

The third essential consideration when developing MARTHA's software is reliability, a necessity given that this system could run for hours before launch and must not crash or terminate unexpectedly. Three design decisions underscore this robustness. First is strict memory management. MARTHA's MCU has limited RAM, which can quickly be exceeded if not controlled closely. As such, all memory allocation is performed during initialization, with no additional allocations occurring afterward, preventing runtime memory exhaustion. Circular arrays are used to hold buffers of new data within these memory constraints. The second is error handling. We acknowledge the likelihood of sensor errors, so drivers that repoll until valid data is acquired are used. Other systems, such as flight status, are gracefully bypassed if parameters such as the current sensor rate fall outside of nominal ranges. Operations continue seamlessly, even with a missing SD card. Third is using a single-threaded, super loop architecture. This architecture eliminates the complexities inherent in multi-threading, such as race conditions and deadlocks. The result is a streamlined, deterministic design that helps eliminate the likelihood of software-induced errors. MARTHA's reliability is derived from its lack of runtime allocation, robust error handling, and single-threaded architecture.

MARTHA's software architecture demonstrates a strategic balance of portability, performance, and reliability, achieved through cross-platform development tools, efficient C++ implementation, and robust error-handling mechanisms.

IV.Mission Concept of Operations Overview

The CONOPS Overview is a comprehensive section detailing the sequence of phases that the CURE team's mission will undergo, from pre-assembly to landing. The overview of the CONOPS phases is described in Fig. 17 below.

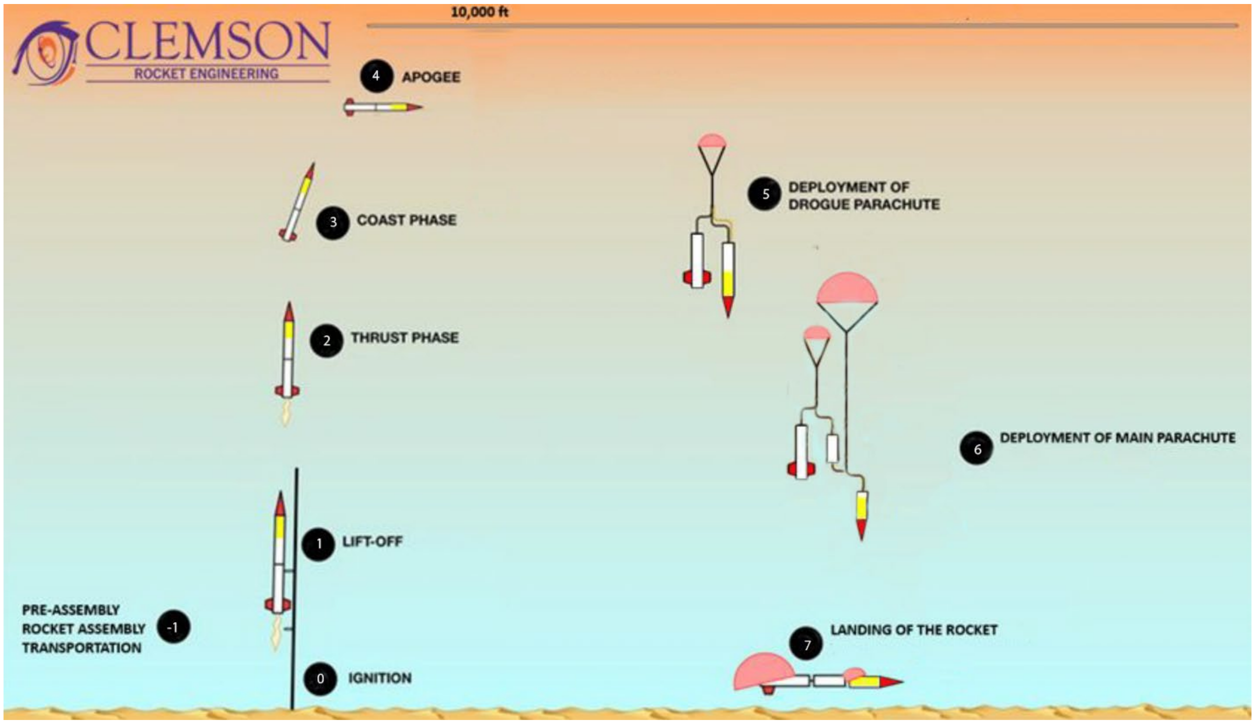

Fig. 1714 CONOPS Overview

The CONOPS Overview illustrates these phases, outlining the nominal operations and interactions of all subsystems during each stage, beginning with Phase -1: Pre-Assembly, Vehicle Assembly, and Transportation. Here, the team assembles and prepares the vehicle for launch. Then, the mission progresses through ignition, lift-off, thrust, coast, apogee, parachute deployment, and landing. Each phase is described, highlighting the role of various subsystems such as avionics, propulsion, and recovery systems and defining the critical events that signify transitions between phases. These transitions are triggered by specific mission events such as the ignition signal, motor burnout, reaching apogee, and altitude milestones for parachute deployment, all culminating in the safe recovery of the vehicle post-mission. This structured approach ensures clarity in mission planning and execution, allowing for precise coordination and monitoring of each phase in relation to the mission's overarching goals and objectives.

A. Phase –1 Pre-Assembly, Rocket Assembly, Transportation

During the pre-assembly phase, all members of the team will work to assemble the payload and avionics bays. Once both the avionics and payload system are assembled and the electronics for payload is turned on, both bays will be secured into the rocket body. Once the bays are secured in their respective body tubes, each body tube will be secured together, and the rocket will be carried and loaded on the pad.

B. Phase 0 Ignition

Once the rocket is loaded onto the pad, cameras will be turned on, avionics bay will be armed, and tracking will be verified, the e-matches will be loaded into the motor. After a confirmed avionics signal from the spectator area, Spaceport officials will ignite the e-matches and the rocket will begin accelerating upwards.

C. Phase 1 Lift-Off

After motor ignition, the motor will burn for 3.9 seconds. According to motor information, the rocket should leave the 17 *ft* ESRA rail at a velocity of 103 *ft*/s. The flight computer detects launch

Phase 2 Thrust Phase

According to simulations, the M2500T motor will provide an average thrust of 2,500 N. As previously mentioned, the thrust phase of the flight will take place between T+0 and T+3.9 seconds.

D. Phase 3 Coast Phase

Following motor burnout, the rocket will coast until apogee. This phase will occur between T+3.9 and T+24.6 seconds.

E. Phase 4 Apogee

According to simulations, the predicted apogee is 10,240 ft. This altitude will be confirmed through altimeters in the Payload and Avionics bays. Apogee will be reached at T+24.6 seconds.

F. Phase 5 Deployment of Drogue Parachute

At apogee, the StratoLogger CF will deploy the drogue parachute from the drogue parachute bay. The AIM, the secondary flight computer, will deploy the drogue parachute two seconds after apogee has been reached. Each recovery event occurs at T+24.6 and T+26.6 seconds respectively. Drogue will inflate and decrease vertical velocity to 65 *m/s*.

G. Phase 6 Deployment of Main Parachute

Once 1,000 ft has been reached, the StratoLogger CF will deploy the main parachute. The AIM, the secondary flight computer, will deploy the main parachute two seconds after 1,000 ft has been reached. This is predicted to occur at T+161 seconds. Main will inflate and decrease vertical velocity to 15 *m/s*.

H. Phase 7 Landing of the Rocket

After the rocket has landed at around T+222 seconds, the recovery team will recover the rocket. To accomplish this, the recovery team will use GPS to track the rocket’s location.

V.Conclusion and Lessons Learned

A. Conclusion

Throughout the year, CURE has worked to develop our launch vehicle, "We'll 'C' What Happens," and its incorporated subsystems. Following last year's launch vehicle, we have grown and further developed systems within the vehicle's flight programs to ensure a successful flight. Through SRAD Avionics systems with the MARTHA boards, the further development and testing of the team's Active Aero system, and the environmental testing project onboard the Payload, the CURE team has established projects that can be continued and improved for years. We completed the rocket in time for a successful test launch on April 13th, 2024. This launch was the first successful test launch in team history after the team failed to finish the rocket in time to complete a test launch the previous two years.

B. Lessons Learned

1. Overview

Last year's vehicle, while completing a largely successful flight, was plagued by intermittent issues that prevented a test flight, prevented the use of a functional payload, delayed launch at the 2023 Spaceport America Cup, and led to the loss of the nosecone and payload sections at parachute ejection. As such, significant steps were taken at an organizational and systematic level to ensure that a successful test flight was completed, a functional payload was flown, and no components were lost during launch operations. This year's goal was to accomplish a test flight of the vehicle on an M1800 in March or April 2024.

2. Organizational Management

Over the past year, it has become evident that our organizational structure and management needed substantial revision to encourage growth and continued success. Our organization has had to adapt as the technical demands of creating a launch vehicle have evolved from primarily mechanical to heavily incorporating electrical and software systems. The Clemson University Rocket Engineering organization underwent a comprehensive restructuring in response to these evolving technical challenges. The restructuring included a complete overhaul of the leadership framework, as depicted in Fig. 1 Clemson University Rocket Engineering Organization Chart.

One of the significant changes in this restructuring was the division of the chief engineer role into two distinct positions: one focusing on mechanical systems and the other on electrical systems. Previously, the chief engineer role was more hands-on, directly involved in designing every launch vehicle subsystem. We have transitioned this position to a high-level systems engineer role to oversee the integration of diverse technical aspects better. Additionally, we introduced the role of Chief Software Architect, tasked with overseeing the integration of all software subsystems.

As part of this organizational shift, we also revised our constitution to detail the organization's mission, clarify who and what we represent, and define the role of every person and leadership position within CURE. This year marked our first successful test launch, indicating that these changes steer us in the right direction. With this momentum, we are setting ambitious goals to design and launch a vehicle by the end of December 2024. This trajectory reflects our capability to achieve greater technical heights and highlights our commitment to continual improvement and innovation within our team.

3. Structures

The launch vehicle was successfully prepared, with successful ejection tests performed by the second week of March, but the launch had to be canceled due to weather. This offered an ideal opportunity to complete additional integration tests to improve the team's experience in preparing the vehicle for flight in a prompt manner. This process informed the assembly checklists and improved systematic processes for integrating the avionics bay and payload bays. After prepping the rocket for approximately four hours, the team successfully launched a test on April 13th, 2024. However, high winds and loss of tracking meant a total search time of approximately twelve hours was required to locate the vehicle after it drifted into a densely forested area. While debriefing and after reviewing onboard footage, it was determined that the shear pins retaining the main parachute bay failed upon drogue deployment. However, the main parachute failed to exit the deployment bag during descent. Despite this, the vehicle was in perfect condition, having landed softly into a tree with no structural or cosmetic damage. It was determined that the couplers were a poor fit, resulting in potential flex. The shear pins were undersized, so after the test launch, a new set of well-sized couplers were manufactured, the shear pin calculations were reiterated, and the sizing was corrected. The failure of the main parachute to deploy resulted from a failure in the integration checklists, and it was determined that the deployment bag was not secured to the body of the rocket before flight. This mistake was mitigated by successfully deploying the drogue parachute and soft landing in the tree, but it could have resulted in significant damage to the airframe. As such, all checklists concerning recovery integration were refined and corrected to ensure all connection points were verified prior to the complete assembly of the rocket.

Additional lessons were learned after the 2023 Spaceport America Cup. The 2023 vehicle had a nominal flight, but upon drogue ejection, the tender descender structurally failed, and the main parachute had an incomplete deployment at apogee due to entanglement, likely with the tender descender. Due to this undue force, the eight screws securing the payload tube and nose cone to the avionics body tube ripped out of the body tube, and the blue tube coupler and the payload tube and nose cone were lost. The motor tube coupler, a COTS wound fiberglass coupler, buckled on landing. SRAD carbon fiber couplers were developed using in-house composite techniques to provide higher strength and durability couplers than those used previously, as the SRAD body tubes of the same manufacturing techniques have proven highly reliable over multiple launches. External fasteners have also been minimized to decrease the opportunity for zippering or tear out, and the remaining external fasteners have been selected with higher strength and wider heads to prevent tear out. Finally, due to a lack of success using COTS tender descenders, the development of this vehicle prioritized a dual bay deployment system due to its relative simplicity and reliability.

4. Avionics

Avionics has developed the first iteration of a standardized COTS electronics bay for use in future flights. This was a large step towards future developments and taught us useful information on how to design rugged and reliant designs for the future. We found that the Siemens industrial control locking switches worked well for this application. Our flight computer arming switches provide more than sufficient locking power to heavily mitigate the chances of incidental power outages to out COTS flight computers. Although it may seem excessive, being able to rely on our COTS electronics allows our SRAD electronics to develop faster. The use of aircraft connectors[6] provides solid connections that can still be removed. We liked this design over a DE-9 connector[7], which we used previously, since this design could mount into the frame of the rocket and did not rely on screw terminals. Upon recovery at the Spaceport America Cup 2023, we found that the connection to the charges had been severed by the drogue parachute's black powder charge. The wires had disconnected since the force of the charge tore the wires from the screw terminals. This was because the connector itself was not mounted into anything and was merely attached to the structure airframe of the vehicle. Integrating connectors into the airframe allows a more secure and protected connection.

Additionally, we have learned to begin to revamp and innovate our technical review process throughout multiple areas. With MARTHA, mistakes that could have been caught were not due to insufficient design checks. With our COTS electronics bay, failure to abide by proper checklists and precautions damaged the bay during test flight and risked more substantial damages. Detailed checklists that encompass all areas of the vehicle pre-assembly, assembly, integration, and transport, with checks throughout the process have been an emphasis for avionics to ensure that preventable mistakes can be avoided in the future.

The development of MARTHA as a lead into PCB design taught us many lessons. In addition to the lessons surrounding more thorough design checks and reviews, we learned from an organizational structure and technically the process of developing a PCB. Developing a process to order something that may require technical dialogue between the one ordering and the manufacturer was a challenge when operating as a student organization of a university. From a technical perspective, developing both a knowledge base and design management system for E-CAD was something we learned how to manage. We implemented a standardized revision numbering system, revision history on each design that categorizes the changes between each design to better understand and document possible non-conformities, as well as a shared design archive for all E-CAD versions. Formalizing our documentation and testing process will be an emphasis in the future, as we believe that it is not at the level it should be at.

We implemented a new formal orientation process for the purposes of upskilling new Avionics members and giving them the tools to succeed. Avionics is often considered the Subteam with the highest floor and barrier to entry, so lowering this barrier and increasing involvement will pay long term dividends for the team and its understanding of rocketry. This project was a success. Although it ended up encompassing most of the year for our new members, as opposed to the planned Fall semester, each member said that they enjoyed the project, got it working, and launched it with their L1 certification flight in April. We felt still, though, that the project could be simplified further and appeal to broader groups while still providing technical rigor and learning. Formalizing the introduction process to the Subteam gives great benefit to building a knowledge base for all members on the Subteam, with new members working on a project with a known solution, allowing everyone to be of help.

In the future, we hope to integrate our lessons accrued as a Subteam to a shared CURE library/repository for future years of the team. This would include designs, tips, use cases, suggestions, and other such material that would allow for knowledge to be transferred throughout the years.

5. Payload

One of the main driving aspects of this year's payload was remedying issues plaguing previous payload designs. Where previous designs had many different subassemblies that needed to be installed separately in a specific sequence, this year's current payload could be assembled completely outside the rocket and mounted using a set of purposely easily accessible screws. Previous payloads had many difficult-to-machine parts, but this year's payload utilized machined parts requiring minor and straightforward modifications. One major problem in previous years with manufacturing was the creation of blind tapped holes. As running a tap too deep into a blind hole can lead to chips clogging the hole or the tap bottoming out and snapping, this year's payload only features nine total blind-tapped holes, all of which had generous amounts of untapped depth to allow for chip and tool clearance. However, some of the main issues the current design faced were with the internal sensor bay. The components must be wired into a single wiring harness inside the 3D-printed insert. While the 3D printed insert aided in assembling the upper CubeSat section by keeping the electronics in a single part, connecting each sensor module by directly soldering a wiring harness led to difficulties in manufacturing the sensor bay. Plans to improve this aspect of the sensor bay design would be to move away from a wiring harness and to a dedicated PCB or protoboard-based connection system.

Payload as a subteam is a collaboration of every other subteam, requiring knowledge in mechanics, electrical, and software engineering. Because of its all-encompassing nature, a wide variety of personnel are required. The Subteam's major time sink and fault is trying to master these subjects. Instead, with the help of organizational restructuring, the subteam will use the resources and experts from other subteams to guide the development of the payload subsystem. Utilizing the experience of other subteams will help the payload become a more flushed-out subsystem and allow for more focus on the research and "why" of the payload and not just the design.

6. Flight Dynamics

This year, Flight Dynamics made the first attempts at creating an SRAD hand-lay-up carbon fiber nosecone, a first for the club. 3D-printed molds allowed for rapid iteration and parallel testing between positive and negative molds. An initial attempt using a positive mold failed due to difficulties in wrapping the carbon fiber material around the complex geometry of the nose cone, particularly the smaller diameter at the forward end, as well as difficulties in removing the cured composite from the mold. The next attempt involved using a negative mold, allowing for a more consistent surface finish, as the material could be pressed into the mold rather than pulled around it. This resulted in a successful proof of concept, and development will continue next year based on these lessons.

Flight Dynamics also worked on using SolidWorks Flow Simulation to evaluate the pressure that would occur during flight. This would be used to compare nosecones of different lengths and styles to see which would perform the best. The simulations also helped determine if other parts of the rocket would cause significant effects on the stability, namely the hole used for the altimeter. This would be tested against OpenRocket in order to determine what the apogee of the rocket would be with each nosecone design. This year, Flight Dynamics successfully simulated the airflow around different nosecone types. This will be expanded next year to combine this process with the nosecone fabrication efforts to create the nosecone designed for the rocket instead of using a COTS part. The use of SolidWorks Flow Simulation was also combined with the use of OpenRocket, as the maximum velocity of the OpenRocket simulation can be used in the SolidWorks Flow Simulation to create a more accurate view of the pressure and airflow on the nosecone.

This Subteam also incorporated weather and geographical data into the simulations to better predict how the rocket will perform based on the weather conditions on the day of the launch. By looking at the weather patterns of the launch site in the previous year and the differences in the rocket's launch for flights at the same location but on different days, this data can be used in comparison with the simulation data to create more accurate predictions. A log of wind velocities and temperatures at different altitudes at the launch field for the Spaceport America launch site has been created for reference. Next year, this log can also be expanded to the test launch site.

7. IRAD

This Active Aero project is now in its second year of development. During the first year, the team successfully created a working system but chose not to include it in the competition rocket due to insufficient real-world testing. Consequently, this year's ambitious goal was to design a dedicated test vehicle for Active Aero. Throughout this development phase, the team learned how to set up and launch a hybrid high-powered rocket and make the rocket reusable so it could be launched multiple times a day. This preparation has ensured that the team will have a vehicle ready for testing at the start of next year, positioning them for continued success.

In preparation for future flights, the Subteam has identified several areas for structural enhancement. The motor tube will be reinforced by enlarging the fin epoxied fillets to reduce the stress concentration during landing. Additionally, the avionics bay connection to Active Aero will be strengthened with extra screws and new supporting side brackets. This will help withstand the higher forces from a future larger main chute that will reduce the impact velocity. These modifications are designed to extend the lifespan of the test vehicle and reduce maintenance time between flights.

Active Aero's software and electrical side has also found many areas of improvement for future design. The software currently being developed in Active Aero is progressing toward integration with the rest of the Avionics team. Currently, the integration between the two teams, where it would be more efficient to work parallel with the Avionics team, is only partially seamless. The electrical portion, such as wiring and circuitry, also has room for improvement. Generous use of key switches can be limited by more efficient wiring, and errors with the breadboard can be eliminated by using a printed circuit board and developing a method to offload flight data between flights without disassembling the rocket. All are improvements that could be made to reduce the chances of failure.

Appendix A: System Weights, Measures, and Performance Data

A. Rocket Information

The launch vehicle is 10 *ft* and 11 *in* with one stage. The rocket has an external diameter of 6.078 *in*. There are four fins which have a semi-span of 6 *in*, a tip chord of 6.98 *in*, a root chord of 13 *in*, and a thickness of 0.201 *in*. The total vehicle weight is 32.7 *lbm*, the propellant weight is 10.39 *lbm*, and the empty motor case is 7.39 *lbm*. The payload weight is 8.8 *lbm*. The rocket weighs 61.7 *lbm* at liftoff with a center of pressure at 97.765 *in* from the nose, and a center of gravity 84.725 *in* from the nose.

B. Propulsion Information

The motor chosen was a COTS solid Aerotech M2500T[16]. This is an M Class motor with an average thrust of 2,500 *N*, a total impulse of 9,671 *Ns*, and a motor burn time of 3.9 *s*. Using this motor, the rocket would be able to reach the target apogee of 10,000 *ft* with an off-rail velocity of at least 100 *ft/s*, making the launch stable. Based on our simulations in OpenRocket, our rocket would have an off-rod velocity of 103 *ft/s* and predicted apogee of 10,240 *ft.* Shown below in Fig. 18 is the thrust curve for the M2500T motor [10]. During the simulated flight, the rocket showed an average thrust of 2461 *N*, a total impulse of 9573 *Ns*, and a burn time of 3.88 *s*, which is consistent with the standardized values.

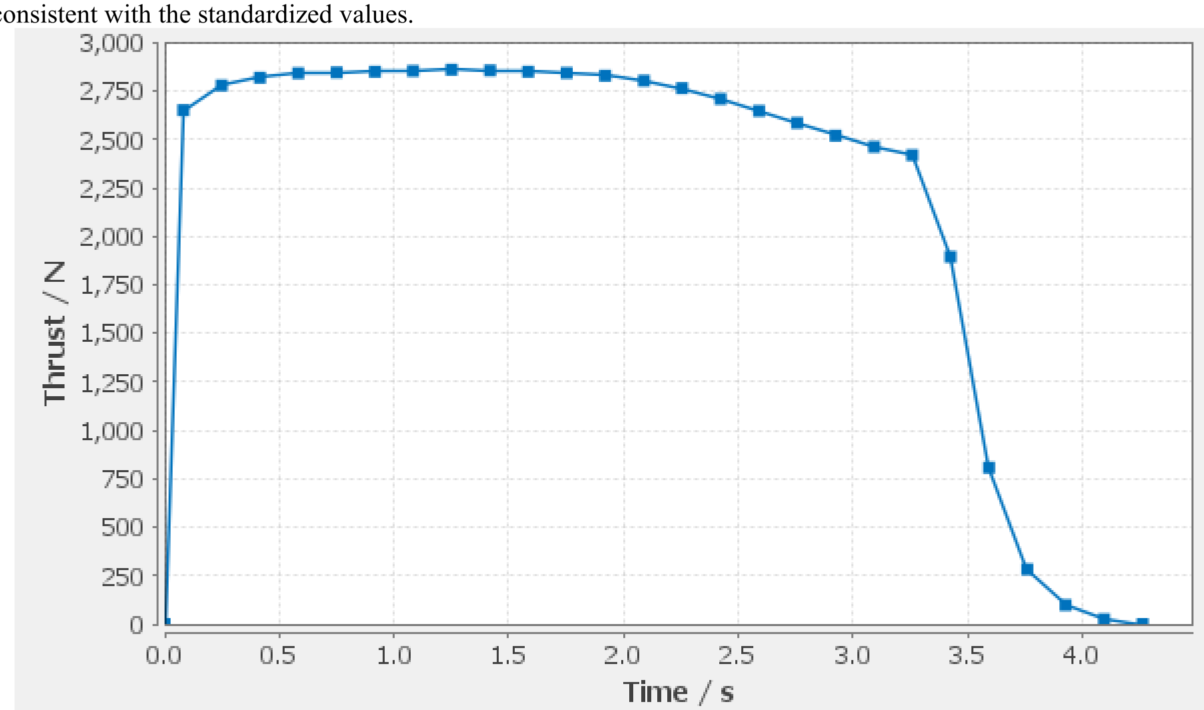

Fig. 15 18 Motor Thrust Curve

C. Predicted Flight Data

Predicted flight data including launch rail length, liftoff thrust-weight ratio (X:1), rail departure velocity, minimum static margin, maximum acceleration (G), maximum velocity, fin flutter velocity, target, and predicted apogee

For the test launch, an OpenRocket simulation was used to predict the apogee of the rocket [10]. Using this program, the predicted apogee was calculated to be 8,497 *ft* with an M1800 motor. Other values from the OpenRocket simulation are shown in Table 2. This motor was used instead of the M2500 motor in order to not go over the site's waiver. The StratoLogger recorded an apogee of 8,123 *ft* and the AIM recorded an apogee of 8182 *ft*, which were off from the predicted value. The graphed altitude values are shown in a figure below. In the original simulation, the rocket was measured to have a mass of 58 *lbm*. To get a predicted apogee closer to the recorded value, the rocket in the simulation would need a mass closer to 61.2 *lbm*. The scale used to measure the mass of the rocket had a broken leg, which was the likely cause of the mass and apogee difference. For the simulation for the final launch, the mass would not be recorded using this scale, which would result in a more accurate value for the mass and prediction of the apogee.

Table 2 Predicted Flight Data from Test Launch

Specification	Value	Units
Launch Rail Length	17	ft
Liftoff Thrust-Weight ratio	6.99	X:1
Velocity off Rail Rod	82.9	ft/s
Maximum Acceleration	337	ft/s^2
Maximum Velocity	870	ft/s
Fin Flutter Velocity	3,719	ft/s
Predicted Apogee	8,497	ft
Stability Margin	1.99	cal
Average Thrust	1803	N
Total Impulse	8213	Ns
Burn Time	4.55	s

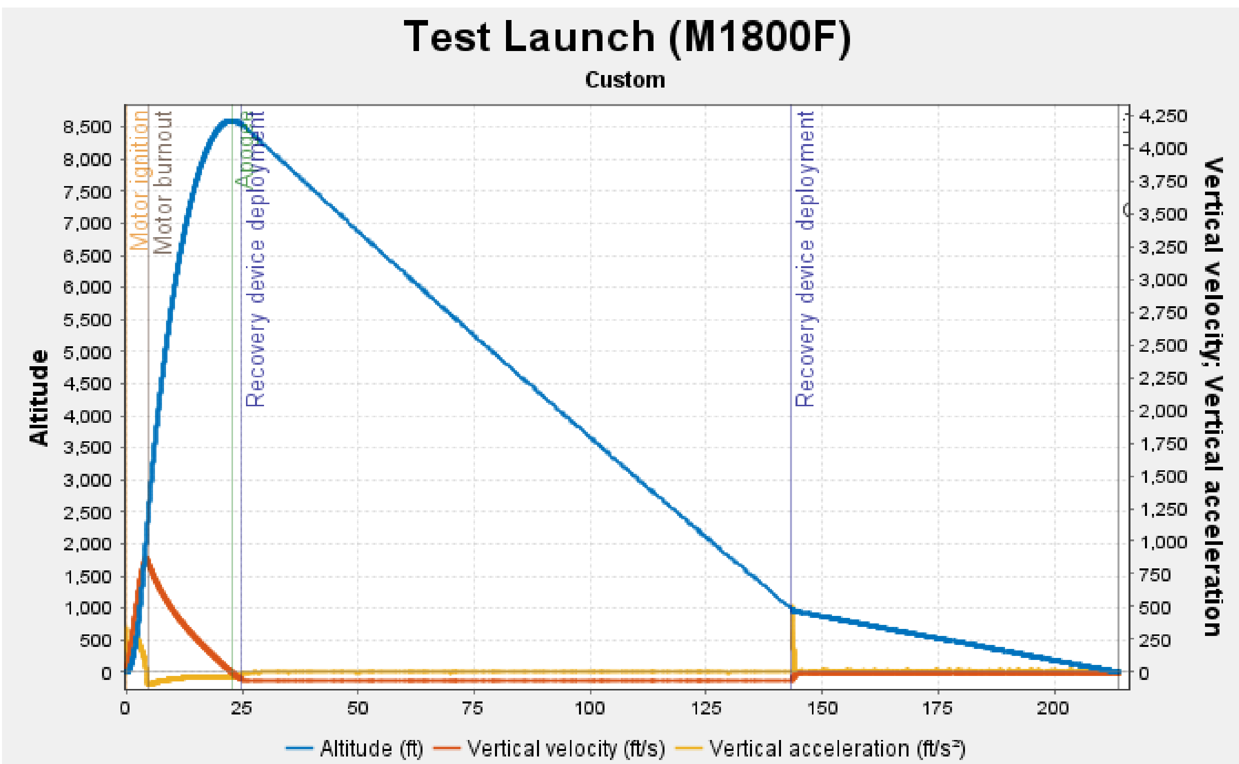

Fig. 1916 OpenRocket Flight Simulation Graph for Test Launch

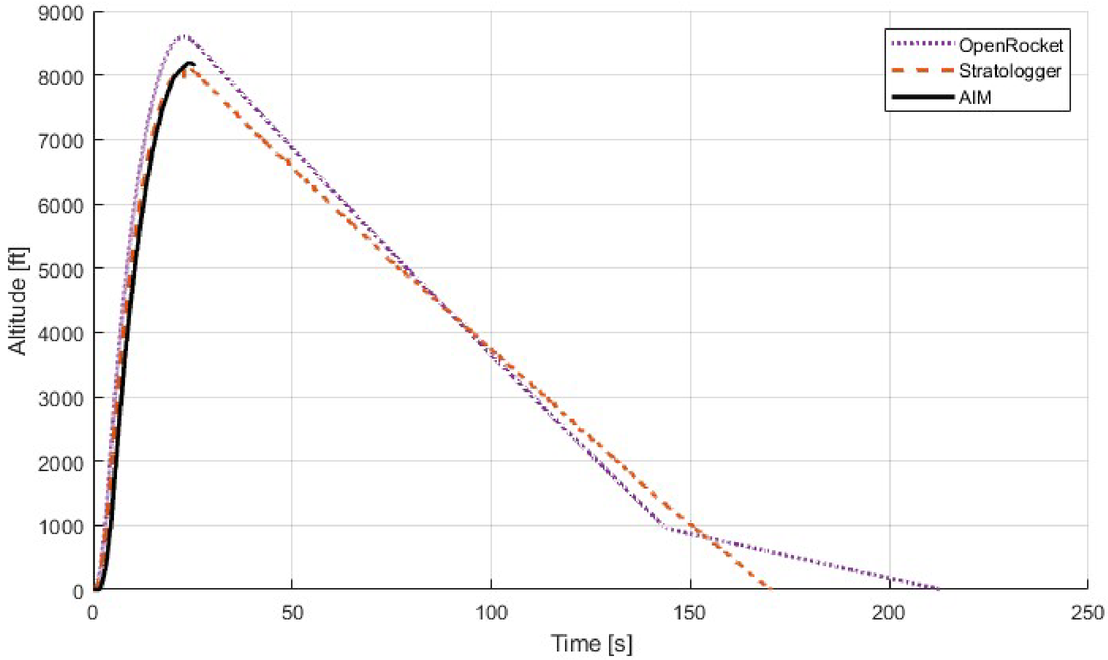

Fig. 20 Altitude Comparison Between Different Sources

For the rocket launch at the Spaceport America Cup, the OpenRocket simulation with a M2500T motor had a predicted apogee of 10,310 *ft*, an off-rod velocity of 103 *ft/s*, and a stability of 2.16 *cal* [10]. These values, alongside other predicted flight data, are shown below.

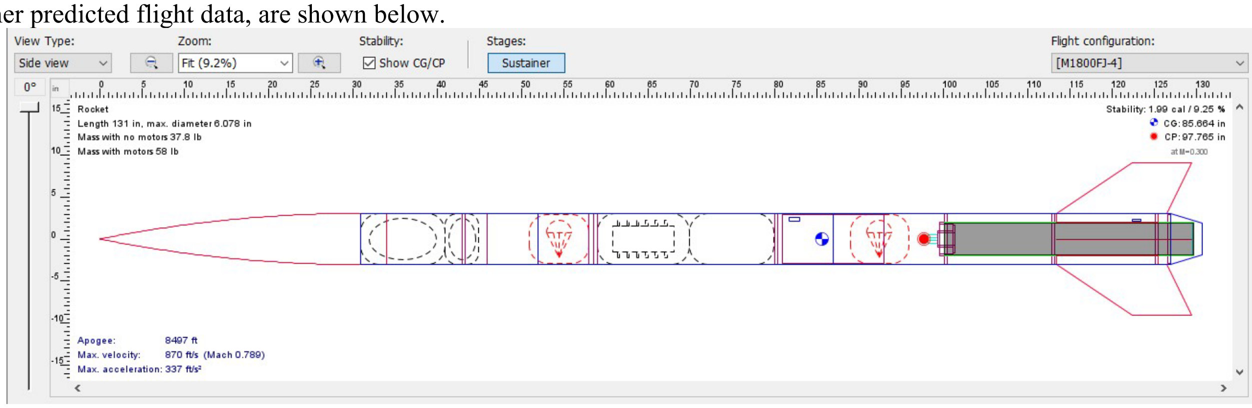

Fig. 21 OpenRocket Model of Test Launch Rocket

Table 3 Predicted Flight Data for Spaceport America Launch

Specification	Value	Units
Launch Rail Length	17	ft
Liftoff Thrust-Weight ratio	9.41	X:1
Velocity off Rail Rod	103	ft/s
Maximum Acceleration	332	ft/s^2
Maximum Velocity	1,035	ft/s
Fin Flutter Velocity	3,719	ft/s
Predicted Apogee	10,310	ft
Stability Margin	2.16	cal
Average Thrust	2461	N
Total Impulse	9573	Ns
Burn Time	3.88	s

D. Simulated Flight Profile

The flight graph below is used to predict the flight of the team's rocket at the Spaceport America Cup. The apogee is predicted to be around 10,310 *ft*. However, in the past, OpenRocket Simulations have overestimated the actual apogee of our rockets at Spaceport, leading us to believe that the apogee will be closer to 10,100 *ft* [10]. In addition, weight can be added to bring the apogee down slightly if space is available on launch day. Based on the current mass of the rocket and the amount of weight that has needed to be added in previous years, the maximum mass that would be added would be 10 *lbm*. This mass will be fastened to either the bulkheads or the payload. The exact location of the added weight will be determined as the most stable location to add weight while still preserving the stability and desired apogee.

The velocity of the rocket as it leaves the launch rod is 103 *ft/s*. As this is higher than 100 *ft/s*, the rocket will be stable off of the pad. The stability was 2.16 *cal*. The max acceleration of the flight was 332 ft/s^2 and the max velocity was 1,035 *ft/s*. Two seconds after reaching apogee the drogue chute deploys and decreases the velocity of the rocket to 64 *ft/s*. The drogue chute is deployed 1,000 *ft* above the ground and decelerates the rocket to 15 *ft/s* when it hits the ground.

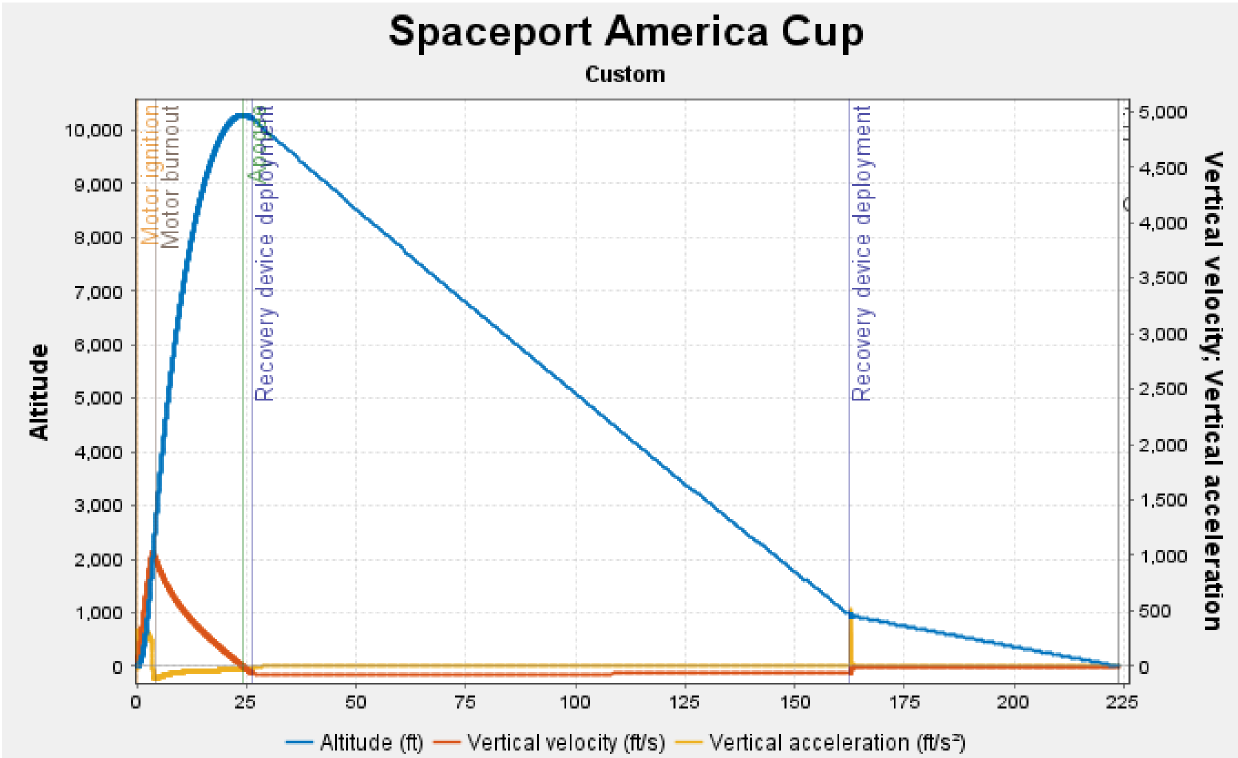

Fig. 22 OpenRocket Flight Simulation Graph

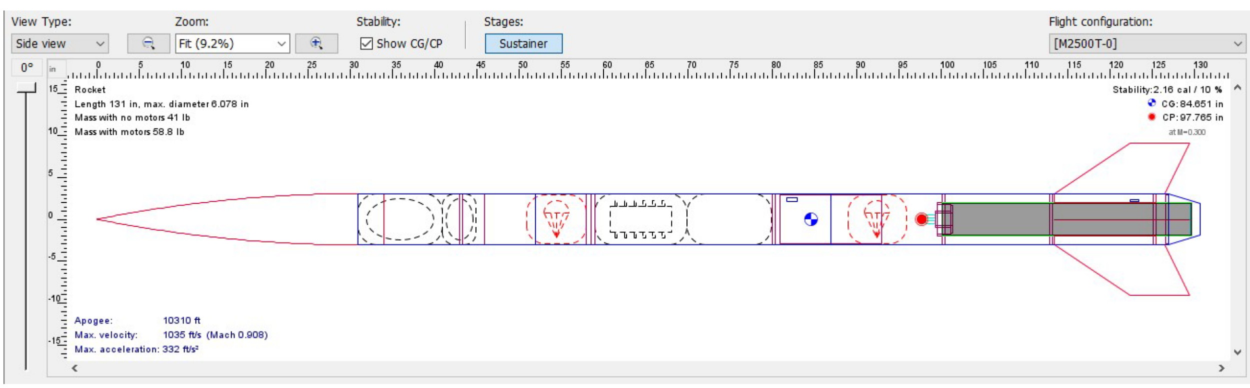

Fig. 23 OpenRocket Model of Spaceport America Rocket

E. Recovery Information

Recovery information, including the COTS and redundant altimeters used, drogue primary and backup deployment charges, drogue deployment altitude, drogue descent rate, main primary and backup deployment charges, main deployment altitude, main descent rate, shock cords and mechanical links.

The primary flight computer is a StratoLogger CF[26] and the secondary is an AIM[2]. Both the primary main and drogue charge is 4 grams of 4F black powder and the secondary charge for both is 4.5 grams of 4F black powder. Each charge uses two e-matches per charge. The primary flight computer deploys the drogue at apogee and the secondary flight computer deploys drogue at two seconds after apogee is reached. Under drogue, the vertical velocity will be 65 *m/s*. The primary deploys the main parachute at 1000 *ft* and the secondary flight computer deploys the main two seconds after 1000 *ft* is reached. Under main, the vertical velocity will be 15 *m/s*. See Recovery Subsystems for mechanical hardware specifications.

Appendix B: Project Test Reports

A. Recovery System Testing

A.1 Dual redundancy

1.a. Both the StratoLogger and AIM flight computers use independent batteries and arming switches.

i Power connections are made through XT-30[29] connectors that are secure through friction fit.

ii Arming switches are Siemens industrial control locking switches[24]. Switch locks into place and has flown multiple times.

iii Alkaline 9 *V* battery provides uptime greater than six hours in launch detect mode for each altimeter.

iv Twisted pair connection provides protection against EMI.

1.b. Two different flight computers provide dissimilar dual redundancy.

i Mitigates failure modes caused by flight computer hardware/software.

1.c. Both Featherweight GPS trackers use independent batteries and contain onboard arming switches

i The manufacturer supplied 3.7 *V* 400 *mAh* 1S LiPo battery from Featherweight[13] provides uptime of six hours per tracker [6].

1.d. Use of 8-pin aircraft connector for ejection charge lines ensures solid connection between COTS electronics bay and parachute bays.

i Twisted pair wirings on all charge lines mitigate accidental firings due to EMI.

ii Each ejection charge line wires in parallel to two e-matches, eliminating a single point of failure of lighting for all charges.

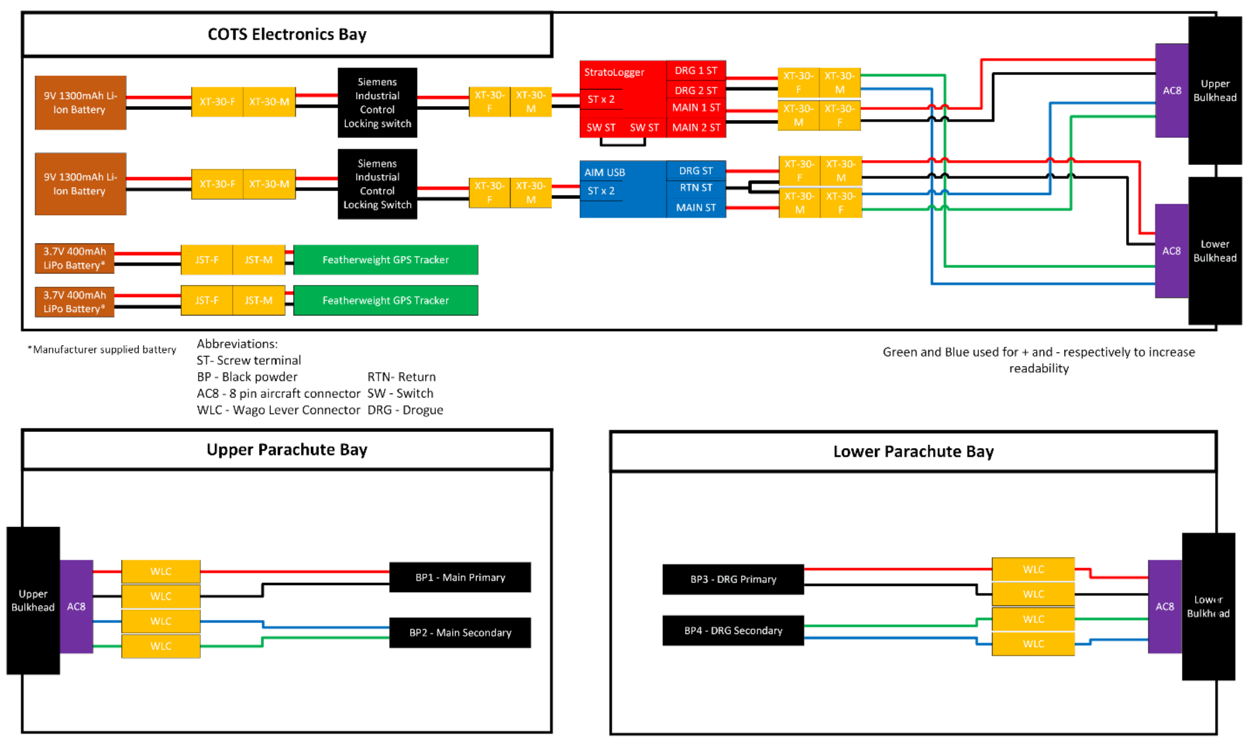

Fig. 1724 COTS Electronics Wiring Diagram

A.2 System tests

Type Electronics Function
Date 2 December 2023
Description
Power on test of flight computers while integrated into COTS electronics bay.
Result
Both flight computers booted with no issue and entered ready to launch state.
Action items None needed.

Type Battery Drain
Date 14 February 2024
Description
Test flight computers' battery drain characteristics at flight temperatures to gauge longevity.
Result
Both flight computers sustained ready for launch state for over six hours at launch conditions (~105°F) with an indistinguishable decrease in battery voltage.
Action items None needed.

Type Electronics Function
Date 4 March 2024
Description
Integration of flight computers and GPS trackers within COTS electronics bay. Test wiring connections between flight computers and respective pins on aircraft connectors for ejection charges.
Result
All systems reported nominal. All connections and wiring verified as correct using multimeter in continuity mode.
Action items None needed.

Type Deployment
Date 9 March 2024
Description
Deployment testing of flight computers lighting e-matches on primary drogue channel. Fully integrated test confirming proper wiring, adequate charge weights, mechanical construction, integration, and proper body tube separation.
Result
One test completed with primary drogue charge. Successful firing of approximately 1.5-gram black powder charge from StratoLogger flight computer, unsuccessful separation of body tubes from one another. The test planned for a 3.5-gram charge. The scale used for weighing of charges was found to be inaccurate due to the scale not being able to measure small enough quantities and due to environmental factors like wind interfering with measurments, leading to insufficient charge strength and failed deployment.
Action items
Eliminate use of digital scales when weight black powder charges for all future tests. Transition to volumetric measuring using black powder tubes with gram markings for accurate measurements.

Type Deployment
Date 12 March 2024
Description

Second deployment test, lighting e-matches on both primary drogue and main charges. Use direct wiring, no flight computer for deployment. Confirm adequate charge weights, mechanical construction, integration, and proper body tube separation.

Result

Successful deployment of both primary drogue and main charges in two different tests. Successful separation of body tubes using 4-grams of black powder, creating separation of approximately 20 *ft*.

Action items None needed.

Type Electronics Function
Date 12 April 2024
Description

Verification of e-match lighting by primary and secondary flight computer systems while fully integrated into the vehicle. Verify proper wiring and connections through aircraft connectors within integrated vehicle. Simulated charge deployment through flight computer interface software.

Result

Successful light of all e-matches by all channels on both primary and secondary flight computers.

Action items None needed.

Type Deployment
Date 12 April 2024
Description

Fully integrated deployment test of primary drogue and main charges. Manual lighting of e-matches through direct wiring from battery. Confirm adequate charge weights, mechanical construction, integration, and proper body tube separation.

Result

Two successful tests of primary drogue and main charges using 4-grams of black powder. Consistent measurement of separation at approximately 20 *ft*.

Action items None needed.

Type Flight Test
Date 13 April 2024
Description

Flight test recovery electronics through launch to approximately 8100 *ft*. Verify integrity of wiring, structure, and deployment in flight conditions.

Result

Successful deployment of drogue parachute. Successful separation, but no deployment of main parachute. Assignable cause of main parachute bag not being clipped in. Improper programming of secondary altimeter caused premature firing of secondary drogue charge. As a result, the secondary avionics arming switch[4] failed during drogue deployment due to high *g* load, leading to midflight power-off of secondary flight computer. Issues with GPS tracker connectivity before and during flight leading to expanded recovery efforts. Due to previous reliability and testing, as well as similar issues from other teams, the determined cause of the GPS failure was the use of the new BlueRaven app [4].

Action items

Increase specificity and depth on assembly and integration checklists to mitigate parachute bags and timing of secondary charges issues. Replace secondary arming switch with like model of primary arming switch. Return to previously used reliable Featherweight FIP app to mitigate GPS issues.

A.3 Air-Start/Staged Flights – Motor Inhibit During Flight

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A.4 Air-Start/Staged Flights – Additional Information Requirements

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A.5 Minimum Thrust-to-Weight Ratio

The thrust-to-weight ratio can be calculated with the following equation (1),

$$T{:}W = {}^{T_{init}}/_{W_{tot}} \tag{1}$$

where T_{init} is the initial thrust of the high-powered AeroTech M2500T-P COTS motor supplied by Balsa Machining and W_{tot} is the total launch vehicle weight including all major and subsystems, the payload, and motor. The initial thrust of the M2500T-P is 2577.9 *N* and the total weight is measured to be 60.7 lbm. The thrust-to-weight is calculated using equation (1) as,

$$T{:}W = \frac{2577.9}{60.70}\left[\frac{N}{lbm}\right]\cdot\frac{1.000}{1.000}\left[\frac{lbm}{lbf}\right]\cdot\frac{1.000}{4.48822}\left[\frac{lbf}{N}\right] = 9.462{:}\,1\;[-]$$

where the thrust-to-weight ratio is 9.462. Note, on earth a *lbm* is equal to a *lbf*. The minimum thrust-to-weight ratio required is 5:1, where we have designed our vehicle to have a higher ratio by a factor of 1.89.

B. SRAD Propulsion System Testing

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C. SRAD Pressure Vessel Testing

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D. SRAD GPS Testing

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E. Payload Recovery System Testing

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Appendix C: Test Launch Data Analysis

A. Data Summary

The MARTHA attached to our main rocket during the test launch collected 33.8 megabytes of data over the course of 10.5 hours including 268,000 unique acceleration entries at a rate of 7 entries per second. Software optimization since the launch has increased the logging rate to 100 samples-per-second, which will be reflected in the data during this launch. In Fig. 25, roughly 3.5 hours after initialization, the first rise in acceleration is due to the burn of the rocket motor, reaching a peak of about 8 *g*. The acceleration then gradually tapers off until it reaches zero, indicating apogee, at which point the drogue parachute deploys causing approximately 12 *g* of acceleration due to both the primary and secondary black powder charges going off at the same time. After the parachute deploys, a series of acceleration spikes as the recovery systems fully deploy, causing force loads on the vehicle. These forces taper off and represent the carry of the winds as the vehicle drifts back to the ground. This weather at the launch site during the test launch was heavily windy, so these results are in line with expectations.

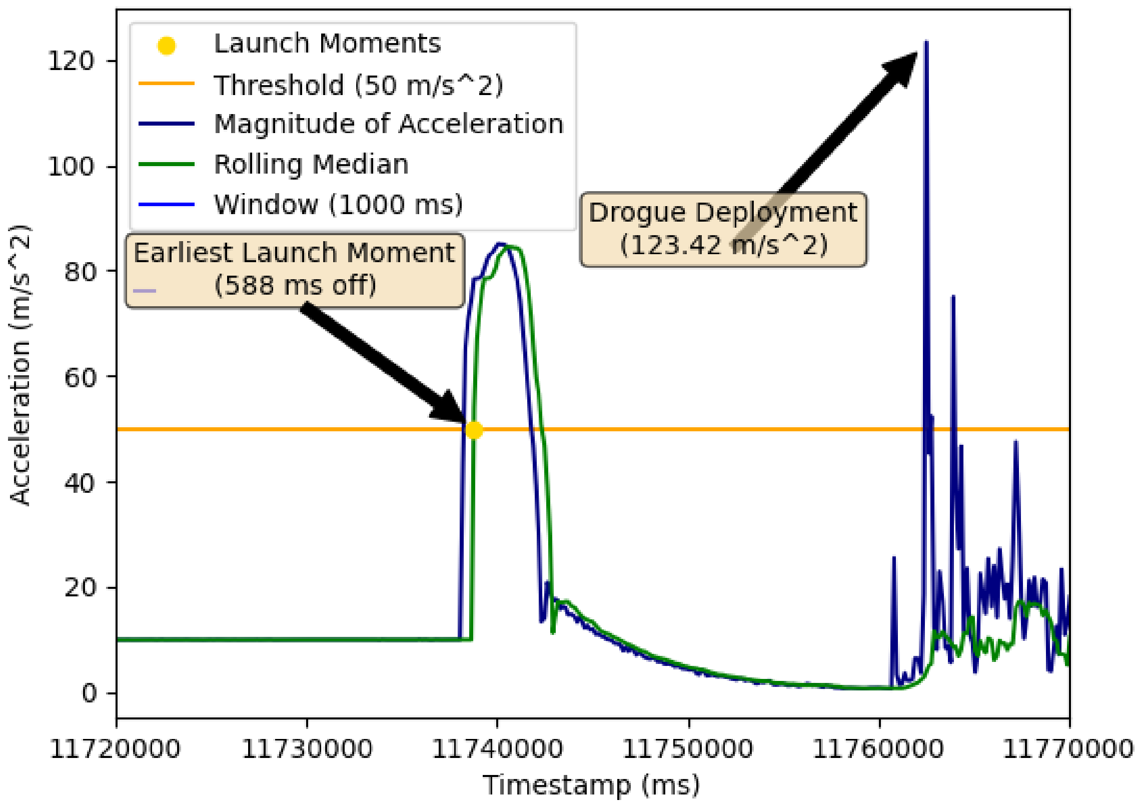


Fig. 25 MARTHA Acceleration at Launch

B. Data Application for Launch Detection

The similarity in launch characteristics between this test and our next launch means we can use this data to refine our launch detection algorithm's parameters. The first insight comes from the initial 'hump' representing launch being far wider than subsequent spikes due to the rocket motor's sustained acceleration versus the brief acceleration caused by other events such as parachute deployments and random bumps. To filter out the non-sustained accelerations, we employ a median-based approach. We calculate the median acceleration across a specified window size. For the median to exceed the threshold, at least half the values within the window must exceed it, effectively eliminating any brief spikes. This is demonstrated by the green line in the acceleration graph, which only rises during the launch. To determine the optimal window size and threshold, we loaded the data into a script that simulates MARTHA's live data processing. We tested numerous combinations, finding that a 1000-millisecond window and a 50 m/s^2 threshold successfully detect the launch event with only a 588-millisecond delay while reliably filtering out false positives. Due to the window size being one second, the detection delay can never be less than half a second, as it takes that long to fill up half of the temporal array that the median is taken on.

Appendix D: Hazard Analysis

Appendix D: Hazard Analysis offers an in-depth examination of potential hazards associated with the project, focusing on aspects such as hazardous material handling, transportation, and storage of propellants, among other safety-critical design components. This analysis is designed to ensure the safety of all operating personnel by meticulously detailing the risks involved and presenting effective mitigation strategies for each identified hazard. By methodically addressing both procedural and design-related safety issues, this appendix aims to minimize risks and enhance overall operational safety, adhering to regulatory compliance and engineering best practices. Our hazard matrix can be seen in Table 4, below.

Table 4 Hazard Analysis

Team 21	**We'll 'C' What Happens**			**5/10/2024**
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Epoxy lands in eyes, on skin, or is ingested during manufacturing process	Improper Eye Protection Improper glove and lab coat skin coverage Improper face and respirator use	Medium; Large amounts of epoxy are used throughout manufacturing process, so proper PPE is a must	High attention detail and strict enforcement of PPE measures while handling epoxy resin or hardener	Low.
Explosion of solid-propellant rocket motor during launch with blast or flying debris causing injury	Motor end closures fail to hold	Medium; Visual inspections are the most that can be done, but there may be subsurface cracking that can only be detected with ultrasound.	Inspect grains and ensure they are in proper condition.	Low.
	Motor case unable to contain normal operating pressure		Inspect motor case for damage during final assembly before launch	
	Cracks in propellant grain		Only essential personnel in launch crew will be a minimum 500 feet from rocket at launch, in abidance with TRA guidelines. However, ESRA has a system for personnel to be 2000 feet, decreasing possibility of injury by a factor of 16.	
Rocket deviates from nominal flight path, intercepts personnel at high speed	Under stable rocket steering into high wind as it departs from rail	Medium; Payload weighed less than expected during test launch.	Weight has been added to the payload to ensure a stable flight.	Low.
	Over stable rocket tipping over as it departs from rail		Refrain from launching in winds exceeding 20 *mph*, but design launch vehicle to remain nominal in winds above this limit	

	Coupler failure on motor ignition		Aero-structures have been checked for any crack propagation and replaced as necessary.	
Recovery system fails to deploy, rocket or payload comes in contact with personnel at an excessive speed	Recovery Systems overheat.	Medium; while battery drain tests have been performed high heat can cause lack of hardware and power function	Thermal protection via deployment bag.	Low.
	Power malfunction.		Ensure recovery systems are flight tested and successful.	
	Wet black powder.		Follow proper checklists, ensuring all steps are followed.	
Recovery system partially deploys, launch vehicle comes in contact with personnel	Recovery Systems overheat.	High; due to previous launches not including in-depth checklists, drogue or main non-deployment has occurred.	Thermal protection via deployment bag.	Medium.
	Power malfunction.		Ensure recovery systems are flight tested and successful.	
	Wet black powder.		Follow proper checklists, ensuring all steps are followed.	
Black powder charges prematurely ignite outside the launch vehicle.	Improper handling of black powder	Low; black powder is stored and transported in airtight, AC-controlled locations. Black powder is only handled by experienced personnel.	Ensure black powder is storage container is correctly sealed.	Low.
	Improper storage of black powder		Ensure black powder is secured during transportation.	
Black powder charges prematurely ignite inside the vehicle.	Improper handling of black powder	Medium; High heat may cause electronic failure or other hazards. Yanking of e-matches can cause premature activation.	Ensure black powder is storage container is correctly sealed.	Low.
	Improper storage of black powder		Ensure cautious handling of e-matches.	
	E-Matches prematurely go off.		Ensure following of proper checklists.	
Rocket motor does not ignite when given command, but ignites during investigation.	Delay of e-match signal.	Medium; risk of accident can always occur.	Proceed with extra caution when approaching a failed motor ignition.	Medium.
			Wait minute after attempted motor ignition, as required by TRA guidelines.	

			Encourage competition officials to maintain proper handling of their Wilson FX system which has a double relay safety mechanism.	
Recovery system deploys during assembly or prelaunch, causing injury.	Flight computers are prematurely powered and engage.	Medium; Due to the nature of black powder and energetics, danger is always there.	Ensure electronics bay does not stop beeping.	Low
	E-match prematurely activated, causing deployment.		Independent switches for flight computer power on and arming charges.	
			Provide enough slack in e-matches and do not pull on them.	

Appendix E: Risk Assessment

Appendix E: Risk Assessment provides a comprehensive overview of the risks and reliability concerns pertinent to the mission. This section meticulously catalogs all identified failure modes that could jeopardize mission success. It presents these in a structured matrix aligned with the mission phases outlined by the CONOPS. A detailed mitigation strategy is elaborated for each risk identified, addressing potential issues through specific process improvements and design modifications. This appendix aims to ensure that participants are fully informed of the potential challenges and the proactive measures to mitigate these risks, thereby enhancing the project's overall reliability and success rate. The values for likelihood are dependent on historical data of all teams flying at the SAC. The varying levels of likelihood and impact can be seen in Table 5 Risk Level Designation.

Table 5 5Risk Level Designation

Level	Likelihood	Impact
1	Minimal Chance (1-2%)	No effect on the mission
2	Possible (2-5%)	Minor impact on technical performance
3	Probable (5-10%)	Affects mission success
4	Highly Possible (10-20%)	Significant risk to mission critical systems
5	Definite Chance (>20%)	Human Risk

Table 6 presents a detailed Risk Assessment for the project. It outlines the potential failure modes of various components and systems, their effects, inherent risk levels, and the respective mitigation plans to reduce these risks. Each entry in the table identifies a specific potential failure, describes the possible consequences of such a failure, assesses the risk in terms of likelihood and impact, and details the actions taken to mitigate the risk to more manageable levels. The mitigation strategies encompass procedural adjustments, enhanced manufacturing practices, rigorous testing, and quality control measures. This structured approach ensures that risks are systematically identified, assessed, and mitigated to support the stability and safety of the project. The table also illustrates the effectiveness of the mitigation strategies by comparing initial and mitigated risk levels, thereby highlighting the tangible benefits of the risk management processes employed.

Table 66 Risk Assessment Table

Potential Failure Mode	Potential Effects of Failure	Risk Levels	Mitigation Plan	Mitigated Risk
Improperly cut Body Tube	Higher Drag, non-rigid body joints	Likelihood: 2 Impact: 1	Sanding of Body Tube edges, smooth surface finish	Likelihood: 1 Impact: 1
Crack propagation from holes in airframe	Loss of rigidity in body tube, structural failure of body tube	Likelihood: 2 Impact: 2	Reinforce holes with epoxy	Likelihood: 1 Impact: 2
Improperly secured fins	Loss of fin, catastrophic loss of rocket	Likelihood: 3 Impact: 4	High attention to detail throughout manufacturing process, through-wall and tip to tip layup	Likelihood: 2 Impact: 4
Improperly secured bulkheads	Shift of Avionics or Payload, loss of stability	Likelihood: 3 Impact: 2	High attention to detail, testing of each bulkhead	Likelihood: 1 Impact: 1
Fins bent or damaged	Erratic flight behavior	Likelihood: 4 Impact: 3	Use of fin jig and level, and careful storage during transport. Fin covers made from pool noodles to protect tips.	Likelihood: 2 Impact: 3

Centering Rings out of alignment	Erratic flight behavior	Likelihood: 3 Impact: 2	Quality control of manufactured angles during construction. Verification of proper alignment with test flight.	Likelihood: 1 Impact: 2
Improperly secured Camera Shroud	Increased Drag, loss of shroud	Likelihood: 3 Impact: 1	Ensure proper bolted connection between body surface and camera shroud	Likelihood: 2 Impact: 1
Avionics wires caught or snagged during integration	Damage to avionics systems	Likelihood: 4 Impact: 1	Use of integration lists and visual inspection throughout integration process. Ensure properly lacked wire runs and quick connectors.	Likelihood: 2 Impact: 1
Payload detaches during descent	Loss or damage to payload	Likelihood: 2 Impact: 1	Flight tested to ensure connection.	Likelihood: 1 Impact: 1
Motor retention fails	Motor falls out of rocket after boost	Likelihood: 2 Impact: 3	Secure forward and aft retention with epoxy and screws, forward eye bolt fully screwed in	Likelihood: 1 Impact: 3
Drogue parachute becomes entangled	Higher than expected descent velocity	Likelihood: 1 Impact: 2	Careful packing of drogue parachute, deploy main parachute prior to excessive velocity and flight test the software.	Likelihood: 1 Impact: 2
Main parachute fails to fully deploy	Higher than expected descent velocity	Likelihood: 4 Impact: 3	Careful packing of main parachute using properly stored packing bag, checklist of line connections	Likelihood: 3 Impact: 2
Main parachute deploys at apogee	Excessive drift of rocket	Likelihood: 4 Impact: 1	Careful packing of main parachute, ejection testing, testing of shear pins. Ensure properly sized ejection charges to prevent hammering. Perform realistic ground tests followed by flight tests.	Likelihood: 3 Impact: 1
Arming switch fails and a flight computer turns off.	Minor loss of data, due to two other redundant flight computers.	Likelihood: 2 Impact: 1	Ensure switches are fully armed in place and are connected to avionics bay correctly.	Likelihood: 1 Impact: 1
Recovery Systems Overheat on the Pad.	Potential loss of vehicle, no chute deployment.	Likelihood: 3 Impact: 4	Ensure recovery systems are flight tested and there is temperature mitigating finish to the vehicle. Arrive and launch early.	Likelihood: 2 Impact: 3

Loss of GPS signal from trackers within vehicle during flight.	Potential loss of vehicle.	Likelihood: 3 Impact: 3	Dual redundancy of trackers, eliminating single point of failure. Monitor battery voltage of GPS throughout preflight and launch. Use of RF transparent materials in line of the antenna's toroidal propagation pattern. Screen record phone GPS interface during flight to record path of vehicle throughout flight. Use easily distinguishable colors to increase rocket's visual footprint on landing	Likelihood: 1 Impact: 2
No ignition from e-match charges.	No motor ignition.	Likelihood: 3 Impact: 3	Ensure e-matches are correctly attached. Follow pre-launch checklists.	Likelihood: 2 Impact: 2
Premature motor ignition.	Potential motor explosion and human injury.	Likelihood: 2 Impact: 5	Ensure e-matches are correctly attached. Follow pre-launch checklists. Coordinate with ESRA Solid PAS personnel to ensure the Wilson FX is disarmed prior to installing igniter.	Likelihood: 1 Impact: 4
Parachute deploys at motor burnout.	Destruction of vehicle.	Likelihood: 1 Impact: 4	Ensure Avionics correctly detects apogee, using applicable filters and delays Ensure barometric holes are properly sized and positioned. Ensure forward retainer on motor is secure. Avionics are flight tested.	Likelihood: 1 Impact:3
Motor fails to burn all fuel during lift-off.	Potential failure to apogee.	Likelihood: 3 Impact: 2	Ensure COTS motor is structurally sound and grain is good.	Likelihood: 2 Impact: 2
Vehicle rail guide breaks during ignition.	Potential human risk and vehicle deviation.	Likelihood: 4 Impact: 5	Ensure rail guide is properly installed and follow preflight checklists. Ensure rail and rail guide are properly aligned before launch.	Likelihood: 2 Impact: 4
Motor does not produce enough thrust for lift-off.	Potential failure to apogee or	Likelihood: 2 Impact: 3	Ensure COTS motor is structurally sound and grain is good. Ensure	Likelihood: 1 Impact: 2

	failure to launch.		motor simulations are correct. Use a trusted motor vendor and a certified M-class motor.	
Rocket deviates from nominal flight path.	Potential human risk.	Likelihood: 4 Impact: 5	Ensure rail is properly fastened and follow preflight checklists. Angle rails away from flight line and in accordance with TRA guidelines.	Likelihood: 2 Impact: 3
Trailer involved in crash.	Potential human risk. Potential risk to launch vehicle.	Likelihood: 3 Impact: 5	Ensure to travel with a diverse Subteam pool. Follow all driving laws and regulations. Ensure trailer and towing vehicle are properly fitted for travel.	Likelihood: 2 Impact: 4
Team transportation is involved in an accident.	Potential human risk.	Likelihood: 2 Impact: 5	Ensure to travel with a diverse Subteam pool. Follow all driving laws and regulations. Ensure travel vehicle is properly fitted for travel.	Likelihood: 2 Impact: 4
Organization funds run out.	Potential risk of mission failure. Potential to have no launch vehicle.	Likelihood: 5 Impact: 4	Team properly budgets each fiscal year and adheres to a strict budget. Enough funds are in excess to allow for emergency funds as necessary.	Likelihood: 1 Impact: 1
Team runs out of time for vehicle manufacturing.	Potential risk of mission failure via nonflight.	Likelihood: 5 Impact: 4	Ensure vehicle is assembled and undergo a successful test flight with enough time for manufacturing and assembly after flight.	Likelihood: 1 Impact: 1

Appendix F: Assembly, Preflight, Launch, Recovery, and Off-Nominal Checklists

The Off Nominal checklist covers alternate process flows for dis-arming/safeing the vehicle/system based on identified failure modes. The first point of each subsection within each checklist indicates whether one of these failure modes has occurred. The failure mode can be found below the yes/no question this with the letter/number combination of the specific failure, as well as an explanation of the failure, with possible notes/other failure modes extending into the misc. notes section of the subsection. Each subsection of the Off Nominal checklist lists the identified failure modes for each of the other checklists (Assembly, Preflight, Launch, and Recovery) that require dis-arming/safeing; with the subsections of each failure mode containing the subsequent process flow within. The Off-Nominal checklist is not all encompassing, and only includes failure modes for which dis-arming/safeing of the vehicle is needed.

Precautions include the following:

The use of clear, unambiguous flight ready language. The traditional "Go No Go" terminology has significant risk associated if the "No" is not copied, resulting in a false "Go" signal. As such Green/Red terminology is used to eliminate this risk.

A. Assembly Checklist:

A.1 Ejection Charge Preparation ☐

1.a. Drogue Primary ☐

i Apply proper PPE per ESRA specifications ☐
ii Prepare rubber glove finger, tape, two e-matches, and precision scale ☐
iii Check continuity of each e-match, visually inspect for damage ☐
iv Measure out **4.0 *grams*** of 4F black powder, close black powder container ☐
v Pour black powder into glove finger ☐
vi Insert both primary drogue e-matches into powder inside the glove finger ☐
vii Tape glove finger tightly closed and wrapped, ensuring e-matches are secured, and black powder is sealed and can hold until the BP is burnt ☐
viii Place assembled ejection charge into charge well ☐
ix Clearly label charge as "DROGUE PRIMARY CHARGE" ☐

1.b. Drogue Secondary ☐

i Apply proper PPE per ESRA specifications ☐
ii Prepare rubber glove finger, tape, two e-matches, and precision scale ☐
iii Check continuity of each e-match, visually inspect for damage ☐
iv Measure out **4.5 *grams*** of 4F black powder, close black powder container ☐
v Pour black powder into glove finger ☐
vi Insert both secondary drogue e-matches into powder inside the glove finger ☐
vii Tape tightly closed glove finger and wrapped, ensuring e-matches are secured, and black powder is sealed and can hold until the BP is burnt ☐
viii Place assembled ejection charge into charge well ☐
ix Clearly label charge as "DROGUE SECONDARY CHARGE" ☐

1.c. Main Primary ☐

i Apply proper PPE per ESRA specifications ☐
ii Prepare rubber glove finger, tape, two e-matches, and precision scale ☐
iii Check continuity of both e-matches, visually inspect for damage ☐
iv Measure out **4.0 *grams*** of 4F black powder, close black powder container ☐
v Pour black powder into glove finger ☐
vi Insert both primary main e-matches into powder inside the glove finger. ☐
vii Tape glove finger closed, ensuring e-matches are secured, and black powder is sealed ☐
viii Clearly label the charge as MAIN PRIMARY CHARGE ☐

1.d. Main Secondary ☐
- i Apply proper PPE per ESRA specifications ☐
- ii Prepare rubber glove finger, tape, two e-matches, and precision scale ☐
- iii Check continuity of e-matches, visually inspect for damage ☐
- iv Measure out **4.5 *grams*** of 4F black powder, close black powder container ☐
- v Pour black powder into glove finger ☐
- vi Insert both secondary main e-matches into powder inside the glove finger ☐
- vii Tape glove finger closed, ensuring e-matches are secured, and black powder is sealed ☐
- viii Clearly label charge as "MAIN SECONDARY CHARGE" ☐

A.2 Parachute Bay Preparation ☐

2.a. Drogue Parachute Preparation ☐
- i Visually inspect each panel of parachute for rips, tears, or punctures ☐
- ii Visually inspect full length of each shroud line and shock cord for severed, frayed, torn, or brittle sections ☐
- iii Lay parachute flat on a stable, clean working surface sheltered from wind and dust ☐
- iv Following manufacturer guidelines, fold parachute in half such that the shroud lines align cleanly, and there are no large wrinkles in the parachute ☐
- v Fold towards the center panel by panel, such that the shroud lines remain organized, until it meets the shape of a triangle with a rounded bottom edge ☐
- vi Perform a Z-fold such that the top point of the triangle remains on top of the folded parachute ☐
- vii Perform a Z-Fold of the shroud lines, ensuring lines remain untangled ☐
- viii Wrap final length of shroud lines once, and no more, around folded parachute such that the parachute exits the parachute bay prior to unfolding ☐
- ix Group parachute and lines together, and set in sheltered, clean place ☐

2.b. Main Parachute Preparation ☐
- i Visually inspect each panel of parachute for rips, tears, or punctures ☐
- ii Visually inspect the full length of each shroud line and shock cord for severed, frayed, torn, or brittle sections ☐
- iii Lay parachute flat on a stable, clean working surface sheltered from wind and dust ☐
- iv Following manufacturer instructions, fold parachute ☐
- *v* Carefully insert parachute into deployment bag ☐
- *vi* Following manufacturer instructions, organize shroud lines onto deployment bag ☐
- *vii* Set packed parachute in sheltered, clean place ☐

2.c. Shock Cord Preparation ☐ ☐
- i Create a knot 10 ft from one end of the cord ☐ ☐
- ii Insert a quick link through loops placed at the ends of the shock cord and in the knot ☐ ☐
- iii Place the swivel at both ends of the shock cords with an additional quick link to eventually attach to the eyebolts ☐ ☐
- iv Fold the shock cords in a Z fold and wrap one wrap of painter's tape around the fold to hold it in place ☐ ☐
- v Repeat again for the second shock cord ☐

A.3 Avionics Bay Preparation ☐

3.a. Pre-Assembly Checklist ☐

i Prepare three new Duracell 9 Volt batteries and two Li-Po Featherweight batteries ☐

ii Check with a multimeter that each battery is fully charged, 9 Volts for the 9 Volt and 4.2 Volts for the Li-Po's ☐

iii Using multimeter, check continuity of each of the four power wires from the battery harness to each flight computer ☐

iv Check continuity of each of the eight ejection charge lines from the flight computer to the charge lever connectors ☐

v Check continuity of both flight computer switches in both the on and the off position ☐

vi Connect the featherweight trackers to the ground stations and confirm tracking works on both trackers ☐

vii If necessary, program the featherweight trackers to the correct designated frequency ☐

3.b. Assembly Checklist ☐

i Insert two fully charged 9 Volt batteries into the battery slots at the bottom of the avionics bay ☐

ii Connect each battery to the harness ☐

iii Place the battery cover on top of the batteries and tighten the screw to secure it in place ☐

iv Briefly turn on each flight computer using the switches to ensure both power on and correct startup beep sequence ☐

v Ensure both flight computer power switches are in the off position by listening to if each flight computer is beeping correct sequence ☐

vi Cut two new sections of Alien Tape approximately the same size of one of the Li-Po batteries ☐

a. Place each Alien Tape behind each of the featherweights on the other side of the fiber glass supports ☐

vii Remove the protective film from each tape ☐

viii Firmly place each battery on the tape and press down for 30 seconds ensuring the wire is pointed in the same direction as the receptacle on the featherweights ☐

ix Insert each battery into the featherweight ensuring that the red wire corresponds to the + terminal and the black wire corresponds to the – terminal ☐ ☐

x Briefly turn on each featherweight and ensure there are lights on the boards ☐ ☐

xi Turn off both featherweight trackers and ground stations ☐

xii Cut one section of Alien Tape approximately the same size as a 9 Volt battery ☐

a. Place the tape behind the MARTHA board on the other side of the fiberglass support.

b. Remove the protective film on the tape ☐

c. Firmly place the 9 Volt battery on the tape and press down for 30 seconds ☐

d. Connect the battery harness to the battery ☐

xiii Briefly turn on MARTHA and check that the lights turn on ☐

xiv Turn off MARTHA ☐

3.c. Post-Assembly Checklist (Completed immediately before the bay is inserted into the airframe) ☐

i Check that the battery cover is properly screwed in and tight ☐

ii Check that all XT-30 connectors are fully connected ☐

iii Tighten all screw terminals ☐

iv Briefly turn on each flight computer and check that it beeps out correct sequence ☐ ☐

v Turn off both flight computers ☐ ☐

vi Turn on MARTHA and check that all the proper lights turn on ☐

vii Turn on each featherweight tracker and check the lights turn on ☐ ☐

viii Connect the trackers to their ground stations and connect the ground stations to the designated tracking phones ☐ ☐

a. Ensure proper tracking of both trackers is maintained throughout the rest of assembly, preflight, launch, and recovery.

A.4 Payload Bay Preparation ☐

4.a. Electric Component Pre-Assembly Checklist ☐

- i Prepare 3s2p configuration 18650 cell and an additional 1860 cell ☐
- ii Measure cell voltages with a multimeter to ensure the batteries are fully charged ☐ ☐
  - a. 3s2p between 12 *V* and 12.6 *V* ☐
  - b. Single cell between 4 *V* and 4.2 *V* ☐
- iii Gather sensor bay ☐

4.b. Mechanical Component Pre-Assembly Checklist ☐

- i Gather fasteners for assembly:
  - a. PH CS M4x-0.7 x 10 | Q: 15 ☐
  - b. SH M5x0.8 x 20 | Q: 3 ☐
  - a. M5x0.8 Hex Nut | Q: 3 ☐
  - b. SH 4-40 1/3 *in* | Q: 32 ☐
  - c. HC 1/4 *in* 20 | Q: 2 ☐
  - d. 1/3 *in* 1300 *lbf* eyebolt ☐
  - e. 1/3 *in* locknut ☐
- ii Prepare extended socket wrench for ¼" 20 hex cap screws ☐
- iii Prepare M2, M4, and 4-40 Allen wrenches ☐
- iv Prepare Phillips head screwdriver ☐
- v Gather 3 split 3 micro cameras ☐
- vi Gather 3 3D printed camera mounts ☐
- vii Gather 3 spacer plates ☐

4.c. Payload Assembly ☐

- i Insert cameras into camera mounts ☐
- ii Assemble camera section:
  - a. Attach assembled camera mounts to lower bulkhead with PH CS M4 screws ☐
  - b. Attach spacer plates to lower bulkhead with PH CS M4 screws ☐
  - c. Attach interface bulkhead to spacer plates with PH CS M4 screws ☐
- iii Assemble CubeSat ☐
  - a. Attach side plates to intermediate plates with 4 4-40 screws ☐
  - b. Attach back plate to intermediate plates, top and bottom plates, and side plates with 12 4-40 screws ☐
  - c. Insert sensor bay into bottom section of CubeSat ☐
  - d. Attach CubeSat to interface bulkhead with 3 M5 screws ☐
  - e. Check that the power switches are in the off position ☐
  - f. Wire power from batteries to ESP32-S3 Feather in sensor bay through lower intermediate plate of CubeSat ☐
  - g. Fasten batteries in middle 1U section of CubeSat ☐
  - h. Attach front plate to intermediate and side plates with 8 4-40 screws ☐

4.d. Airframe Attachment Check list ☐

- i Screw eyebolt into the center of the bottom bulkhead ☐
- ii Tighten locknut on eyebolt ☐
- iii Slide bay into airframe ☐
- iv Screw in all three ¼-20 screws through the carbon fiber bulkhead into the bottom bulkhead of the bay ☐
- v Ensure the screws are tightened ☐
- vi Check to ensure the switches for the cameras can be accessed ☐

A.5 Booster Preparation

- i Apply Proper PPE according to ESRA specifications ☐
- ii Following manufacturer guidelines, assemble motor ☐
- iii Insert loaded motor casing with aft threaded shoulder installed into motor tube ☐
- iv Install boat tail, tightening all four fasteners ☐
- v Install forward eyebolt, tightening securely ☐

A.6 Airframe Integration

6.a. Drogue Parachute Bay Integration ☐

- i Ensure drogue is folded neatly and shroud lines are not tangled in any way ☐
- ii Ensure Z folds are still held together via the painter's tape ☐
- iii Ensure the ends of the shock cords have two quick links attached with a swivel between them. A total of four quick links and two swivels ☐
- iv Take the primary black powder charge and clip the leads into the Wago Lever Connectors[28] ☐
- v Take the secondary charge and clip the leads into the orange clips that correspond to the primary charge ☐
- vi Place both charges into the aluminum charge wells, secure them down with duct tape ☐
- vii Attach the drogue to the quick link that is attached to the knot, tighten the quick link ☐
- viii Attach the shorter end of the shock cord to the eyebolt in the motor tube and attach the other end to the eyebolt at the bottom of the avionics tube ☐
- ix One last visual confirmation that the Black powder chargers are secured in the charge well and that the e-match has not become disconnected ☐
- x Slide the avionics and the motor tube together ☐
- xi Screw in the 6-32 shear pins through the tube and coupler ☐
- xii Ensure the connection is rigid ☐

6.b. Main Parachute Bay Integration

- i Ensure the main is folded neatly and shroud lines are not tangled in any way ☐
- ii Ensure Z folds are still held together via the painter's tape ☐
- iii Ensure the ends of the shock cords have two quick links attached with a swivel between them. A total of four quick links and two swivels ☐
- iv Take the primary black powder charge and clip the leads into the orange clips that correspond to the primary charge. ☐
- v Take the secondary charge and clip the leads into the orange clips that correspond to the primary charge ☐
- vi Place both charges into the aluminum charge wells, secure them down with duct tape ☐
- vii Attach the main to the quick link that is attached to the knot, tighten the quick link ☐
- viii Clip the main bag to the quick link that is on the shorter end of the shock cord ☐
- ix Attach the shorter end of the shock cord to the eyebolt in the payload tube and attach the other end to the eyebolt at the top of the avionics tube ☐
- x One last visual confirmation that the Black powder chargers are secured in the charge well and that the e-match has not become disconnected ☐
- xi Slide the avionics and the motor tube together ☐
- xii Screw in the 6-32 shear pins through the tube and coupler ☐
- xiii Ensure the connection is rigid ☐

B. Preflight Checklist:

B.1 Lower Rail to horizontal position ☐

1.a. Remove vehicle from transport truck and carry to pad ☐

1.b. Slide lower rail guide onto rail, ensuring no undue stress on the rail guide, until the upper rail guide slides onto rail ☐

1.c. Slide rocket fully down rail ☐

1.d. Remove nose cone tip protection ☐

i Rotate rail into vertical position with appropriate angle for given conditions ☐

ii Lock rail tightly in place ☐

iii Turn on cameras ☐

iv Rotate each flight computer switch to the on position and ensure both are beeping ☐

B.2 Vehicle is vertical and locked in place on pad ☐

2.a. Arm COTS flight computers ☐

i Primary altimeter ☐

a. Rotate the primary locking switch to the on position.

b. Listen for successful startup sequence of primary altimeter, StratoLogger ☐

1) Observe beep pattern for main deployment of 1000 *ft* AGL ☐

c. Listen for beeps indicating continuity on both primary deployment lines ☐

ii Secondary altimeter ☐

a. Rotate the secondary locking switch to the on position. ☐

b. Listen for successful sequence on secondary altimeter, AIM ☐

1) Observe beep pattern for main deployment of 1000 *ft* AGL ☐

c. Listen for a second set of beeps, distinct from StratoLogger, indicating continuity on both secondary deployment lines. ☐

iii Verify that both flight computers are on, in ready to launch mode, and have continuity across all charges ☐

2.b. Payload Electronics ☐

i Enable payload cameras with locking power switch flip ☐

ii Enable payload experiment with locking power switch flip ☐

2.c. GPS trackers ☐

i Not applicable – GPS trackers are already enabled.

2.d. SRAD Avionics ☐

i Not applicable – SRAD avionics is already enabled.

2.e. Arm Motor ☐

i Insert e-match, which is wrapped around a wooden dowel for stability, up the motor ☐

ii Clip the ends of the e-match to the alligator clips supplied by the competition ☐

iii Using duct tape, tape down the ends of the e-match to ensure it does not become disconnected due to weather conditions ☐

iv Ensure continuity in the e-match ☐

C. Launch Checklist:

C.1 SRAD Avionics Green/Red ☐

1.a. Not applicable – SRAD avionics already running.

C.2 Payload Green/Red ☐

2.a. Not applicable – Payload electronics already running.

C.3 GPS Green/Red ☐

3.a. Both trackers have GPS lock and are tracking properly on the designated phones ☐ ☐

C.4 Visual Tracking Green/Red ☐

4.a. Team has a visual lock on the vehicle ☐

D. Recovery Checklist:

D.1 Flight completed:

1.a. Include off nominal checklist? **Yes** ☐ **No** ☐

i Off nominal points: ______________________________

____

1.b. Record vehicle GPS location from primary/secondary Featherweight GPS trackers ☐ ☐

i Primary GPS location: ______________________________

ii Secondary GPS location: ______________________________

1.c. Record any flight anomalies:

i Unfired black powder charges ☐

ii Unexpected vehicle fragmentation ☐

iii Ruptured batteries ☐

iv Miscellaneous: ______________________________

1.d. Picked up GPS + radio pack from recovery tent & complete MCC check-in ☐

1.e. Route to vehicle approved by team's Safety Officer ☐

i Route to vehicle confirmed by MCC ☐

1.f. Recovery team personnel deemed fit by team's Safety Officer ☐

1.g. All clear to depart received from MCC ☐

1.h. Misc. notes: ______________________________

____

D.2 Recovery team deployed:

2.a. Include off nominal checklist? **Yes** ☐ **No** ☐

i Off nominal points: ______________________________

____

2.b. Arrived at planned vehicle exit location ☐

2.c. Confirm GPS locations are within same area as previously ☐ ☐

i Primary GPS location: ______________________________

ii Secondary GPS location: ______________________________

2.d. Exited recovery vehicle at planned location:

i Complete check-in with MCC ☐

2.e. Time of vehicle exit:______________________________

2.f. Begin on foot search for vehicle ☐

i MCC check-ins every 30 minutes: ______________________________

ii Notable events during search: ______________________________

2.g. Misc. notes: ______________________________

____

D.3 Vehicle Located:

3.a. Include off nominal checklist? **Yes** ☐ **No** ☐

i Off nominal points: ______________________________

____

3.b. Vehicle spotted ☐

i Time of vehicle spotting: ______________

ii Visual assessment of possible flight anomalies: ______________________

iii All parts of vehicle are present ☐

a. Parts not found with vehicle: ______________________

iv All battery systems are intact ☐

a. Ruptured batteries: ______________________

v Confirmation by Safety Officer of depletion of all energetics ☐

a. Unspent energetics: ______________________

b. All hazards disarmed and removed from vehicle by Safety Officer ☐

vi All clear to approach vehicle given by team's Safety Officer ☐

3.c. GPS location of vehicle: ______________________

3.d. Record apogee of primary/secondary recovery altimeters through beep readings ☐ ☐

i Primary altimeter apogee [ft]: ______________________

ii Secondary altimeter apogee [ft]:______________________

iii Recovery altimeters powered off ☐ ☐

3.e. If applicable: Removal of vehicle sections from flora ☐

3.f. Payload powered off ☐

i Payload experiment powered off ☐

ii SRAD camera system powered off ☐

3.g. SRAD avionics powered off ☐

i Record state indication of primary/secondary SRAD flight computers through LED blinks ☐

a. Primary final state: ______________________

b. Secondary final state: ______________________

ii MARTHA boards powered off ☐ ☐

3.h. Vehicle fully powered off ☐

3.i. MCC check-ins: ______________________

3.j. Misc. notes: ______________________

____

D.4 Return to base camp:

4.a. Include off nominal checklist? **Yes** ☐ **No** ☐

i Off nominal points: ______________________________

____

4.b. All vehicle sections present at landing area collected ☐

i Time of departure from vehicle landing area: ______________________

4.c. Arrived at recovery vehicle ☐

i Time of arrival to recovery vehicle:______________________

ii All clear from Safety Officer to begin vehicular return to base camp ☐

4.d. Arrival at base camp

i Complete final MCC check-in & return GPS + radio pack ☐

ii Brought vehicle to post flight inspection ☐

4.e. Notable events during return:______________________

4.f. Misc. notes: ______________________

____

4.g. Completed recovery of vehicle ☐

E. Off-Nominal Checklist

E.2 Assembly:

2.a. Battery punctured ☐

- i Report to MCC battery rupture and possible fire ☐
- ii If fire announce to people in the area ☐
  - a. If deemed safe, flight dynamics will quickly remove the motor from the area
  - b. If deemed safe, energetics team will quickly remove any energetics from the area
- iii Retreat from the vehicle ☐
  - a. Maintain safe yet observable distance in case hazard increases ☐
- iv Once fire is extinguished, assess damage and determine if the vehicle is still able to fly ☐
  - a. If so replace battery and continue ☐
  - b. If not abort launch ☐

2.b. GPS signal lost ☐

- i Try and reconnect without disassembling ☐
- ii Disassemble avionics airframe, remove bay and check battery voltage and restart trackers if necessary ☐
- iii Consult manual for troubleshooting tips ☐

2.c. Coupler or airframe fractures ☐

- i Assess damage ☐
  - a. If very minor, continue ☐
  - b. If repairable, use epoxy and carbon fiber to fix the area ☐
  - c. If not repairable, abort ☐

2.d. Flight computer does not power on ☐

- i Check wiring and if all connectors are fully connected ☐
  - a. If necessary check continuity ☐
- ii Check battery voltages ☐
- iii Check switches to make sure they are functioning properly ☐
- iv Tighten screw terminals ☐
- v Consult manual of flight computer for further troubleshooting ☐
- vi Replace flight computer if necessary ☐

2.e. Black powder charge tears ☐

- i Clean up any spilled black powder ☐
- ii Mix any contaminated black powder with water to dispose of it ☐
- iii Make a new black powder charge ☐

E.3 Preflight:

3.a. Battery punctured ☐

- i Report to MCC battery rupture and possible fire ☐
- ii Retreat from the vehicle ☐
  - a. Maintain safe yet observable distance in case hazard increases ☐
- iii Abort launch ☐

3.b. GPS signal lost ☐

- i Hold launch ☐
- ii Try and reconnect without disassembling ☐
- iii Abort launch and return to setup area ☐
- iv Disassemble and check battery voltage and restart trackers if necessary ☐

3.c. Coupler or airframe fractures ☐

- i Assess damage ☐
    - a. If very minor, continue ☐
    - b. If repairable abort and return to base camp, use epoxy and carbon fiber to fix the area ☐
    - c. If not repairable, abort ☐

3.d. Flight computer stops beeping or does not complete booting ☐

- i Check that power switch is in correct position ☐
- ii Turn the switch off for 30 seconds and back on ☐
- iii Abort launch and disassemble and troubleshoot ☐

E.4 Launch:

4.a. GPS signal loss ☐

- i Have two people quickly move to opposite ends of the launch site to get different vantage points and follow the vehicle's descent closely ☐
    - a. Use a phone's GPS to mark area where the vehicle was seen by the two members and focus search efforts on the area where each line of sight crosses ☐

4.b. Motor chuff ☐

- i Replace igniter ☐
    - a. If second failure, remove vehicle from rails and return to base camp ☐
        - 1) Replace motor ☐

E.5 Recovery:

5.a. Unspent energetics ☐

- i Safety Officer inspects vehicle ☐
    - a. Others remain at a safe distance ☐
    - b. Photograph unspent charge for failure analysis ☐
- ii Disconnect charges from wiring ☐
- iii Open unspent charge, pour unused black powder into designated water bottle to make inert ☐
- iv Repeat for all charges ☐

5.b. Unexpected vehicle fragmentation ☐

- i Identify debris field ☐
- ii Photograph sections of debris field ☐
- iii Analyze any missing sections of the vehicle ☐
- iv Collect fragments by hand or in bag depending on size and quantity of debris ☐

5.c. Ruptured battery(s) ☐

- i Report to MCC battery rupture and possible fire ☐
- ii Retreat from the vehicle ☐
    - a. Maintain safe yet observable distance in case hazard increases ☐
- iii Once the fire is extinguished, assess the damage and determine the vehicle's condition ☐
- iv If safe to do so, remove other batteries and energetics from vehicle immediately ☐

5.d. Loss of GPS signal ☐

- i Attempt to regain connection by changing location ☐
- ii Proceed to last known location as documented in checklist and begin search ☐
- iii If not found at the last known location/immediate area, contact MCC, giving description ☐

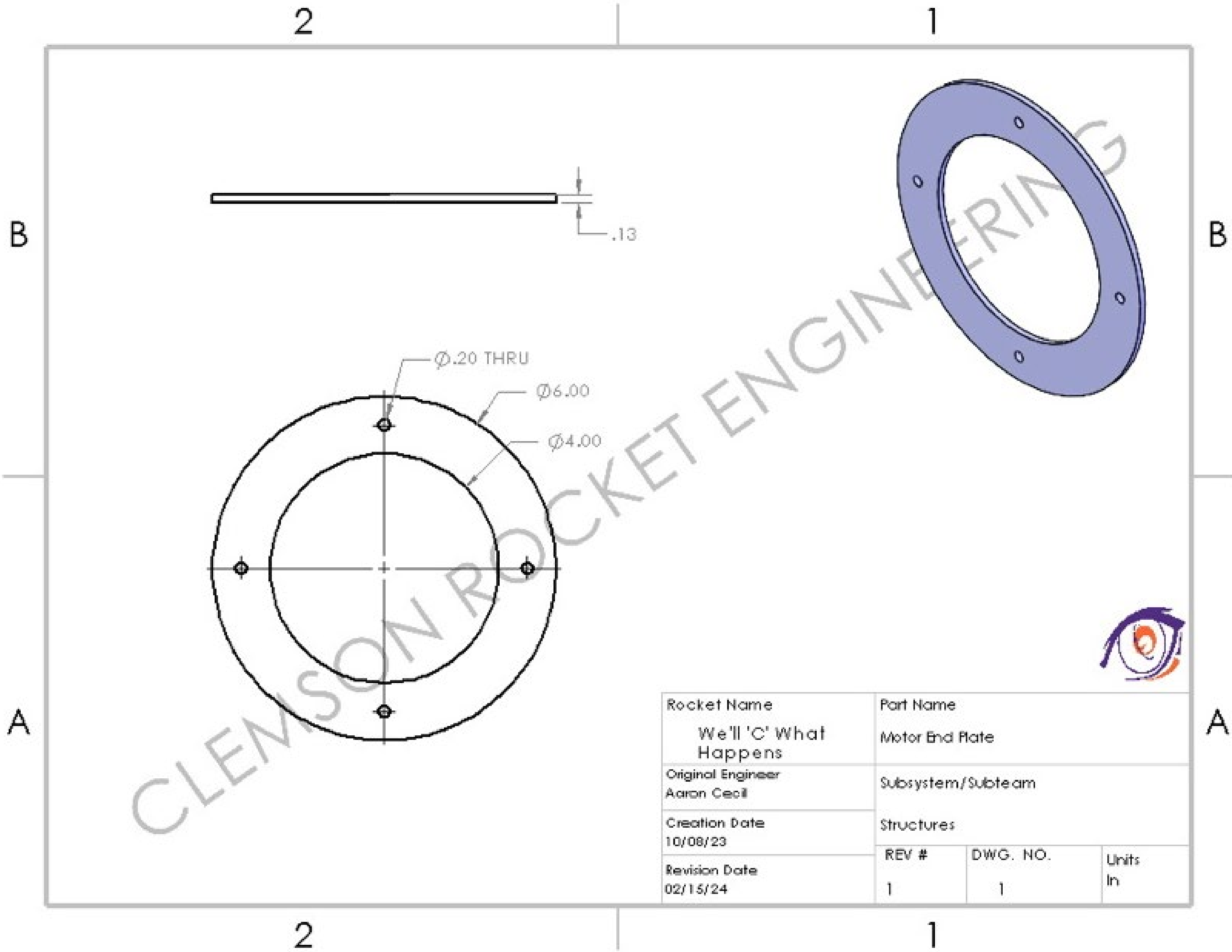
5.e. Heat stroke/medical situation ☐
   i Mitigate heat issues through proper attire and hydration ☐
   ii Contact MCC relaying situation and urgent need for medical assistance ☐
   iii If the situation has caused incapacitation, remain with the affected recovery team member ☐
   iv If movement is possible and travel feasible/not a risk to affected member or other recovery team members, return to recovery vehicle and relay as such to MCC ☐
      a. This is only in the extreme case that an immediate need to enter a climate controlled environment is required, otherwise a shelter in place policy is enforced.

5.f. Radio pack failure ☐
   i Return to recovery vehicle/base camp immediately ☐
   ii Return radio pack and explain failure ☐
   iii Receive new pack and begin recovery again ☐

5.g. Vehicle is irretrievable ☐
   i Take photos of vehicle location and condition ☐
   ii Mark GPS location of vehicle ☐
   iii Return to base camp and assess proper tools for recovery ☐

Appendix G: Engineering Drawings

Appendix G: Engineering Drawings provides a comprehensive collection of detailed, revision-controlled technical drawings essential for defining the significant subsystems and components involved in the mission. This appendix is meticulously structured to include individual drawings for SRAD subsystems or components, each contributing to the overarching schematic of the top-level assembly. These engineering drawings are a crucial reference for the precise construction and assembly of the vehicle, ensuring all participants can visually understand and follow the technical specifications required for successful implementation. Drawings begin on the following page.



2
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B
A
.13
Ø.20 THRU
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Ø4.00
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Rocket Name
We'll 'C' What Happens
Part Name
Motor End Plate
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/08/23
Revision Date
02/15/24
REV #
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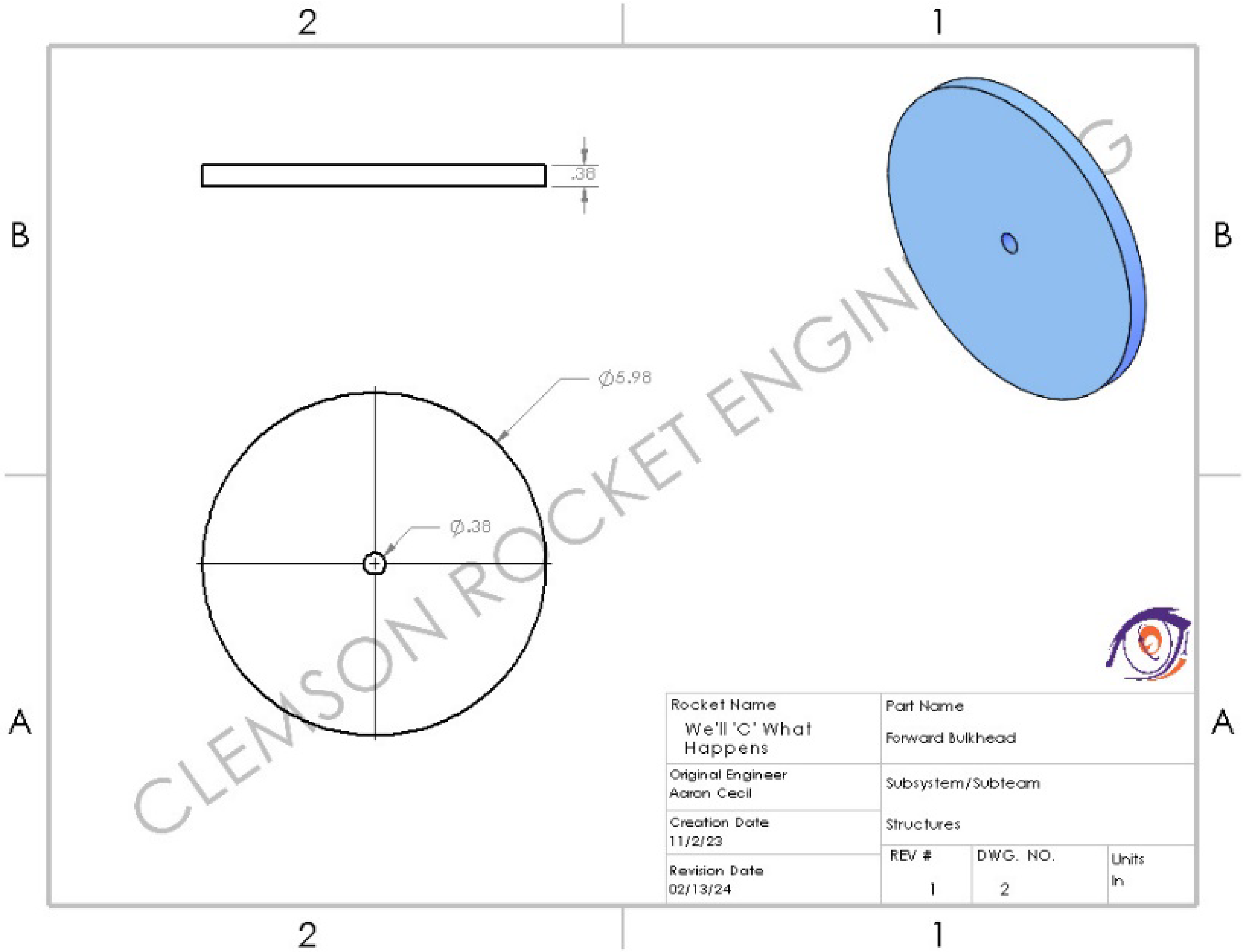

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Ø.38
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Rocket Name
We'll 'C' What Happens
Part Name
Forward Bulkhead
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
11/2/23
Revision Date
02/13/24
REV #
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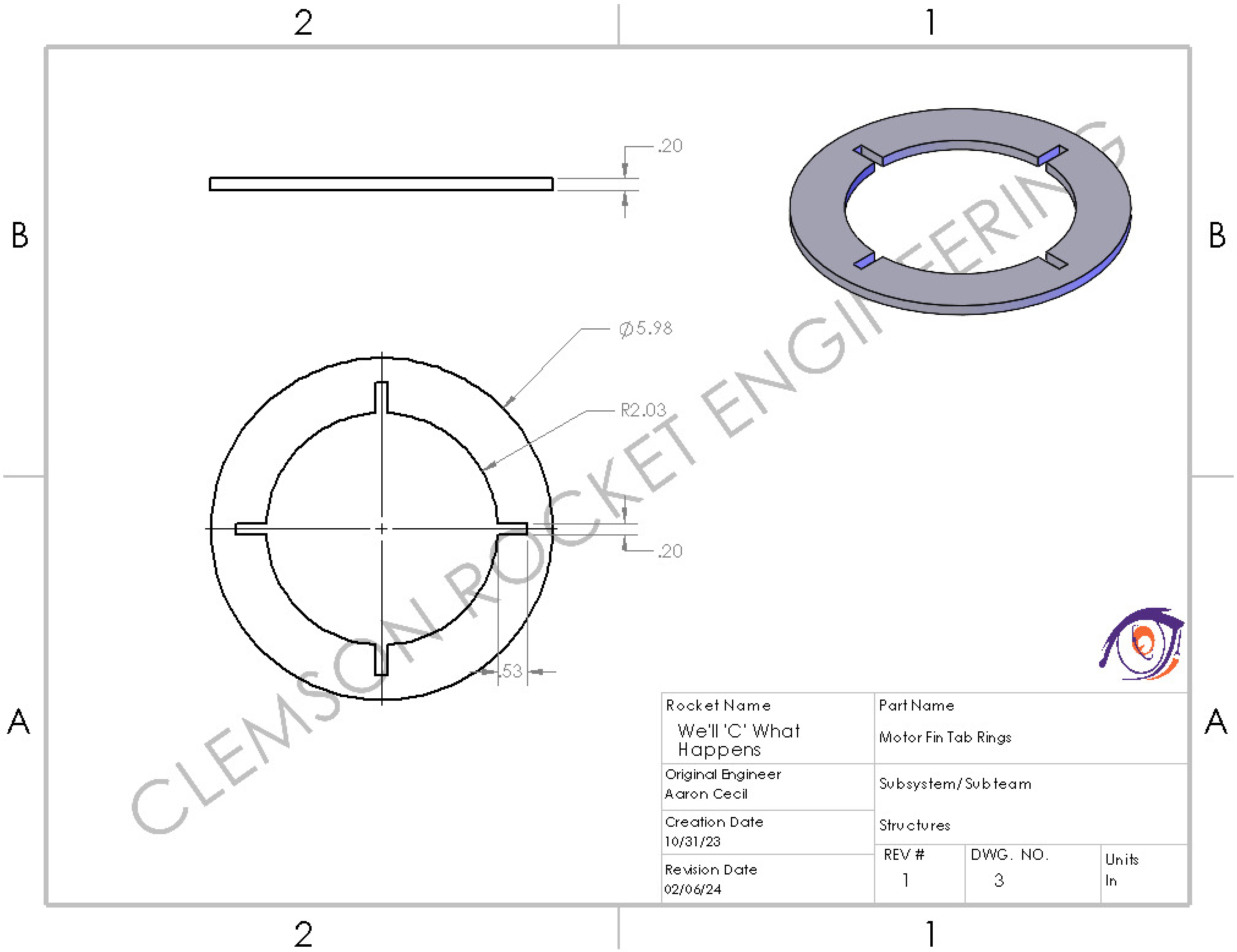
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Part Name
Motor Fin Tab Rings
Original Engineer
Aaron Cecil
Subsystem/Subteam
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Creation Date
10/31/23
REV #
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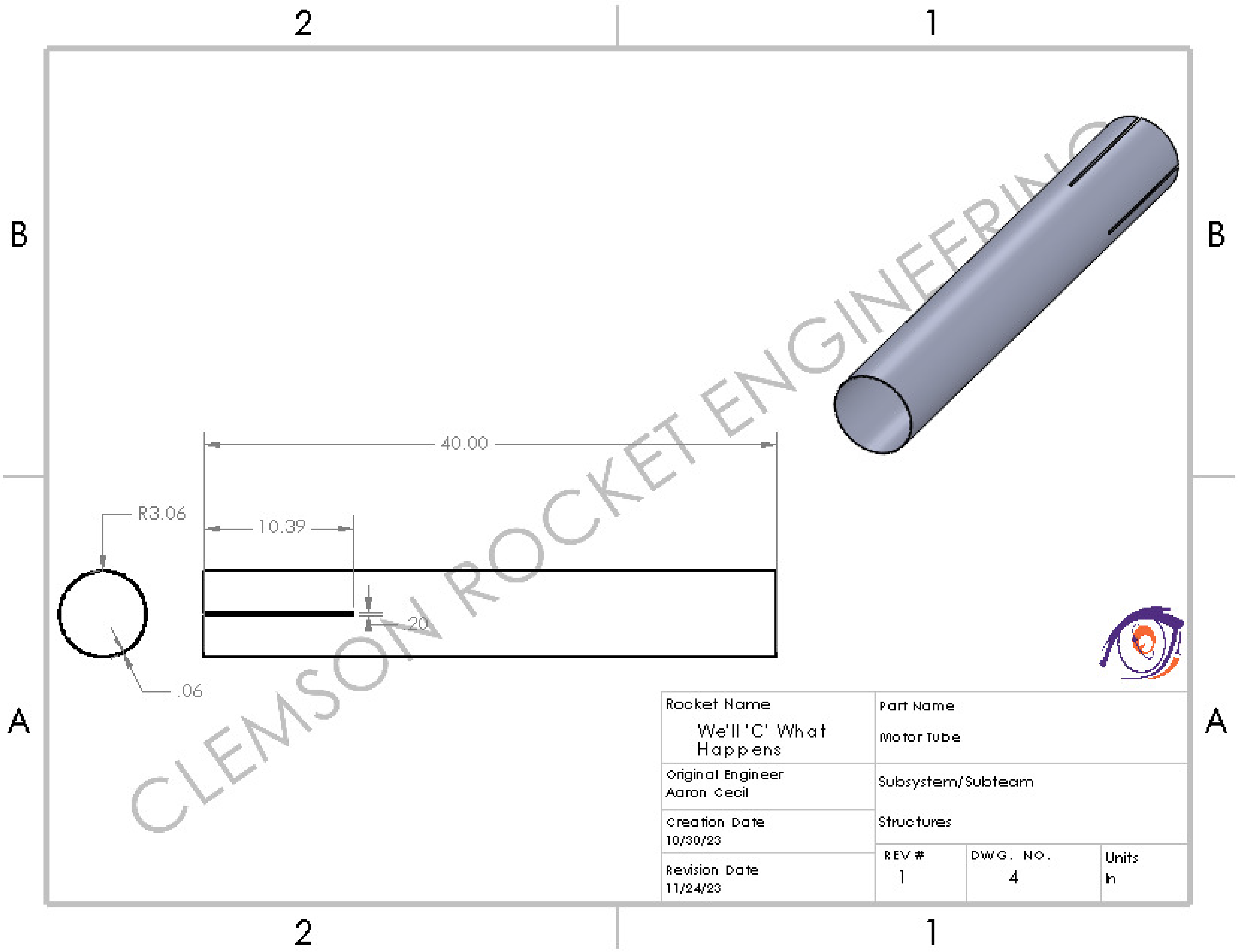
In
Revision Date
02/06/24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Rocket Name
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Part Name
Motor Tube
Original Engineer
Aaron Cecil
Subsystem/Subteam
Creation Date
10/30/23
Structures
Revision Date
11/24/23
REV #
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4
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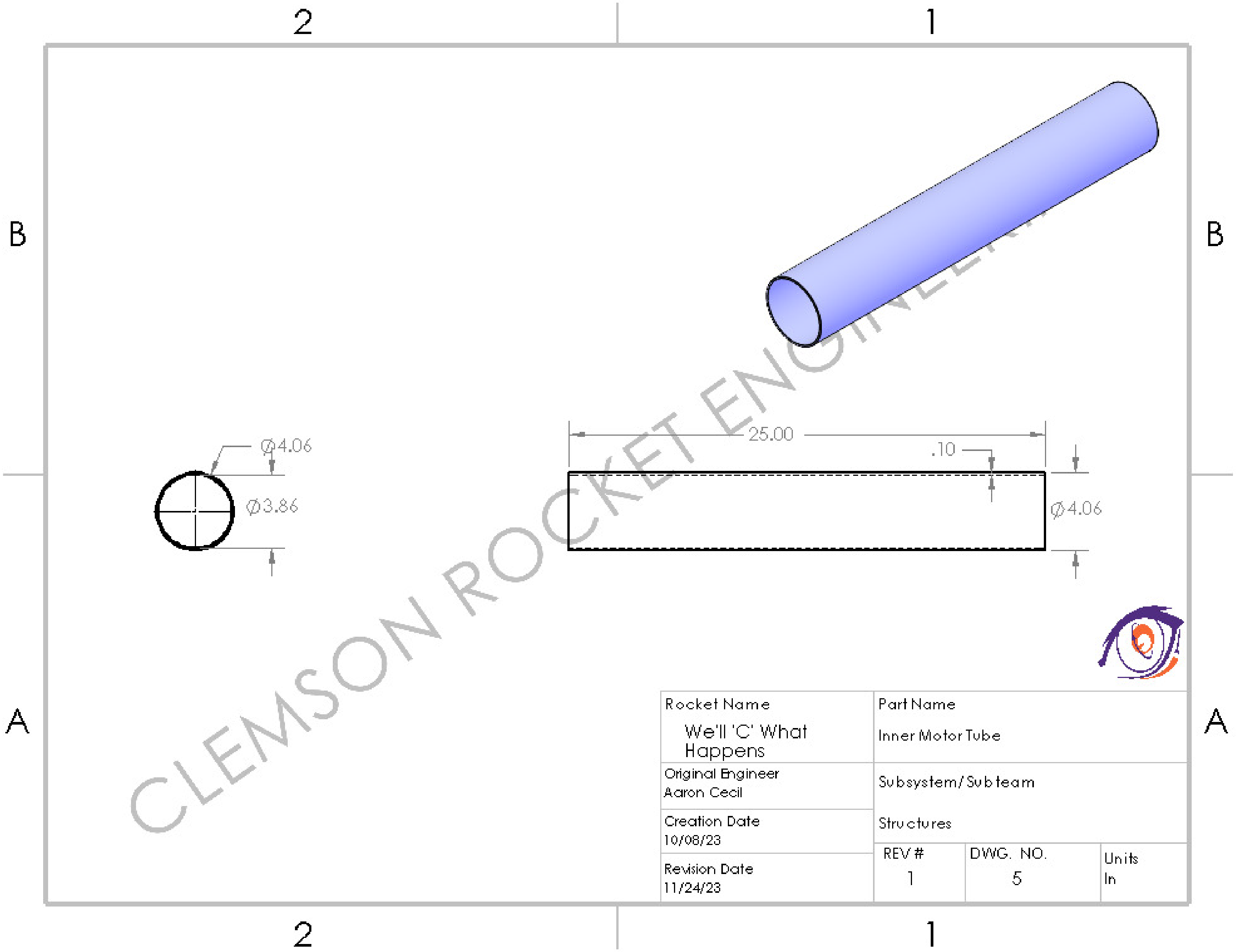
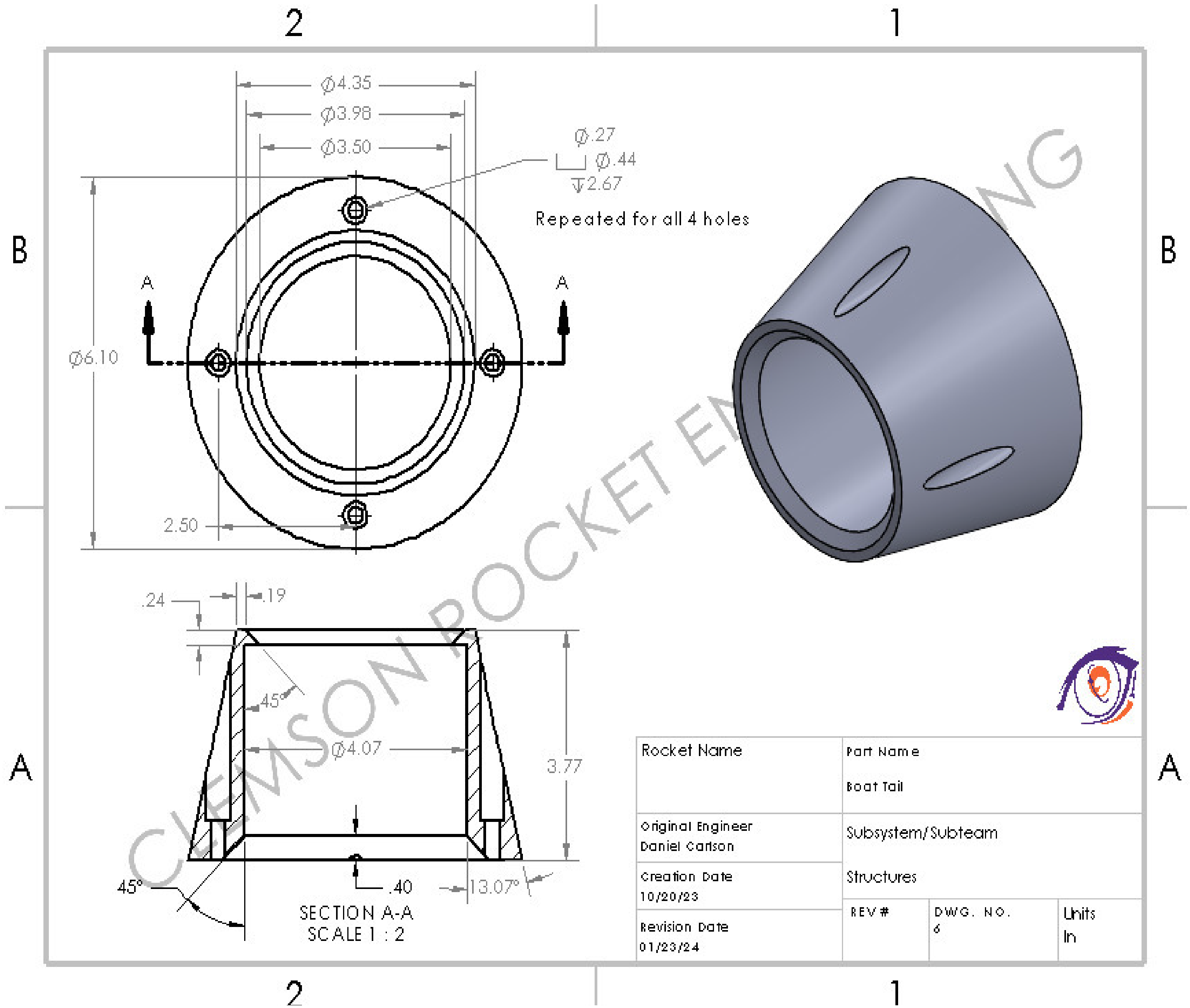
In



Rocket Name	Part Name		
We'll 'C' What Happens	Inner Motor Tube		
Original Engineer Aaron Cecil	Subsystem/Subteam		
Creation Date 10/08/23	Structures		
Revision Date 11/24/23	REV # 1	DWG. NO. 5	Units In



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Ø3.98
Ø3.50
Ø.27
⌴ Ø.44
↧2.67
Repeated for all 4 holes
Ø6.10
2.50
A
A
.24
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45°
Ø4.07
3.77
45°
.40
13.07°
SECTION A-A
SCALE 1 : 2
Rocket Name
Part Name
Boat Tail
Original Engineer
Daniel Carlson
Subsystem/Subteam
Structures
Creation Date
10/20/23
Revision Date
01/23/24
REV #
DWG. NO.
6
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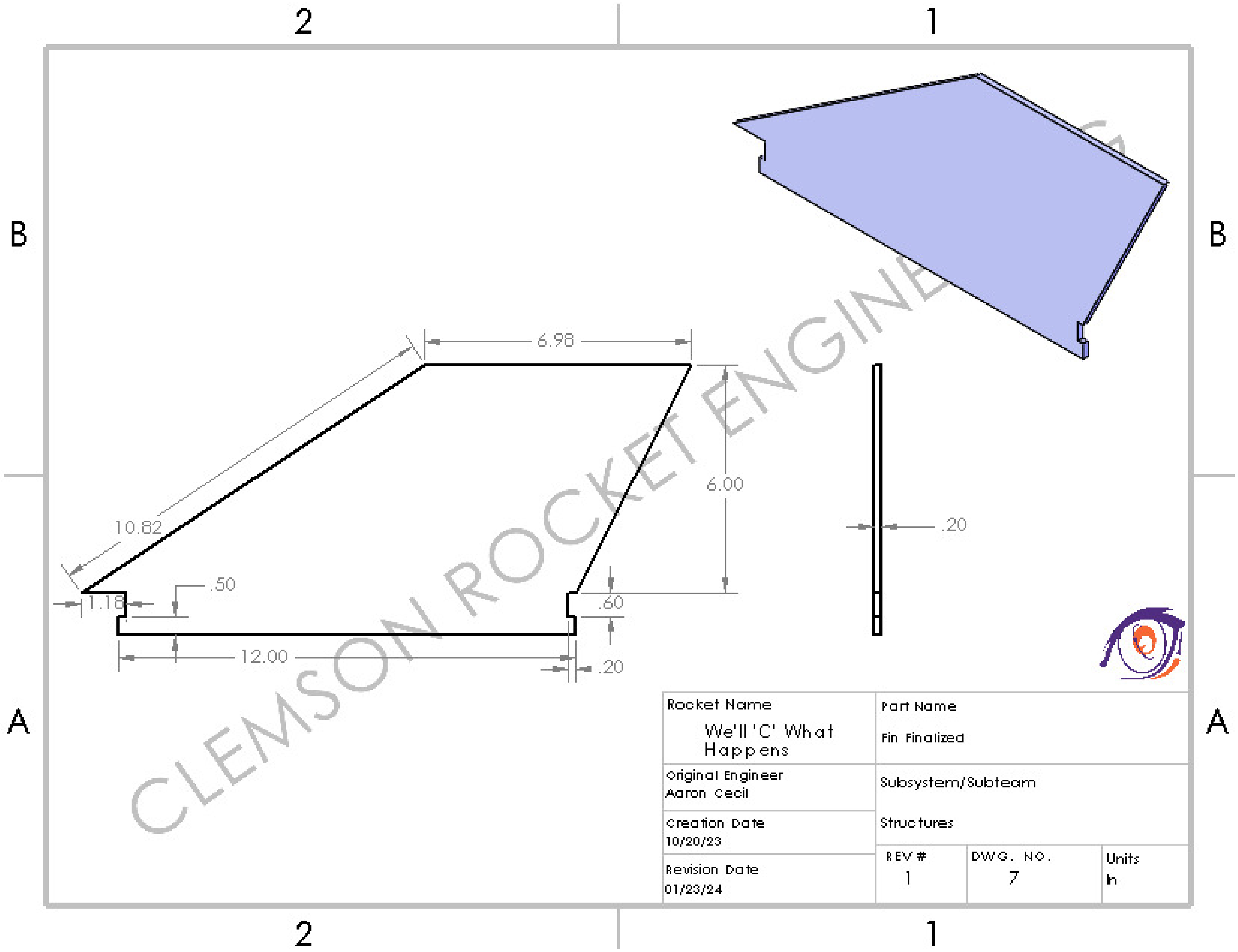
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Rocket Name
We'll 'C' What Happens
Part Name
Fin Finalized
Original Engineer
Aaron Cecil
Subsystem/Subteam
Creation Date
10/20/23
Structures
Revision Date
01/23/24
REV #
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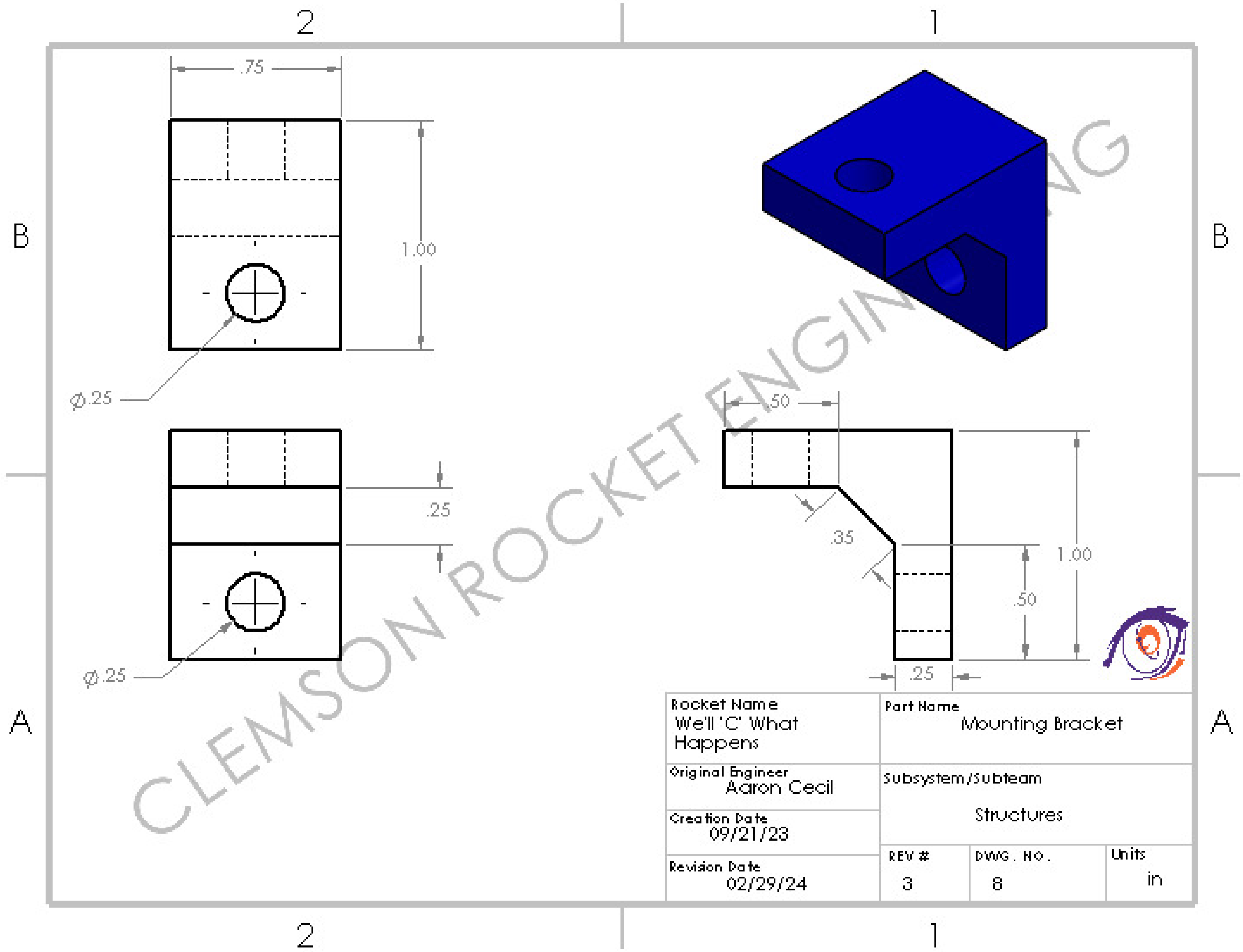
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Rocket Name
We'll 'C' What Happens
Part Name
Mounting Bracket
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
09/21/23
Revision Date
02/29/24
REV #
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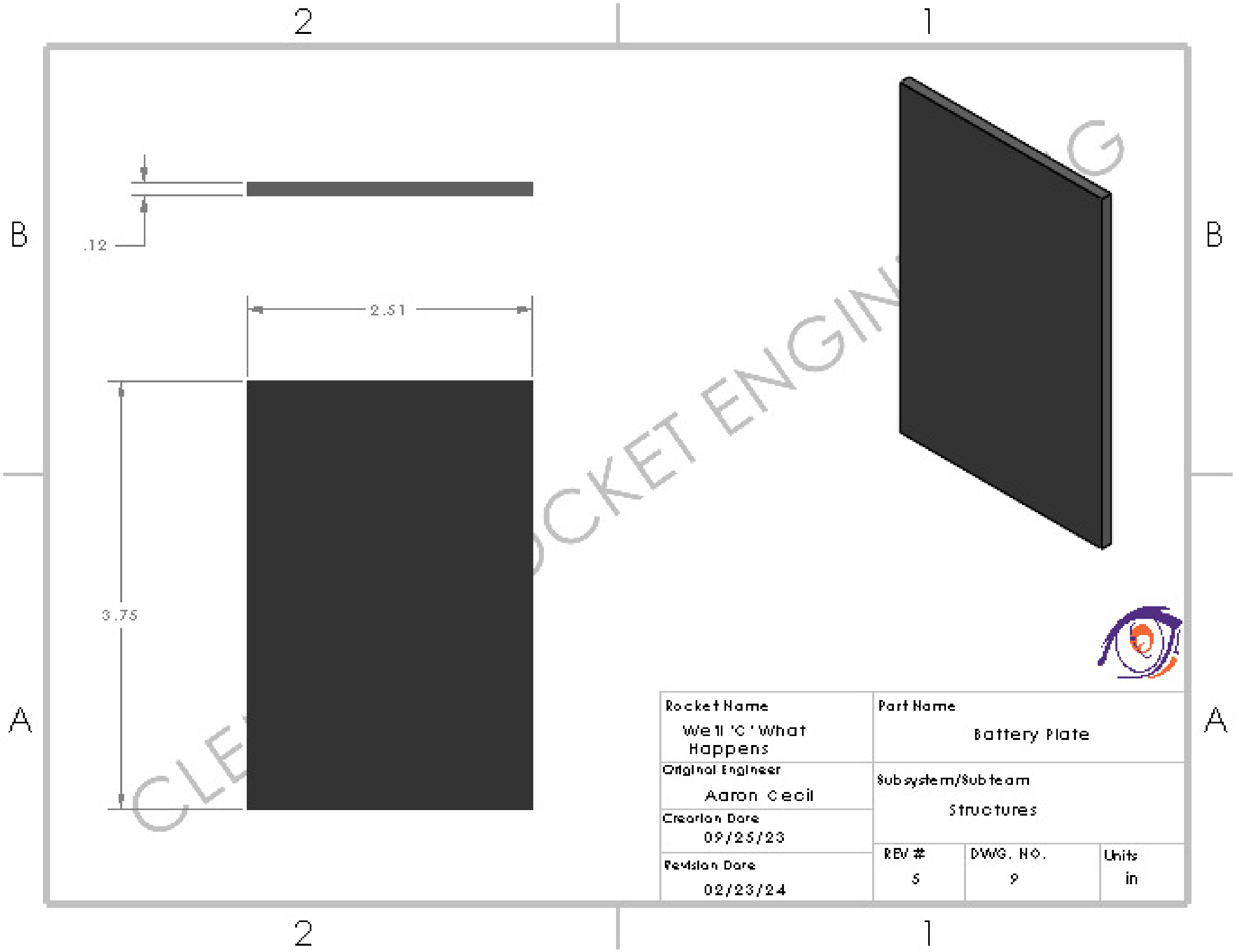
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OCKET ENGIN
G
Rocket Name
We'll 'C' What Happens
Part Name
Battery Plate
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
09/25/23
Revision Date
02/23/24
REV #
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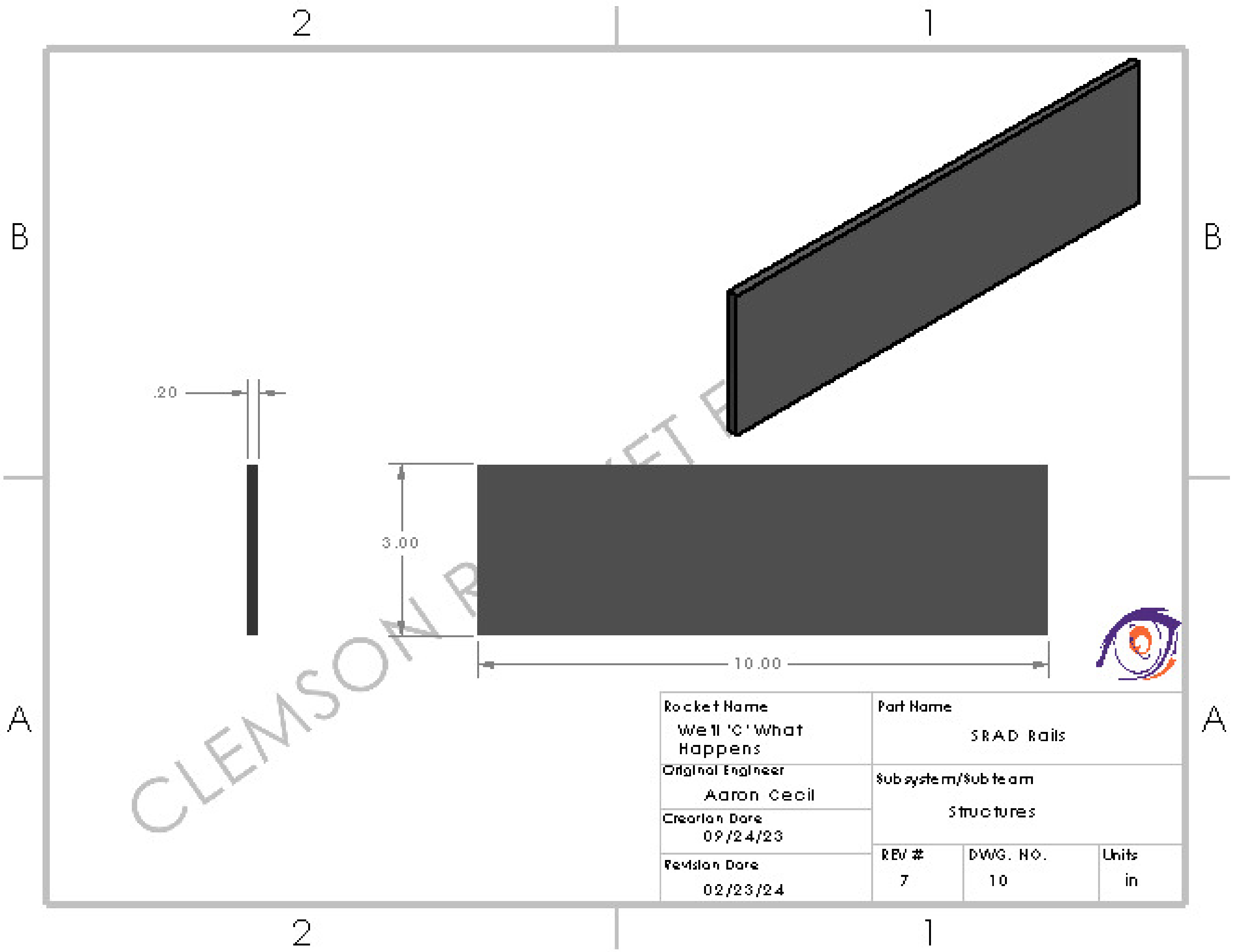
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10.00
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Part Name
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Original Engineer
Aaron Cecil
Subsystem/Subteam
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Creation Date
09/24/23
Revision Date
02/23/24
REV #
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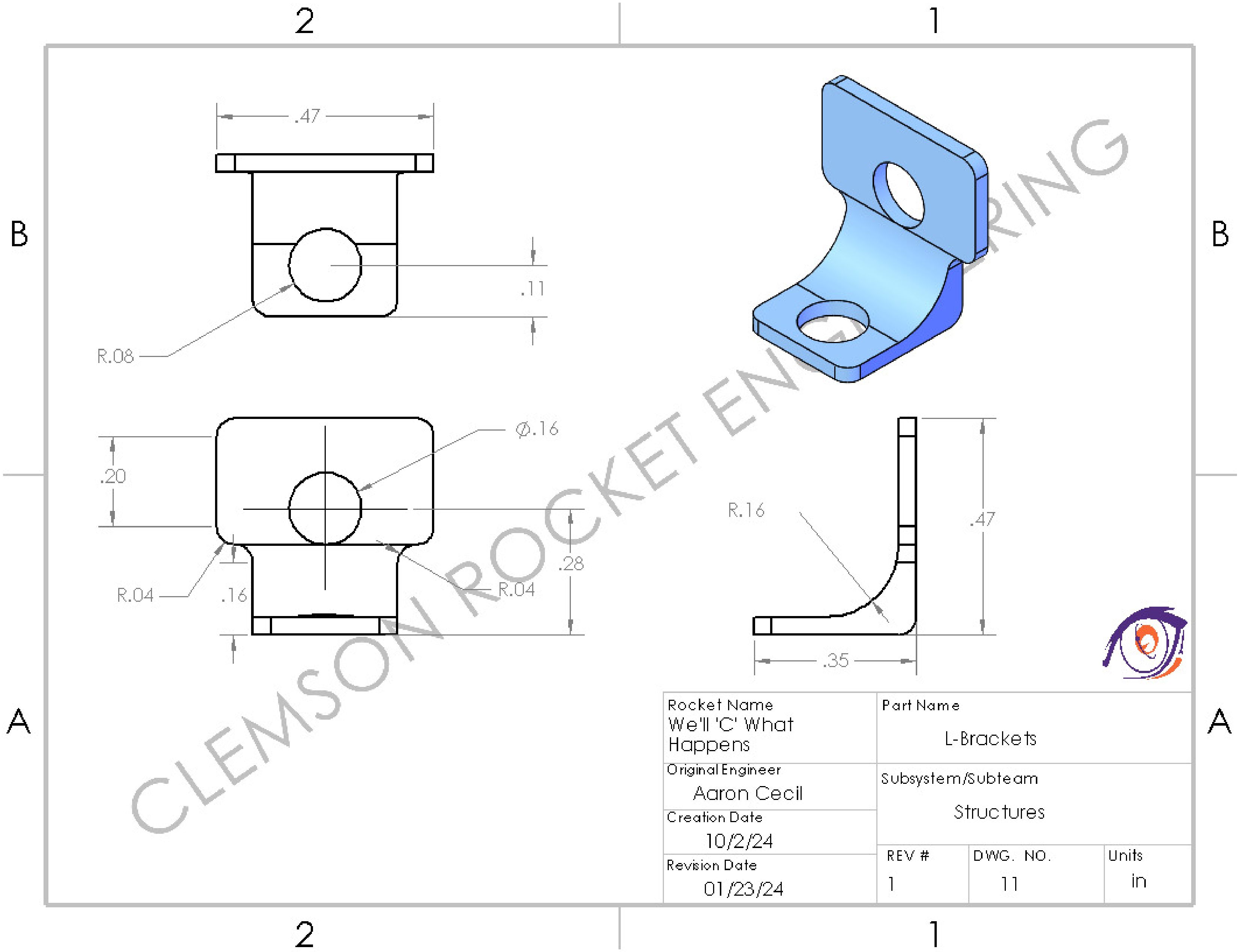
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R.08
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R.04
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R.04
R.16
.47
.35
Rocket Name
We'll 'C' What Happens
Part Name
L-Brackets
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/2/24
Revision Date
01/23/24
REV #
1
DWG. NO.
11
Units
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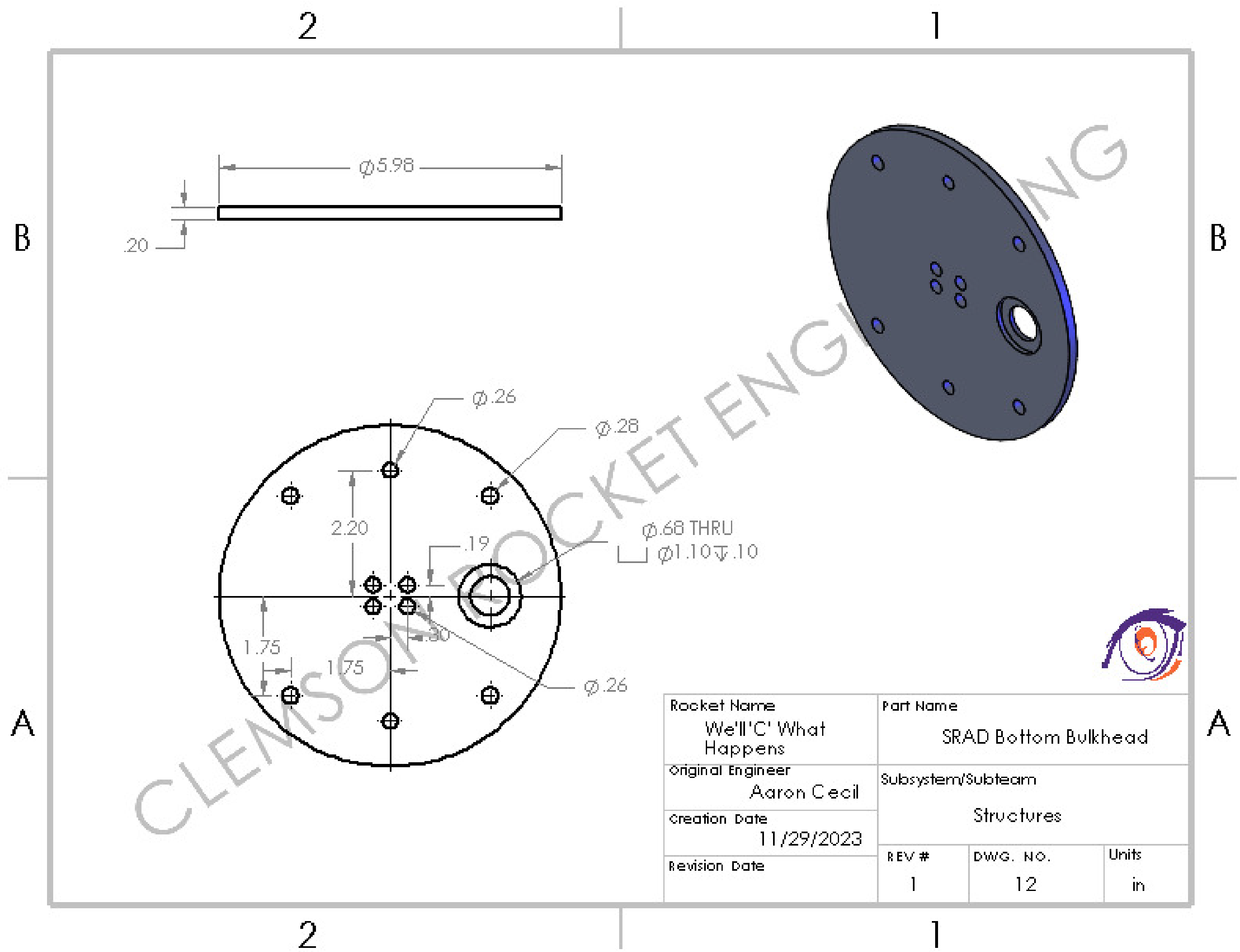

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ϕ.26
ϕ.28
2.20
.19
ϕ.68 THRU
ϕ1.10 ↧ .10
1.75
1.75
.30
ϕ.26
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' What Happens
Part Name
SRAD Bottom Bulkhead
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
11/29/2023
Revision Date
REV #
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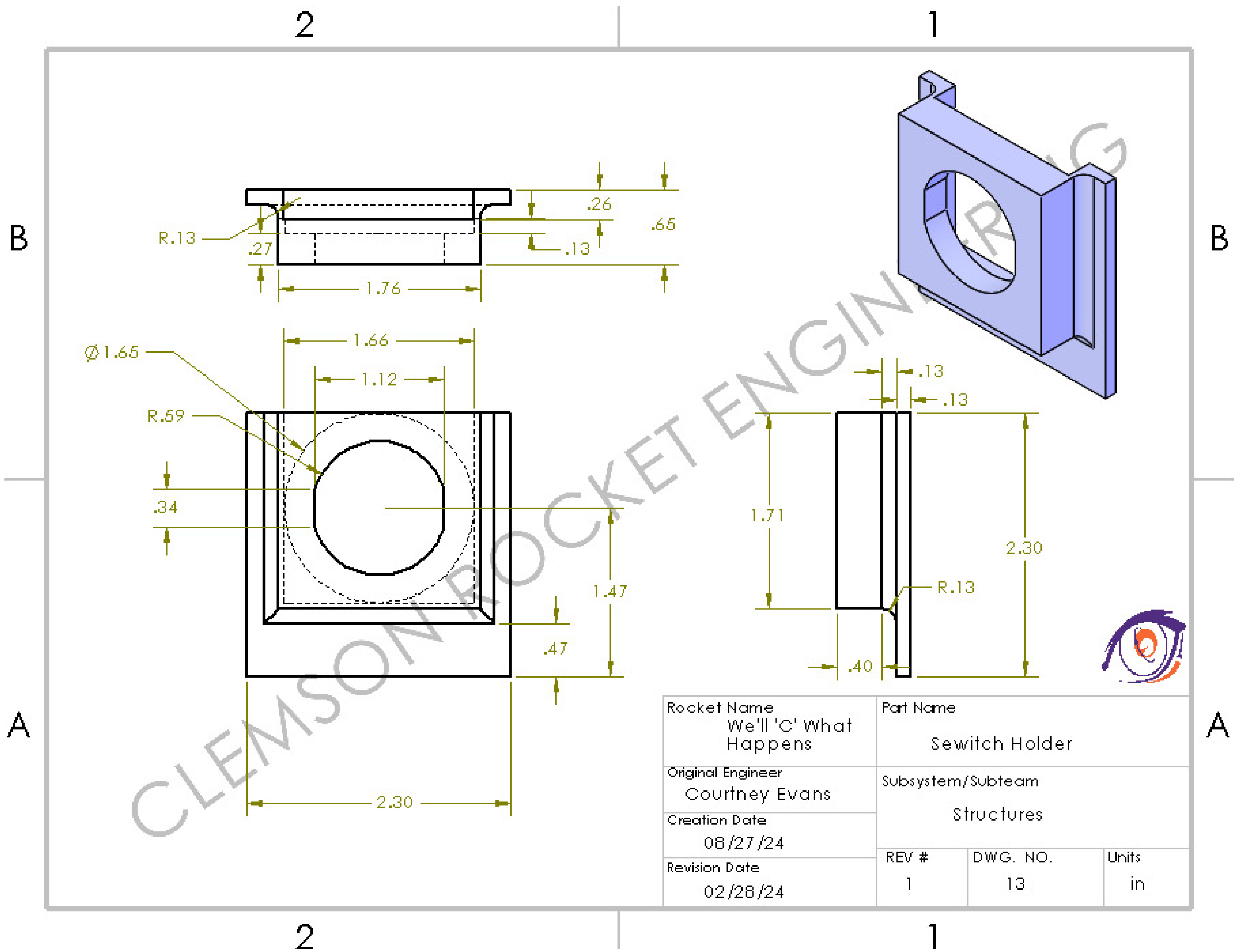

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.13
.13
1.71
2.30
R.13
.40
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Rocket Name
We'll 'C' What Happens
Part Name
Sewitch Holder
Original Engineer
Courtney Evans
Subsystem/Subteam
Structures
Creation Date
08/27/24
Revision Date
02/28/24
REV #
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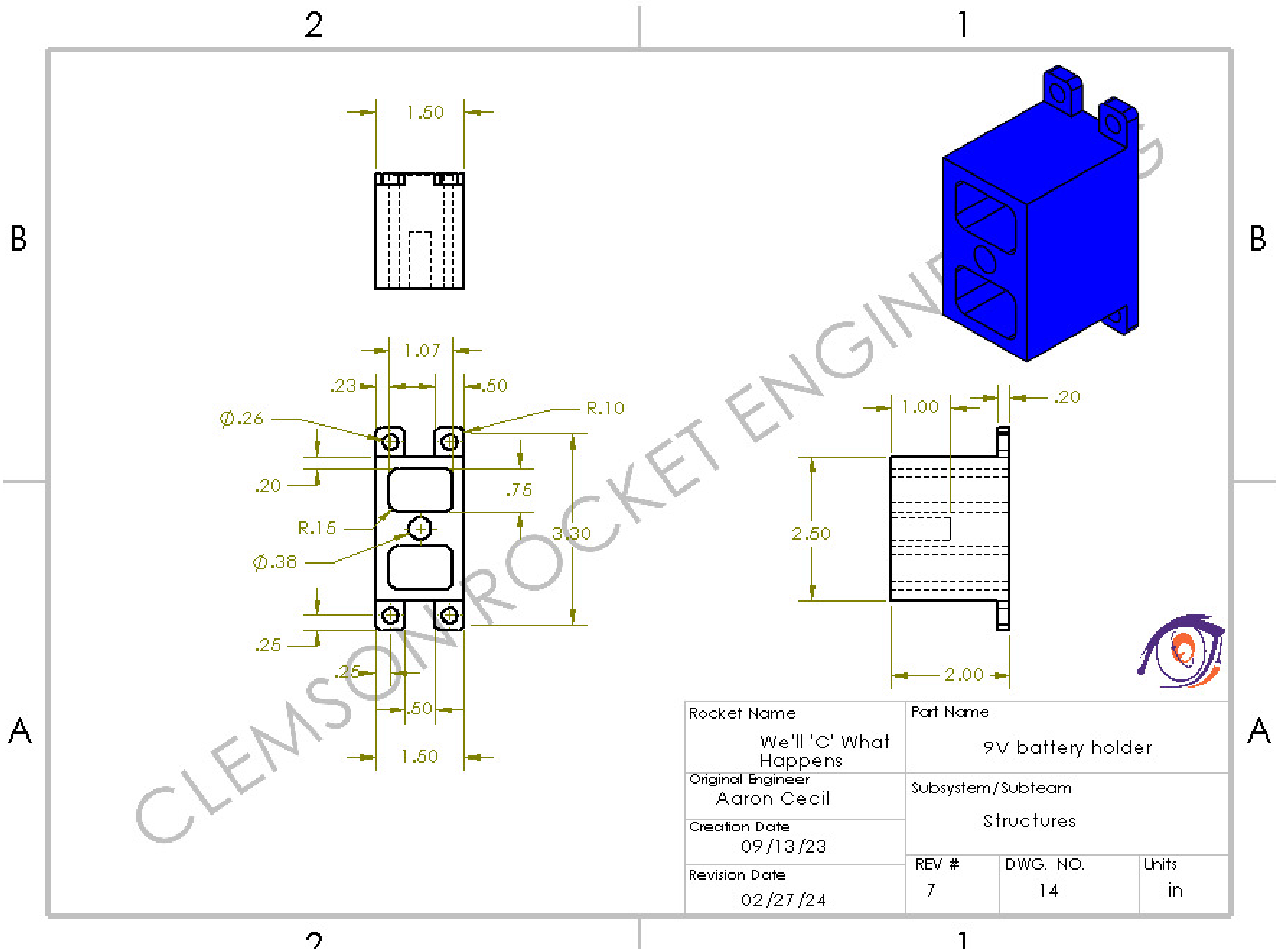

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Original Engineer: Aaron Cecil	Subsystem/Subteam: Structures		
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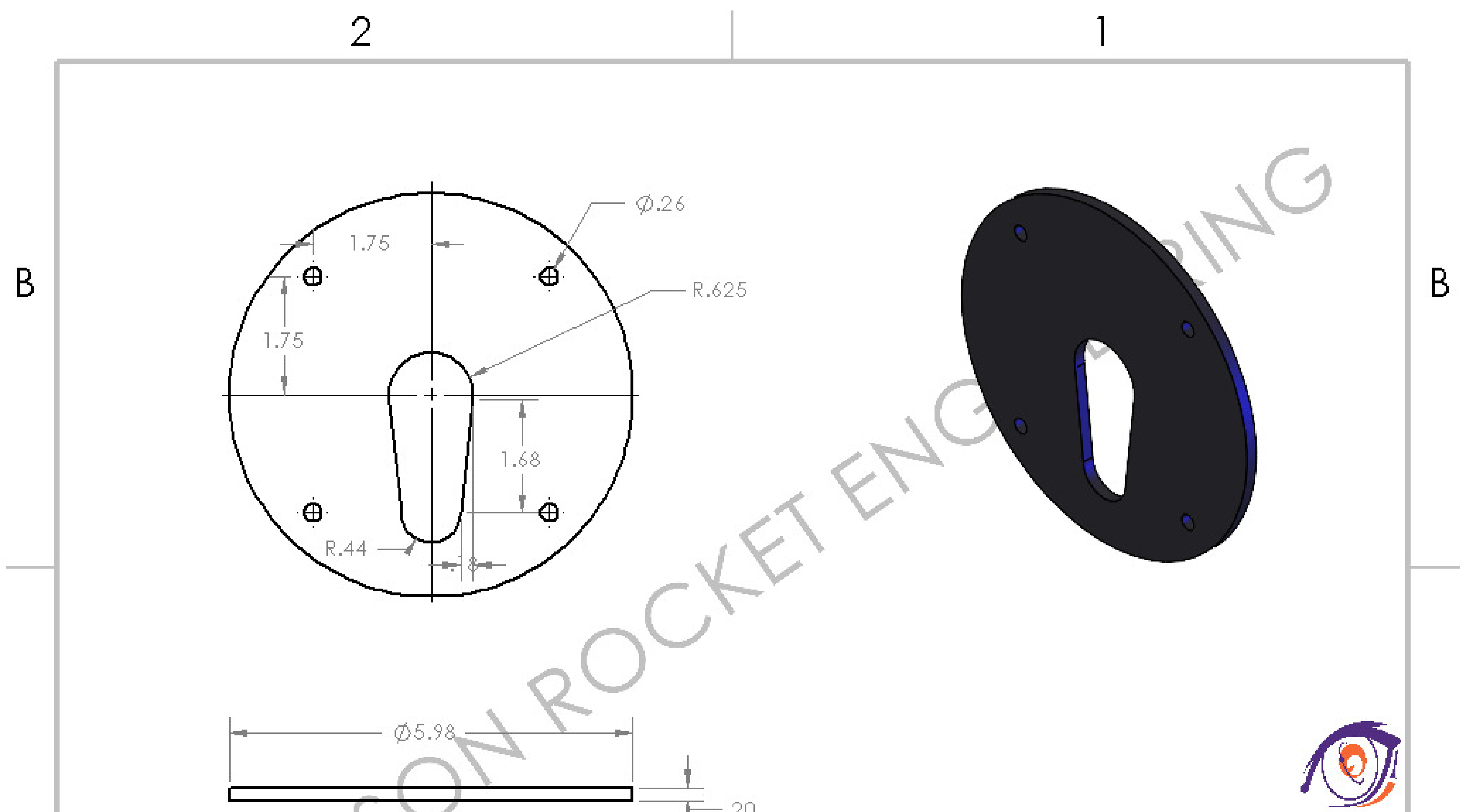
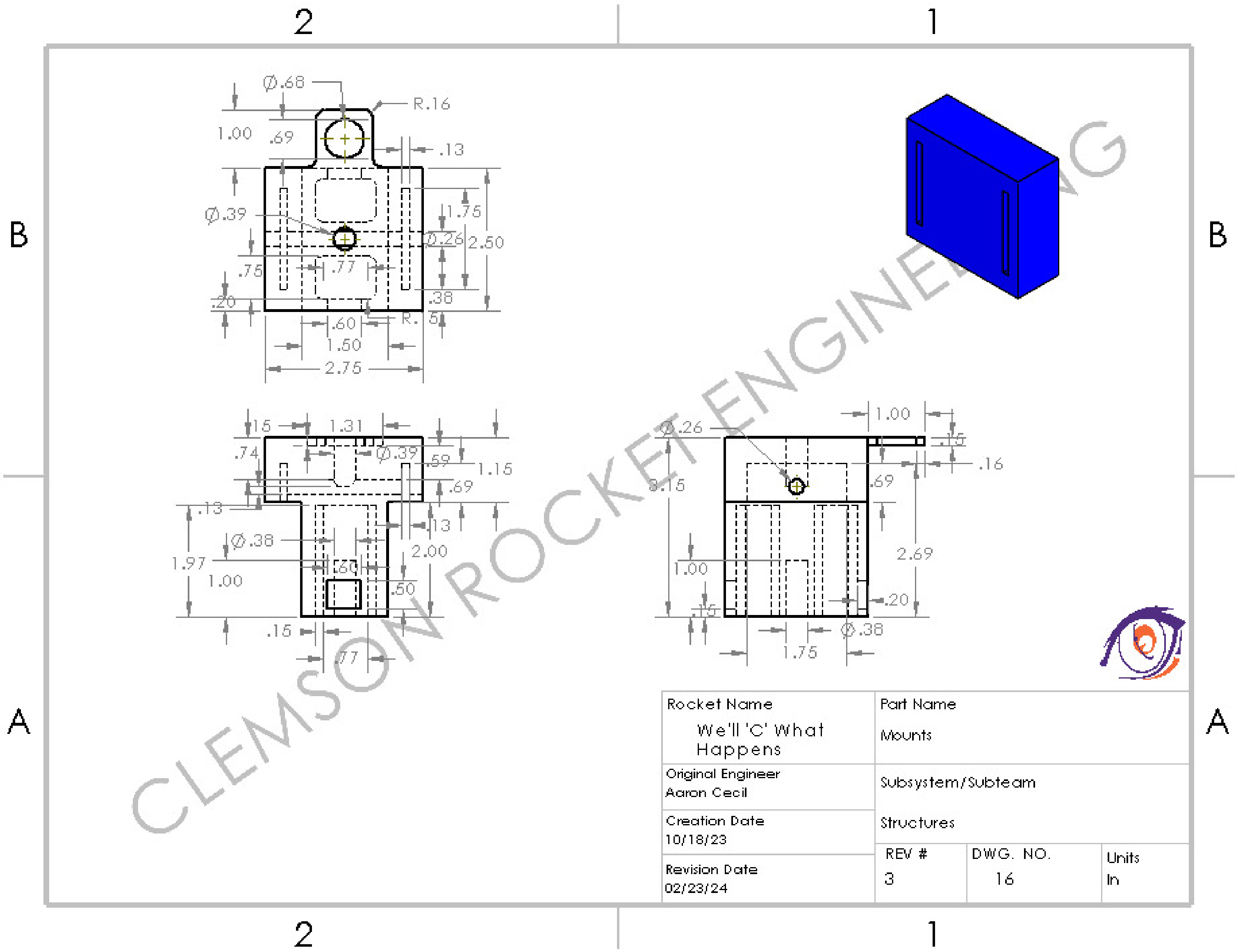
Revision Date: 02/27/24	7	14	in



Rocket Name	Part Name		
We'll 'C' What Happens	COTS Lower Bulkhead		
Original Engineer Daniel Carlson	Subsystem/Subteam Structures		
Creation Date 10/20/23			
Revision Date 01/23/24	REV # 4	DWG. NO. 15	Units In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Rocket Name
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Part Name
Mounts
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/18/23
Revision Date
02/23/24
REV #
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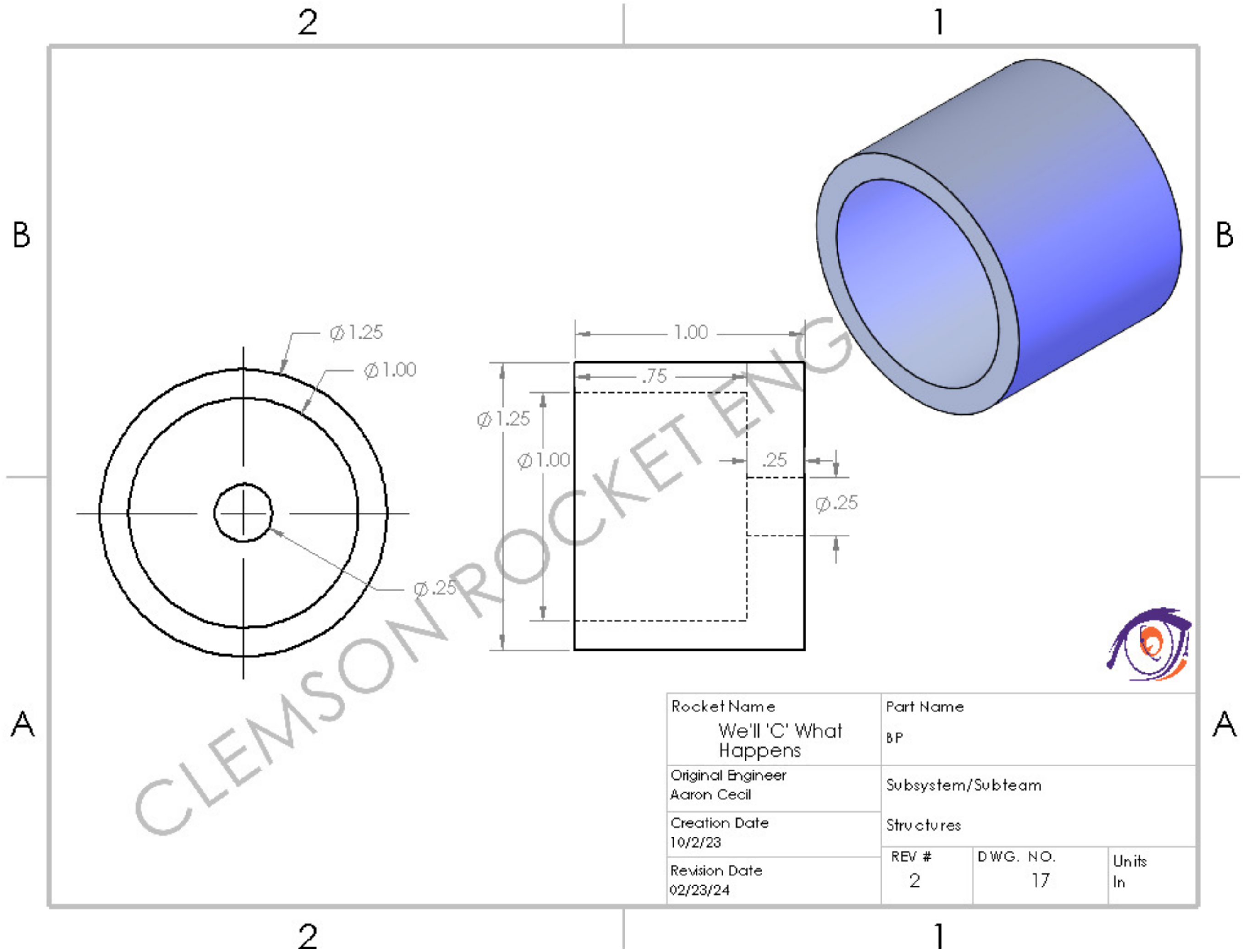
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Ø1.25
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Ø.25
1.00
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Ø1.25
Ø1.00
.25
Ø.25
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Rocket Name
We'll 'C' What Happens
Part Name
BP
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/2/23
Revision Date
02/23/24
REV #
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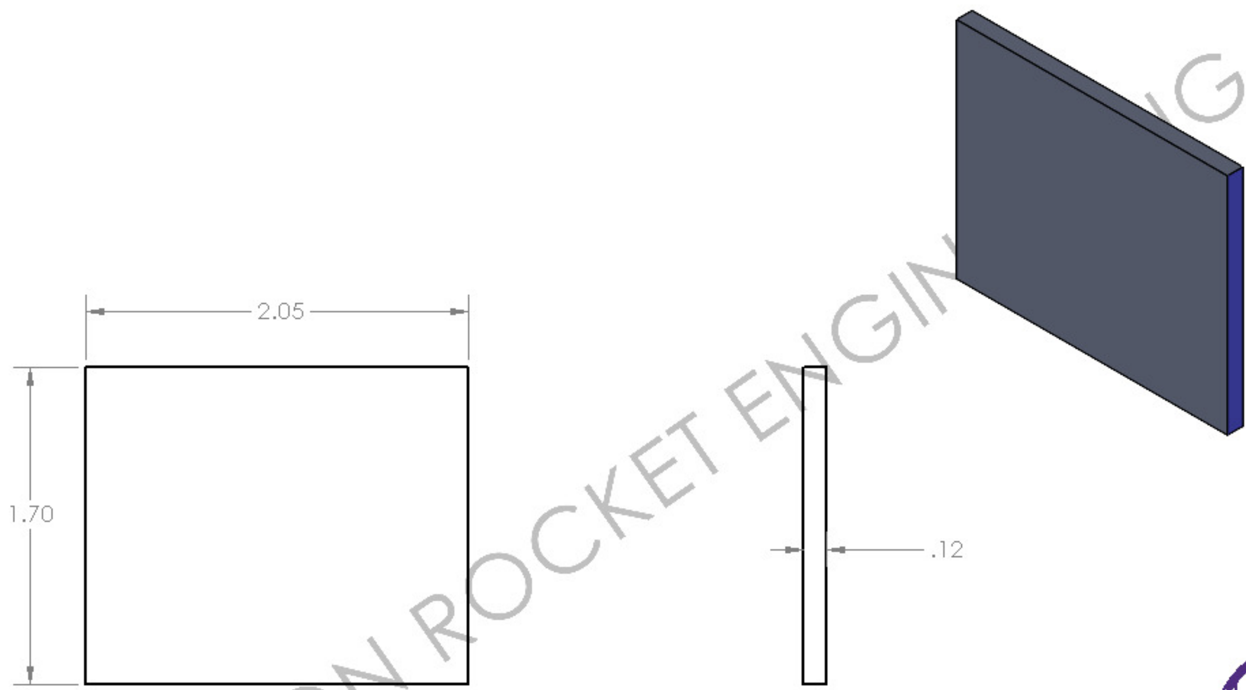

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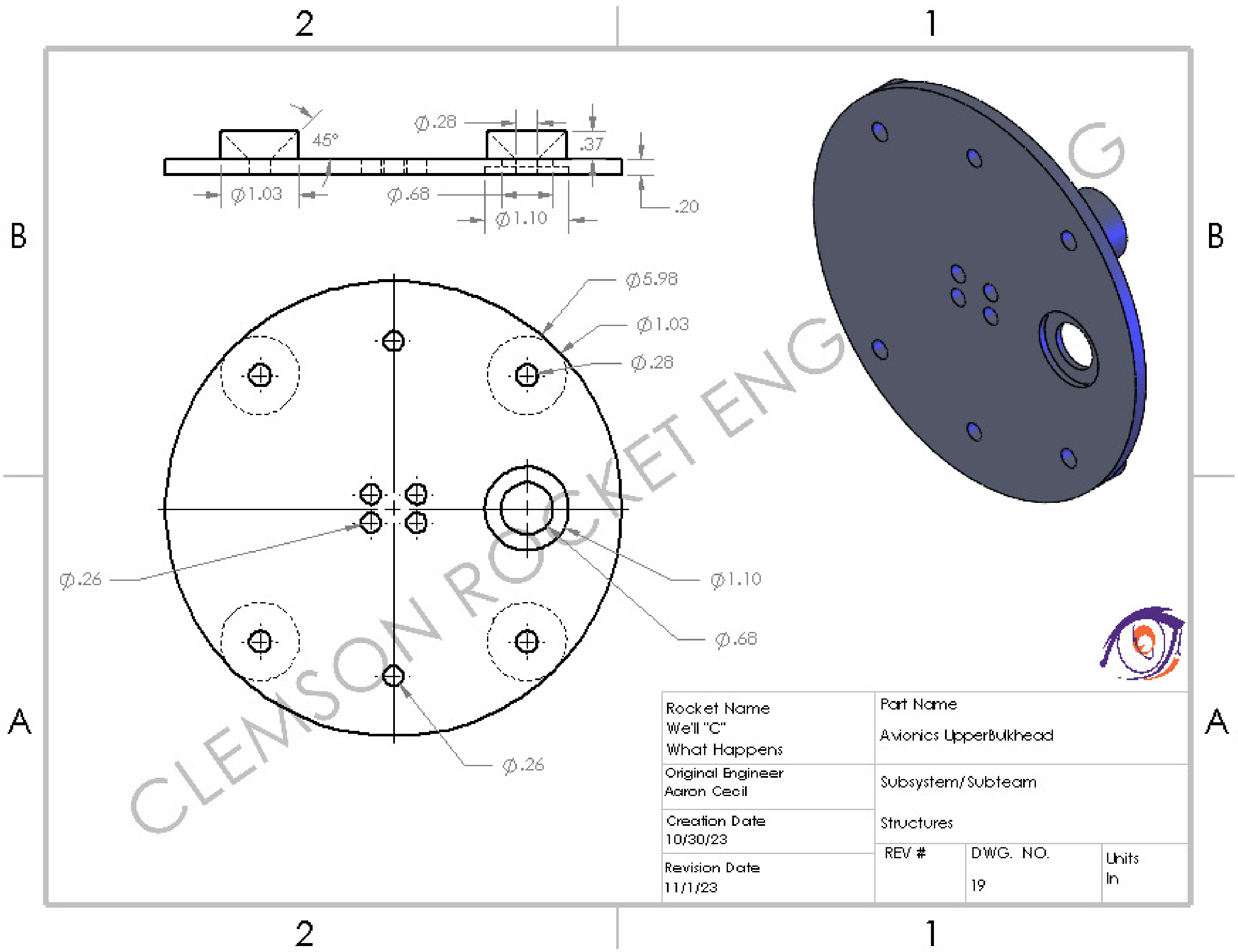
We'll 'C' What Happens	Switch Plate		
Original Engineer Aaron Cecil	Subsystem/Subteam		
Creation Date 10/10/23	Structures		
Revision Date 11/2/23	REV # 6	DWG. NO. 18	Units In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45°
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∅.68
∅1.10
∅5.98
∅1.03
∅.28
∅.26
∅1.10
∅.68
∅.26
CLEMSON ROCKET ENG
Rocket Name
We'll "C"
What Happens
Part Name
Avionics UpperBulkhead
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/30/23
Revision Date
11/1/23
REV #
DWG. NO.
19
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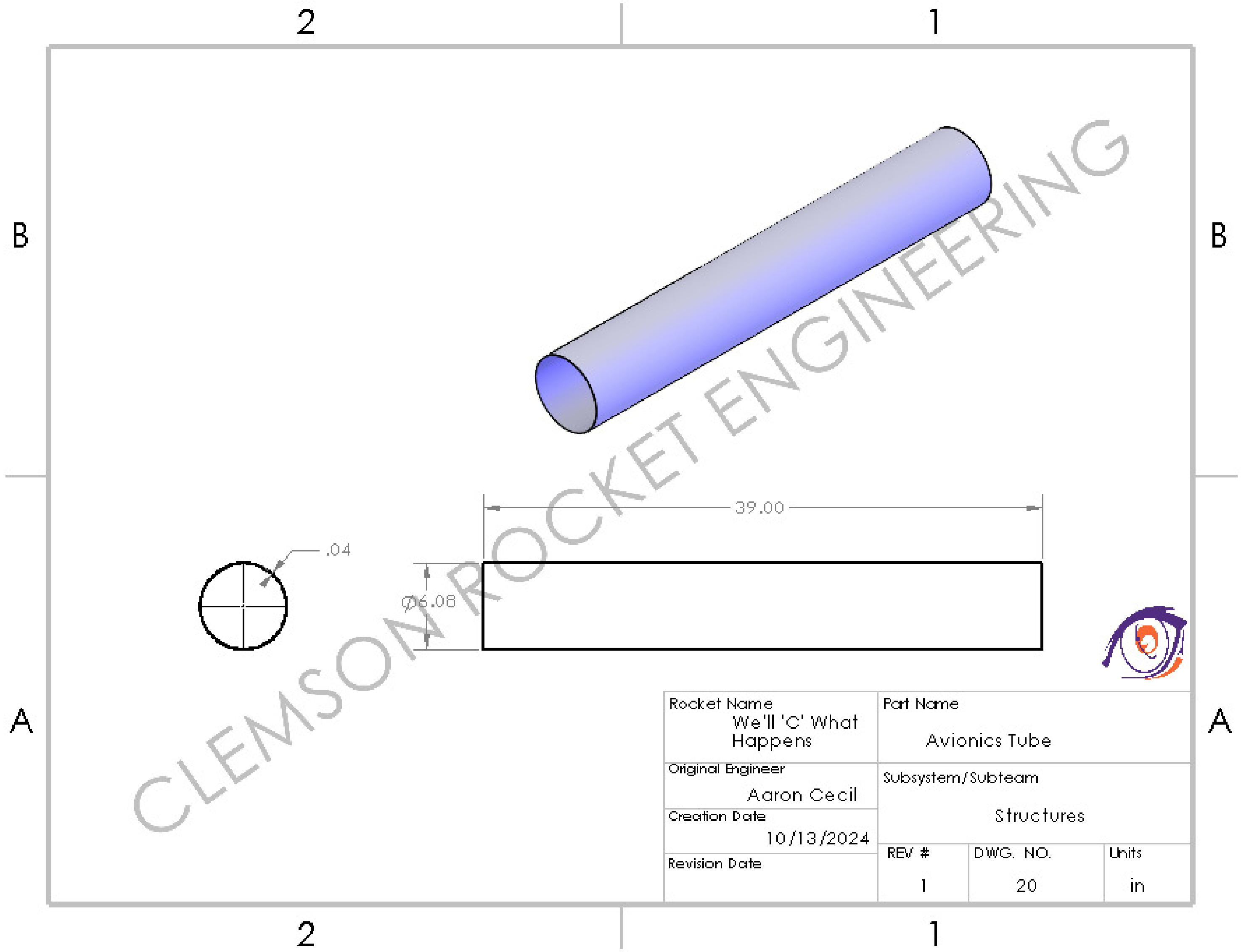
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B
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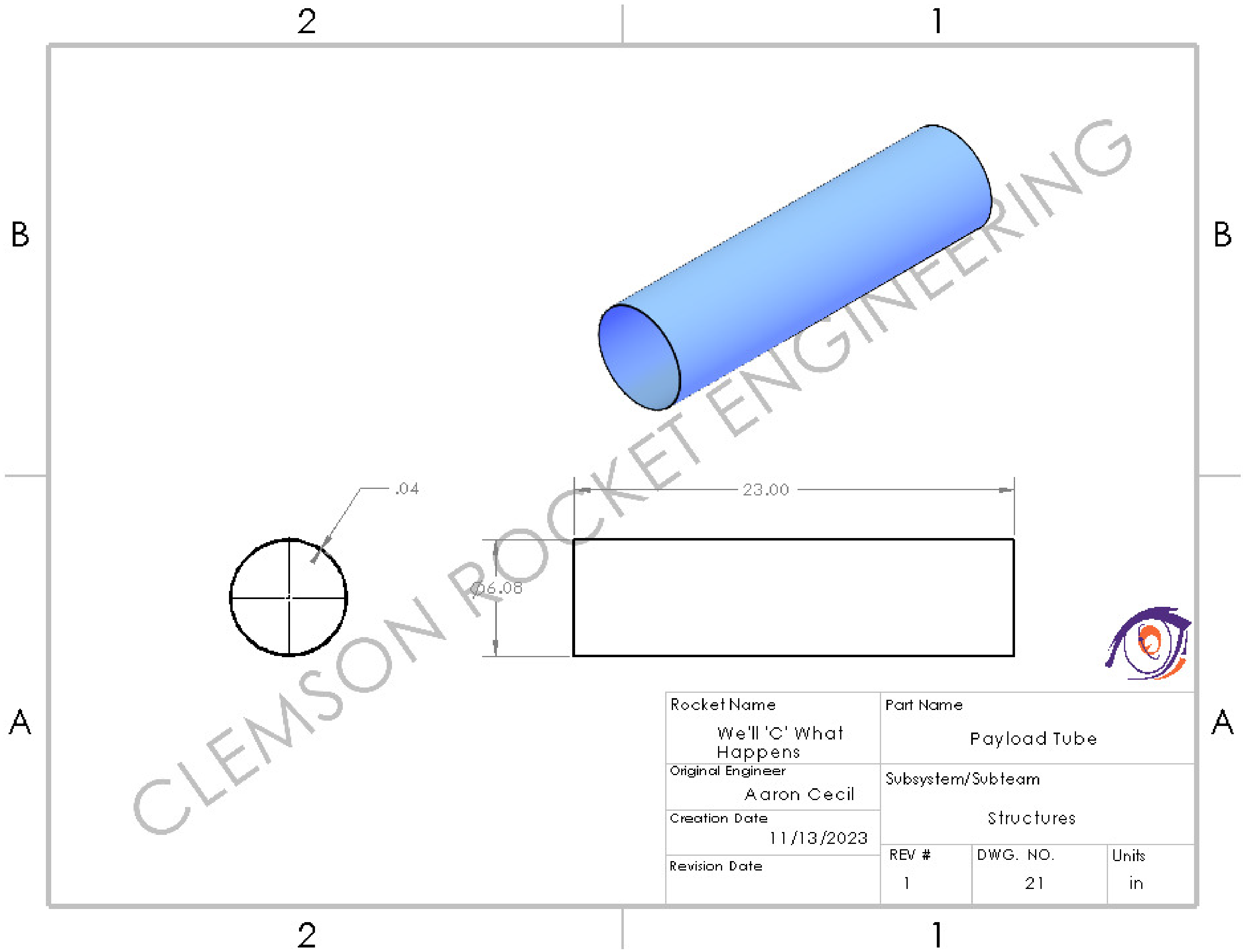
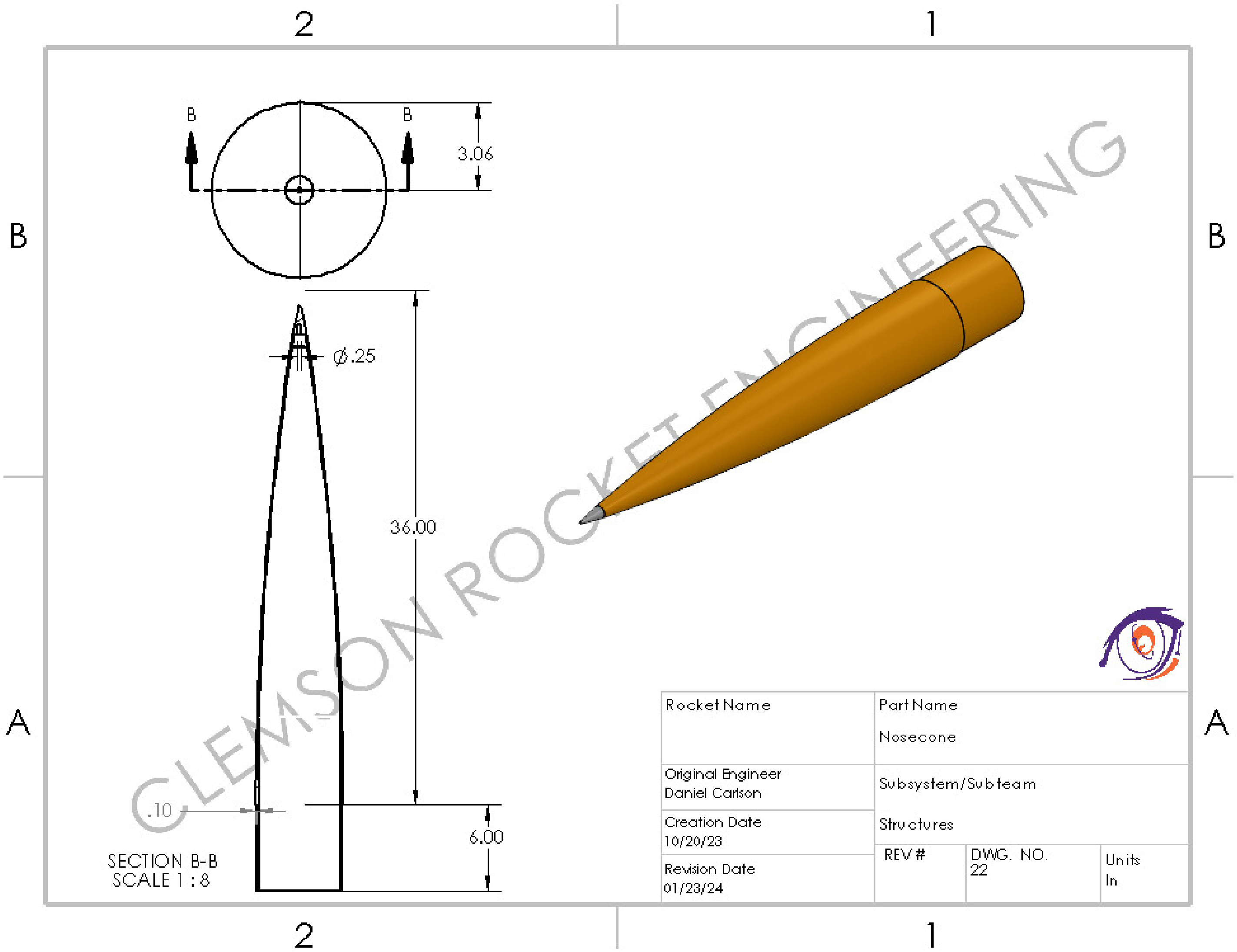
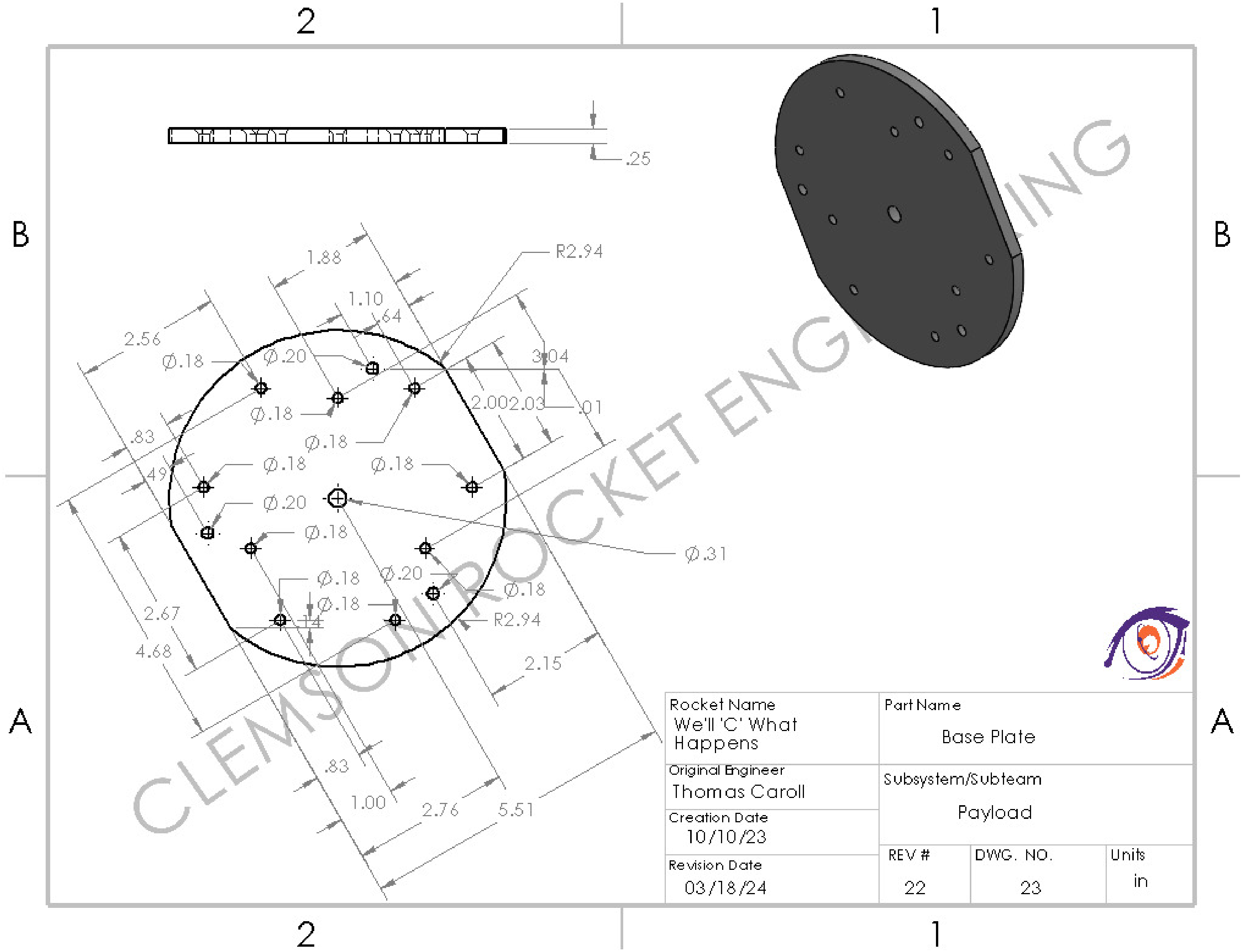
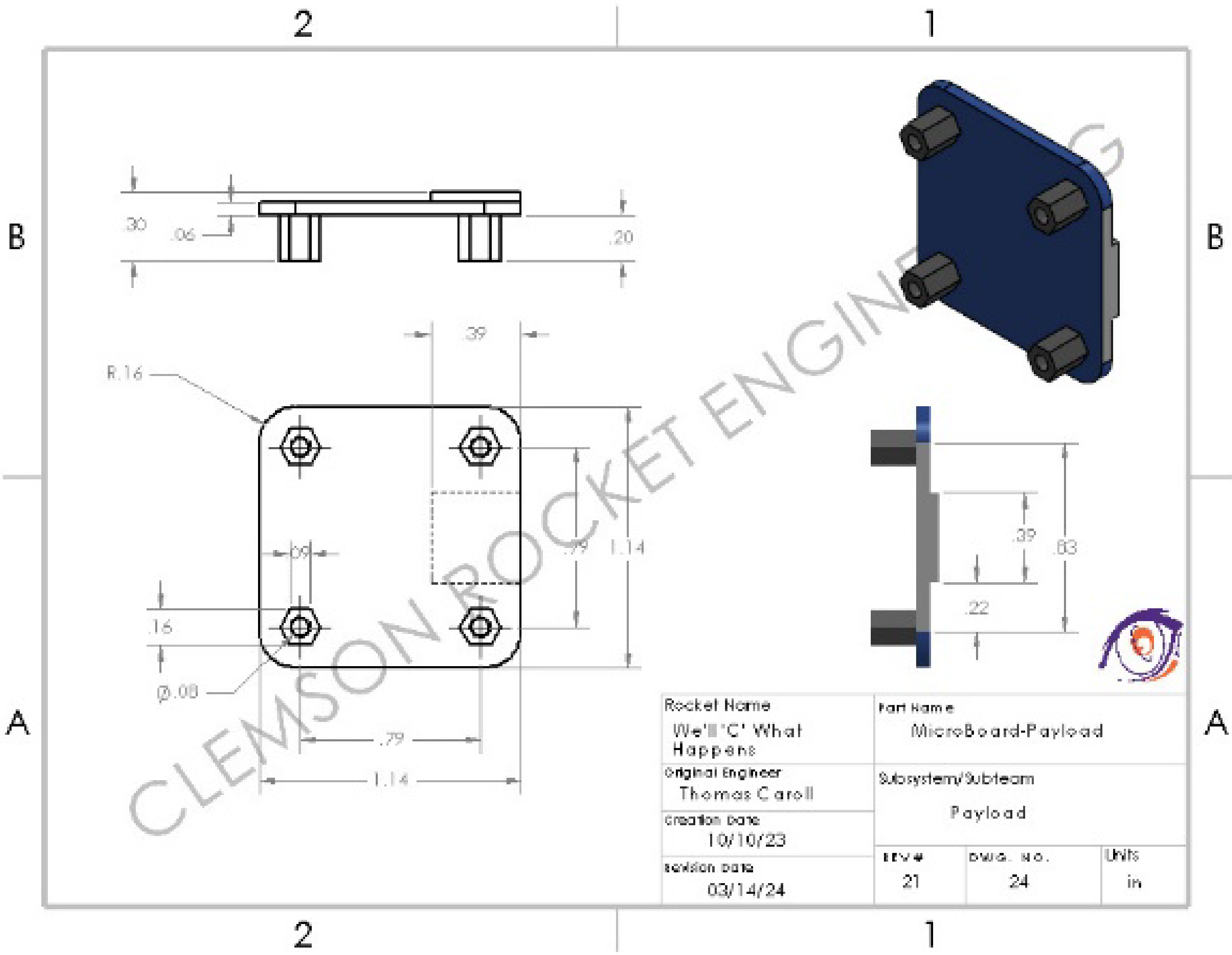
39.00
.04
Ø6.08
Rocket Name
We'll 'C' What Happens
Part Name
Avionics Tube
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
10/13/2024
Revision Date
REV #
1
DWG. NO.
20
Units
in

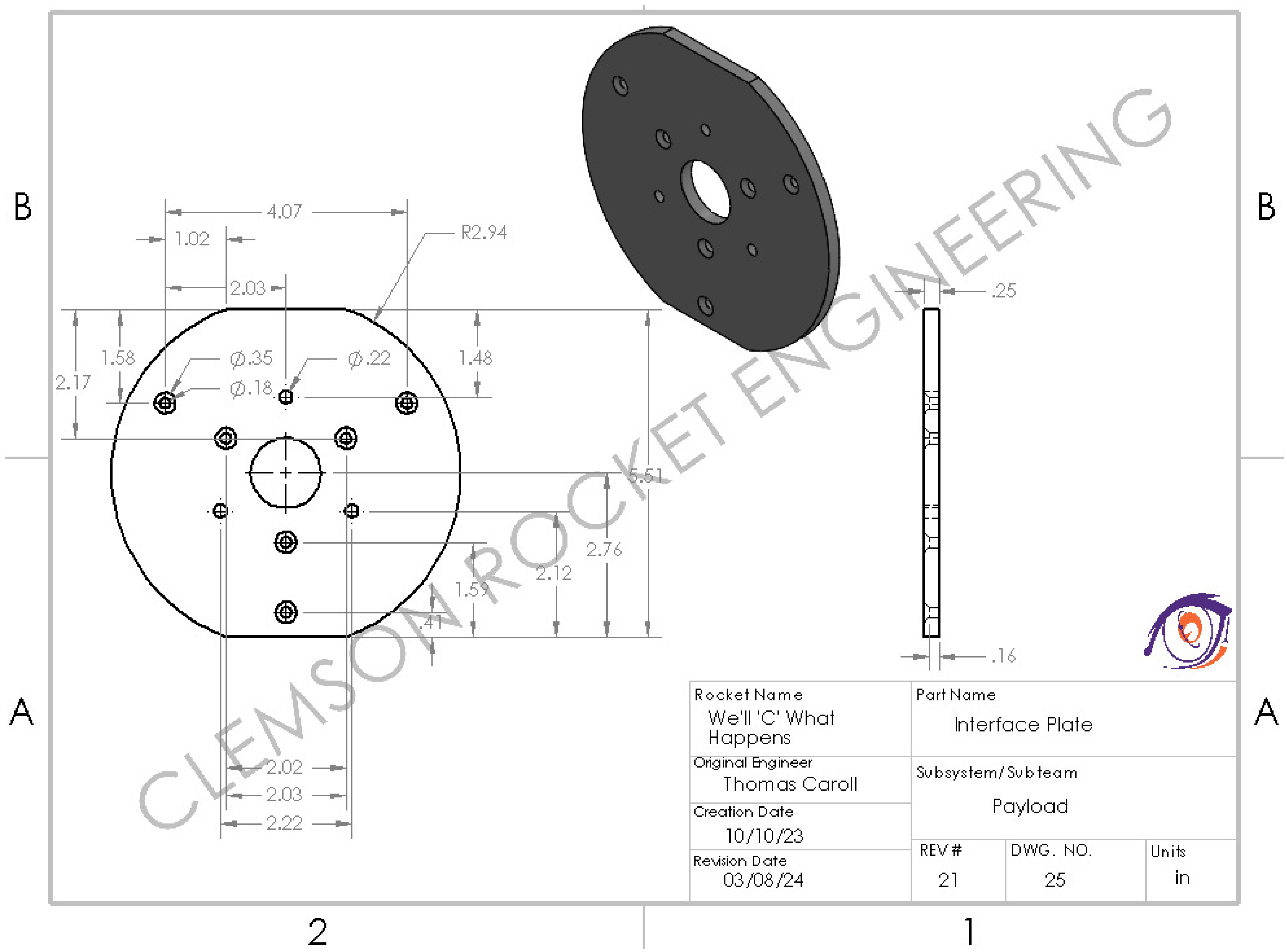

2
1
B
A
.04
23.00
Ø6.08
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' What Happens
Part Name
Payload Tube
Original Engineer
Aaron Cecil
Subsystem/Subteam
Structures
Creation Date
11/13/2023
Revision Date
REV #
1
DWG. NO.
21
Units
in

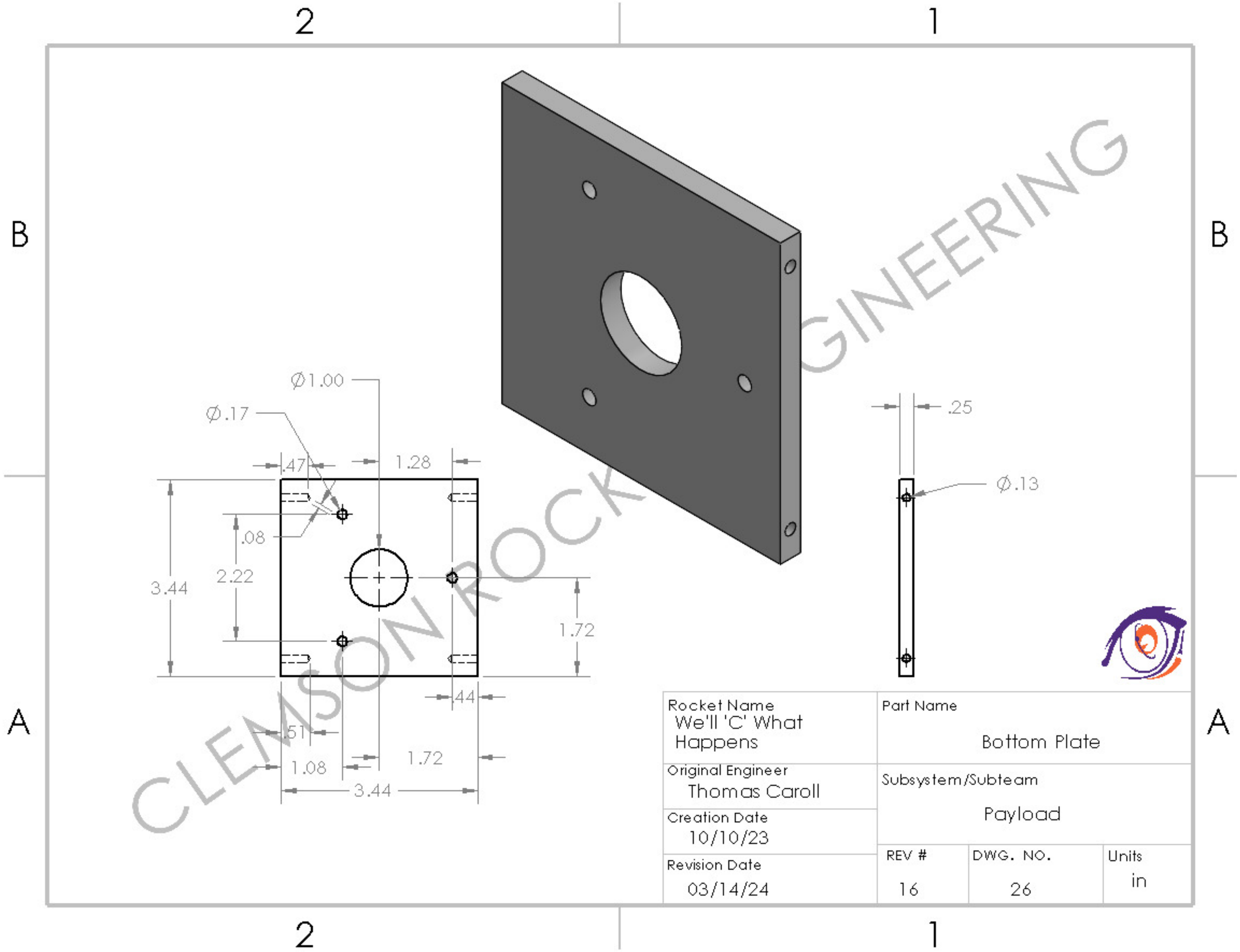

2
1
B
A
B
B
3.06
Ø.25
36.00
6.00
.10
SECTION B-B
SCALE 1 : 8
CLEMSON ROCKET ENGINEERING
Rocket Name
Part Name
Nosecone
Original Engineer
Daniel Carlson
Subsystem/Subteam
Structures
Creation Date
10/20/23
Revision Date
01/23/24
REV #
DWG. NO.
22
Units
In

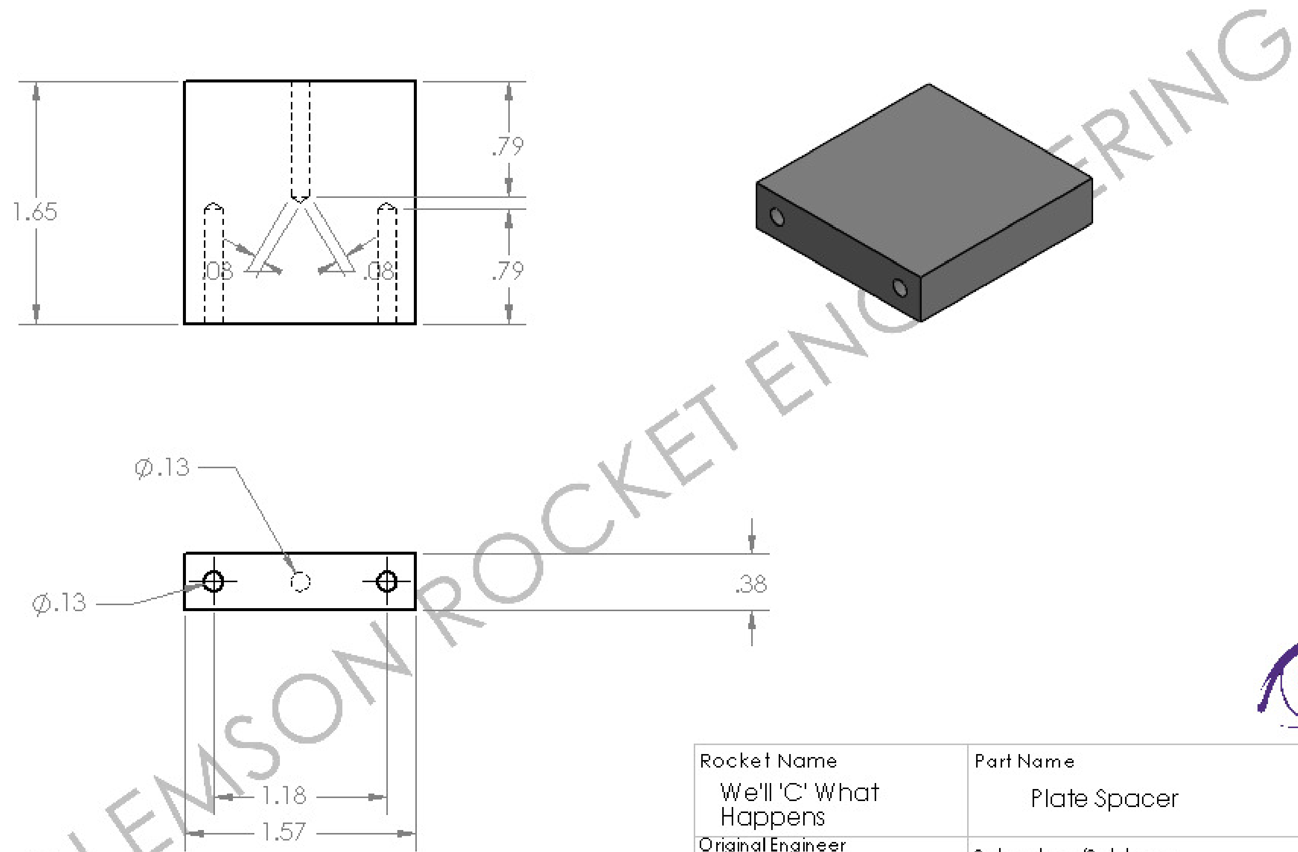


2
1
B
A
.25
1.88
1.10
.64
2.56
R2.94
3.04
2.00
2.03
.01
Ø.18
Ø.20
Ø.31
.83
.49
2.67
4.68
.14
R2.94
2.15
.83
1.00
2.76
5.51
Rocket Name
We'll 'C' What Happens
Part Name
Base Plate
Original Engineer
Thomas Caroll
Subsystem/Subteam
Payload
Creation Date
10/10/23
Revision Date
03/18/24
REV #
22
DWG. NO.
23
Units
in

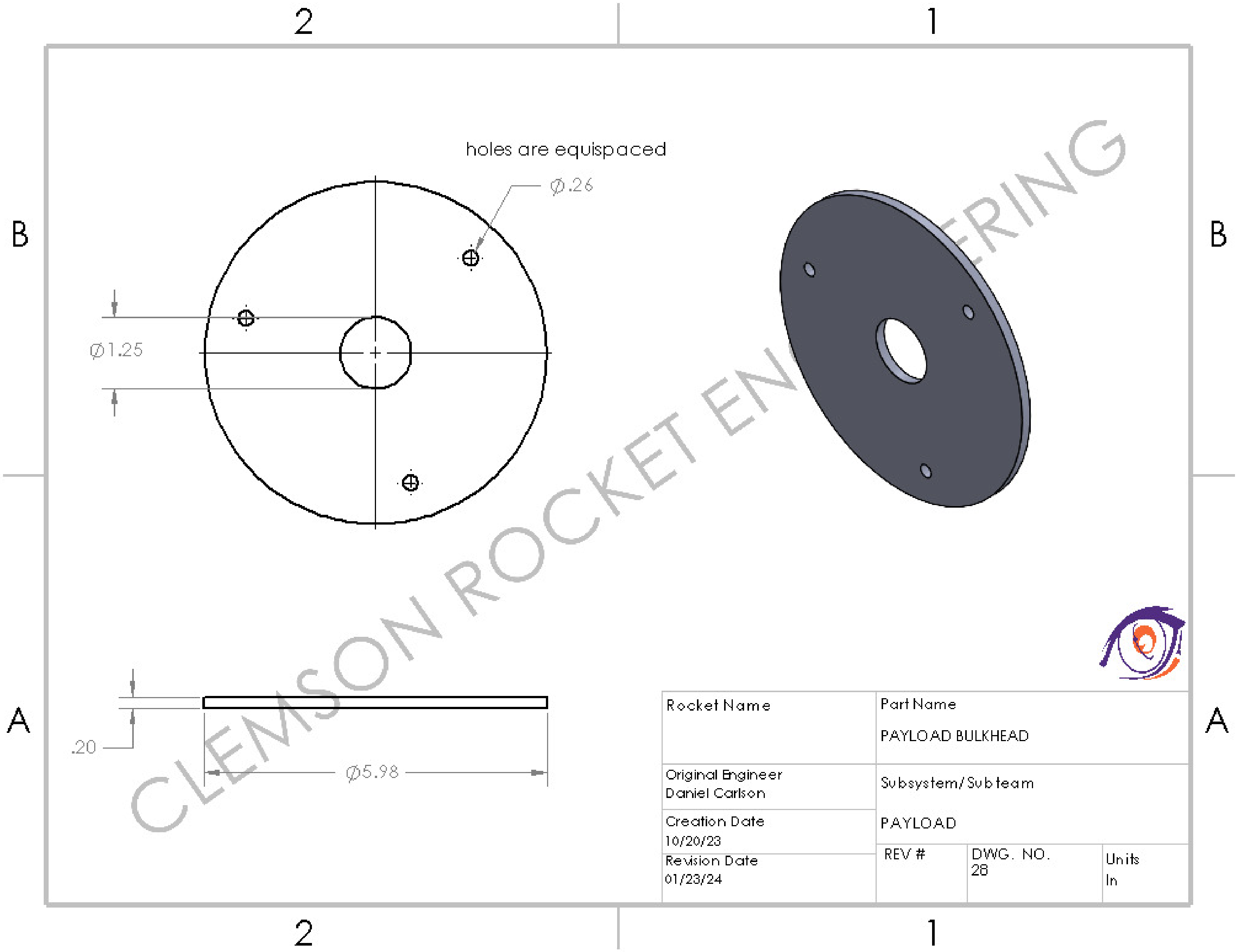

2
1
B
A
.30
.06
.20
.39
R.16
.09
.79
1.14
.16
Ø.08
.79
1.14
.39
.83
.22
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' What Happens
Part Name
MicroBoard-Payload
Original Engineer
Thomas Caroll
Subsystem/Subteam
Payload
Creation Date
10/10/23
Revision Date
03/14/24
REV #
21
DWG. NO.
24
Units
in

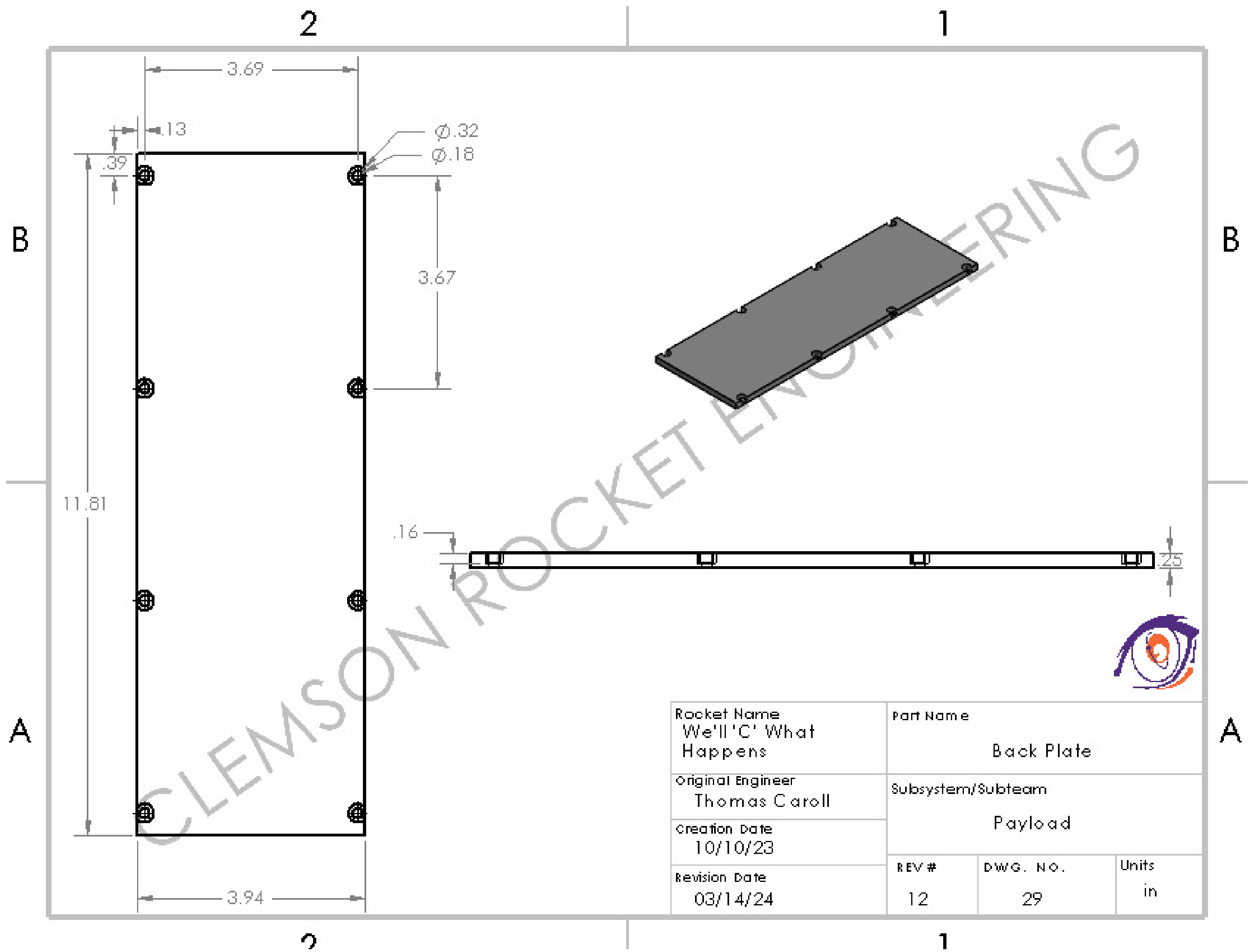

B
A
2
1
4.07
1.02
2.03
R2.94
1.58
2.17
∅.35
∅.18
∅.22
1.48
5.51
2.76
2.12
1.59
.41
2.02
2.03
2.22
.25
.16
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' What Happens
Part Name
Interface Plate
Original Engineer
Thomas Caroll
Subsystem/Subteam
Payload
Creation Date
10/10/23
Revision Date
03/08/24
REV #
21
DWG. NO.
25
Units
in

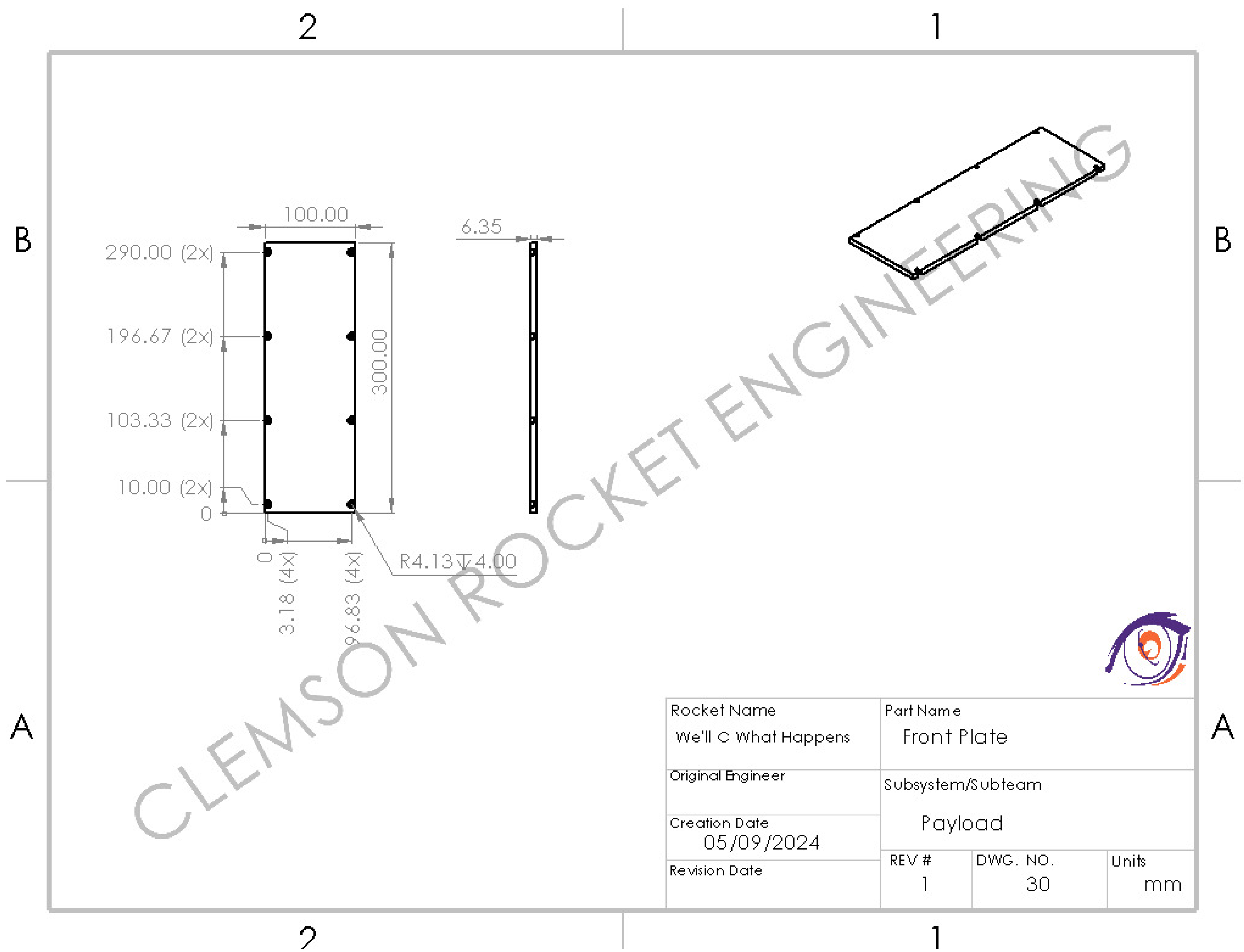

2
1
B
A
Ø1.00
Ø.17
.47
1.28
.08
2.22
3.44
1.72
.44
.51
1.08
1.72
3.44
.25
Ø.13
CLEMSON ROCK
GINEERING
Rocket Name
We'll 'C' What Happens
Part Name
Bottom Plate
Original Engineer
Thomas Caroll
Subsystem/Subteam
Payload
Creation Date
10/10/23
Revision Date
03/14/24
REV #
16
DWG. NO.
26
Units
in

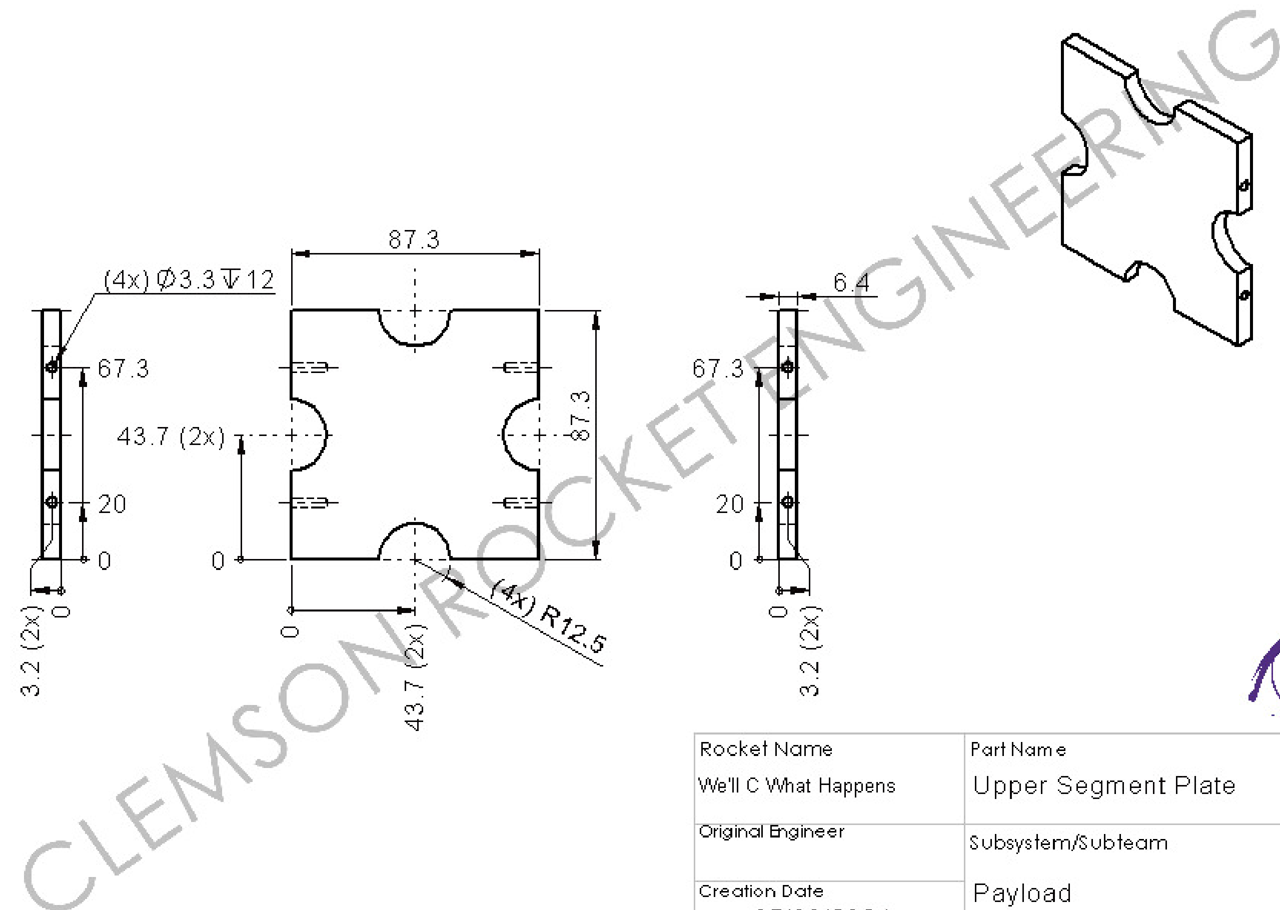


Rocket Name	Part Name		
We'll 'C' What Happens	Plate Spacer		
Original Engineer: Thomas Caroll	Subsystem/Subteam: Payload		
Creation Date: 10/10/23			
Revision Date: 03/14/24	REV #: 21	DWG. NO.: 27	Units: in

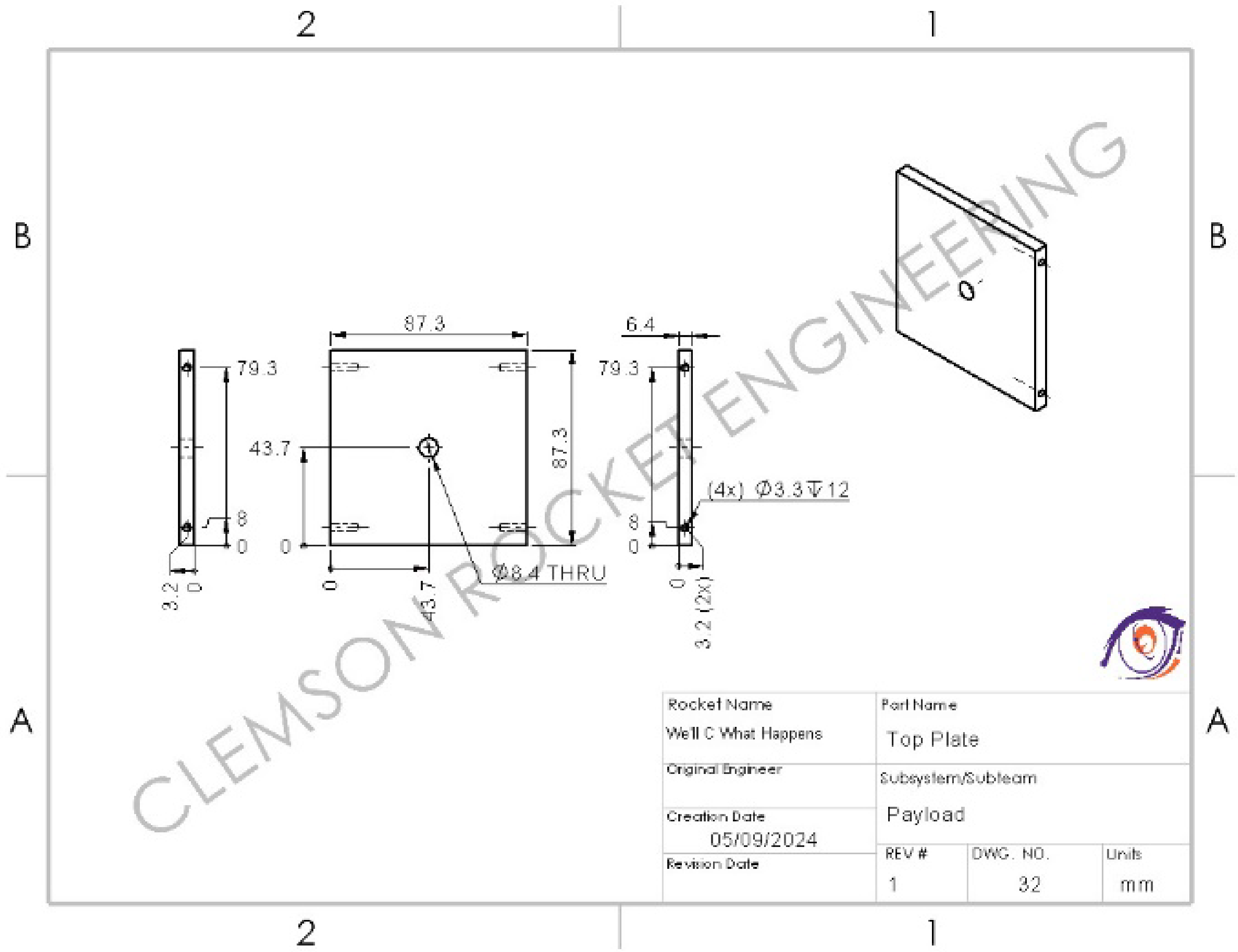

holes are equispaced
Ø.26
Ø1.25
.20
Ø5.98
Rocket Name
Part Name
PAYLOAD BULKHEAD
Original Engineer
Daniel Carlson
Subsystem/Subteam
PAYLOAD
Creation Date
10/20/23
Revision Date
01/23/24
REV #
DWG. NO.
28
Units
In


2
1
B
A
3.69
.13
.39
Ø.32
Ø.18
3.67
11.81
3.94
.16
.25
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' What Happens
Part Name
Back Plate
Original Engineer
Thomas Caroll
Subsystem/Subteam
Payload
Creation Date
10/10/23
Revision Date
03/14/24
REV #
12
DWG. NO.
29
Units
in

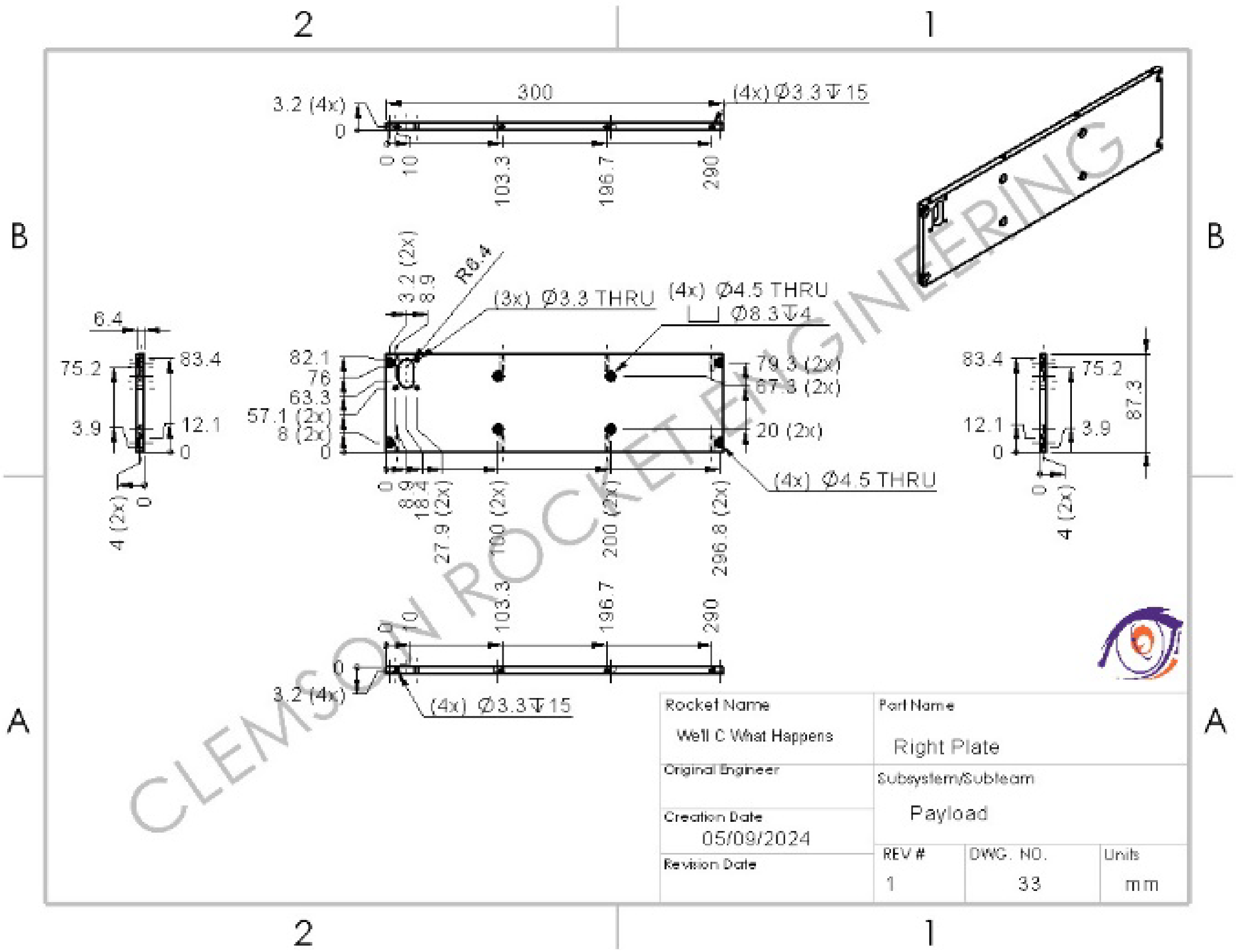

100.00
6.35
290.00 (2x)
196.67 (2x)
103.33 (2x)
10.00 (2x)
0
300.00
0
3.18 (4x)
96.83 (4x)
R4.13 ⊽ 4.00
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll C What Happens
Part Name
Front Plate
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
30
Units
mm

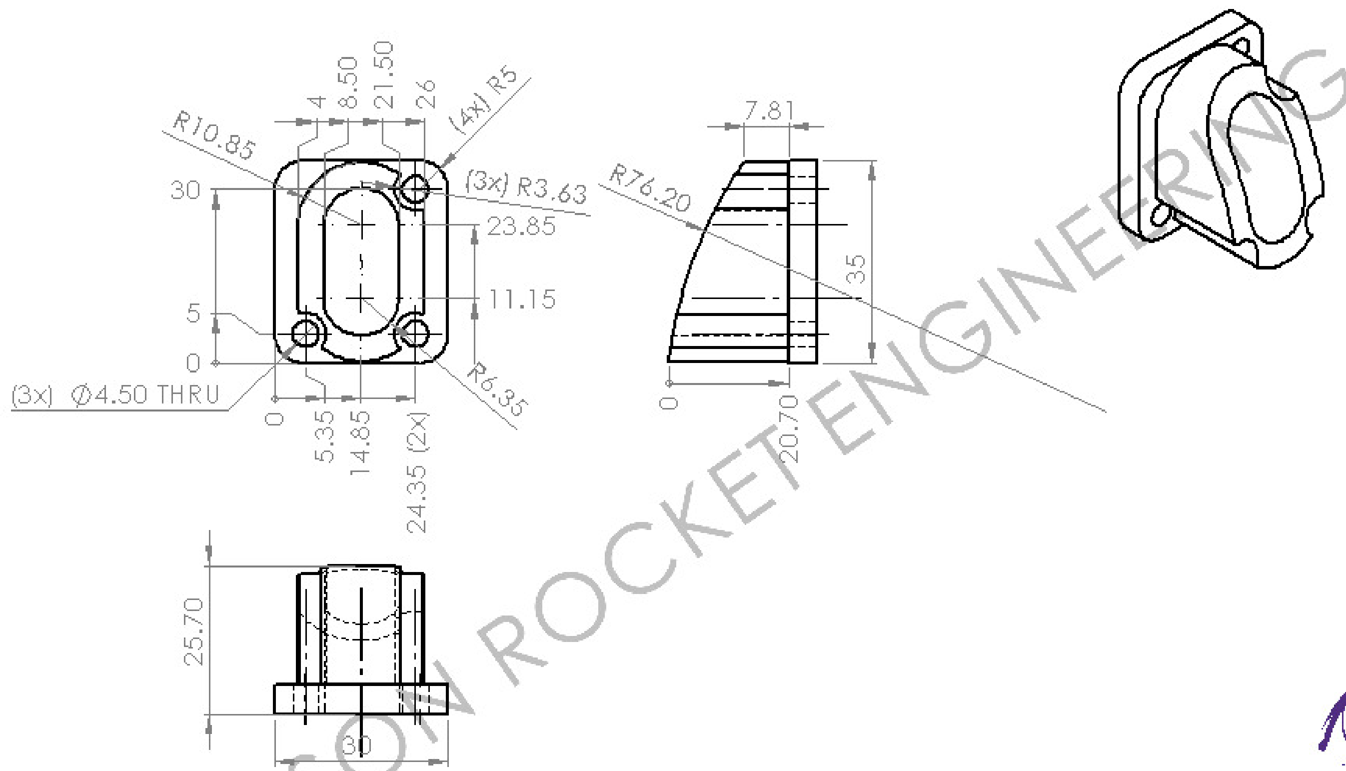


Rocket Name	Part Name		
We'll C What Happens	Upper Segment Plate		
Original Engineer	Subsystem/Subteam		
Creation Date 05/09/2024	Payload		
Revision Date	REV # 1	DWG. NO. 31	Units mm

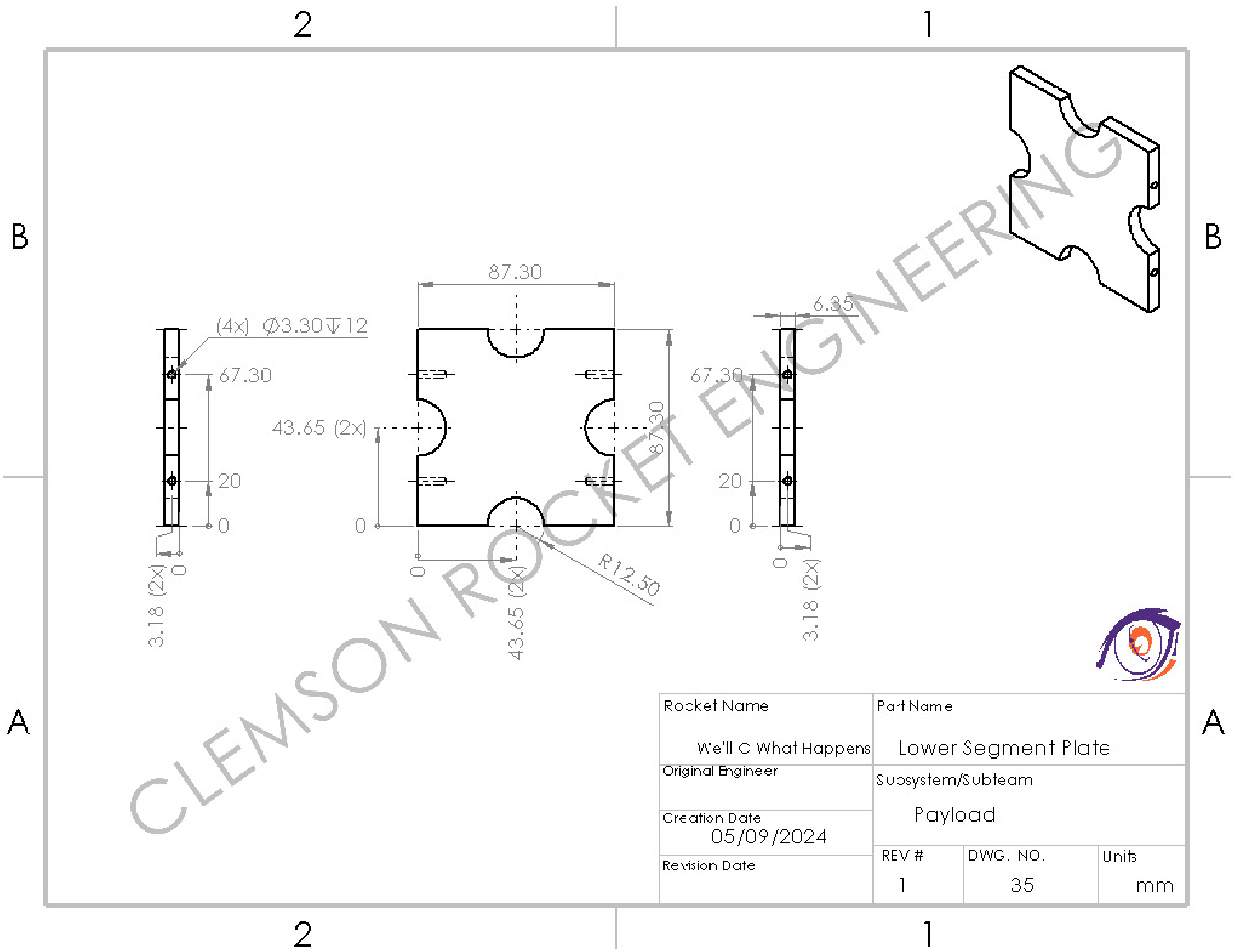


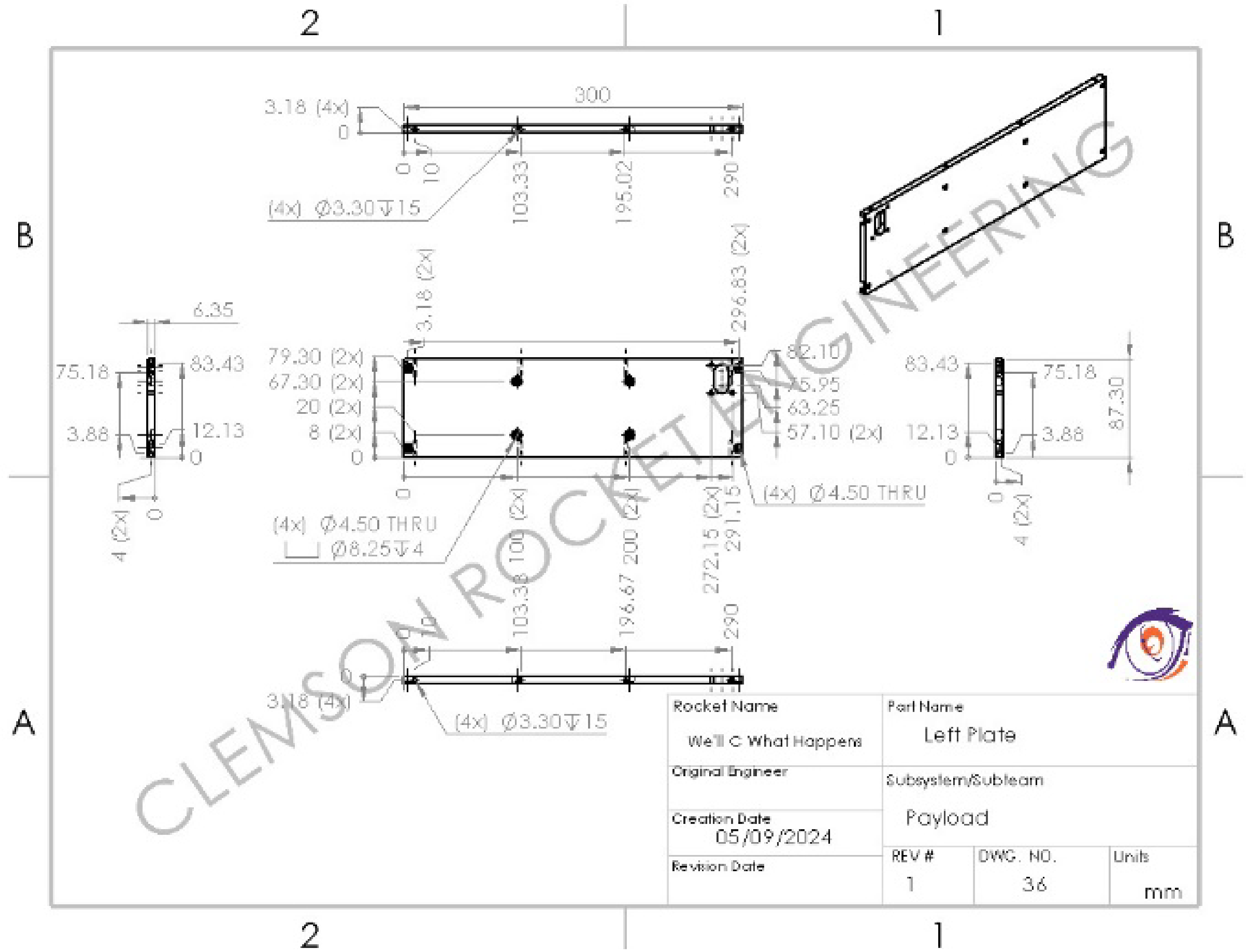
87.3
6.4
79.3
43.7
8
0
3.2
87.3
Ø8.4 THRU
(4x) Ø3.3 ↧12
3.2 (2x)
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll C What Happens
Part Name
Top Plate
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
32
Units
mm


300
(4x) Ø3.3↧15
3.2 (4x)
(3x) Ø3.3 THRU
(4x) Ø4.5 THRU
⌴ Ø8.3↧4
(4x) Ø4.5 THRU
R6.4
79.3 (2x)
67.3 (2x)
20 (2x)
83.4
75.2
87.3
12.1
3.9
6.4
4 (2x)
82.1
76
63.3
57.1 (2x)
8 (2x)
103.3
196.7
290
27.9 (2x)
100 (2x)
200 (2x)
296.8 (2x)
CLEMSON ROCKET ENGINEERING
Rocket Name
Well C What Happens
Part Name
Right Plate
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
33
Units
mm

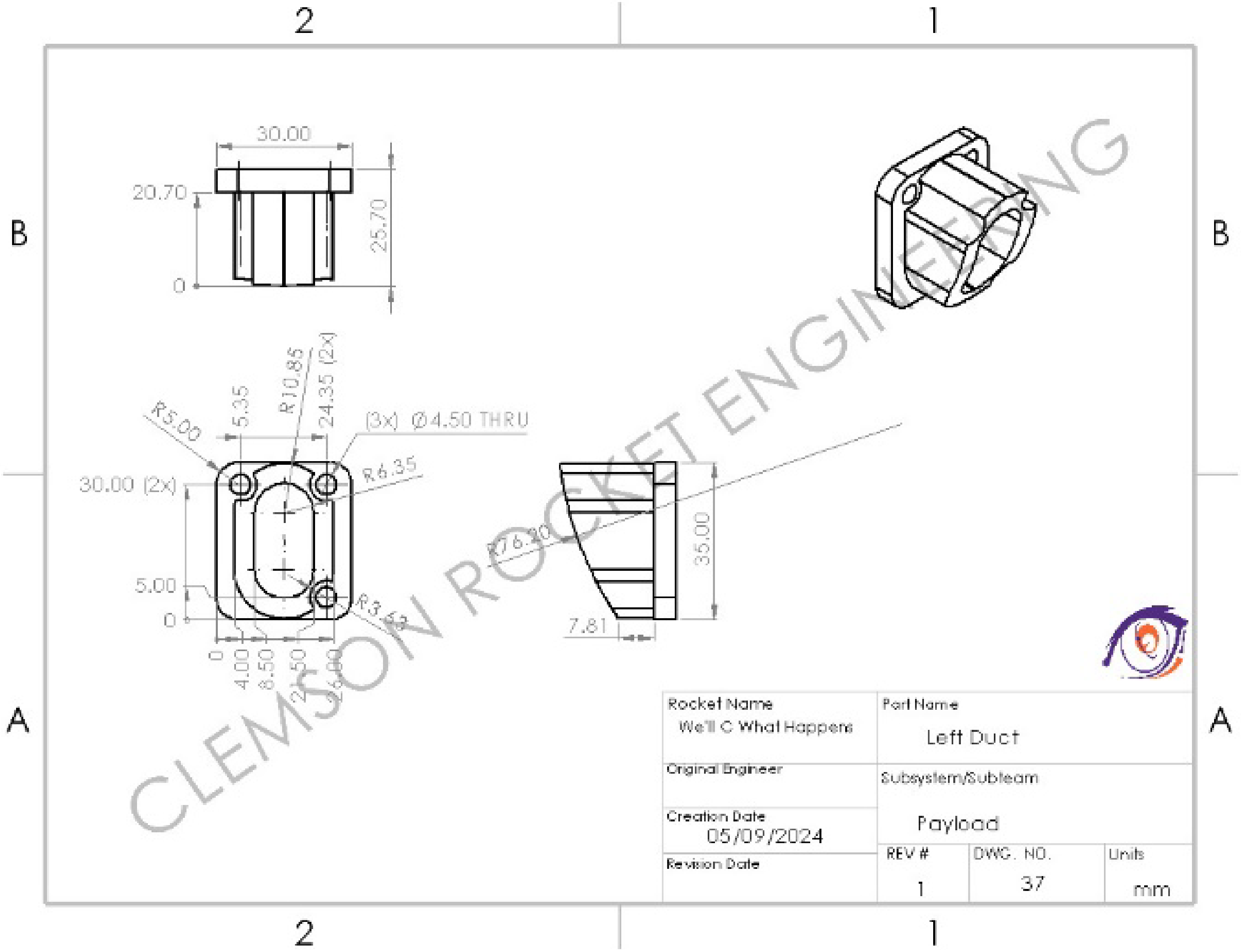


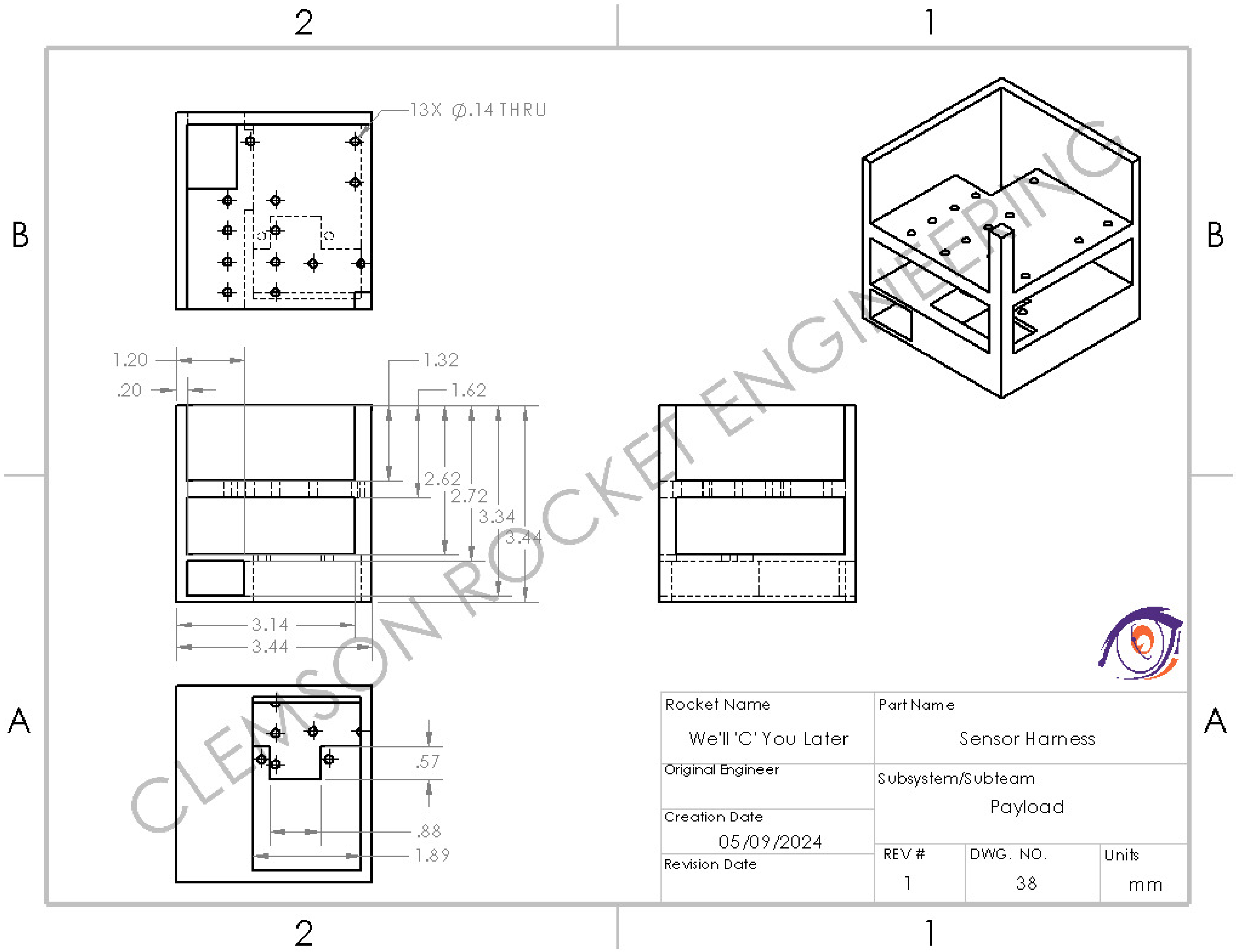
Rocket Name	Part Name		
We'll C What Happens	Right Duct		
Original Engineer	Subsystem/Subteam		
Creation Date 05/09/2024	Payload		
Revision Date	REV # 1	DWG. NO. 34	Units mm


2
1
B
A
87.30
(4x) Ø3.30 ↧ 12
67.30
43.65 (2x)
20
0
3.18 (2x)
6.35
87.30
R12.50
43.65 (2x)
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll C What Happens
Part Name
Lower Segment Plate
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
35
Units
mm



Rocket Name: We'll C What Happens	Part Name: Left Plate
Original Engineer:	Subsystem/Subteam: Payload
Creation Date: 05/09/2024	
Revision Date:	REV #: 1 / DWG. NO.: 36 / Units: mm


30.00
20.70
25.70
0
R5.00
5.35
R10.85
24.35 (2X)
(3X) Ø4.50 THRU
R6.35
30.00 (2X)
5.00
0
R3.63
0
4.00
8.50
21.50
26.00
R76.20
35.00
7.81
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll C What Happens
Part Name
Left Duct
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
37
Units
mm


13X ⌀.14 THRU
1.20
.20
1.32
1.62
2.62
2.72
3.34
3.44
3.14
3.44
.57
.88
1.89
CLEMSON ROCKET ENGINEERING
Rocket Name
We'll 'C' You Later
Part Name
Sensor Harness
Original Engineer
Subsystem/Subteam
Payload
Creation Date
05/09/2024
Revision Date
REV #
1
DWG. NO.
38
Units
mm

Appendix H: Component Inventory and Product Specifications

This appendix is a comprehensive inventory of the various parts and products used to construct our rocket. It includes detailed specifications and sourcing information for each component, from structural elements to electronic systems. This appendix provides an apparent reference for the materials and technologies implemented, ensuring transparency and facilitating future replication or modification of the rocket design. Vendor details and relevant technical parameters, such as dimensions, materials, and performance characteristics, accompany each item. This resource is intended to support the understanding and evaluating of our vehicle's design and functionality by providing essential data at a glance.

[1]ADXL345, 3-Axis Accelerometer Breakout Board | Adafruit Industries LLC, MPN: 1231
[2]AIM, Dual Deployment Altimeter | Entracore, Model: 09139
[3]AMS1117-3.3, IC LDO REG 3.3V 1 A SOT223 | EVVO, MPN: AMS1117-3.3
[4]AutomationDirect Selector Switch, Two positions - 22 mm size | AutomationDirect, MPN: GCX1350
[5]BMP388, Precision Barometric Pressure and Altimeter | Adafruit Industries LLC, MPN: 3966
[6]CESS Aviation Connectors, 0.63 *in* Diameter Plug and Socket | CESS, MPN: JCX
[7]DB9 Male Breakout Board, Screw terminals - Right angle - Ultra thin| MDFLY, ASIN: B07ZT56BJF
[8]DragonPlate, EconomyPlate ~ 1/4 in×24 in×24 in | Allred & Associates Inc., SKU: FEPL08T902424
[9]Drogue Parachute, Elliptical 48 in-8.6 lbf at 20 ft/s | Fruity Chutes Inc., SKU: CFC-48-N-OB
[10]Eyebolt, 3/8-in 3-9/32-in Plain Coarse Thread | Hillman, Model: 320604
[11]FEATHERS3, 2.4GHz ESP32-S3 Transceiver | Adafruit Industries LLC, MPN: 5399
[12]Featherweight GPS Ground Station, Base Station Enclosure Unit | Featherweight Altimeters, Model: Ground Station
[13]Featherweight GPS Tracker, Antenna Unit | Featherweight Altimeters, Model: Tracker
[14]LIS3MDLTR, Ultralow-power 3-axis Magnetic Sensor | STMicroelectronics, Model: LIS3MDLTR
[15]LSM6DSOX, 3D Digital Accelerometer and 3D Digital Gyroscope | STMicroelectronics, Model: LSM6DSOXTR
[16]M2500T-P, AeroTech High Powered Motor | Balsa Machining Service, Catalog #: 13250P
[17]Main Parachute, Custom 120 in-50 lbf at 20 ft/s | Fruity Chutes Inc., SKU: CFC-120-N-CC
[18]MPL3115A2, I2C Barometric Pressure/Altitude/Temperature Sensor | Adafruit Industries LLC, MPN: 1893
[19]PMSA003I, STEMMA QT Air Quality Sensor | Adafruit Industries LLC, MPN: 4632
[20]Quick Link, 3/8-in – 2,640 lbf Rating | National Hardware, Model: N100-285
[21]RunCam Split 3, 165° DC 5-20 V M12 Lens | RunCam, SKU: SPLIT-HD-3DM
[22]Shear Pin, 6-32 Thread – 3/8" Long | McMaster-Carr, MPN: 92942A728
[23]Shock Cord, Large, 9/16 in – 3000 lbf Rating | Fruity Chutes, SKU: SCN-688-10
[24]Siemens Selector Switch, Non-Illuminated - two positions - 30 mm size | Siemens, MPN: 52SA2AABK1
[25]STM32F103C8T6, Arm® Cortex®-M3 32-bit RISC Core MCU | STMicroelectronics, Model: STM32F103C8T6
[26]StratoLogger CF, Compact Footprint StratoLogger Altimeter | PerfectFlight Direct, SKU: SLCFA
[27]Swivel, Stainless Steel Barrel Swivel – 3000 lbf Rating | Rocketman Parachutes, Model: 3000-Barrel-Swivel
[28]Wago Lever Connector, 12-24 AWG Splicing Connector | WAGO, SKU: 1006737809
[29]XT-30 Connectors, Gold Plated Pins | DFRobot, MPN: FIT0586

Acknowledgments

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This mission could not be complete without the extensive guidance and help from our mentor, Peter Tarlé. Without his effort, this organization could not run as it does.

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