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

Team 50 Project Technical Report to the 2026 IREC

Daniel Young*
Virginia Tech, Blacksburg, Virginia, 24061

Vanessa Bushell†
Virginia Tech, Blacksburg, Virginia, 24061

Cannon Biscoe‡
Virginia Tech, Blacksburg, Virginia, 24061

J. Cian Capacci§
Virginia Tech, Blacksburg, Virginia, 24061

Brady Rehkop¶
Virginia Tech, Blacksburg, Virginia, 24061

This report details Team 50 Virginia Polytechnic Institute and State University's launch vehicle for the 2026 International Rocket Engineering Competition (IREC). The IREC, hosted by the Experimental Sounding Rocketry Association (ESRA), is the world's largest rocket engineering competition with over 170 student teams competing from 22 countries. Competing in the 10K Commercial off the shelf (COTS) category, the team's mission is to launch a rocket to an attitude of exactly 10,000 feet using a COTS motor. To meet this objective, the team has spent the past year designing, building, and testing Carbo Fibezilla, a roughly 10-foot sounding rocket featuring a custom carbon fiber airframe and an air brake system. The following report is a comprehensive review of the specifications and design process of the rocket and its subsystems.

*Team Lead, Aerospace and Ocean Engineering
†Treasurer, Industrial and Systems Engineering
‡Aerostructures Lead, Aerospace and Ocean Engineering
§Avionics Lead, Electrical and Computer Engineering
¶Subsystems Lead, Aerospace and Ocean Engineering

Executive Summary

This technical report is the final paper submission to ESRA as part of the 2026 IREC. This report serves as a comprehensive breakdown of the launch vehicle created by Team 50, Virginia Polytechnic Institute and State University. The objective is to identify and document the design decisions, manufacturing processes, and validation techniques used by the team throughout the year.

Carbo Fibezilla is a dual-deploy, dual-separation L3 rocket. One of its standout features is the Student Research and Designed (SRAD) carbon fiber airframe. Upgrading from last year, the team has replaced a fiberglass upper body tube with carbon fiber, reducing the overall weight of the rocket by several pounds, and has attached more externally mounted patch antennas to the thrust structure for telemetry downlink through the carbon fiber. This project was set up as a test at the 2025 IREC, and was fully integrated into this rocket. To meet the 10,000 ft apogee goal, the team has developed the Active Drag System (ADS), which is a mechanism for air breaking. The ADS deploys four flaps during flight to slow the rocket sooner and reach a precise apogee. A custom flight computer controls the ADS using a sensor suite and upgraded Inertial Measurement Unit (IMU) for improved altitude measurement. For this flight computer, the team developed SRAD Printed Circuit Board (PCB)s and flight algorithms. The rocket also carries a payload which will be used as a test bed for electronic equipment. Sensors that may be used on future flights can be placed into this payload for flight testing before they are truly flight critical. Finally, the team will be participating in the live video challenge using the onboard cameras and the new ground station developed.

The team has completed two successful full-scale test launches of Carbo Fibezilla using the team's competition motor, the M2400T. Both tests resulted in a smooth and easy recovery with no damage to the rocket and allowed for testing of the subsystems and their electronics. All flight critical systems have been both ground and flight tested, live onboard video has been received, and all supplemental analysis has been complete to prepare the team for the 2026 IREC. The team looks forward to a successful flight and recovery.

Contents

Nomenclature

ABS	Acrylonitrile Butadiene Styrene
ADS	Active Drag System
AEDL	Aerospace Engineering Design Lab
AGL	Above Ground Level
CAD	Computer Aided Design
Cd	Coefficient of Drag
CFD	Computational Fluid Dynamics
CG	Center of Gravity
CNC	Computer numerical control
CONOPS	Concept of Operations
COTS	Commercial off the shelf
CP	Center of Pressure
DTEG	Design Test and Evaluation Guide
EHS	Environmental Health and Safety
ESRA	Experimental Sounding Rocketry Association
FEA	Finite Element Analysis
FOR	Flyer of Record
FPU	Floating Point Unit
FS	Factor of Safety
GPIO	General Purpose Input/Output
GPS	Global Positioning System
HPR	High Powered Rocketry
I2C	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
IREC	International Rocket Engineering Competition
LCO	Launch Coordination officer
Li-Ion	lithium-ion
LNA	Low-Noise Amplifier
OSD	On-Screen Display
PA	Power Amplifier
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PWM	pulse width modulation
RF	Radio Frequency
RSO	Range Safety Officer
SPI	Serial Peripheral Interface
SRAD	Student Research and Designed
TRA	Tripoli Rocketry Association
TWR	thrust to weight ratio
UART	Universal Asynchronous Receiver/Transmitter

I. Introduction

A. Mission Statement

Rocketry at Virginia Tech is a student-led, competitive design team at Virginia Polytechnic Institute and State University in Blacksburg, Virginia, U.S. The team aims to provide members with realistic, hands-on engineering experience and promote interest in high-powered rocketry on campus and in the surrounding community. As a design team, Rocketry at Virginia Tech provides a safe environment for students of all majors and years to operate high-power rockets, practice engineering design principles, and earn L1, L2, or L3 certifications. Each year, the team works toward competing in the IREC, hosted by the ESRA. At IREC 2026, Rocketry at Virginia Tech will be competing in the 10,000 ft apogee with COTS propulsion category. Following last year's success at IREC, our team has challenged itself to reevaluate past projects and innovate upon them for this year's competition rocket.

B. Team Structure

Rocketry at Virginia Tech is made up of 35 undergraduate students and 4 graduate students from every academic year and 5 different engineering majors. Leadership on the team consists of one team lead, one treasurer, and three technical subteam leads. The responsibilities of each subteam vary greatly but are highly collaborative to ensure that the subsystems of the project are not isolated in their development. The team lead, treasurer, and subteam leads work with each other to ensure that all IREC guidelines are adhered to, that the integration of the rocket can be accomplished as smoothly and efficiently as possible, and that the team and associated advisors and mentors stay informed. The team also has two L1 certification managers and one safety officer. The team's L1 Certification Managers work to help the general team members earn their L1 High Powered Rocketry (HPR) Certifications by hosting information and building sessions. The safety officer ensures that all team members are earning and maintaining Environmental Health and Safety (EHS) training. Figure 1 presents the breakdown of team leadership, in addition to recognizing the faculty advisors who have mentored, and supported Rocketry at Virginia Tech in pursuit of our mission.

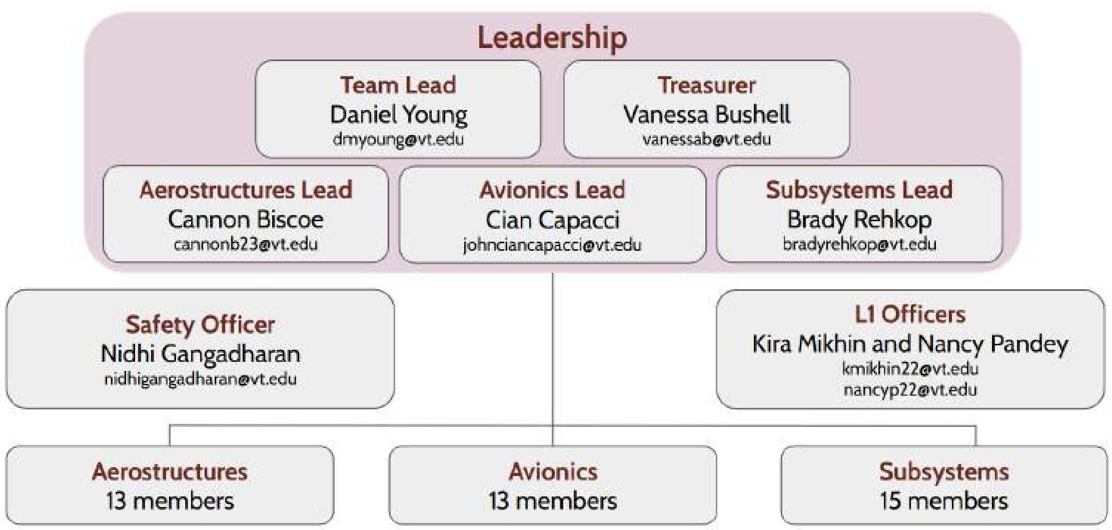


Fig. 1 Rocketry at Virginia Tech 2025-2026 Team Structure.

C. Mentors and Stakeholders

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

Rocketry at Virginia Tech's primary faculty advisor, Dr. Kevin Shinpaugh, is a collegiate professor of the Kevin T. Crofton Department of Aerospace and Ocean Engineering who works with a variety of university design teams including NASA SLVT, NASA Robotic Mining Competition, RASC-AL RoboOps, RockSat-X, and other design teams.

He is a level 2 certified TRA member. Dr. Shinpaugh provides additional support at team certification launches as the Launch Coordination officer (LCO) as well as hosts team Undergraduate Research meetings for bi-weekly updates and consistent feedback on how to improve. Rocketry at Virginia Tech's secondary faculty advisor, Dr. Jeffrey Walling, is a collegiate professor of the Bradley Department of Electrical and Computer Engineering. He provides support in the form of weekly Undergraduate Research meetings with a focus on the electrical and computer subsystems on the rocket.

The team received financial support from a variety of sponsors. Financial support was provided by corporate sponsors, such as L3Harris Technologies, Lockheed Martin, and Blue Origin. Other support was provided by the Student Engineers' Council at Virginia Tech and the Kevin T. Crofton Department of Aerospace and Ocean Engineering. Rocketry at Virginia Tech was able to manufacture the team's 2026 launch vehicle through the use of the Aerospace Engineering Design Lab (AEDL) and its equipment, a lab space owned and operated by the Kevin T. Crofton Department of Aerospace and Ocean Engineering. Lastly, the team received mentoring regarding current and past projects from its extensive alumni network now employed at various companies including L3Harris, Lockheed Martin, SpaceX, Norththrop Grumman, Aerojet Rocketdyne, TORC Robotics, and others.

II. Mission Concept of Operations Overview

An overview of the launch vehicle concept of operations is shown in Figure 2. Once the pre-flight checklist is completed, and the RSO allows the team to continue to the pads, the team will continue with the rocket arming sequence. After all personnel are ensured to be a safe distance from the vehicle, ignition will occur. The motor will provide thrust until burnout at approximately 793 m Above Ground Level (AGL). This begins the coast phase of the ascent. Once the coast phase begins, onboard telemetry systems will verify motor burn has ended. They accomplish this using a timer that begins at the start of acceleration and comparing to expectations and by detecting the start of negative acceleration. From this time onward, during the coast phase, the ADS will deploy and retract as necessary to get the rocket as close to 10,000 ft as possible until apogee. The ADS will retract again at the start of descent just as the first apogee charge should be ignited by the primary recovery electronics. Should it be determined by the ADS that the rocket will not reach 10,000 ft, then the system will not deploy.

At apogee, the vehicle will begin the recovery sequence. At approximately T_{apogee} s, the onboard recovery system will eject the drogue parachute. The rocket will descend at approximately 25.9 m/s. At 244m the rocket will undergo its second recovery event, ejecting the nose cone to allow for the main parachute to exit and deploy from the upper body tube. At this point the rocket will descend at 5.0 m/s and land at around 170 seconds after launch. During the duration of the flight, the payload, recovery system, and ADS will each transmit Global Positioning System (GPS) coordinates to a ground station. Both recovery events will be armed with additional backup black powder charges for redundancy, further detailed in the Recovery Subsystem section.

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

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

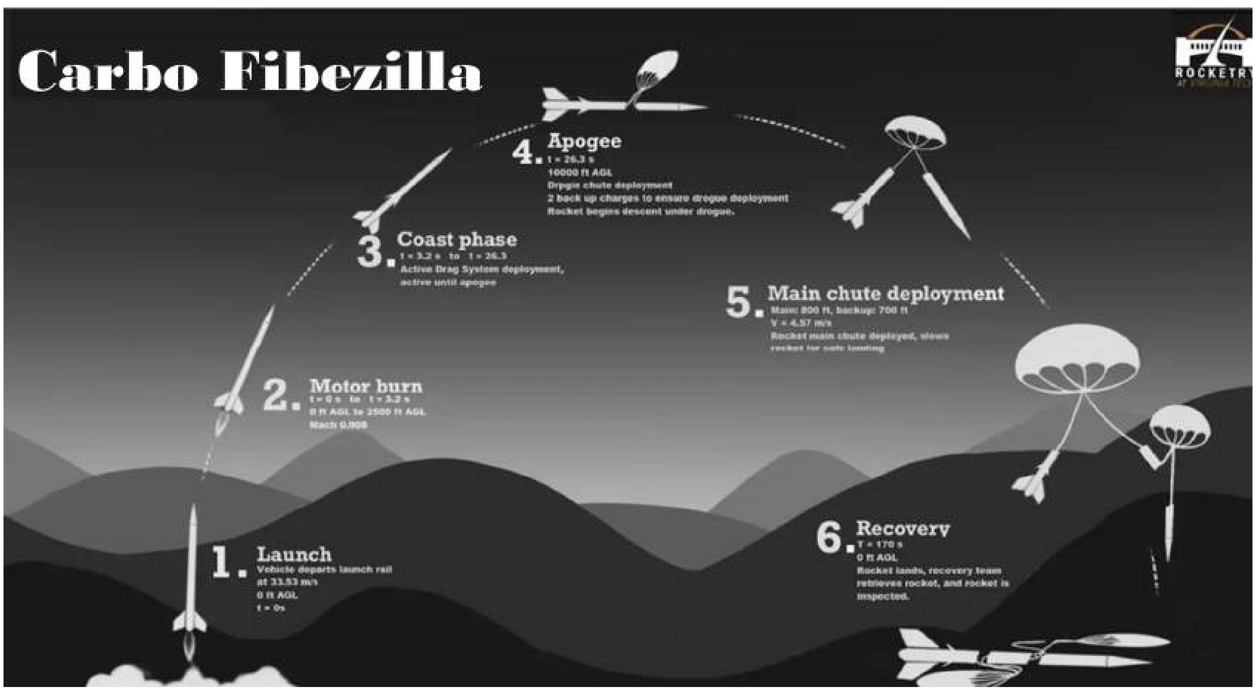


Fig. 2 Concept of operations graphic

III. System Architecture

A. Overview

Rocketry at Virginia Tech's 2026 launch vehicle, named 'Carbo Fibezilla,' is a typical dual-deploy, dual-separation L3 rocket configuration with additional interdisciplinary projects to better accommodate the rules and requirements for IREC. These projects include the ADS with an SRAD flight computer for air brake deployment and rocket state estimation, an autonomous on-board camera control with live video streaming capability, externally mounted antennas on an SRAD carbon fiber thrust structure for the purpose of RF pass-through to use for GPS and telemetry; and an 4.4 lb, 3U Cubesat payload sensor suite. Carbo Fibezilla will be flying on an Aerotech M2400T, chosen both for the thrust to weight ratio (TWR) and resultant apogee (10,601 ft) closest to the target (10,000 ft) it provides. More details on these subsystems and the decisions surrounding their designs are found in the following sections.

B. Vehicle Trajectory and Flight Characteristics

Table 2 Mass Breakdown of the 2025-2026 Launch Vehicle

Subteam	System	Mass (g)
Structures	Nosecone	1,656
Structures	Aeroshell	7,286
Structures	Fins	420
Avionics	Active Drag System	1,361
Avionics	Electronics Bay	1,676
Recovery	Chutes + Hardware	2,326
Payload	3U CubeSat	2,003
Propulsion	Casing Hardware	2,758
Propulsion	Propellant	3,693
Liftoff		23,179
Burnout		19,486

Table 3 Predicted flight data of the 2025-2026 launch vehicle.

Characteristic	Value	Unit
Liftoff TWR	10.21	N/A
Off-Rail Velocity	108	ft/s
Liftoff Stability	1.93 / 10.2	Cal /Percent
Burnout Mach	0.866	N/A
Maximum Velocity	993	ft/s
Maximum Acceleration	11.4	g
Uncorrected Apogee	10,601 ft	ft
Corrected Apogee	10,000	ft

Table 4 Simulation atmospheric data for Saragosa, Texas based on historical data in the month of June.

Characteristic	Value	Unit
Atmospheric Pressure	0.997	atm
Temperature	35	$^{\circ}C$
Elevation Angles	6	$^{\circ}$

C. Propulsion Narrative

Rocketry at Virginia Tech's 2026 launch vehicle is a COTS solid motor-powered launch vehicle measuring 117 in in length with a body diameter of 6.17 in. The vehicle structure is designed to carry propulsion, avionics, recovery, payload, and telemetry subsystems to an apogee of 10,000 ft AGLand will fly on an AeroTech M2400 [1]. The thrust structure includes the motor tube, fins, centering rings, tailcone, and a bulkhead, all being made of SRAD carbon fiber. The thrust structure provides motor retention and transfers thrust loads into the airframe during flight. The vehicle's aerostructure is made of two SRAD carbon fiber body tube and tailcone, COTS fiberglass couplers, and a COTS 5.5:1 Von Karman nose cone. The team uses a mixture of COTS fiberglass plates and SRAD carbon fiber plates for the centering rings and bulkheads used throughout the vehicle. The vehicle is estimated to have a mass of 51.1 lbs at liftoff; this decreases to 43.0 lbs by burnout and chute deployment due to loss of propellant mass. OpenRocket was used to run all flight tests, with the data being validated and the simuation being adjusted following test launches. Although RASAero II were considered, it was not able to accurately predict the drag produced by the ADS and camera shrouds. All models were run at local atmospheric pressures of 0.997 bar and temperatures of $35°C$ according to historical weather data for Saragosa, Texas in June. Simulated launch elevation angles are $84 \pm 1°$ in accordance with IREC Requirement 10.1. Assuming a 4.88 m (17.0 ft) launch rail is provided by ESRA, the vehicle will have an off-the-rail velocity of 108 ft/s . Stability margin is computed in dimensionless calibers using equation 1:

$$Stability\ Margin = \frac{C_g - C_p}{D_{airframe}} \tag{1}$$

where Center of Pressure (CP) and Center of Gravity (CG) are the distances from the tip of the vehicle to its center of pressure and center of mass, respectively, and $D_{airframe}$ is the vehicle's body diameter. Based on this, the vehicle has a stability margin of 1.93 calibers when leaving the launch rail, rising to 2.82 as the center of mass shifts forward during flight. This stability range, in addition to the estimated off-the-rail velocity, satisfies the stability requirements (10.2 and 10.3) outlined by IREC.

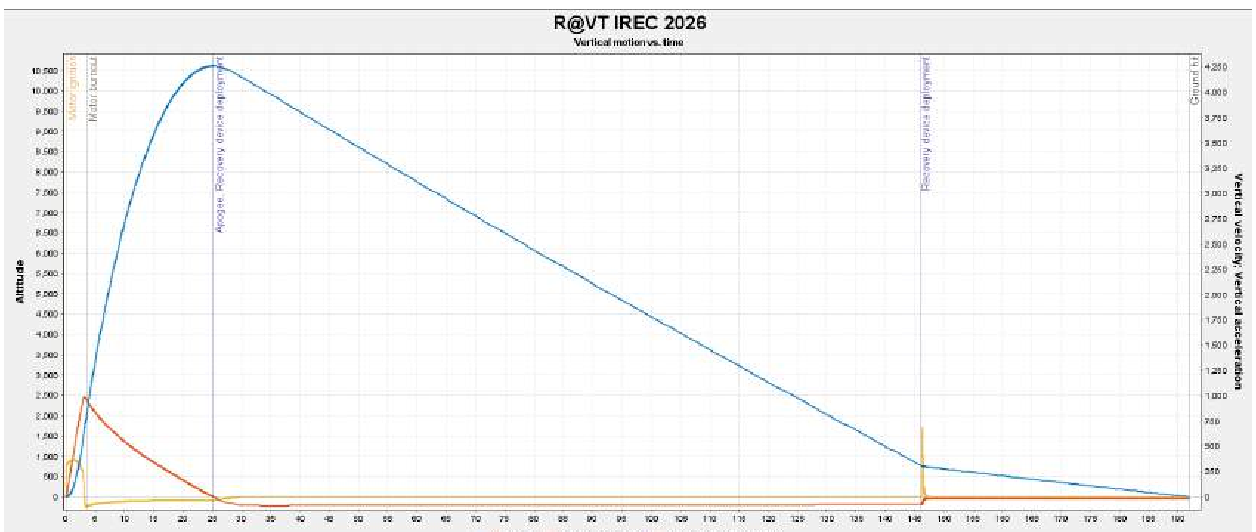


Fig. 3 Model of rocket flight in Open Rocket

Based on the average of the model's uncorrected (without ADS deployment) apogee prediction, the vehicle is expected to achieve an apogee of 10,601 ft AGL in 0 mph winds and a 6 ∘ launch angle. The tendency of the vehicle to overshoot the target apogee is intended to ensure the vehicle is capable of breaking 10,000 ft with the remaining altitude to be removed by ADS deployment.

D. Aerostructure Subsystem

1. Vehicle Architecture

The launch vehicle is designed to house all subsystems critical for flight and recovery, including the payload, COTS solid rocket motor, recovery systems, and ADS. The vehicle is fitted with a 3 grain Aerotech M2400T solid rocket motor, has an overall length of 297.18 cm (117 in), and an outer diameter of 15.7 cm (6.17 in). The mass of the launch vehicle is broken down in 2 and the full architecture is shown in 4. Each of the components listed and shown will be discussed in depth.

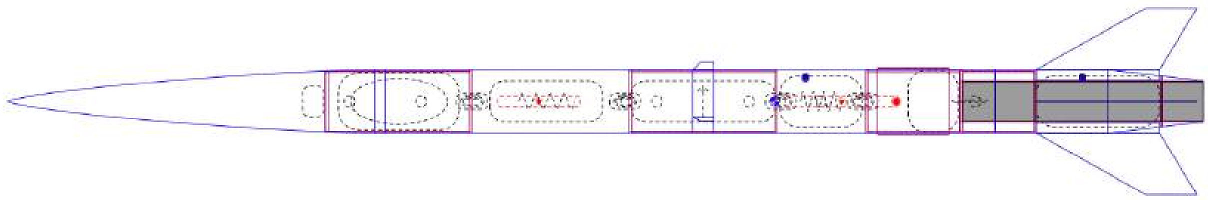


Fig. 4 Architecture of 2025/2026 Rocket in OpenRocket

The Von Karman shaped nose cone of the rocket is a COTS component, with a length of 91 cm (35.83 in) and base diameter equal to the airframe outer diameter. All of the COTS structural components used throughout the rocket are purchased through Wildman Rocketry and are filament wound G10 fiberglass. The nose cone houses a GPS module used as a redundant tracking system. The payload bay is a 35.88 cm (14.125 in) coupler which spans 9.84 cm (3.875 in) into the nose cone, the maximum distance allowed by the nose cone geometry, and 23.5 cm (9.25 in) into the upper airframe. All couplers are COTS and have an outer diameter of 14.99 cm (5.9 in). The switchband on the payload bay is 2.54 cm (1 in) and has the screw switches for the payload as well as the GPS module.

The upper airframe is SRAD carbon fiber and has a length of 76.2 cm (30 in). The manufacturing of all SRAD components will be discussed in the subsequent sections. This airframe houses the main recovery parachute. The nature of all recovery systems will be covered in III.E.

Much like the payload bay, the recovery bay is a COTS coupler with a length of 35.56 cm (14 in) and fits 15.24 cm (6 in) into both the upper and lower airframes. The recovery bay has a 5.08 cm (2 in) switchband that has two shrouds and screw switches to arm the recovery bay once the vehicle is vertical. The shrouds house a camera and antenna used to compete in the live video challenge, which will be reviewed in III.E.7.

The lower airframe is SRAD carbon fiber and spans 69.85 cm (27.5 in) in length. This airframe houses the drogue parachute and the ADS, which sits in a coupler internally mounted in the airframe. This coupler has a forward bulkhead that is sealed during flight to protect the ADS and ensure the necessary pressure seal for separation. The internal coupler is 22.70 cm (8.938 in) long and sits 8.89 cm (3.5 in) from the aft of the lower airframe, where it interfaces with the thrust structure bulkhead. The rocket separates between the lower airframe and the thrust structure to allow for integration of the ADS but does not separate during flight and is riveted together. The coupler between these components is 17.78 cm (7 in) long and spans 8.26 cm (3.25 in) into the upper airframe, the maximum distance allowed by design due to the limited space provided by the 3 grain motor tube and placement of the fins. The coupler is permanently mounted 9.53 cm (3.75 in) into the short airframe tube of the thrust structure using epoxy.

The thrust structure, which is fully SRAD carbon fiber, contains the motor tube which is held inside the short body tube segment and boat tail. The motor tube is 59.69 cm (23.5 in) long and has an outer diameter of 10.21 cm (4.02 in). The short body tube segment is 27.94 cm (11 in). The boat tail is 23.50 cm (9.25 in) long and tapers from the diameter of the airframe to the outer diameter of the motor tube. There are 4 fins attached to the motor tube through the wall of the airframe/boat tail. The fins are 0.76 cm (0.30 in) thick, and the profile dimensions are highlighted in 5. The manufacturing and attachment of the fins is described in III.D.3. At the forward end of the motor tube, there is a SRAD carbon fiber bulkhead. This bulkhead serves as the thrust plate in which the motor interfaces and is mounted to for retention purposes. The motor is retained using a washer and bolt that threads through the thrust plate into the motor's forward closure. The ADS sits on top the thrust plate and is aligned and held in place by threaded rods that span from the thrust plate to the bulkhead forward of the coupler that houses the ADS. This system is used so that the ADS is not load bearing, as all of the loads will transfer through the coupler and threaded rods. The lower airframe, and coupler that lies within, have slots cut into them to allow for attachment of the ADS flaps from the exterior of the rocket. There are 4 slots for the pins that drive the flaps and 4 slots for where the flaps connect and hinge from the ADS.

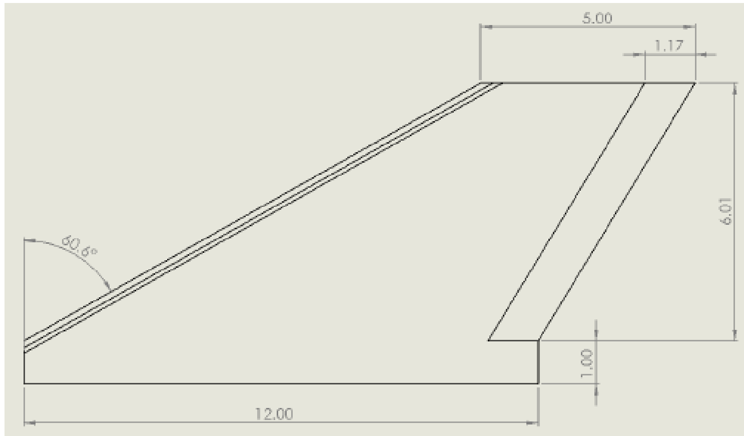


Fig. 5 Dimensions of Fins

On the exterior of the thrust structure are externally mounted patch antennas. Carbon fiber is conductive and does not allow for outgoing transmission from internal systems so the rocket uses external antennas on the thrust structure to have telemetry and tracking in the largely carbon fiber aft of the rocket. The antennas are arranged in four groups located between each set of fins, with three antennas installed in each group for a total of twelve antennas. The sets of antennas consist of GPS, 2.5 GHz, and 433 MHz LoRa, although the 2.5 GHz is not being used at competition due to new channel regulations. The details of the transmission out of these antennas is further highlighted in the III.G.5 section and the manner in which they are mounted is explained in III.D.5.

2. Airframe

The team manufactures the primary airframe structure using a combination of SRAD carbon fiber composite components. The upper and lower airframe sections, along with the short body tube integrated within the thrust structure, are fabricated through a wet layup composite process using 6k carbon fiber cloth wrapped around a 6-inch diameter aluminum mandrel. These components can be seen in 6

Prior to the layup, the mandrel is prepared with a mold release system to ensure proper removal of the cured composite tube. The mandrel is first coated with an even layer of petroleum jelly, followed by a wrap of wax paper, which acts as a barrier between the aluminum and the carbon fiber composite. Three layers of carbon fiber cloth are wrapped around the mandrel and thoroughly wetted using the West System epoxy resin to ensure complete fiber saturation and proper bonding between layers.

After the layup is completed, the mandrel is mounted on a rotating fixture and positioned above a space heater to aid in the curing process. The tube is allowed to cure for approximately four hours under continuous rotation to prevent resin pooling and promote uniform material distribution. Following the initial curing stage, each tube undergoes multiple rounds of post-processing. This process includes sanding the outer surface using a rotary hand sander to remove imperfections and ensure a consistent cylindrical geometry. After sanding, an additional layer of epoxy resin is applied to further smooth the surface and improve the aerodynamic quality of the airframe. This post-processing step is critical in ensuring that the finished airframe tubes closely match the idealized geometry used in aerodynamic simulations while also minimizing surface irregularities that could negatively affect drag performance.

Once post-processing is complete and the final epoxy layer has cured, the tubes are removed from the mandrel using a custom designed press system that allows the tube to be pushed off while preserving the structural integrity of the composite material. The airframe tubes are then trimmed to their final design lengths. Following trimming, additional structural and avionics integration features are added, including pressure relief holes, shear pin holes at separation interfaces, and internal coupler mounting regions.

The boattail is constructed using a composite layup process similar to that used for the airframe tubes; however, a custom mold is used instead of a cylindrical mandrel. The team designs and 3D prints a boattail mold that matches the aerodynamic geometry required for the launch vehicle. Once printed, the mold serves as the base structure around which the carbon fiber layup is performed. Carbon fiber cloth is wrapped around the mold and saturated with epoxy resin in the same manner as the airframe layups. After curing, the mold is extracted from the composite structure, leaving behind the finished carbon fiber boattail.

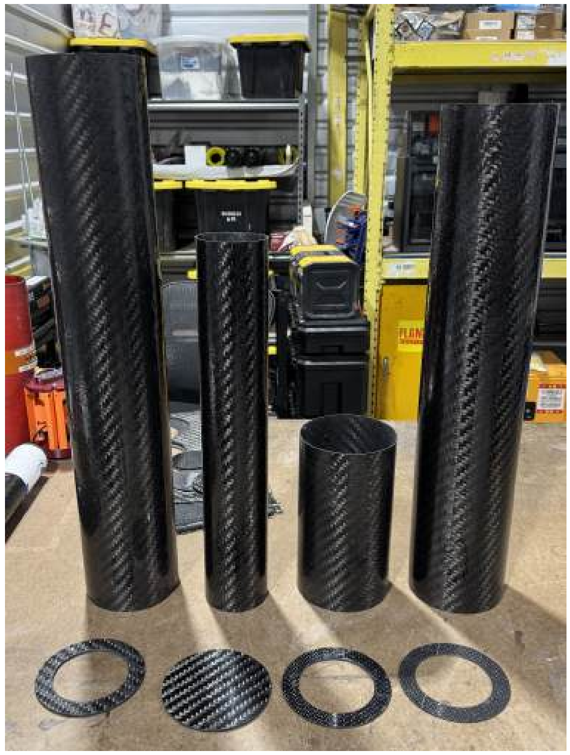


Fig. 6 SRAD Structural Components

3. Fins

The rocket fins are constructed using a sandwich composite structure consisting of a Nomex honeycomb core placed between single layer carbon fiber face sheets. The fin manufacturing process begins with the fabrication of the composite sandwich panel. A sheet of 3k carbon fiber cloth is placed on the same granite slab as before, covered with mylar, which acts as a non-adhesive barrier to prevent epoxy from bonding to the slab. The carbon fiber is then saturated with West System epoxy resin to ensure complete fiber wetting. A sheet of Nomex honeycomb core is placed on top of the wetted carbon fiber layer, and the layup is compressed between the two granite slabs and left to cure.

After the initial layup cures, the upper slab is removed, and a second sheet of carbon fiber is prepared on the granite slab using the same process. The partially completed layup, consisting of the carbon fiber and Nomex core, is then flipped onto the wetted carbon fiber layer. This forms the final sandwich structure with Nomex honeycomb enclosed between two carbon fiber face sheets. The completed layup is again compressed and allowed to cure.

Once cured, the composite panel is cut into the fin geometry using a Computer numerical control (CNC) water jet. Two fins are produced from each composite layup panel. The cut geometry includes gaps at the leading and trailing edges, where a 3D printed edge structure is temporarily adhered to the fin structure using super glue. After positioning these edge components, the entire fin is coated with epoxy resin and wrapped with an additional sheet of carbon fiber around the leading edge in a continuous “taco-style” configuration to create a seamless structural skin across the entire fin. To consolidate the layup, the fin is wrapped in a thin sheet of mylar and a cloth. The mylar serves as a mold release surface while the cloth absorbs excess resin during consolidation. The entire assembly is then placed in a vacuum bag and vacuum sealed to remove trapped air and compress the composite layers.

After the epoxy cures, the fin is removed from the vacuum bag and undergoes post processing. Excess carbon fiber is trimmed away, the surfaces are sanded using a rotary sander, and additional epoxy layers are applied as necessary to produce a smooth finish. The completed fins are then prepared for integration into the fin can assembly. The fins between each step of the described manufacturing process are shown in 7

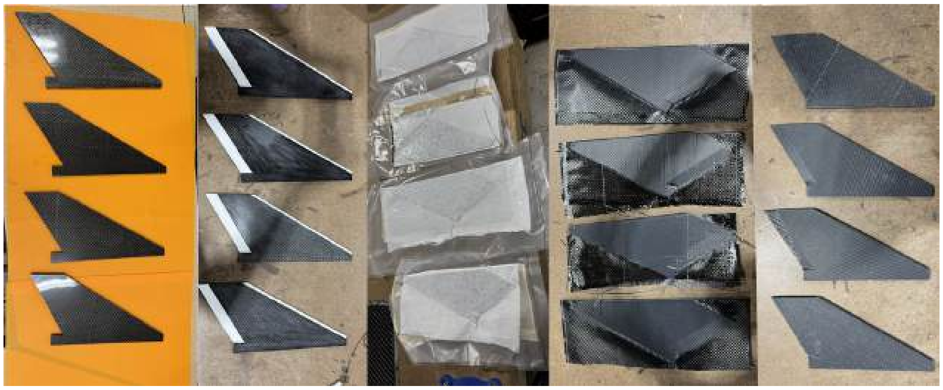


Fig. 7 SRAD Fin Manufacturing Steps

4. Internal Structural Components

In addition to the external structure, the aerostructures sub-team also manufactures internal architecture which is used to align components and house sub-systems. These components include the centering rings, bulkheads, and the motor tube.

The centering rings and thrust bulkhead, shown in 6, are manufactured from flat carbon fiber composite plates produced in house. The thrust bulkhead consists of two composite plates mounted together, with the lower one being a centering ring, allowing for the motor tube to adjoin with the bulkhead and be centered. These plates are fabricated using a layered composite layup process designed to produce rigid structural sheets that can later be machined into the required component geometries. The manufacturing process begins by placing a sheet of mylar on top of a polished granite slab. Mylar is used because epoxy resin does not chemically bond to its surface, allowing the cured composite sheet to be easily removed. The desired number of carbon fiber cloth for the given component is then placed on top of the mylar sheet. Centering ring layups consist of 5 layers of 3k carbon fiber, while the components of the thrust bulkhead are made up of 8 layers of 6k carbon fiber. Between each layer, the carbon fiber cloth is saturated with epoxy resin to ensure complete fiber wetting and strong interlayer bonding. After the layup is completed, a second sheet of mylar is placed on top of the composite layers, followed by an additional granite slab. This configuration applies uniform pressure across the composite layup during curing, helping to remove trapped air and produce a flat sheet with consistent thickness. The layup stack is left to cure for approximately 48 hours. Once cured, the plate is cut into the required centering rings and bulkhead geometry using a CNC waterjet.

The motor tube is manufactured using the same wet layup composite process as the primary airframe tubes. However, the layup is performed on a mandrel sized to match the diameter of the motor casing used within the thrust structure. The manufacturing follows the same steps of mandrel preparation, carbon fiber layering, epoxy saturation, and rotational curing. After curing, the motor tube undergoes the same post processing steps of sanding and epoxy finishing to ensure proper integration with the centering rings and the thrust structure assembly.

5. Component Assembly

Once all of the individual structural components have been manufactured or purchased, they must be assembled to form the rocket structure. As previously mentioned, the nose cone is COTS and requires no assembly. The couplers that make up the payload bay and recovery bay are COTS fiberglass 6” coupler material cut to the desired size. The couplers are both fitted with switchbands made out of COTS fiberglass 6” airframe material. These switchbands are adhered to the coupler sections using West System epoxy. The section of the lower airframe that houses the ADS contains a coupler as well. This coupler is epoxied into the lower airframe using West System epoxy. The upper airframe does not have any components connected to it and requires no additional steps after its manufacturing. The remaining component assembly goes towards the thrust structure of the rocket.

To begin the thrust structure assembly, the fins are attached directly to the composite motor tube to form the fin can structure. Fin locations are first marked on the motor tube to ensure accurate spacing and alignment. An alignment jig is used during installation orient fins perpendicular to the surface tangent. Once aligned, each fin is temporarily tacked into place using super glue. After all fins are in place, a cross laser level is used to ensure proper alignment of the 4 fins, and centering rings are epoxied into place on both sides of the fin assembly to aid in centering the fin can within the body of the thrust structure. After this step carbon fiber reinforcement patches are applied to permanently secure the fins to the motor tube. To prepare the bonding surfaces, the motor tube and fin tabs are sanded and cleared with isopropyl alcohol to improve adhesion. A layer of West System epoxy is applied to the prepared surfaces, and a sheet of 3k carbon fiber is placed so that it spans from the fin tab of one fin, across the motor tube, and up the tab of the adjacent fin. The carbon fiber is then saturated with additional epoxy to fully bond the structural reinforcement patch. Each reinforcement patch is applied individually, allowing sufficient time for the epoxy to cure between layups. During curing, the fin can is positioned so that the bonding surface remains horizontal to prevent resin from flowing and ensure uniform bonding. Once the fins are structurally bonded to the motor tube, the surrounding thrust structure components are integrated.

Before the fin can is mounted into the body of the thrust structure, the patch antennas must be adhered to the surface of the short body tube. Electrical tape is applied to any location where a patch antenna is to be placed to ensure the antennas do not short on the conductive surface. With the tape in place, the antennas are adhered in the desired location and small feed-through holes are drilled through the thrust structure so the antenna cables can be routed cleanly to the onboard electronics. The surface of the short body tube is then coated with a layer of epoxy to encase the antennas to the surface of the tube and eliminate the likelihood of antennas detaching during flight.

With the short body tube prepared for integration, four equally spaced slots are cut into the short body tube section and the boattail. These slots are the width of the fins and their length corresponds with how far the fins protrude cord-wise into the adjoining sections. The short body tube and boattail are dry-fitted over the fin can and adjusted until they fully slide together with minimal excess gaps. Small slots are also cut into the outer edge of the forward centering ring to allow for patch antenna wiring to feed out of the thrust structure. The state of the thrust structure at this point in the processes can be viewed in 8. An epoxy fillet is applied between the centering rings and the body tube/boattail wall that they connect to. Note that all epoxy fillets are silica-thickened West System epoxy. To permanently encase the fin can into the thrust structure body, external epoxy fillets are created along each fin root where it meets the boattail and short body tube surfaces. Additional carbon fiber patches are placed along the connecting seam between the short body tube and boattail. The coupler that connects the thrust structure with the lower airframe, during full rocket integration, is now slid into the forward end of the short body tube until it meets the forward centering ring. Channels are cut into this coupler to account for where the antenna wiring passes through. This coupler is permanently mounted into place with epoxy between the coupler and body tube as well as a fillet where it meets the centering ring. Finally the thrust bulkhead is placed on top of the motor tube and filleted on both sides. Prior to attachment, the antenna wires are threaded through the bulkhead, where they will eventually connect to the ADS that sits on top of the bulkhead.

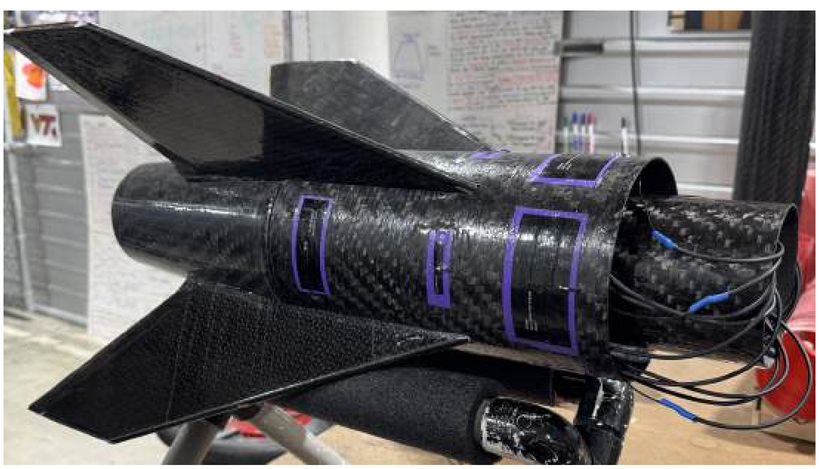


Fig. 8 Thrust Structure Assembly

6. Fin Flutter Analysis

Fin flutter is a critical failure mode that must be considered in the design of launch vehicle fins. During flight, high dynamic loads generated by aerodynamic forces can produce aeroelastic instabilities. As the fins lose dynamic stability, they can begin to vibrate, and these oscillations can grow in amplitude if not damped. These unstable vibrations can lead to deformation, material fatigue, or structural failure, where the fins shear off from the airframe.

To mitigate these risks, the sandwich style composite layup described in III.D.3 was used. This composite style, as opposed to a solid layup, increases stiffness and structural stability while minimizing weight, which improves resistance to bending and deformation. Tensile testing was completed on a MTS 4202 Instron machine in compliance with ASTM D3039 [3]. Two identical dog bone specimen of the fin material were tested. The results of this testing, shown in 9, was used to estimate the effective elastic modulus of the material to predict stiffness and aeroelastic response under load. The results show that the two tested samples produce similar stress–strain curves.

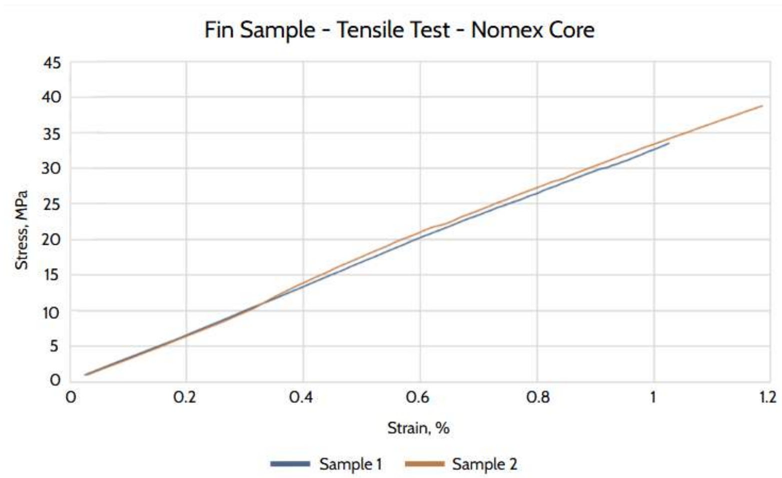


Fig. 9 Tensile Testing Results for Nomex Core Fin Material

The most conservative value of the Young's Modulus (E_{eff}) for the fin material was estimated to be 3.36 Gpa using the lowest slope on the curve. Using Equation 2 , $G_{eff}$was calculated assuming a poisson's ratio (ν) of 0.3.

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

To calculate the flutter velocity (V_f) Equation III.D.6 was used based on the known geometry and material properties of the fins, as well as the estimated atmospheric properties during flight [2]. In III.D.6 a is the speed of sound, AR is the fin aspect ratio, λ is the fin taper ratio, t is the thickness, and c is the root chord. p/p_0 is the ratio of air pressure at altitude to sea level pressure. The projected peak-velocity altitude of 1634 ft was used to determine atmospheric properties and temperatures at the launch site during the competition. The G_{eff} obtained for the fin material was utilized for this calculation

$$V_f = a \times \sqrt{\frac{G_{eff}}{\frac{39.3\times A^3}{\left(\frac{t}{c}\right)^3\times(A+2)} \times \left(\frac{\lambda+1}{2}\right) \times \left(\frac{p}{p_0}\right)}} \tag{3}$$

V_f was determined to be 790 m/s (2591.86 ft/s). Based on these results and a maximum expected vehicle velocity (V_{max}) of 302.67 m/s (993 ft/s), the Factor of Safety (FS) for flutter stability was found to be 2.6. This FS was calculated using 4 and is greater than the FS of 1.5 specified by the IREC requirements.

$$FS = \frac{V_f}{V_{max}} \tag{4}$$

7. Composite Tube Testing

In the interest of expanding analysis capabilities to all composite components, material properties are actively being obtained for the SRAD composite tubes used throughout the rocket. These material properties can later be used in Finite Element Analysis (FEA) to evaluate structures that are too large to test in physical fixtures.

Tensile testing has been performed on dog bone samples of 3 layer thick carbon fiber composite sheet to simulate the material properties of the composite tubes. The samples displayed a brittle failure/ultimate stress of approximately

382.5 MPa as well as a Young's Modulus of about 342.9 GPa. The results of the tensile testing is presented in 10. Using a factor of safety of 1.5 the design tensile yield stress was calculated as 255 MPa.

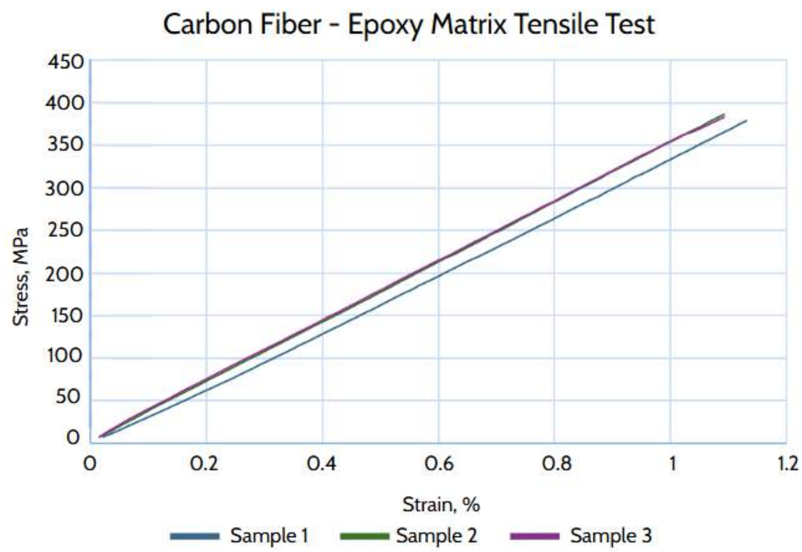


Fig. 10 Tensile Testing Results for Carbon Fiber Tube Material

Samples of the motor tube were also tested under compression using an MTS 4202 Instron machine. The airframe tubes are too large in diameter to test on the available equiptment so analysis was only conducted on the motor tube material. The motor tube samples were trimmed to size so that the height was the same as the diameter (10.21 cm or 4.02 in). Using the results plotted in 11, the tubes were found to have a yield stress of 43.4 MPa and an ultimate stress of 43.7 MPa. The design compressive yield stress was found to be 29.1 MPa.

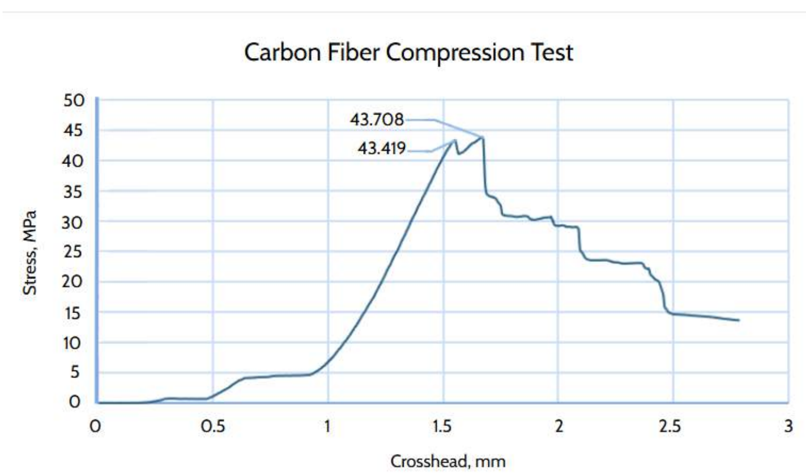


Fig. 11 Compression Testing Results for Carbon Fiber Tube Material

E. Recovery Subsystem

1. Overview

The 2026 recovery system uses a standard dual-deploy architecture with two separating joints in the airframe. Two parachutes are released during flight: a drogue at apogee and a main parachute shortly after.

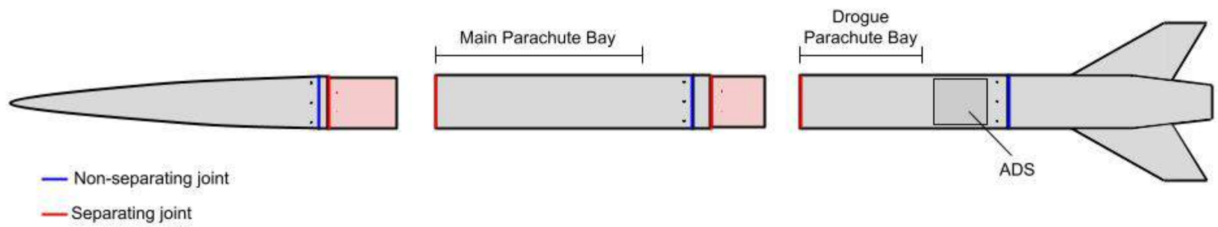


Fig. 12 Location of sperating and non-seperating joints.

As shown in Figure 12, the two separating joints are located aft of the Payload switchband and aft of the Recovery Bay switchband. The Main Parachute and Drogue Parachute Bays are secured with six and four shear pins, respectively, until blown apart by ejection charges. The three non-separating points, located forward of the Payload switchband, forward of the Recovery Bay switchband, and aft of the ADS, are secured for the entire flight with six rivets. At apogee, the primary altimeter ignites a black powder charge to deploy the drogue parachute. In the event that separation does not occur due to a high horizontal velocity, two backup charges are available. The secondary charge, controlled by the secondary altimeter, fires two seconds after apogee. The tertiary charge fires only if the primary altimeter detects a downward vertical velocity exceeding 200 ft/s. The primary altimeter deploys the main parachute at 800 ft AGL, and the secondary altimeter deploys the backup charge at 700 ft AGL.

2. Recovery Hardware

Each harness consists of a parachute, parachute protector, shock cord, three quick links, two U-bolts, and a swivel.

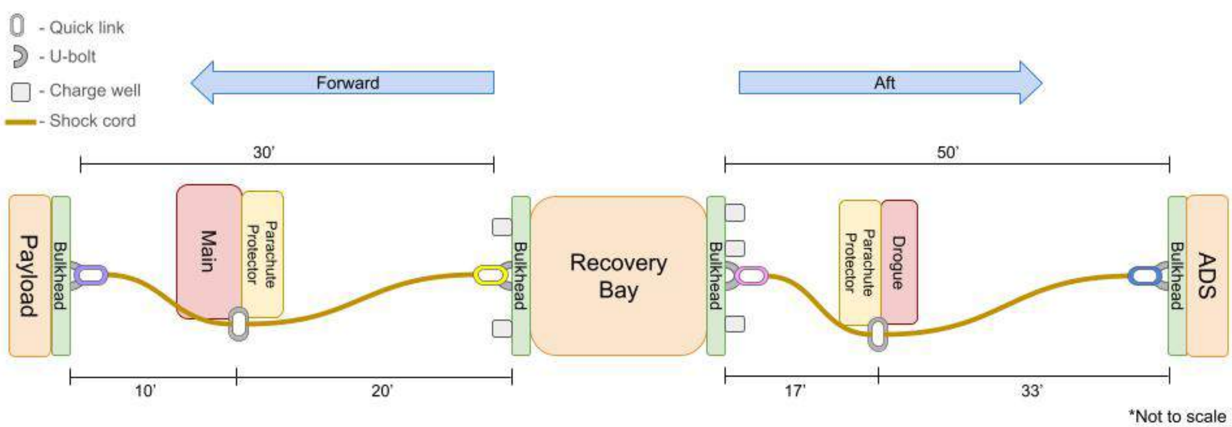


Fig. 13 Diagram of rocket recovery harness.

As shown in Figure 13 above, the shock cord connects the parachute to each separated part of the rocket. Quick links connect the shock cord to each bulkhead's U-bolt and the parachute's swivel. The drogue shock cord has a length of 30 ft, and the main shock cord is 50 ft. Both parachutes are located around one-third of the way down the line so that once separated, parts of the rocket do not make contact. Each quick link color in the figure above correlates to the quick link color used in the Launch Day Checksheet for ease of integration and to decrease risk of human error.

Each recovery hardware component and its material, load capacity, and manufacturer are listed in Table 5 below. All load capacities are taken directly from the component's manufacturer when available.

Table 5 Recovery System Component Specifications

Component	Material	Load Capacity	Manufacturer
Main Parachute	89 ft^2 Ripstop Nylon	32.6–70.6 lbs.	SkyAngle
Drogue Parachute	24 in. Ripstop Nylon	Not Available	SkyAngle
Shock Cord	$\frac{1}{2}$ in. Tubular Kevlar	5800 lbs.	Wildman Rocketry
Parachute Protector	18 in. x 18 in. Kevlar	Not Applicable	Rocketry at Virginia Tech
Quick Link	1/4 in. Stainless Steel	880 lbs.	The Home Depot
Swivel	Not Available	500 lbs.	Wildman Rocketry
U-Bolts	1/4 in. x 3-1/2 in. x 2 in. Stainless Steel	Not Available	The Home Depot

Although an exact load capacity for the U-bolts is not available, multiple flight tests have proved the strength is sufficiently high. The main parachute used for our design is a SkyAngle Cert-3 XL. The drogue used is a Recon Recovery 30 in parachute. The listed parachutes provide a descent rate of 82.0 ft/s under drogue and 16.3 ft/s under main. Apart from providing ideal descent rates, these parachutes were selected based on the strong over-the-crest shroud line construction, weight, and packing size, which was factored into the structural design of the rocket. The main parachute fits into its bay without excessive friction or bunching, which will ensure an ideal deployment and recovery of the rocket. Baby powder is utilized when packing the parachutes to prevent sticking and allows for a smoother parachute deployment.

3. Ejection System and Tests

Five total ejection charges are contained in the rocket during flight. Primary, secondary, and tertiary charges are located on the drogue bulkhead, and primary and secondary charges are located on the main bulkhead.

Table 6 Black Powder Measurements for Each Ejection Charge

Parachute	Level	Black Powder Amount (g)	Trigger
Drogue	Primary	4.0	Apogee
	Secondary	5.0	Apogee + 2 sec
	Tertiary	6.0	Descent rate > 200 ft/s
Main	Primary	5.5	800 ft AGL
	Secondary	6.5	700 ft AGL

All black powder charges use measured black powder packed with cellulose insulation and are ignited with electric matches. Ground testing is performed to determine the base measurement of black powder, then increased depending on how energetic the ground test was. Both parachutes are protected from charge blast with Kevlar blankets and cellulose insulation. Parachute bays are sealed with silicon to ensure proper separation and to protect Recovery Bay electronics. Upon post-flight recovery, altimeters are immediately disarmed to prevent unintended detonation of the tertiary charge.

4. Snatch Force Calculations

5. Recovery Bay

This year's Recovery Bay is moderately shorter than our previous iterations, sitting at about 9.6 inches tall. The system slides onto threaded rods at each of its four corners and attaches to a bulkhead on each end. The Recovery Bay features five inserts for batteries with a door screwed onto the structure to properly secure them. During launch, soft foam is placed within the battery inserts to reduce vibrations. Corner channels were incorporated to improve wire management. The recovery bay also has modular electronic mounts that can be mounted to heat set inserts on two sides with ease. The Recovery Bay is shown in Figure 16 below.

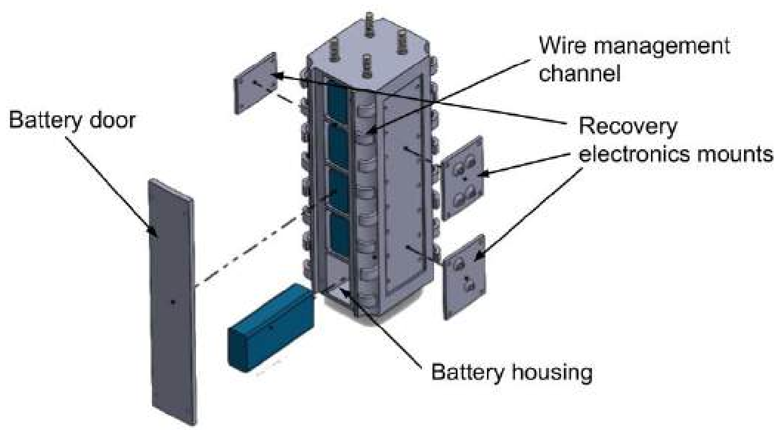


Fig. 14 Recovery Bay model.

6. Recovery Electronics

The active recovery electronics are separated across two bays in the rocket, due to its carbon fiber construction limiting Radio Frequency (RF) transmission ability. A pair of primary and secondary barometric altimeters, a Featherweight Blue Raven and an Altus Metrum EasyMini respectively, comprise the rocket's deployment system; both are mounted in the central recovery bay, along with the rocket's camera equipment. In the nose cone, on top of the forward Payload bulkhead, an additional (Featherweight) COTS and SRAD GPS tracker are mounted, both operating in the unregistered 915MHz frequency band with the ability to change channels on the fly as instructed by ESRA officials. Redundant telemetry on the 433MHz band is also transmitted by the ADSas detailed in its section below.

The recovery altimeters, as with all electronics in the rocket, are powered by combinations of 3.7v 3500mAh 18650 lithium-ion (li-ion) cells, spot welded together into varying configurations based on each system's necessary input voltage and desired total runtime. The combinations used for recovery are a 2S1P (2 cells in series, for an output voltage of 7.4v and a capacity of 3500mAh) for the EasyMini, and 1S2P (2 cells in parallel, for an output voltage of 3.7v and a capacity of 7000mAh) for the Blue Raven, Featherweight Tracker, and SRAD tracker Printed Circuit Board Assembly (PCBA) respectively. These battery packs are assembled and tested by hand, and put through multiple charge-discharge cycles for verification before being wrapped in heat-shrink and labeled according to their corresponding system. Each battery's connection to its system is broken at two points - an XT-60 connector for connection of the battery to the system, and a locking JST-SM connector for robust connection to an external MissileWorks screw switch which is connected inline such that it breaks the positive connection between the system and its battery. This arrangement allows for safe arming of each system at the pad once the rocket is vertical, and minimizes risk of unintentional deployment and unnecessary battery drain. Each altimeter is additionally connected via a labeled harness of leads to each black powder charge it operates on the forward and aft bulkhead of the recovery bay; an additional JST-SM connector allows for disconnection from the bulkhead for servicing, while the on-bulkhead connection is a screw terminal block that allows for easy insertion of the e-match igniters for each deployment charge. A diagram of the wiring for the GPS tracker module in the nose cone is depicted below, while a diagram detailing the wiring of the recovery bay is depicted in the following section detailing the camera system also contained in the recovery bay.

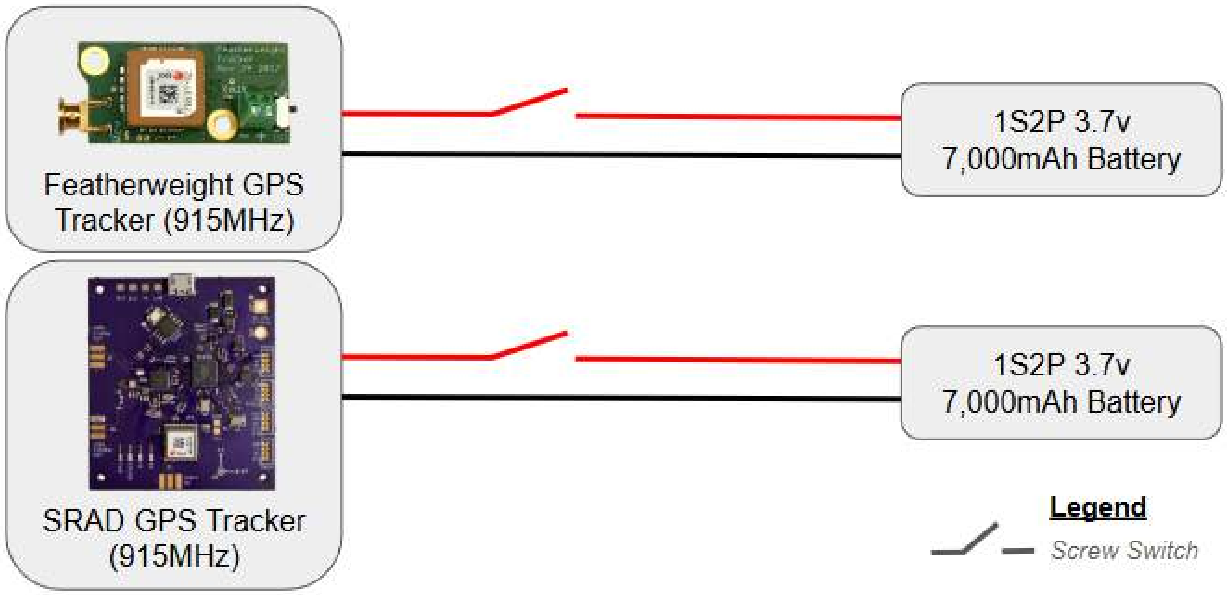


Fig. 15 Nosecone GPS Module Wiring Diagram

7. Cameras

The rocket's recovery bay, in addition to the primary and secondary deployment altimeters, contains two camera processing units - a RunCam Mini DVR unit for recording footage during flight, and a second for adding a Holybro On-Screen Display (OSD) unit providing a HAM technician callsign for 3.3GHz live video transmission to the ground through a 4W transmitter unit. This system runs off of a 4S (14.8v-16.8v) input to minimize current draw, but due to limitations with the form factor of the rocket's recovery bay, that 4S input is provided by two discrete 2S batteries (the same configuration used for the EasyMini secondary deployment altimeter) wired in series. This output is then split into two parallel supplies: a 5v buck regulator used to supply a Raspberry Pi Pico 1W microcontroller used for camera control, and directly into the 4W video transmitter, which provides 5v power to the OSD unit. Though supplied off the same battery, the onboard recorder/camera controller system and the video transmitter/OSD each have their own screw switch to allow for individual power sequencing, bringing the total screw switch count on the recovery bay switchband to 4.

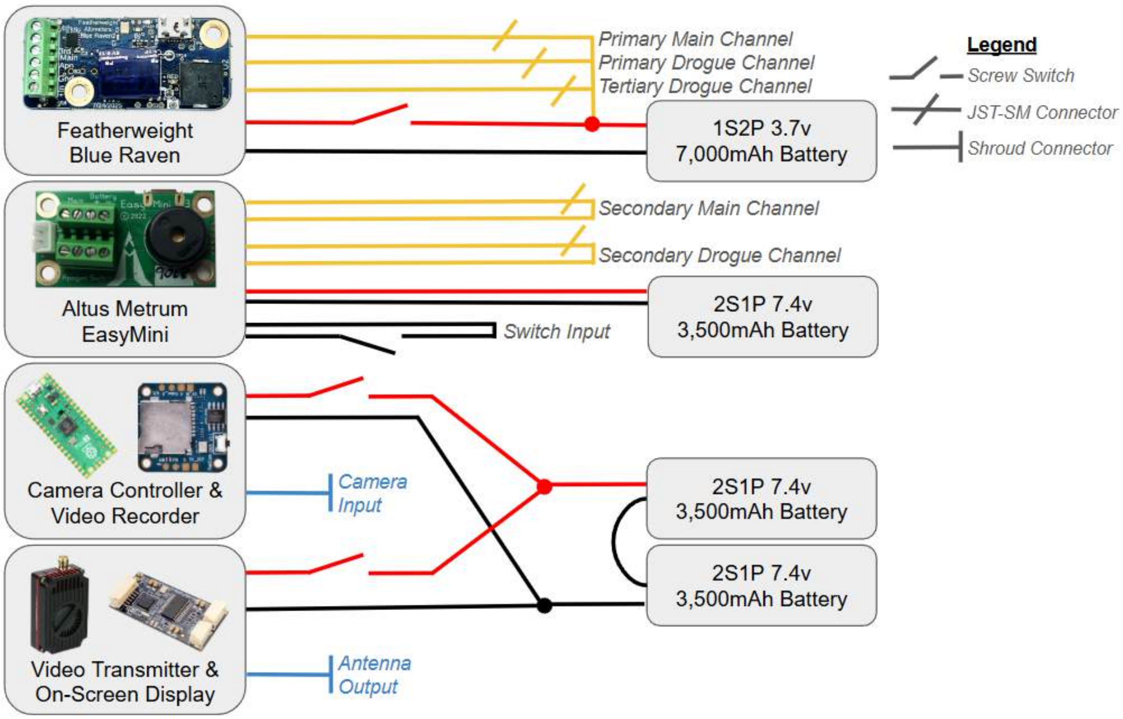


Fig. 16 Recovery Bay Wiring Diagram

To minimize drag induced by the shrouds containing the external camera system components, a single camera is used for both the onboard recorder and the live video transmitter. This camera signal is first passed into the DVR recorder unit, then connected from its dedicated output into the OSD for callsign display, and then finally into the video transmission for downlink to the ground during flight. During insertion of the recovery bay into its corresponding coupler, there are six total connections that must be made between the recovery and camera electronics and the coupler itself: 4 screw switches for each of the separate electronic systems mounted in the recovery bay, an SMA connector from an extension attached the externally-mounted video antenna to the video transmitter, and the 3-pin camera power and signal harness which gets connected to the DVR unit. Each of these connectors barring the video transmitter SMA connection is labeled on both sides for convenience, and all wires are bound to the recovery bay unless intentionally left dangling for coupler connection (i.e. screw switch cables).

F. Payload Subsystem

1. Overview

The payload is designed within a 3U CubeSat form factor, providing a compact structure for integrating the functional components. Modular architecture has been implemented to enable straightforward integration and maintenance of the individual electronic components, allowing for more flexibility during both the development and operation phases. The payload houses a dedicated measurement sensor suite, which is the primary function of the payload to collect data to be analyzed after the flight has been completed. To help ensure reliable performance from the power source for the avionics on board, insulation foam has been added to mitigate the vibrational effects that could loosen wires. Collectively, this design focuses on an adaptable payload to be entered into the SDL Payload Challenge.

2. Payload Structure

As mentioned above, the payload structure is built around a 3U CubeSat configuration, with the primary frame made from Acrylonitrile Butadiene Styrene (ABS) using 3D printing to enable rapid prototyping and design flexibility. Internal electronics mounting plates are also 3D printed, allowing for customized layouts and easy modification as the system evolves. Structural integrity is maintained using threaded rods running along the corners of the assembly, which secure the printed components and provide additional rigidity. The first U is left unenclosed to house the primary electronics, featuring multiple mounting locations to support future expansion or reconfiguration. The second unit (2 and 3U) is dedicated to the battery system, incorporating a fitted holder that allows the battery to slide securely into place within an enclosed compartment which is lined with insulation foam for protection and vibration reduction. This section also includes a removable access door, enabling convenient battery charging and maintenance without requiring full disassembly of the structure.

3. Payload Electronics

As mentioned above, the payload structure was designed primarily with modularity and ease of rapid prototyping of different electronic systems in mind. The core of the payload sensor suite is a Raspberry Pi Pico 1W, which was selected due to the team's experience with the RP2040 microcontroller around which it is based from previous versions of the ADS PCB which incorporated it. Utilizing this familiar platform means that the payload can be quickly modified on the fly, and sensors can be added or removed with only small changes to the 3D-printed mounting plates. Soldered directly to this Pico microcontroller is a dedicated 5v buck regulator, which is used to step down the input battery voltage to a level which the onboard Pico regulator can accept; this is also used to isolate the pico from the screw switch connection used to externally enable it, and the short current jump that can result when the switch is enabled.

For indication of a sign of life from inside the payload, a large red LED is soldered in such a fashion that it points out up against the inner wall of the payload coupler. This is used to verify that the electronics are functioning properly after the coupler has been sealed, as once fully integrated this coupler will be seated inside a carbon fiber body tube, removing the possibility of RF transmissions. The battery powering this LED and the rest of the payload electronics is a 3S3P 11.1v lithium ion pack, designed and assembled for an excess of battery life for the payload to act as a "black box" in the event of an in-flight incident.

As for the sensor suite itself, the payload intentionally was designed with separate sensors from those chosen for other PCB integration across the rocket. As each sensor is mounted on a breakout board and connected via JST-GH hookup cables, it was decided to use dissimilar sensors for comparison of their measurements with the onboard PCB sensors of the same class - this way, if any of them were determined to be faulty, an alternative would already be tested and ready to integrate through the backup breakout ports added to each PCB for this purpose. In flight configuration, the payload features a Bosch BMP581 Temperature and Pressure sensor in combination with an ICM-20948 9DoF IMU (including a rate gyroscope, accelerometer, and magnetometer). Between these two sensors, logged data includes temperature (for registering the testing environment, i.e. desert), barometric pressure and altitude to be compared against the barometric altitude on other rocket electronics, and IMU and magnetometer data from a single chip to compare to the measurements of multiple other sensor chips. Though simple in implementation, this means a wide variety of readings are collected to be compared against other rocket systems, and any and all of these systems can thus have the payload's breakout boards or duplicates of them added in the event of any detected faults during testing.

G. Active Drag System

1. Overview

The ADS is a core subsystem of the 2026 competition rocket, designed and integrated with the singular mission of achieving a precise apogee altitude of exactly 10,000 feet AGL. To accomplish this, the ADS deploys a set of four aerodynamic flaps during the coast phase of flight which increases the total aerodynamic drag force on the rocket. By modulating flap deployment in real time, the system reduces the rocket's vertical velocity, allowing fine-tuned altitude control that passive aerodynamics alone cannot provide. By responding to real-time flight dynamics rather than relying solely on pre-flight simulation, the ADS mitigates the risk of altitude error introduced by motor performance variability and atmospheric uncertainty.

The 2026 ADS is an evolutionary next design of the prior year's system. The overall mechanical architecture and flap deployment concept are retained, but the design has been revised to enhance effectiveness, modularity, and integration with the broader avionics stack. In particular, the electronics and firmware have been completely redeveloped around two new boards, a more capable sensor suite, and more precise data collection. The current design is expected to reduce the rocket's apogee by hundreds of feet relative to the no-drag baseline trajectory.

Fig. 17 Flap Actuation for ADS

The following sections address the four primary ADS subsystem areas: mechanical design of the flap assembly, manufacturing procedures, Computational Fluid Dynamics (CFD), the electronics platform, and the flight control algorithm.

2. Design

The ADS flaps measure 7.00 inches in length with a chord arc length of 3.75 inches and a width of 3.73 inches. These dimensions result in an effective surface area of 24.61 in^2 and total surface area of 61.26 in^2. The curved profile of the flap is designed to conform to the outer mold line of the rocket body tube, minimizing aerodynamic interference in the retracted position while maximizing frontal area when fully deployed.

The flap incorporates an internal aluminum guide slot (approximately 1 inch in channel length) with a small circular hole at the upper end sized to accept the mounting pin. The slot hole is positioned sufficiently high along the flap body to prevent the pin from disengaging during flight loading. This slot-and-pin arrangement, combined with bolted attachment at the top of the ADS support columns using internally mounted lock nuts, constitutes the primary mechanical retention system. The internal lock nuts allow external mounting of the flaps to improve integration. The design ensures that the flaps cannot detach from the rocket even under high aerodynamic loading or shock events.

Fig. 18 Key Dimensions of ADS flaps (GET RID OF TOP FIGURE NOTE)

Flap actuation is accomplished through a rack-and-pinion drive system housed between the two lower disks of the ADS structure. As the servo motor rotates, the pinion gear drives the racks radially outward or inward, translating rotational motion into the linear motion required to extend or retract the four flaps simultaneously. The racks and associated threaded rods were custom-fabricated by an outsourced company using metal additive manufacturing with aluminum to achieve the combination of high strength and tight dimensional tolerances required to withstand flight-induced aerodynamic and inertial loads.

To prevent premature deployment during the high-acceleration boost phase, the ADS employs a dual-redundant locking strategy. A mechanical lock is implemented internally within the ADS housing, providing a fail-safe passive constraint on flap motion independent of any electronic signal. Additionally, the servo motor incorporates an electronically controlled lock driven by the flight computer, which remains engaged until the state machine confirms that the coast phase has begun. This two-layer approach ensures flap deployment cannot occur due to vibration, electromagnetic interference, or software anomaly during motorburn.

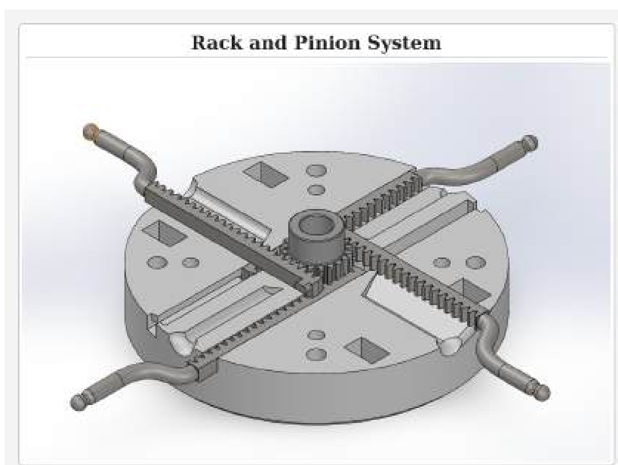


Fig. 19 Rack and pinion system for ADS

The top sandwich disk of the ADS rack-pinion assembly serves a dual structural and electronic function. Structurally, it interfaces with four bolted columns that carry the flap retention hardware, including the top-side locking nuts. Electronically, the disk provides the mounting surface for all onboard avionics and is capped by a top plate that secures the two ADS boards in place.

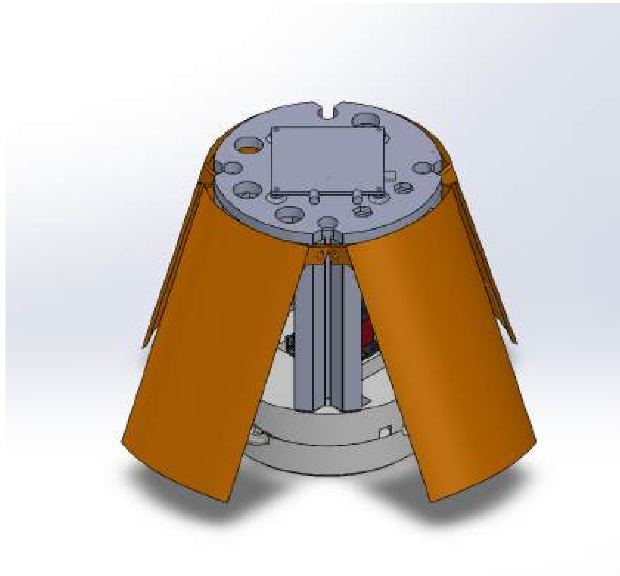


Fig. 20 Full assembly of ADS Computer Aided Design (CAD) model

3. Manufacturing

The flap bodies are constructed using a wet layup carbon fiber process in a custom 3D-printed mold. Each flap comprises five plies of carbon fiber cloth laminated with a thin epoxy layer applied between successive plies. Both the inner and outer surfaces of the mold are coated with petroleum jelly as a release agent to prevent the cured composite from bonding to the tooling.

The aluminum 6061 guide slot insert is embedded within the laminate between the second and third carbon fiber plies, with the slot's extruding geometry accommodated by trimming the overlying plies to fit. Once all five layers have been laid up and the top half of the mold placed, the assembly is clamped and allowed to cure for a minimum of 24 hours at ambient temperature. Following demolding, each flap is trimmed to its final plan dimensions, holes are drilled at the attachment points on each side, and all edges are thoroughly sanded to the required finish. Manufacturing steps and details are outlined in Table 7.

Table 7 ADS Manufacturing Process

Manufacturing Step	Process Detail
Mold	Custom FDM 3D-printed (PLA), petroleum jelly release agent
Layup	5-ply woven carbon fiber, wet epoxy between each ply
Slot Insert	Al 6061, metal 3D printed, positioned between plies 2 & 3
Cure	Clamped, 24-hour ambient cure
Post-processing	Trim to dimension, drill attachment holes, sand all surfaces
Slot Fabrication	Laser-cut and bent on steel edge

4. CFD

To determine the influence of the ADS on the aerodynamic characteristics of the launch vehicle, several CFD models were created using Ansys Fluent. The algorithm of the ADS utilizes the Coefficient of Drag (Cd) of the launch vehicle to determine the necessary ADS deployment. Thus, CFD simulations were run for five different ADS deployment models over many different air speeds to find the rocket's total Cd at these various conditions. The five models are of the rocket's outer surface with the ADS flaps deployed at 0°, 5°, 10°, 15°, and 20°. The simulations were run at air speeds ranging from 50 to 300 m/s, tested in increments of 50 m/s. A large domain around the rocket was simulated to ensure no adverse impacts from the boundary layer. The enclosure was 5 times the rocket to all sides and in front, and 10 times the size in the back. Mesh refinement of 0.7 meters was used.

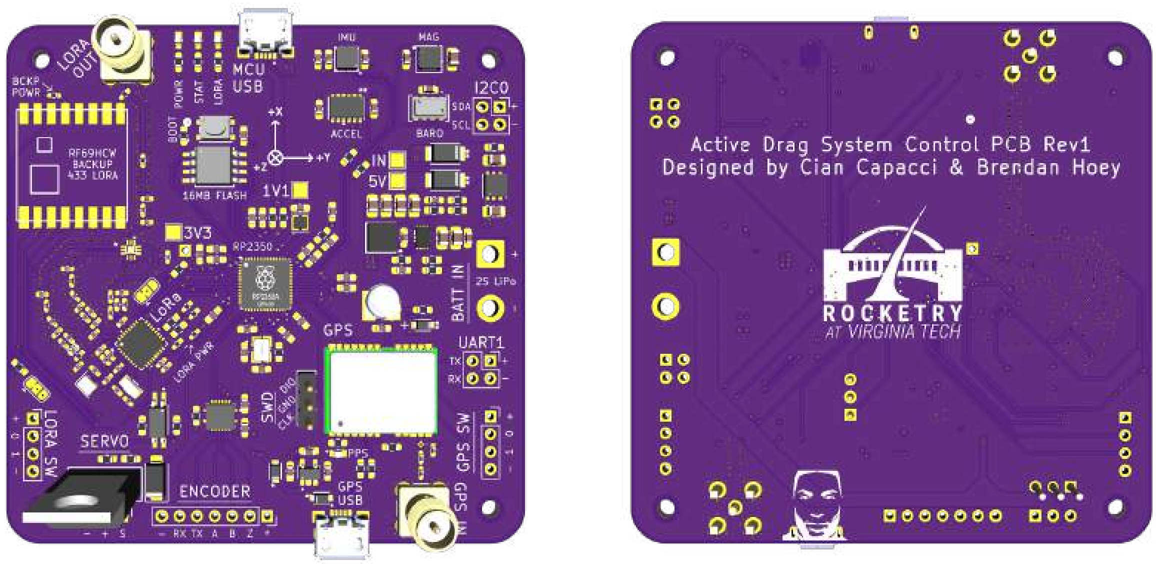
CFD simulations were conducted in Ansys Fluent using an omega-SST model and assuming air as an ideal gas. The inlet of the domain was simulated to have a uniform air velocity, and the exit a uniform atmospheric pressure. Simulations were run until all convergence criteria were met.

The simulations were run to obtain the total drag force on the rocket. Cd values were obtained via the drag equation using the total drag produced by the rocket, fixed fins, and ADS flaps, and the projected area of the rocket and fixed fins, but not including the ADS. This was done in order to simplify comparisons between the ADS deployment states.

Due to the complexity of the geometry and the high computational time of these simulations, many simulations have not been completed yet. Work on the CFD simulations will continue to be done prior to the competition to ensure the rocket has a usable ADS.

5. Electronics

As with previous years, a custom 4-layer PCBA was developed with the purpose of acting as the primary ADS flight computer. The flight computer features a sensor suite commonly found used in commercial recovery altimeters, with additional circuitry for servo power management, GPS and LoRa telemetry, and closed-loop encoder feedback from the actuator. This is a continuation of the development from previous years, with a number of upgrades in this iteration - including a distinct “switchboard” PCBA affixed to the underside of the ADS mounting plate for selection of the desired antenna used for GPS and LoRa telemetry by the ADS from the multiples of each mounted externally on the thrust structure by the ADS.



(a) Front Side

(b) Underside

Fig. 21 ADS Control PCB w/ RP2350 Microcontroller & Onboard GPS/LoRa Radio

Firstly, the sensor suite used by the ADS PCB is mostly unchanged from the previous iteration barring a new IMU - a TE Connectivity MS5607 Barometric Pressure sensor is used for altitude measurement, followed by an Analog Devices ADXL375 3-axis MEMS accelerometer rated to ±200G, and finally a Memsic MMC5983MA magnetometer. The previous iteration’s TDK-Invensense IIM-42653 6-axis IMU has been replaced by a TDK-Invensense ICM-40609-D 6-axis IMU, mainly due to supply limitations. As for the microcontroller, this iteration improves upon its predecessor by upgrading from a Raspberry Pi RP2040 Microcontroller to its successor, the RP2350, featuring dual ARM Cortex-M33 processor cores. This change was made for multiple reasons - primarily due to its inclusion of a dedicated Floating Point Unit (FPU), in addition to multiple improvements to sleep capabilities and fixes to errata in earlier versions that allow for significantly lower power draw. This microcontroller is connected as in the previous iteration to a 16MB flash chip, which is used for logging flight data and storing code for the ADS algorithm.

All sensors connected to the microcontroller communicate via a shared Inter-Integrated Circuit (I2C) bus, and are polled at 500Hz using student-developed drivers. The MS5607 barometric pressure sensor operates, where 24-bit pressure is sampled (in millibar) and compensated with local temperature (in °C). This pressure is converted into altitude (in meters) via a lookup table pre-generated by a script based on the International Standard Atmosphere. The ADXL375 returns 16-bit acceleration data in Gs, which is sampled in all 3 axes; this is roughly the same as the MMC5893MA, which returns 16-bit magnetic field strength data in Gauss. Finally, the ICM-40609-D IMU returns both 16-bit acceleration and 16-bit rotational speed data sampled for all 3 axes, which are measured in Gs and Degrees per Second respectively. The ADXL375 serves as a wider-range counterpart to the IMU, capturing forces that may exceed its more sensitive range that are used to augment state machine transitions and data collection during flight. The MMC5983MA records magnetic field data specifically for ground-truth orientation estimates, and is used for axis assignment and filter initialization while on the rail before flight and heading estimates during it. Finally, the barometric altimeter serves as the primary ground-truth source of altitude data, being used for state machine transitions and actuator lockout in accordance with Design Test and Evaluation Guide (DTEG) regulations.

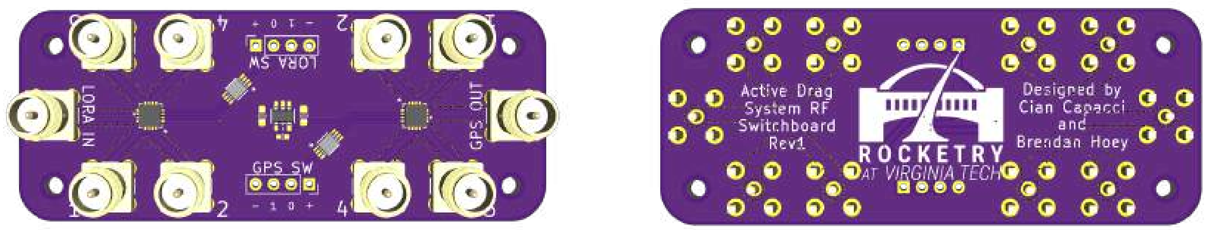
As per previous iterations, the actuator servo for the ADS is a GOTECK GB5009MG servo featuring a 270° range. This servo receives the same 3S battery supply at 11.1v nominal that is used as the power regulator input to the ADS PCB itself, and thus requires a support circuit for supply passthrough. This is comprised of two parts: an optocoupler chained to an N-channel power MOSFET, which via connection to a General Purpose Input/Output (GPIO) pin on the RP2350 allows for discrete control of when the actuator is connected to power at all, in addition to a diode on the pulse width modulation (PWM) signal pin which allows for backfeed-protection for the microcontroller in the event of a hardware failure. In addition to this system, this iteration appends a SameSky AMT-132S quatrature encoder mounted to the ADS actuator shaft; this, in conjunction with a 5v-3.3v level shifter for communication with the RP2350, allows for closed-loop feedback from the servo stack, which the ADS will log and use for verification of the desired deployment percentage during flight.

In addition to the new encoder, this iteration also includes a number of upgrades to the previously offboard telemetry system integrated into the ADS. Firstly, a u-Blox NEO-M8Q integrated GPS unit is mounted on the board with a dedicated USB debug port, a discrete backup battery, and an onboard SMA port for GPS antenna connection. This module is compatible with multiple GPS constellations, including Galileo, GLONASS, GNSS, and BeiDou. It communicates over a standard Universal Asynchronous Receiver/Transmitter (UART) bus with the RP2350, and additionally includes an onboard Low-Noise Amplifier (LNA) in the signal path for improved reception.

Alongside incoming GPS telemetry, the ADS also now features a primary and a backup method of transmitting 433MHz telemetry to the ground, both of which feature reconfigurable frequencies as instructed by ESRA. The primary method is an onboard impedance-matched network based around the LR1121 LoRa Modem. The supporting circuitry for the LR1121 is based on the reference design from Semtech's LR1121DVK1TGKS, which is available through Semtech's website. The reference design is advertised for 490MHz, which was a concern during initial stages of development and warranted further attention to match the desired 433MHz band. After creating the impedance-matching and filtering network in LTspice, the design was swept in simulation from 100MHz to 3GHz and plotted the output voltage over the input voltage - the results of this sweep can be seen in Appendix G. These filtering segments of the supporting circuitry are meant to notch the 2nd harmonic of the fundamental frequency. It was found that the notch filter centers at 930MHz, which shows that the design is optimized towards 465MHz rather than the 490MHz it is advertised as. The RF output of the LR1121 is preceded by a pi-filter, which serves to attenuate any high-frequency harmonics in addition to the 2nd harmonic. Semtech does not provide the optimum load impedance of the internal power amplifiers, so designing an impedance matching network with incorporated filtering would require levels of testing and knowledge the team doesn't possess.

After the impedance matching network, the RF signal traces from the LR1121 run into a SP3T switch designed by Skyworks. This switch takes two select bits to choose between the high power Power Amplifier (PA) path, the low power PA path, or the receiving network path. For our application, the switch will be configured such that the RF signal output is always generated by the high power PA. This is such that the maximum transmission power of 22dBm (158mW) is achieved. The layout of this design requires great attention to detail in the placement of traces and components. All traces longer than 5% of the fundamental wavelength are designed as 50ohm grounded coplanar waveguides. This is the second iteration of this radio system, and it has significantly improved from its predecessor, but as a backup in the event of integration difficulties, the PCB also features a drop-in footprint for a HopeRF RFM69HCW 433MHz transmission module with 100mW of max output power. Both systems are connected to the same SMA port via solderable jumpers for selection, and communicate with the RP2350 over a shared Serial Peripheral Interface (SPI) bus. A set of two solder jumpers connect the chip-select pin on this bus to either the GPIO pin or the power supply rail (an "inactive" signal), allowing for dedicated selection of the desired system with little hardware modification.

Though the ADS only features a single SMA port for incoming GPS and outgoing 433MHz LoRa, there are 4 antennas mounted around the thrust structure; thus, the system needs a mechanism of selecting between them during flight and once the rocket has reached the ground. The solution designed for this is a separate "switchboard" PCB that is mounted on the underside of the ADS mounting plate, featuring 10 total SMA ports: 2 for direct connection to the upper control PCB, and an additional two sets of 4 for connecting the set of 4 GPS antennas and 4 LoRa antennas. A pair of PE42641MLBD SP4T RF switch IC chips are used to select between the 4 possible antennas for each connection, the desired antenna selection being provided over a pair of 4-wire jumpers each containing 2 select bits set by the control PCB during flight.



(a) Front Side

(b) Underside

Fig. 22 ADS Switchboard PCB w/ GPS and LoRa 4-Way Switches

As per previous designs and the rest of our rocket electronics, the ADS control and switchboards are powered by a custom battery pack, specifically in a 3S2P configuration with a nominal voltage of 11.1v. An onboard switching regulator stage shifts this down to 5v for usage by the GPS and encoder, and a second LDO regulator stage further drops this to 3.3v for usage by the RP2350, all onboard sensors, and the onboard LoRa systems. Given the two pairs of 3,500mAh cells, the ADS will have a nominal battery capacity of 7,000mAh, which should give it several days of runtime after landing, granting a wide window for telemetry packets to be received on the ground for maximum chance of recovery.

6. Algorithm

With the multiple upgrades made to the ADS control electronics this year, its algorithm has remained largely unchanged from the previous iteration - though multiple improvements have been made to its implementation. Firstly, as per previous implementations, the control algorithm running on the ADS is implemented in FreeRTOS in C++ - this allows for dedicated coordination between time-sensitive tasks, and discrete control of interrupts and other hardware events necessary for the algorithm to function properly. The RP2350 microcontroller features two separate processor cores, which are both utilized: the first core is responsible for all sensor polling and filter math execution during flight (i.e. all connections to onboard peripherals), while the second is responsible for all aggregate data handling and logging to the onboard flash memory.

Upon power enable (no other initialization or user intervention is necessary), the RP2350 initializes all of its communication buses, then uses them to properly initialize each of the connected peripherals - each sensor is initialized via varying numbers of commands and register writes over I2C, the GPS is enabled and configured over UART serial, and the connected LoRa radio system is initialized over SPI. The first major algorithm initialization is the measurement of a "ground altitude," which is taken by polling the barometric altimeter after it is initialized. Assuming power is enabled on the rail with the rocket vertical, this is stored as a comparison value for onboard filters, and then used to configure an interrupt on the barometric sensor for a detected 30-meter increase in measured altitude. Combined with a second interrupt on the onboard IMU configured to trigger on a >2.5G shock on the Z-axis, these signals are used to notify the system that a launch event has occurred, and to adjust the ADS's behavior accordingly.

The ADS algorithm implements a simple finite state machine tracking the phases of the rocket's flight, which is used to ensure compliance with DTEG for operation of its single actuator only during appropriate phases of flight and under specific conditions. The phases of flight tracked by this FSM are, in order: [Pad → Boost → Coast → Apogee → Recovery → End]. As aforementioned, the Pad → Boost transition is triggered by an interrupt on the barometric altimeter and IMU sensors; while on the pad, the ADS will constantly be overwriting a small circular memory buffer with log data, and on this transition, the last five seconds stored in the buffer will be dumped to the flash rather than all of the data collected at the pad for capacity conservation. A hardware timer is initialized for 10% longer than the expected motor burn time (3.2s for the M2400T), and the end of this timer is combined with a second IMU trigger for lower than 0.9Gs of acceleration on the thrust axis to trigger the end of the Boost phase and the beginning of the Coast Phase. This phase physically ends at the peak of the rocket's flight, and as such, the ADS will use a transition in filtered vertical velocity from positive to negative to transition from Coast to the Apogee phase. This is immediately followed by a transition to the Recovery phase, as the first recovery event is expected to occur immediately following apogee; the rocket will remain in this phase for all of the descent. Finally, the ADS will listen for a stable detected altitude for 3 or more seconds; when this occurs, the ADS will transition to the End state, powering down most of its systems, and configuring its antennas to begin listening and transmitting using whichever antenna is facing upright in the landing configuration based on recorded IMU data.

The way this state machine is implemented is designed specifically to limit the actuation potential for the servo to specific flight conditions. When on the pad and on the ground (i.e. in the Pad or End states), the ADS will cut power to its actuator servo entirely; during all other phases of flight than Coast, it will enable power to it, and constantly feed it a "zero" signal to fully retract the flaps. The only time the ADS is both powered and told to actuate is during the Coast phase - the desired deployment angle is computed in real time at 100Hz during this phase using a combination of onboard sensor data and precomputed drag values. A two-stage Kalman filter has been implemented for this purpose: the first stage integrates IMU accelerometer and gyroscope data with magnetometer readings to estimate the rocket's attitude/heading, and the second uses this attitude to rotate measurements to the earth frame and integrate them into an estimate of vertical altitude and velocity when combined with barometric measurements. These filtered values are then used to project forward an expected apogee, which, if over 10,000ft, is then fed into a formula to calculate the necessary drag coefficient of the rocket to hit 10,000 exactly. Before flight, many CFD simulations of the rocket at various altitudes, velocities, and deployment angles of the ADS flaps; these data points are then integrated into an interpolated function used to calculate the desired deployment percentage as a function of altitude, velocity, and desired drag coefficient, and this function is then implemented in the ADS to provide the desired deployment angle to the actuator servo. Notably, the output of this function is clamped from 0% to 100% to avoid any interpolation errors, and the system will only attempt active control if it is confident in the data feeding its filter math - if there is ever a persistent error in any sensor reADS for more than a few cycles, or if the rocket is detected to be at an attitude greater than 30%, the flaps will be fully retracted.

IV. Conclusion and Lessons Learned

For the 2026 International Rocket Engineering Competition 10k COTS category, Rocketry at Virginia Tech has designed and manufactured a launch vehicle that features a precision altitude control active drag system, a near fully SRAD carbon fiber composite airframe, surface-mounted GPS antennas, and much more. In the process of designing one of the team's most innovative projects to date, Rocketry at Virginia Tech aimed to improve on past iterations of subsystems as well as lay the groundwork for future team members to expand on this work for future successes.

Throughout this year, the team has begun experimenting with making 2-layer PCBs in-house, how to more accurately simulate flights, and how to design for manufacturing and integration. Additionally, since the team underwent a full leadership restructuring last year and doubled its size this year, there were many new lessons learned for how to run operations smoothly. Maintaining rigorous standards for members and clearly communicating expectations was very important for the leads, and having incredibly dedicated members allowed the team to succeed. Finally, with so many new members, the team had to find new ways to document knowledge, including making new training documents, properly maintaining online drives, and hosting information sessions for members when necessary.

With the help of the team's university mentors and generous alumni network, the team was able to construct one of its most innovative projects to date and looks forward to pushing the envelope in the future. Going forward, the team seeks to continue improving its manufacturing, design, and analysis to do more than just build a high-powered rocket, but also to expose its members to industry standard engineering practices by giving them the opportunity to apply what they've learned in the classroom to one of Virginia Tech's most complex student engineering projects.

Appendix A: System Weights, Measures, and Performance Data

Table 8 Basic Rocket Information

Stages	**1**
Length	117"
Airframe Diameter	6.17"
Number of fins	4"
Fin Semi-span	6"
Tip Chord	5"
Root Chord	12"
Fin Thickness	0.3"
Vehicle Structure Weight	32.46 lb
Propellant Weight	8.14 lb
Motor Case Empty Weight	6.08 lb
Payload Weight	4.42 lb
Liftoff Weight	51.1 lb
Center of Pressure (from nose)	86.7"
Center of Gravity (from nose)	74.8"

Table 9 COTS Aerotech M2400T Characteristics

Characteristic	**Quantity**
Manufacturer	Aerotech
Designation	M2400T
Diameter	98mm
Length	23.5"
Total Weight	14.22 lb
Prop Weight	8.14 lb
Avg Thrust	2,400 N
Initial Thrust	2,480 N
Max. Thrust	3,402 N
Total Impulse	7,717 Ns
Burn Time	3.2 s
ISP	213 s
Motor Case	98/7680
Propellant	Blue Thunder

Table 10 COTS Altimeters and Specifications

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

Table 11 COTS Parachutes and Specifications

Parachute Data	Type	Black Powder Charges (Primary, Backup)	Deployment Altitude (Primary, Backup)	Descent Rate
Drogue	Recon 30"	4g/5g/6g	Apogee / Apogee+1s / Apogee+200 ft/s	82 ft/s
Main	SkyAngle Cert-3 XL	5.5g/6.5g	800ft / 700ft	16.3 ft/s

Table 12 Shock Cord and Linkages

Shock Cord + POA Data	Type	Test Strength	Length	Supplier	Knots Used	POA Hardware
Drogue	3/8" tubular Kevlar	3,600 lb	50’	Wildman	Bowline	1/4" quick link + barrel swivel
Main	3/8" tubular Kevlar	3,600 lb	30’	Wildman	Bowline	1/4" quick link + barrel swivel

Appendix B: Project Test Reports

Recovery System Testing - Ejection Testing

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

Recovery System Testing - Ejection Testing Results

Testing determined minimum values of 3 grams for drogue separation and 4 grams for main separation. Shear pin configuration of 4 x 4-40 pins in the drogue parachute section and 6 x 4-40 pins in the main parachute section was also validated.

Charge selection for flight testing was completed using the ground test values as minimums. The primary charges were increased by 1 gram and 1.5 grams over the test value (4 grams for drogue primary and 5.5 grams for main primary) with the redundant charges being further increased. Charge sizing escalates in order of redundancy. Table 13 below includes final charge sizing information for all deployment events.

Table 13 Final Charge Sizing

Event	Primary	Secondary	Tertiary
Drogue	4g	5g	6g
Main	5.5g	6.5g	N/A

Electronics Power Draw Testing

All electronic systems are powered by combinations of 18650 lithium-ion (Li-Ion) battery packs and as such should be evaluated to determine the expected power duration. Table 14 details each onboard electronic system and its associated power consumption and battery information. Additionally listed is the expected duration (calculated using equation 5) of the battery given a constant draw of the maximum observed current draw as a worst case scenario.

$$Battery\ Duration\ (hrs) = \frac{Battery\ Capacity\ (mAh)}{Load\ Current\ (mA)} \tag{5}$$

As can be seen, all critical electronics (e.g. altimeters, payload, and tracking electronics) are able to survive for more than 24 hrs to accommodate any unforeseen long periods between launches at competition.

Flight Testing

Flight testing was used to further validate the vehicle design and onboard systems. Narratives of each test flight are included below and Table 15 shows a brief list of their purpose and results.

Flight Testing - Test Launch 1

The first test launch featured the full 2026 vehicle with varying degrees of subsystem functionality. The flight featured the team's competition motor, the M2400, and all flight critical components were tested, but many other projects were not ready in time. Namely, the ADS, payload, and ground station were not fully operation by this point. The recovery system was fully functional and the rocket's recovery was nominal. Overall, the flight was a full success.

Table 14 Electronics' Power Consumption

Electronic System	Voltage (V)	Maximum Current (mA)	Battery Capacity (mAh)	Expected Duration (hr)
Featherweight GPS Tracker	4.2	106	7,000	82.4
Featherweight Blue Raven	4.2	200	7,000	35
Camera System (Recording + Transmitting)	14.8	980	3,500	3.57
Altus Metrum EasyMini	8.4	10	3,500	350
ADS without Servo Operation	8.4	145	10,500	31.1
ADS with Servo Operation	8.4	921	10,500	5.7

Table 15 Test Flights

FLIGHT	DATE	MOTOR	SYSTEMS TESTED	RESULT
1	02/28/26	M2400	Vehicle structure, recovery system	Success
2	04/11/26	M2400	Full Spaceport configuration, mass reduction, full ADS and payload	Success

Flight Testing - Test Launch 2

The second test launch saw a full IREC 2026 configuration rocket with all systems present as they will be for competition. Nearly all systems were functional, recovery was nominal, the onboard video was successfully received from the ground, and the GPS system was able to transmit positioning data all the way to touchdown. However, the ADS did not successfully deploy. This was due to an integration issue with the newly selected IMU discussed in the ADS section. Additional ground testing has been conducted to resolve this issue. Overall, the flight was considered a success.

Appendix C: Hazard Analysis

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

Appendix D: Risk Assessment

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

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

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

Competition Launch

Team 50 Rocketry at Virginia Tech

Launch Vehicle *Carbo Fibezilla*

International Rocket Engineering Competition 2026

Flyer of Record: Bob Schoner

Launch Location: Midland, Texas

Pre-Launch Day Operations

Action	Executor Initials	Witness Initials
Assemble the motor according to the provided Aerotech motor assembly instructions		
Insert motor into aft booster section		
Secure motor with forward retention bolt		
Assemble and install ADS (See section below)		
Measure out black powder into two gram vials Bundle based on the following charge sizes and label: DROGUE PRIMARY: 4.0 G DROGUE BACKUP: 5.0 G DROGUE FAILSAFE: 6.0 G MAIN PRIMARY: 5.5 G MAIN BACKUP: 6.5 G		
Charge camera batteries		
Charge payload battery		
Charge four recovery batteries		
Charge ADS battery		
Charge Featherweight receiver		

Active Drag System Assembly

Action	Executor Initials	Witness Initials
Check ADS battery voltage with the multimeter and ensure it reads 8.4V nominal.		
Check that the ADS servo is unrotated		
Connect female JST to male JST from LoRa (white) board to GPS (red) board.		
Feed wires through ADS top plate		
Connect battery terminal to RP2040 Micro (Purple) board.		
Connect screw switch JST to female JST on battery line.		
Partially slide ADS assembly along threaded rods.		
Feed wires through ADS.		
Attach SMA adaptors to all cables		
Thread the antenna wires through the top plate of the ADS to connect to the associated GPS (red) or LoRA (white) board(s).		
Plug in antennas.		
Fully slide ADS assembly along threaded rods until flush against the nuts.		
Tape antennas out of the way		
Plug in ADS battery.		
Enable screw switch and ensure that all boards light up to indicate power-on capability. The LED should be blinking green.		
Disable screw switch.		
Thread two nuts and washers (minimum) along threaded rods to be secured to top of ADS assembly.		
Slide airframe onto fin can coupler and secure with 6 rivets		
Double check that the ADS is off		
Coat the ADS bulkhead with a liberal amount of silicone.		
Insert bulkhead onto ADS threaded rods. Make sure the bulkhead is flush on the coupler.		
Put a rubber washer, metal washer, and nut (in that order) on each of the threaded rods. Tighten down all nuts as much as possible.		

Pull ADS pins slightly out of the airframe. Attach each ADS flap with 2 bolts (ensure the pin is in the flap’s slot). Check ADS pin resistance		
Ensure that the ADS flaps can actuate by hand. If flaps struggle to move, slightly loosen the ADS flap bolts. Push flaps all the way in.		
Add top rail guide		

Payload Assembly

Action	Executor Initials	Witness Initials
Check GPS battery voltage with the multimeter and ensure it reads 4.2v nominal.		
Check LoRa battery voltage with the multimeter and ensure it reads 4.2v nominal.		
Check Payload battery voltage with the multimeter and ensure it reads 12.6V nominal.		
Put in payload battery with insulating foam.		
Close and tape down payload door.		
Plug in the payload battery		
Insert the forward flat side of the payload into the coupler.		
Connect payload screw switch to payload.		
Slide in payload making sure to avoid screw switches.		
Plug in screwswitches		
Put on the upper payload bulkhead and route GPS screw switch wires through routing hole.		
Route GPS screw switch wires through GPS bracket.		
Mount GPS bracket to upper bulkhead using nuts and metal washers.		
Add batteries to GPS bracket and secure vertically.		
Connect labeled screw switch JSTs for GPS and LoRa to their switchband connectors.		
Connect GPS [**GNSS IN**] connector to GPS patch antenna. (**large**)		
Connect GPS [**LoRa 915MHz Out**] to LoRa patch antenna. (**small**)		
Connect GPS battery to GPS input.		
Power on ground station hardware and connect to laptop.		

Confirm that LoRa receiver is listening for telemetry (status readout in software).		
Enable LoRa GPS screw switch ● Red [Power] LED should turn on ● Green [Status] LED should flash “heartbeat” pattern		
Confirm that the orange LED is solid on startup and flashes once LoRa GPS lock is found. This may take up to 1 minute.		
Confirm with Ground Station crew that GPS telemetry is being received once GPS lock is found.		
Validate telemetry (lat/lon/alt) using cellphone maps.		
Disable LoRa GPS screw switch.		
Confirm on Ground Station that no more packets are being received from GPS telemetry.		
Enable Featherweight tracker screw switch, and confirm packets are being received on receiver after ~1 minute.		
Disable Featherweight tracker screw switch.		
Enable Payload screw switch, and confirm that power LEDs on all electronics have turned on to affirm successful power-up.		
Disable Payload screw switch.		
Coat the aft payload bulkhead with a liberal amount of silicone.		
Put other bulkhead onto the threaded rods. Make sure bulkheads are flush on the coupler.		
Put a rubber washer, metal washer, and nut with thread lock (in that order) on each of the threaded rods. Tighten down all nuts as much as possible.		
Attach nosecone to payload coupler and secure with 6 rivets.		

Recovery Bay Assembly

Action	Executor Initials	Witness Initials
Check battery voltages with the multimeter and ensure they read nominally: - Blue Raven Battery: 4.2V - EasyMini Battery: 8.4V - VTX Battery 1: 8.4v - VTX Battery 2: 8.4v		
Check that there is an SD card in the onboard camera		
Connect labeled battery terminals to labeled female connectors		
Add foam to batteries and secure batteries in place		
Connect drogue charge connectors		
Slide recovery bay into coupler and simultaneously connecting all labeled screw switch connectors, camera connectors, and VTX antennas.		
Apply silicone to the drogue parachute bulkhead and secure with nuts and washers		
Thread Main parachute bulkhead onto recovery bay		
Connect labeled deployment charge connectors from altimeters to main parachute bulkhead PM & BM = Primary Main & Backup Main		
Apply silicone to the main parachute bulkhead before securing with nuts and washers.		
Tell everyone to be quiet.		
Enable one screw switch at a time to ensure each appropriate electronic is enabled (lights enabled); Disable screw switch after each enable Ensure Blue Raven connects to phone while on.		
While live video transmitter is enabled, check to ensure that video is being received on ground station. (Greg)		

Day Of Launch Operations

Action	Executor Initials	Witness Initials
Turn on both altimeters, GPS, and camera to check for beeps/lights. Ensure applications connect properly (one by one)		
Check voltage at screw terminals to ensure that all deployment channel connections are made FS, PD, PM ~4.2V BD, BM ~8.4V		
Disable all screw switches and remove screws.		
Have someone hold the screws and KEEP TRACK OF THEM.		
Ejection Charges: Strip and cut end of e-matches Screw into screw terminals Ensure wire is being clamped, not plastic part of match Check continuity BEFORE ADDING BP Measure out black powder amount for each charge DROGUE PRIMARY: 4.0 G DROGUE BACKUP: 5.0 G DROGUE FAILSAFE: 6.0 G MAIN PRIMARY: 5.5 G MAIN BACKUP: 6.5 G Bend e-match and place on top of black powder Pack with dog barf and tape it closed Repeat 4x, i.e. for each charge well		
Thread (30’) main shock cord through upper airframe and attach yellow (longer side) quick link to join main recovery bay bulkhead and long end of shock cord (knot furthest from parachute knot)		
Insert main side of recovery bay into upper airframe and secure with 6 rivets		
Untape chutes		
Lay out parachute and ensure shock cord has no knots		
Fold main parachute and add baby powder liberally throughout process (Have someone hold parachute together tightly)		
Attach purple (shorter side) quick link to nosecone bulkhead with the short side of shock cord (knot closest to parachute knot)		
Connect parachute quicklink to shock cord.		
Cover parachute with chute protector		
Add cup of dog barf into opposite side of main airframe		

Put baby powder in main airframe.		
Thread some of the shock cord into main airframe		
Place main parachute into main airframe (chute protector facing in)		
Thread rest of shock cord into main airframe and add more baby powder to folded parachute / along edges of nose cone coupler		
Insert nose cone coupler into upper main airframe and secure with 6 shear pins		
Attach chute protector to the drogue chute		
Lay out drogue parachute, add baby powder to it, and ensure lines are detangled		
Fold drogue parachute whilst adding baby powder liberally throughout the process		
Cover drogue chute with chute protector		
Have someone hold the drogue tightly		
Attach blue quick link to join ADS bulkhead and long end (31') of shock cord (furthest from parachute knot)		
Attach pink quick link joining R-bay drogue bulkhead and short end (17') of drogue shock cord (closest to parachute knot)		
Thread shock cord into thrust structure while adding baby powder.		
Place drogue with parachute protector into thrust structure (chute protector facing out)		
Add one cup of dog barf into thrust structure		
Insert recovery bay & top half of rocket into thrust structure and secure with 4 shear pins		
Pack the following to bring to pad: - Chris' Rocket Supplies screwdriver - Screw switch screws - Shear pins - Wood block - Ignitor - Ignitor stick - Wire strippers - Featherweight tracker - Flathead		

Launch Pad Preparations

Action	Executor Initials	Witness Initials
Check vehicle weight with OpenRocket values. If fail, see emergency item 4.		
Record final ambient temperature and pressure values.		
Record how many grams of BP were used.		
Mark vehicle CG and CP with Vinyl stickers.		
Record final off the rail velocities.		
Assemble igniter and tape to the outside of the rocket.		
Engage hand radios between launch crew and by-stander crew if needed.		
Have 2-3 members go to other side of launch site to triangulate rocket landing (in case of GPS failure).		

On The Rail Operations

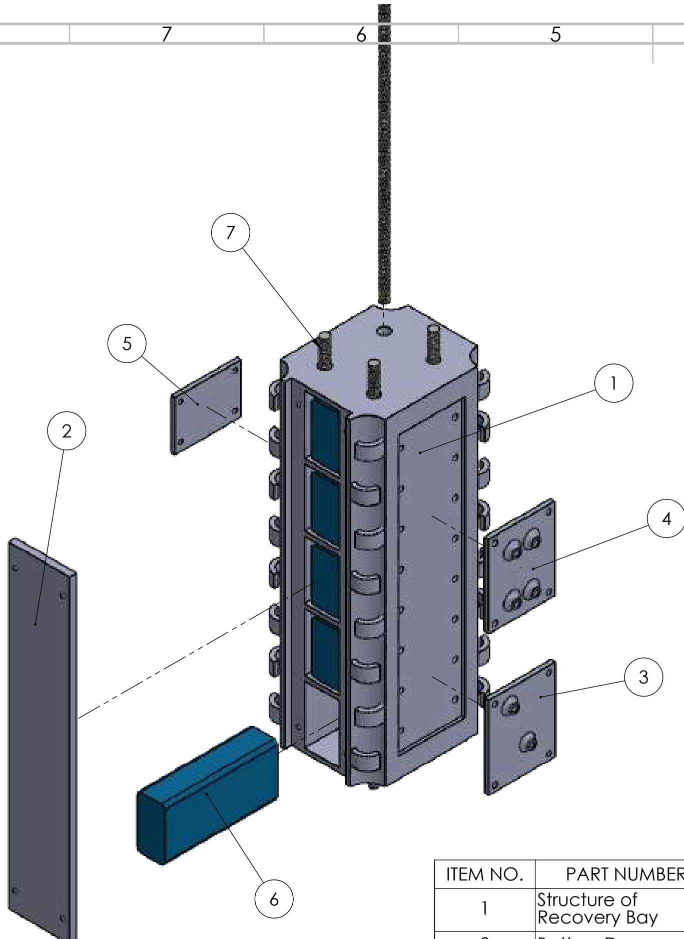
Action	Executor Initials	Witness Initials
Take off fin covers		
Put rocket on rail		
Turn on payload while horizontal		
Enable Featherweight tracker and connect via Bluetooth while horizontal		
Raise up rocket to lock in place		
Measure rod angle and make note		
Enable GPS by turning on labeled screw switch		
Enable ADS		
Enable EasyMini altimeter by turning on labeled screw switch		
Listen for beeps to verify battery voltage and continuity on both deployment channels		
Enable Blue Raven by turning on labeled screw switch		
Connect to Blue Raven via Bluetooth to verify battery voltage and continuity on both deployment channels		
Verify GPS lock from Featherweight tracker		
Verify GPS lock from incoming telemetry from LoRa PCB		
Insert motor ignitor until it cannot be inserted any further		
Spark test launch box leads		
Clamp pad leads on to igniter leads; ensure that igniter leads wrap around the pad leads and do not / will not touch each other		
Take weather conditions and note prior to launch (e.g. wind speed / gust speed, air pressure, humidity, cloud cover)		
Launch rocket and recover		

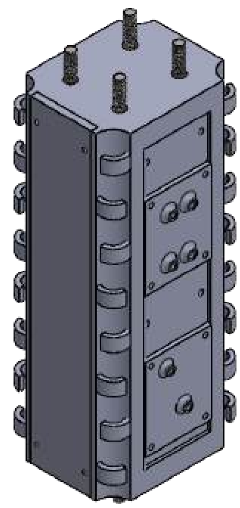
Emergency Procedures

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

Appendix F: Engineering Drawings

Recovery Bay and Camera Engineering Drawings





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Structure of Recovery Bay	3D PRINTED ABS	1
2	Battery Door	3D PRINTED ABS	1
3	Blue Raven Mount	3D PRINTED ABS	1
4	Easy Mini Mount	3D PRINTED ABS	1
5	RunCam Mount	3D PRINTED ABS	1
6	battery	LITHIUM-ION CELLS	5
7	rod	1/4" X 20 ALUMINUM THREADED ROD	4

SUBSYSTEM TITLE: RCV 1

PART TITLE: RecoveryBayAssembly

DRAWN BY: Brady Rehkop

A3

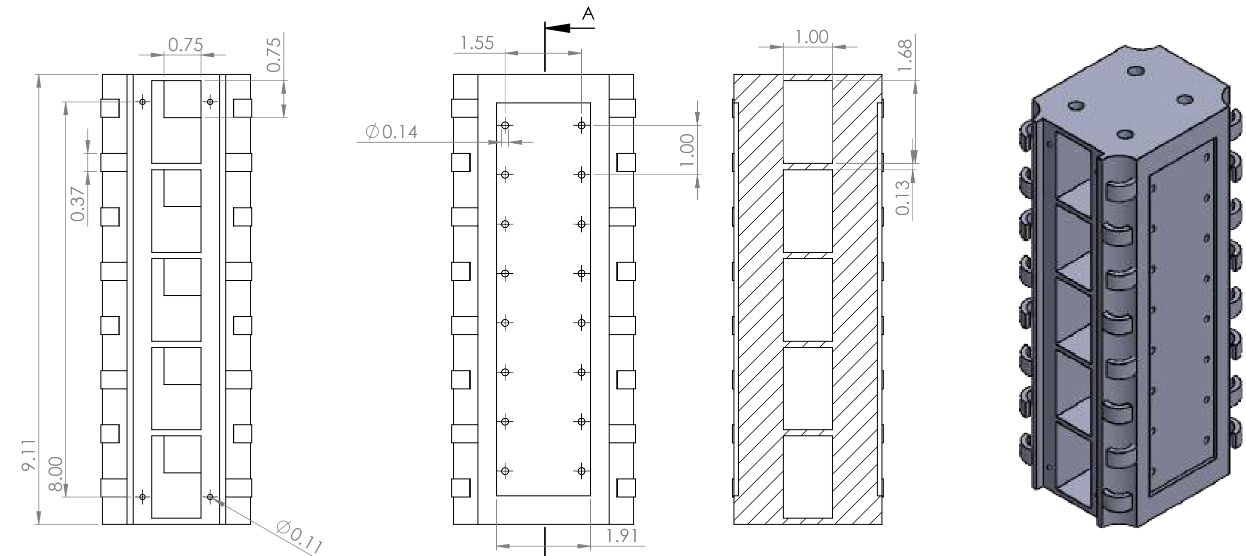
DATE: 04/30/2026

UNIT: INCHES

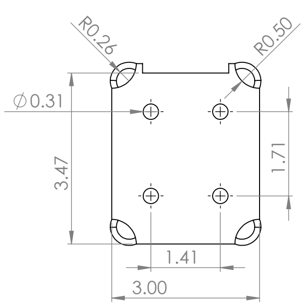
SCALE:1:2

DO NOT SCALE DRAWING

SHEET 1 OF 8

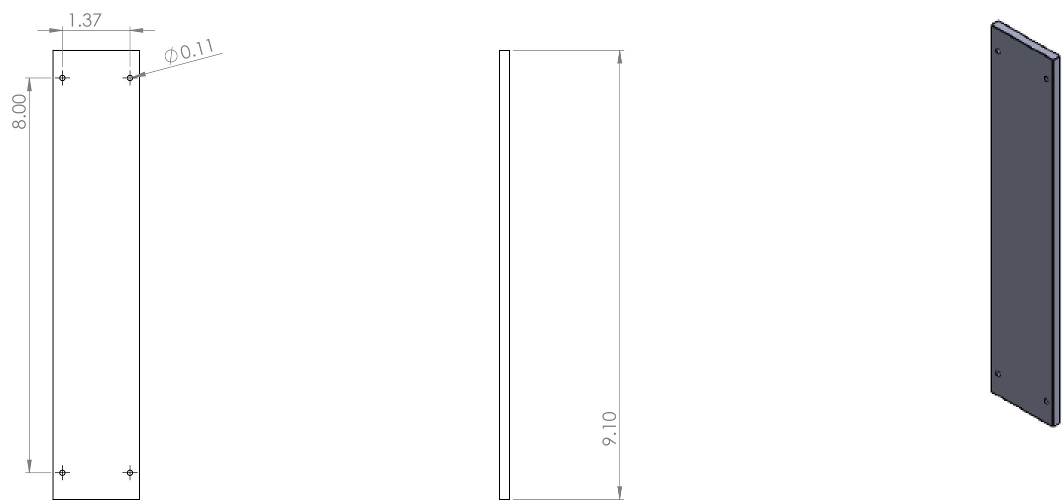


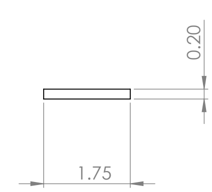
SECTION A-A



1. ELECTRONIC BOARD MOUNTS ARE BOLTED TO RIGHT FACE (ABOVE)
2. ELECTRONICS MOUNT IS COPIED ON OPPOSITE FACE
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

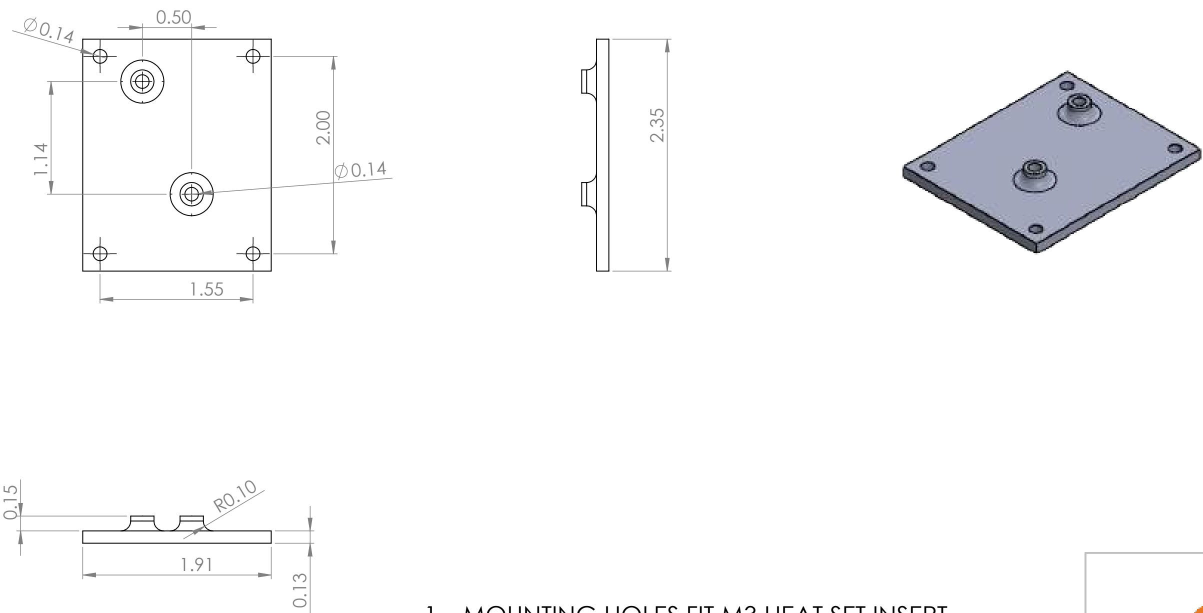
SUBSYSTEM TITLE:	RCV 2
PART TITLE:	RecoveryBayDrawing
DRAWN BY:	Brady Rehkop
DATE: 04/30/2026	UNIT: INCHES
SIZE	A3
SCALE:1:2	DO NOT SCALE DRAWING
	SHEET 2 OF 8





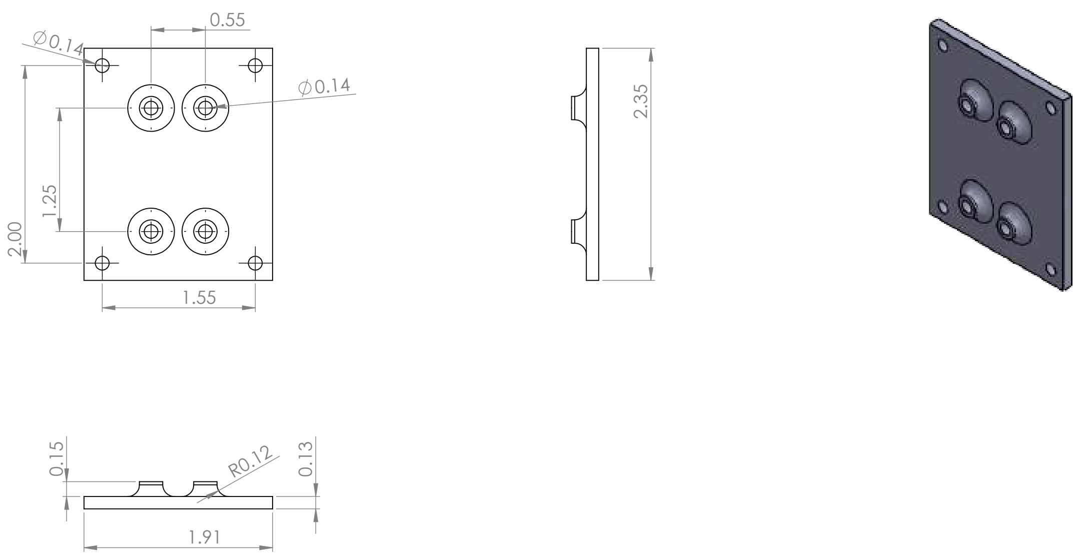
1. BATTERY DOOR MOUNTS TO FRONT FACE OF RECOVERY BAY
2. 2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE:	RCV 3
PART TITLE:	RecoveryBayDrawing
DRAWN BY:	Brady Rehkop
DATE:	04/30/2026
UNIT:	INCHES
SIZE	A3
SCALE:1:2	DO NOT SCALE DRAWING
SHEET 3 OF 8	



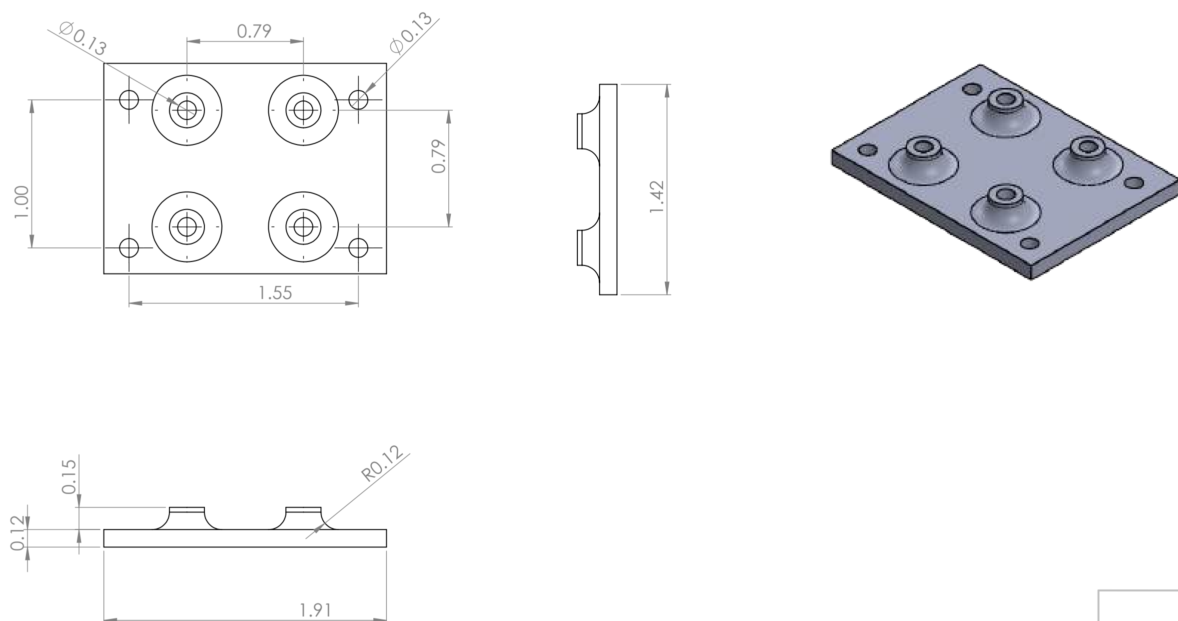
1. MOUNTING HOLES FIT M3 HEAT SET INSERT
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE: RCV 4		
PART TITLE: BlueRavenMount		
DRAWN BY: Brady Rehkop		A3
DATE: 04/30/2026	UNIT: INCHES	
SCALE:1	DO NOT SCALE DRAWING	SHEET 4 OF 8



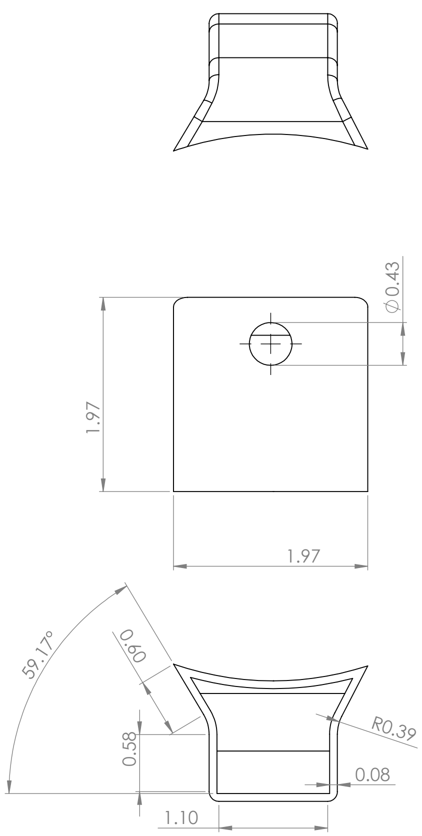
1. MOUNTING HOLES FIT M3 HEAT SET INSERT
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

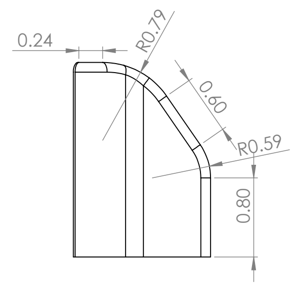
SUBSYSTEM TITLE: RCV 5			
PART TITLE: EasiMiniMount			
DRAWN BY: Brady Rehkop			A3
DATE: 04/30/2026	UNIT: INCHES		
SCALE1:1	DO NOT SCALE DRAWING		SHEET 5 OF 8

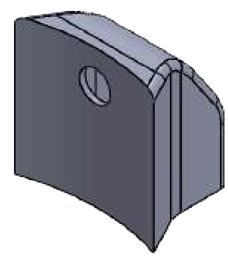


1. MOUNTING HOLES FIT M2.5 HEAT SET INSERT
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE:	RCV 6
PART TITLE:	RunCamMount
DRAWN BY:	Brady Rehkop
DATE:	04/30/2026
UNIT:	INCHES
	A3
SCALE3:2	DO NOT SCALE DRAWING
	SHEET 6 OF 8

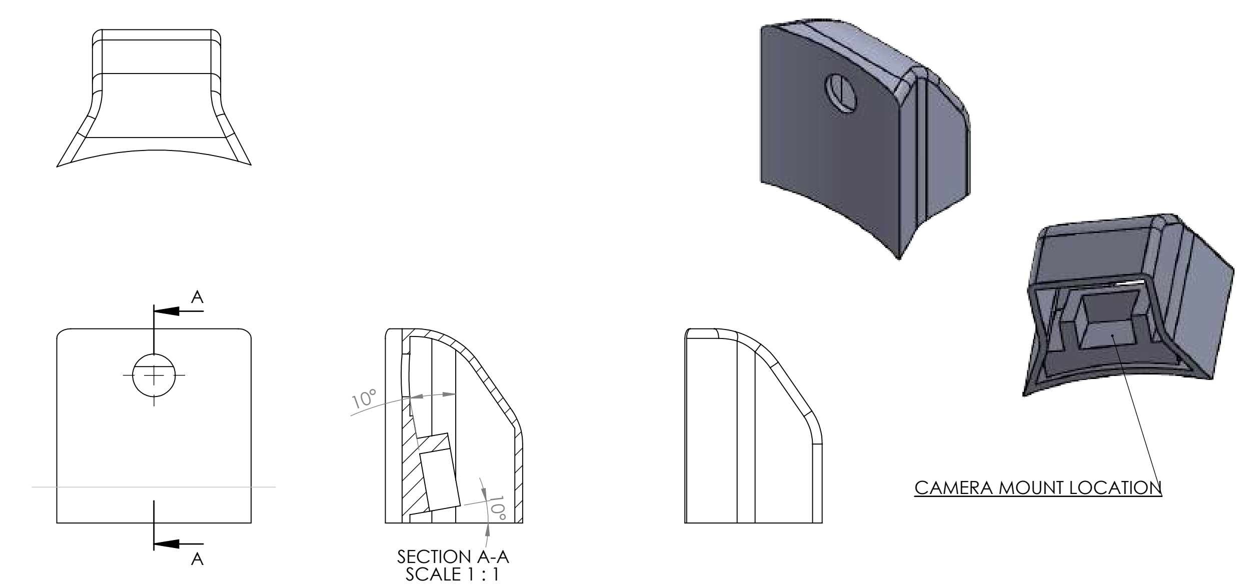


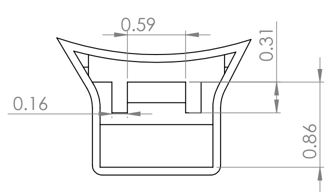




1. FRONT FACE HAS DIAMETER FITTING ROCKET EXTERIOR DIAMETER
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE:	CAM 1
PART TITLE:	AntennaShroud
DRAWN BY:	Brady Rehkop
DATE:	04/30/2026
UNIT:	INCHES
SIZE	A3
SCALE1:1	DO NOT SCALE DRAWING
	SHEET 7 OF 8





1. ALL DIMENSIONS ARE THE SAME AS "ANTENNA SHROUD" WITH THE EXCEPTION OF THE DIMENSIONED CAMERA MOUNT
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE: CAM 2

PART TITLE: CameraShroud

DRAWN BY: Brady Rehkop

DATE: 04/30/2026

UNIT: INCHES

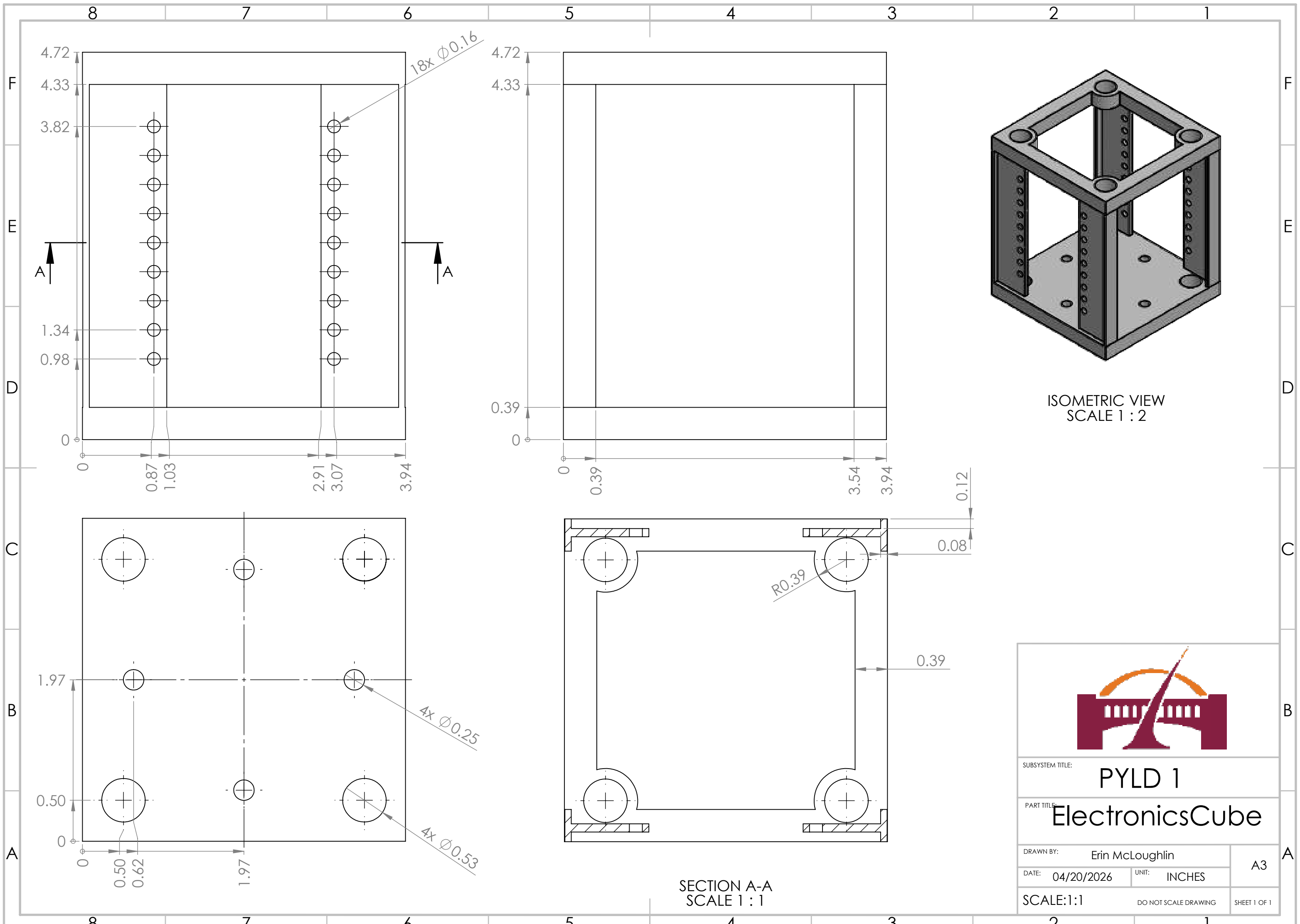
A3

SCALE1:1

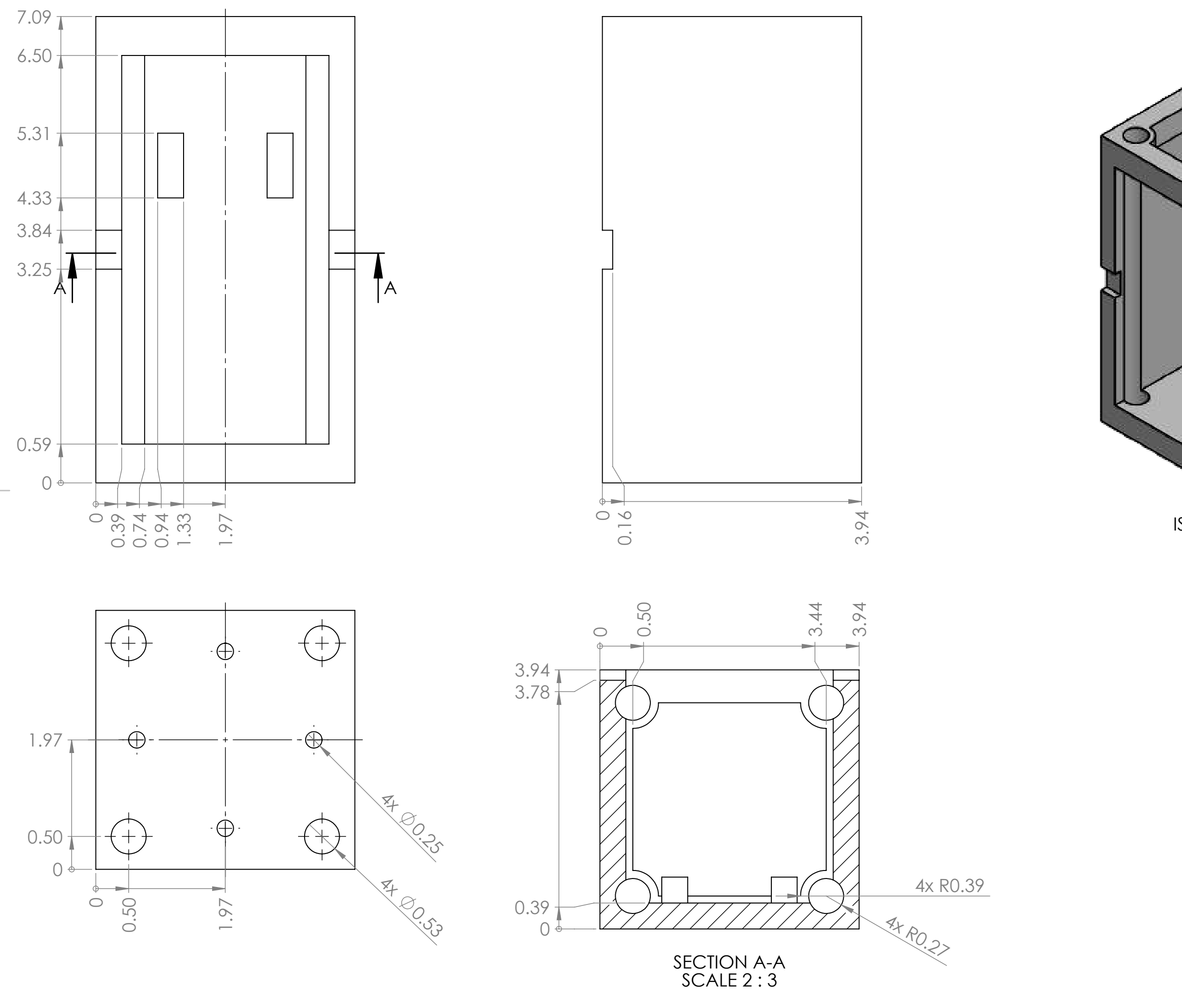
DO NOT SCALE DRAWING

SHEET 8 OF 8

Payload Engineering Drawings



SUBSYSTEM TITLE:	PYLD 1
PART TITLE:	ElectronicsCube
DRAWN BY:	Erin McLoughlin
DATE:	04/20/2026
UNIT:	INCHES
	A3
SCALE:1:1	DO NOT SCALE DRAWING
SHEET 1 OF 1	



SUBSYSTEM TITLE: PYLD 2

PART TITLE: PAYLOAD

DRAWN BY: Erin McLoughlin

A3

DATE: 04/30/2026

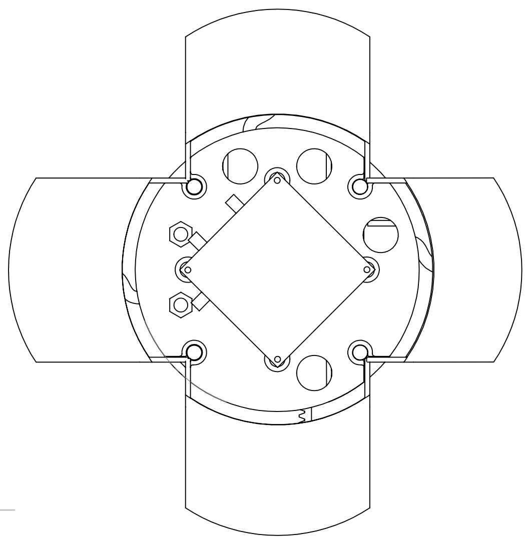
UNIT: INCHES

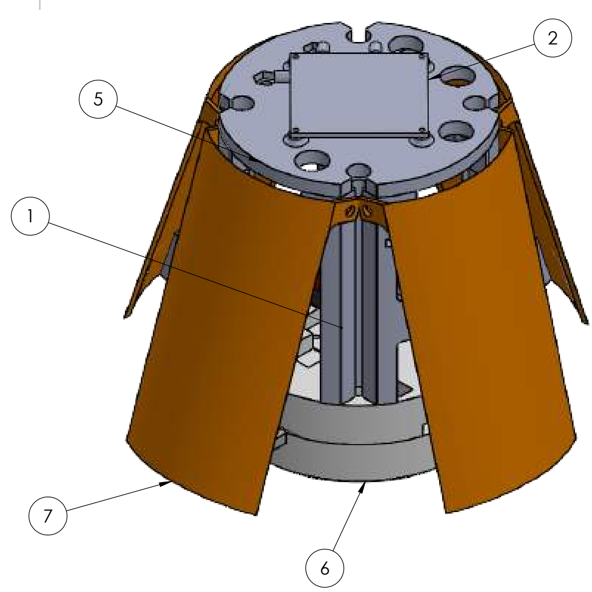
SCALE:2:3

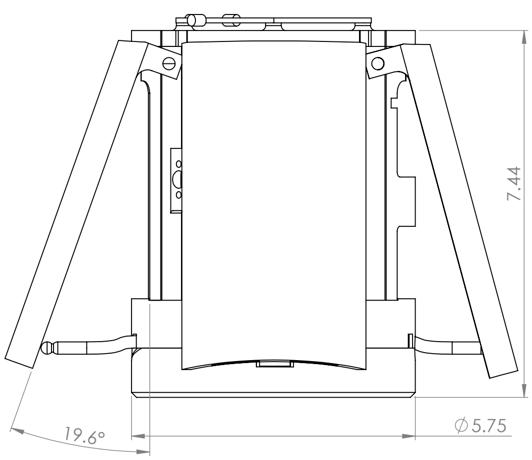
DO NOT SCALE DRAWING

SHEET 1 OF 1

ADS Engineering Drawings







1. COLUMNS ARE BOLTED TO SANDWHICH THROUGH INNER CIRCULAR HOLES
2. FLAPS ARE BOLTED TO TOP OF COLUMN AND SLOTED INTO RACK PINS

△3 SEE ATTACHED DRAWINGS FOR DETAILS

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
△3 1	Battery Column PRINT 2026	3D PRINTED ABS	1
2	Beramin_Tracker	CUSTOM MANUFATURED PCB BOARD	1
△3 3	Column 2026 PRINT	3D PRINTED ABS	1
△3 4	Column Switch 2026 PRINT	3D PRINTED ABS	1
△3 5	PCBdisk 2026 PRINT	3D PRINTED ABS	1
△3 6	Sadnwhich Assembly	BOLTED ASSEMBLY	1
△3 7	ADS-Full-Flap-2026	MANUFACTURED ASSEMBLY	4

SUBSYSTEM TITLE: ADS 1

PART TITLE: Full ADS Assembly

DRAWN BY: ETHAN GEORGE

DATE: 04/29/2026 UNIT: INCHES

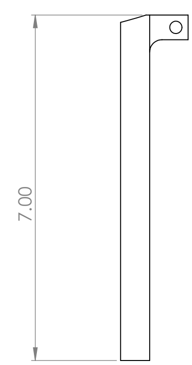
A3

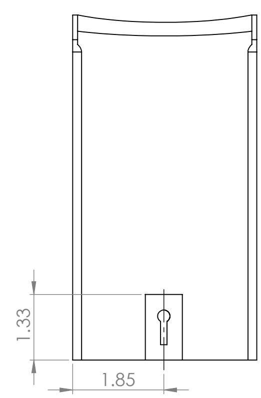
SCALE:2 DO NOT SCALE DRAWING SHEET 1 OF 1

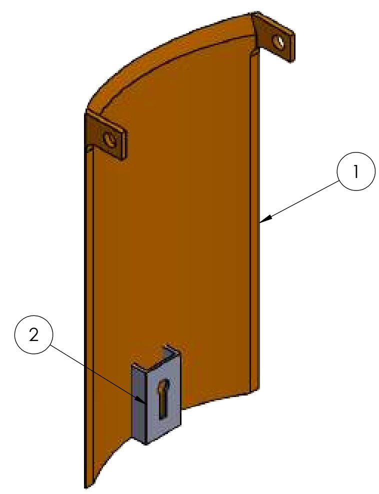
1. ALL PARTS AND ASSEMBLIES DESIGN AND MANUFACTURED BY ROCKETRY AT VIRGINIA TECH IN THE AEROSPACE ENGINEERING DESIGN LAB

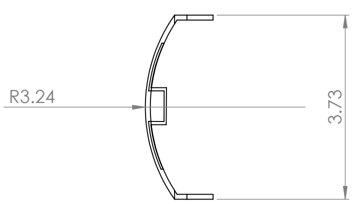
2. ASSMEPLY WAS COMPLETED BY PRESSING THE CARBON FIBER AND SLOT IN A 3D PRINTED MOLD

3. SEE ATTACHED DRAWINGS FOR DETAILS









ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ADS-Flap-2026	5-LAYER CARBON FIBER	1
2	ADS-Slot-2026	THIN STEEL, BENT IN HOUSE	1

SUBSYSTEM TITLE: ADS 2

PART TITLE: ADS-Full-Flap-2026

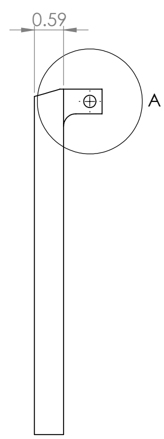
DRAWN BY: ETHAN GEORGE

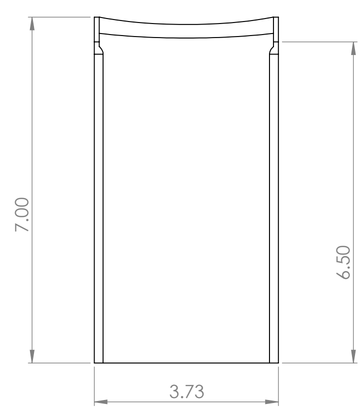
DATE: 04/29/2026 UNIT: Inches A3

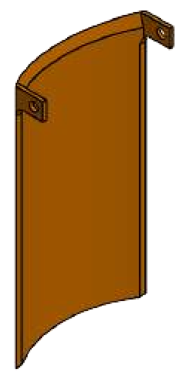
SCALE:1:2 DO NOT SCALE DRAWING SHEET 1 OF 1

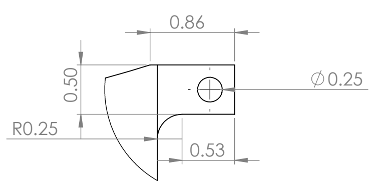
1. FLAPS ARE FULL MANUFACTURED WITH EPOXY HARDENED CARBON FIBER THAN DREMALLED BASED ON DRAWING DIMENSIONS

2. FLAPS ARE CONNECTED TO ADS THROUGH BOLT AND LOCK NUT THROUGH THE BOLT HOLES SHOWN IN DETAIL A

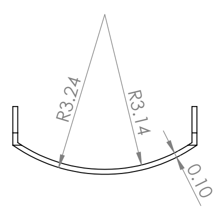








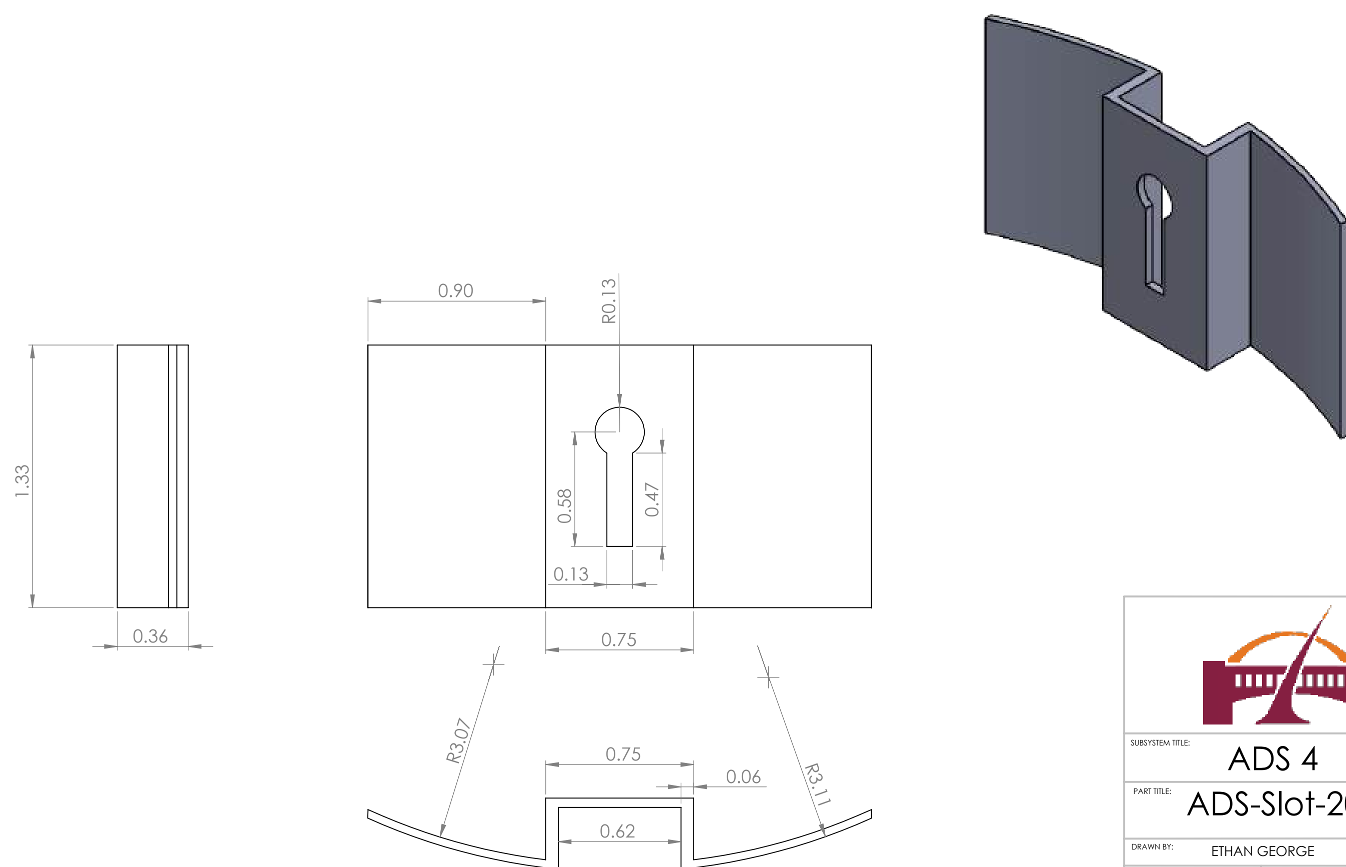
DETAIL A
SCALE 1 : 1



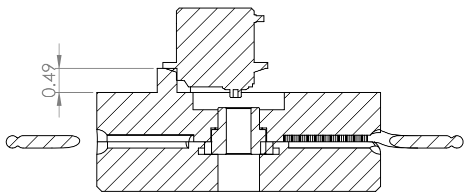
SUBSYSTEM TITLE:	ADS 3
PART TITLE:	ADS-Flap-2026
DRAWN BY:	ETHAN GEORGE
DATE:	04/29/2026
UNIT:	INCHES
	A3
SCALE:1:2	DO NOT SCALE DRAWING
	SHEET 1 OF 1

1. SLOTS ARE LAZER CUT AND BENT IN HOUSE TO FIT THE DRAWING DIMENSIONS

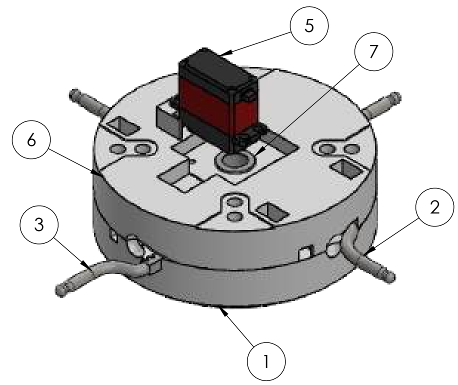
2. STEEL PLATES ARE CUT FROM A .06 IN SHEET

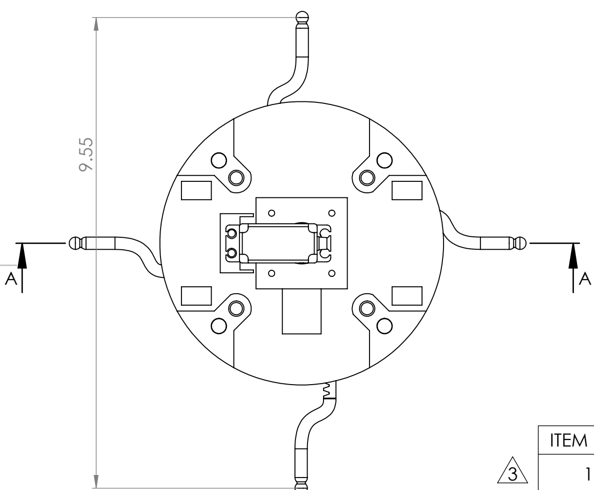


SUBSYSTEM TITLE:	ADS 4
PART TITLE:	ADS-Slot-2026
DRAWN BY:	ETHAN GEORGE
DATE:	04/29/2026
UNIT:	INCHES
SIZE	A3
SCALE:2:1	DO NOT SCALE DRAWING
	SHEET 1 OF 1



SECTION A-A
SCALE 1 : 2



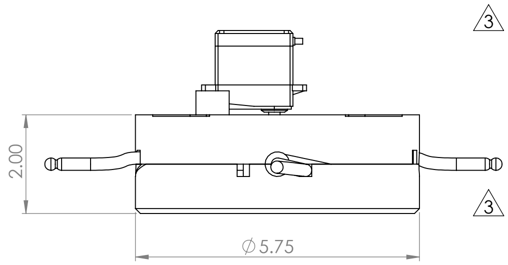


1. FULL SANDWHICH IS ASSEMBLED BY FITTING RACKS INTO SLOTS, ALLIGNING WITH GEAR, THEN BOLTING UPPER AND LOWER PEICES TOGETHER

2. SERVO SHAFT IS EXPOYED TO GEAR TO ENSURE ROATATION BETWEEN SERVO AND GEAR

△3 SEE ATTACHED DRAWINGS FOR PART DETAILS

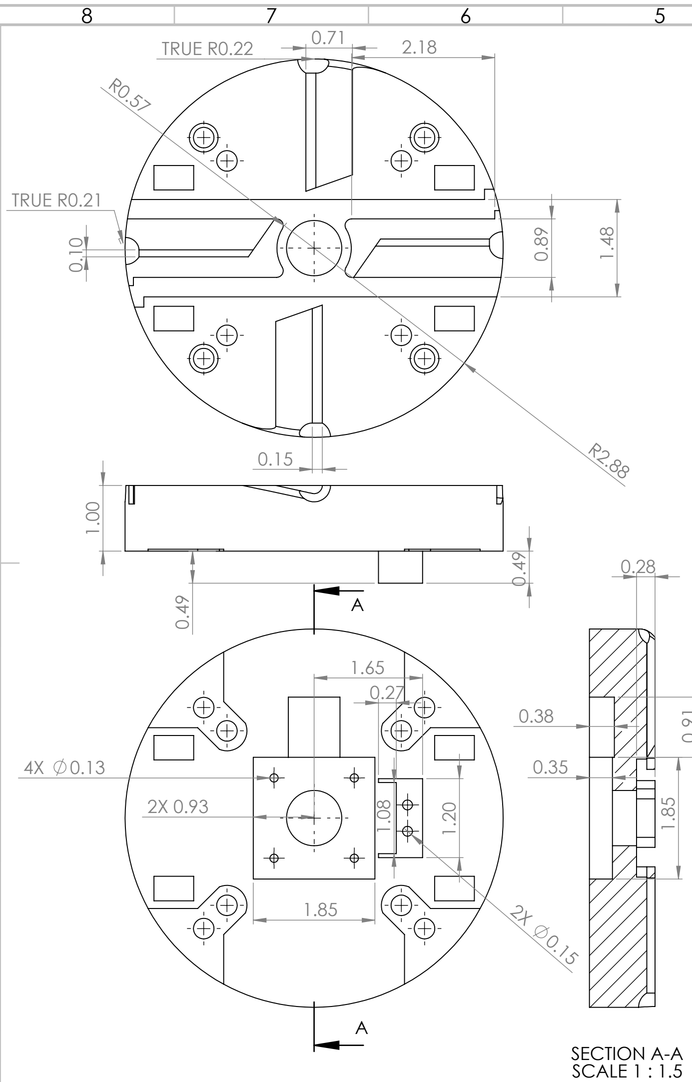
	ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
△3	1	Lower Sandwich NEW	ABS 3D PRINTED MODEL	1
△3	2	Rack_Pin (2)	ORDER METAL PRINTED ALUMINUM	2
	3	Rack_Pin_invertedFixed	INVERTED RACK TO FIT IN UPPER SAND AND STAY ON SAME PLANE FOR ACTUATION	2
	4	Same_Sky_AMT132S-0048-1000-S	AMT132S-V ENCODER DIGI KEY	1
	5	Servo TiankongRC TD8120MG	HIGH TOURGE SERVO	1
△3	6	Upper Sandwhich 2026 PRINT	ABD 3D PRINTED MODEL	1
	7	5172T12	Metal Gear - 20 Degree Pressure Angle	1

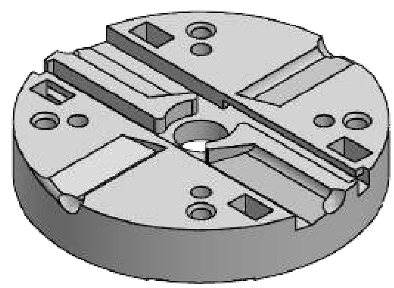


SUBSYSTEM TITLE: ADS 5

PART TITLE: Sandwhich Assembly

DRAWN BY: ETHAN GEORGE			A3
DATE: 04/29/2029	UNIT: INCHES		
SCALE 1:2	DO NOT SCALE DRAWING		SHEET 1 OF 1

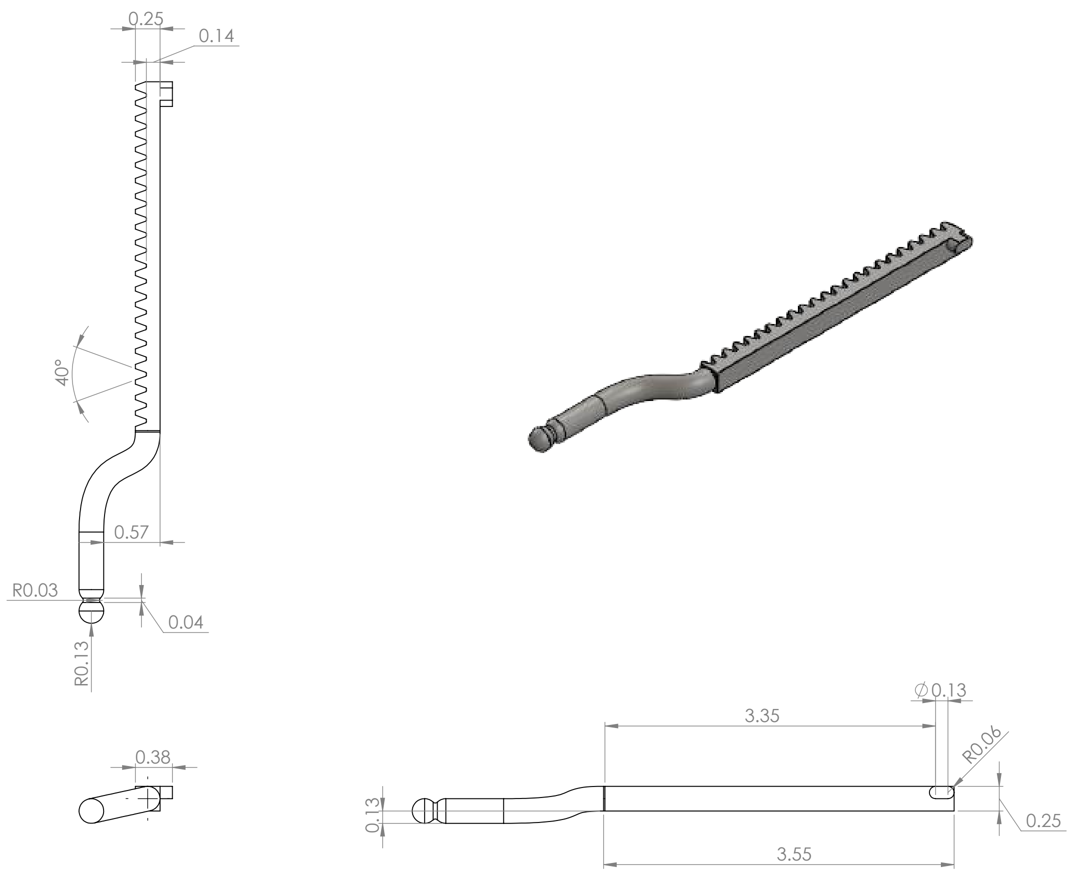




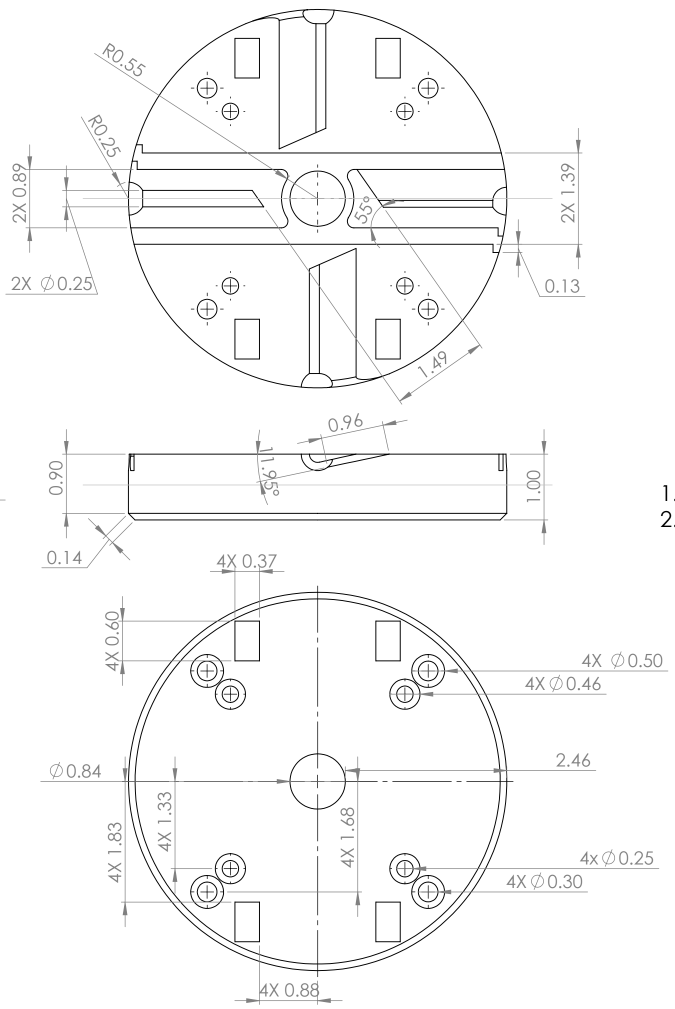
1. ALL UNDIMENSIONS HOLES HAVE THE SAME DIMENSIONS AS THE ATTACHED LOWER SANDWHICH PART
2. MIDDLE SLOT FITS ENCODER WITH SERVO SCKRED TO EXTRUDING HOLD

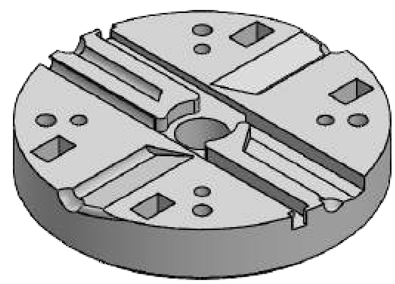
SUBSYSTEM TITLE: ADS 6		
PART TITLE: UPPER SANDWHICH		
DRAWN BY: ETHAN GEORGE		A3
DATE: 04/29/2026	UNIT: INCHES	
SCALE:1:2	DO NOT SCALE DRAWING	SHEET 1 OF 1

1. BALL JOINT END HAS INVERTED VERSION TO ALLOW ACTUATION ON SAME AXIS ACROSS SANDWHICH ASSEMBELY
2. FULL RACK IS MODEL AND 3D PRINTED METAL ALUMINUM



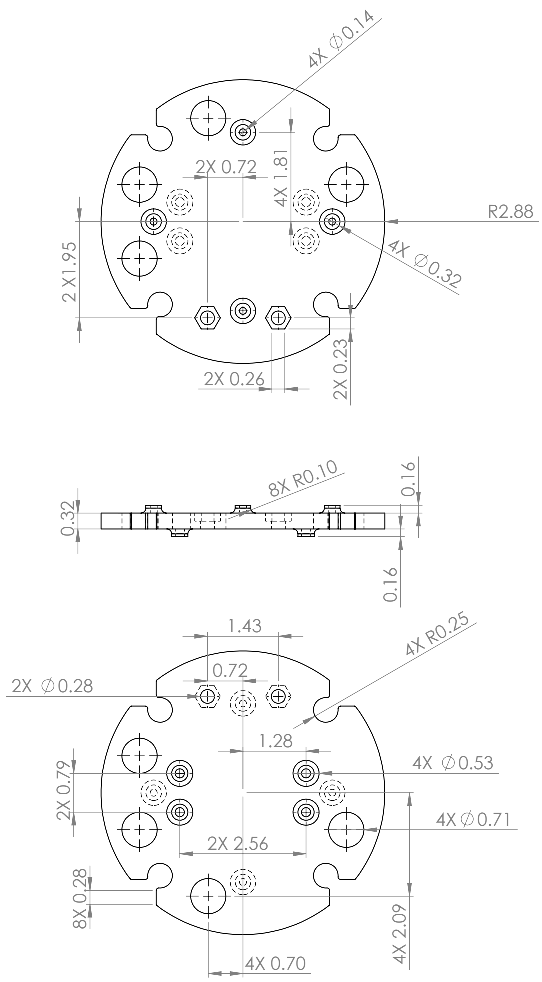
SUBSYSTEM TITLE:	ADS 7
PART TITLE:	RACK PIN
DRAWN BY:	ETHAN GEORGE
DATE: 04/29/2026	UNIT: INCHES
SCALE:1:1	DO NOT SCALE DRAWING
A3	SHEET 1 OF 1

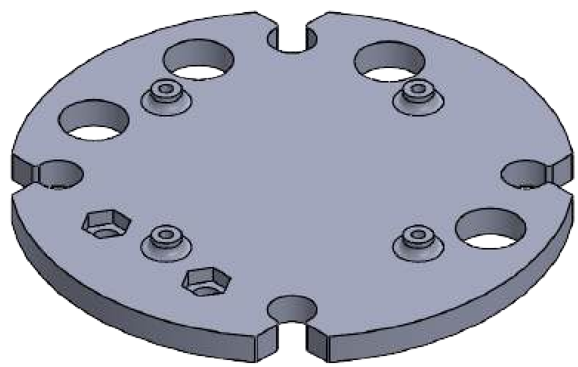




1. SANDWHICH HOUSES SLOTS TO FIT RACK PIN AND GUIDE ACTUATION
2. PART IS FULLY 3D PRINTED WITH ABS FILIMENT

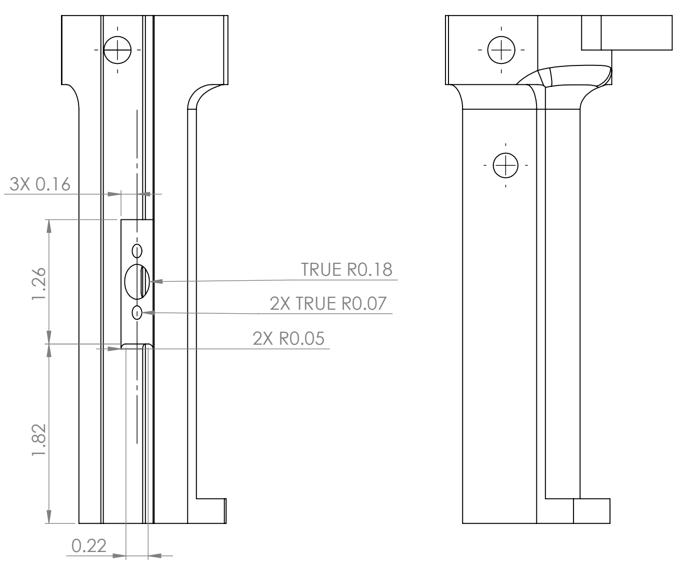
SUBSYSTEM TITLE: ADS 8			
PART TITLE: LOWER SANDWHICH			
DRAWN BY: ETHAN GEORGE			A3
DATE: 04/29/2026	UNIT: INCHES		
SCALE:1:2	DO NOT SCALE DRAWING		SHEET 1 OF 1

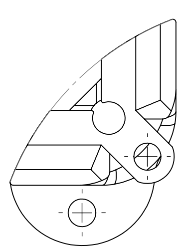


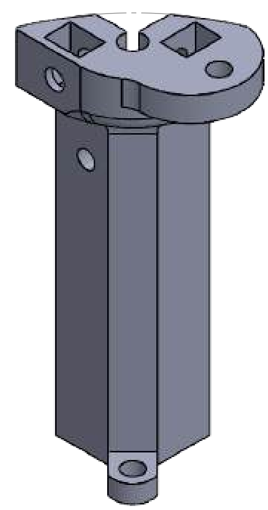


1. PART IS FULLY PRINTED IN HOUSE WITH ABS FILIMENT
2. BOLTED TO TOP OF COLUMNS AND HOLDS BOTH CUSTOM PCBS

SUBSYSTEM TITLE: ADS 9	
PART TITLE: PCB DISK	
DRAWN BY: ETHAN GEORGE	A3
DATE: 04/29/2026 UNIT: INCHES	
SCALE:1:2 DO NOT SCALE DRAWING	SHEET 1 OF 1







1. ALL DIMENSIONS ARE THE SAME AS "STANDARD COLUMN" WITH THE EXCEPTION OF THE DIMENSIONED SCREW SWITCH INSERTS
2. PART FULLY PRINTED WITH ABS FILIMENT

SUBSYSTEM TITLE: ABS 10

PART TITLE: SWITCH COLUMN

DRAWN BY: ETHAN GEORGE

DATE: 04/29/2026

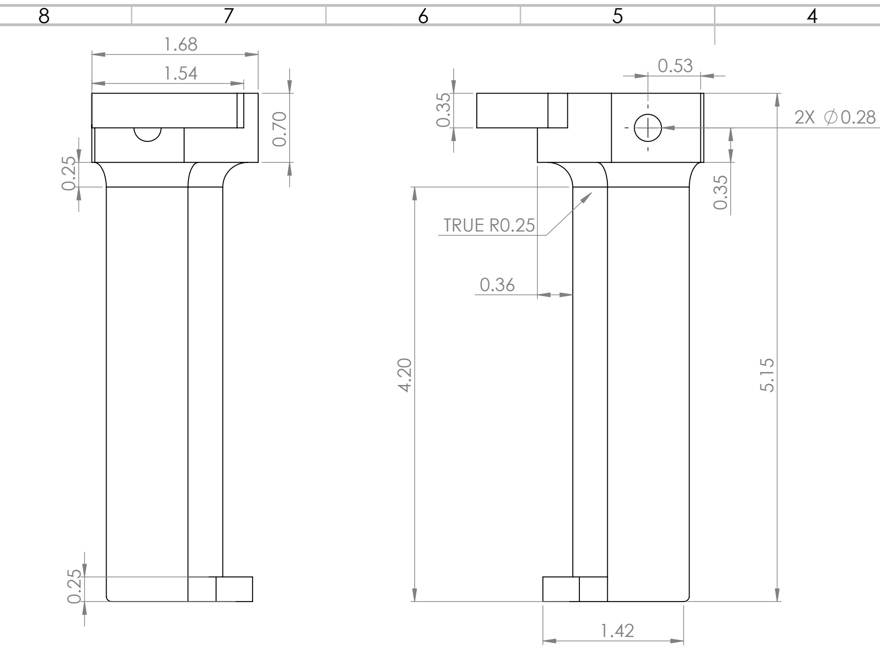
UNIT: INCHES

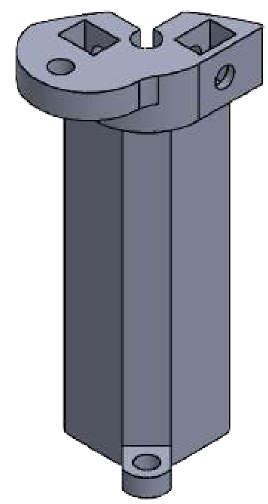
A3

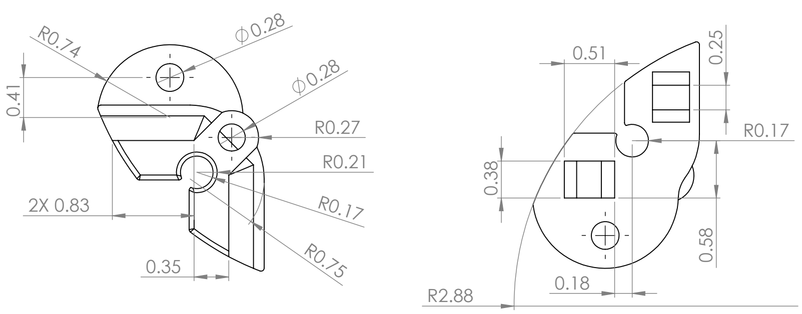
SCALE:1:1

DO NOT SCALE DRAWING

SHEET 1 OF 1



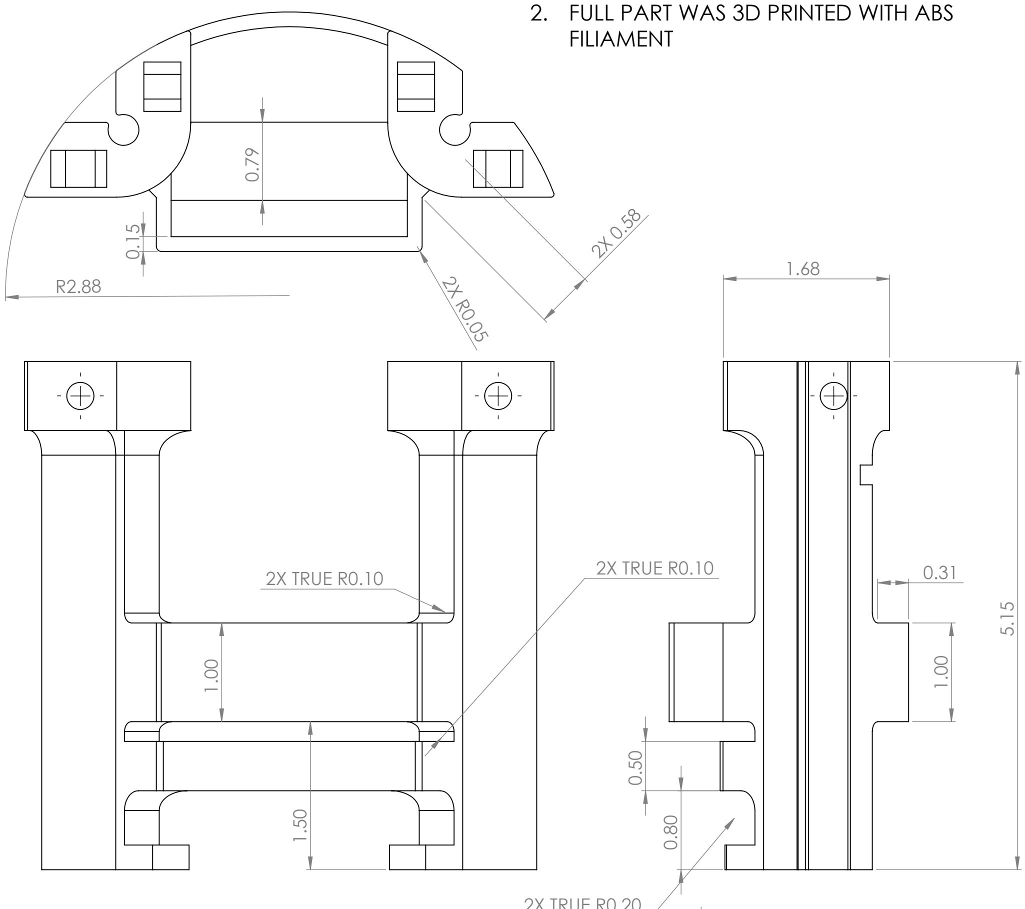


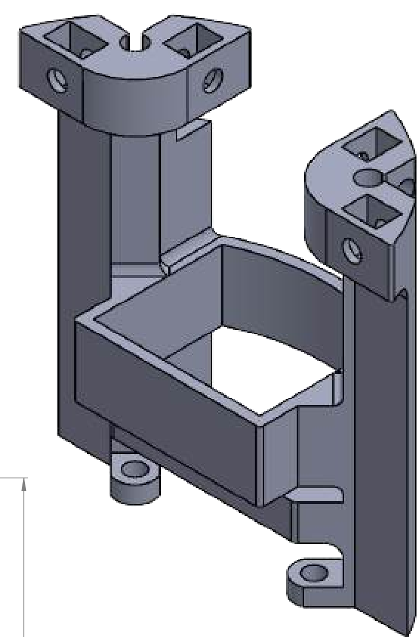


1. PART IS FULLY 3D PRINTED WITH ABS FILIMENT
2. SLOT HOLES USED TO EXPOY IN LOCK NUTS FOR FLAP CONNECTIONS

SUBSYSTEM TITLE:	ABS 11
PART TITLE:	STANDARD COLUMN
DRAWN BY:	ETHAN GEORGE
DATE:	04/29/2026
UNIT:	INCHES
SIZE	A3
SCALE:1:2	DO NOT SCALE DRAWING
SHEET 1 OF 1	

1. BOTH SIDE COLUMNS ARE THE SAME DIMENSIONS AS "STANDARD COLUMN"
2. FULL PART WAS 3D PRINTED WITH ABS FILIAMENT





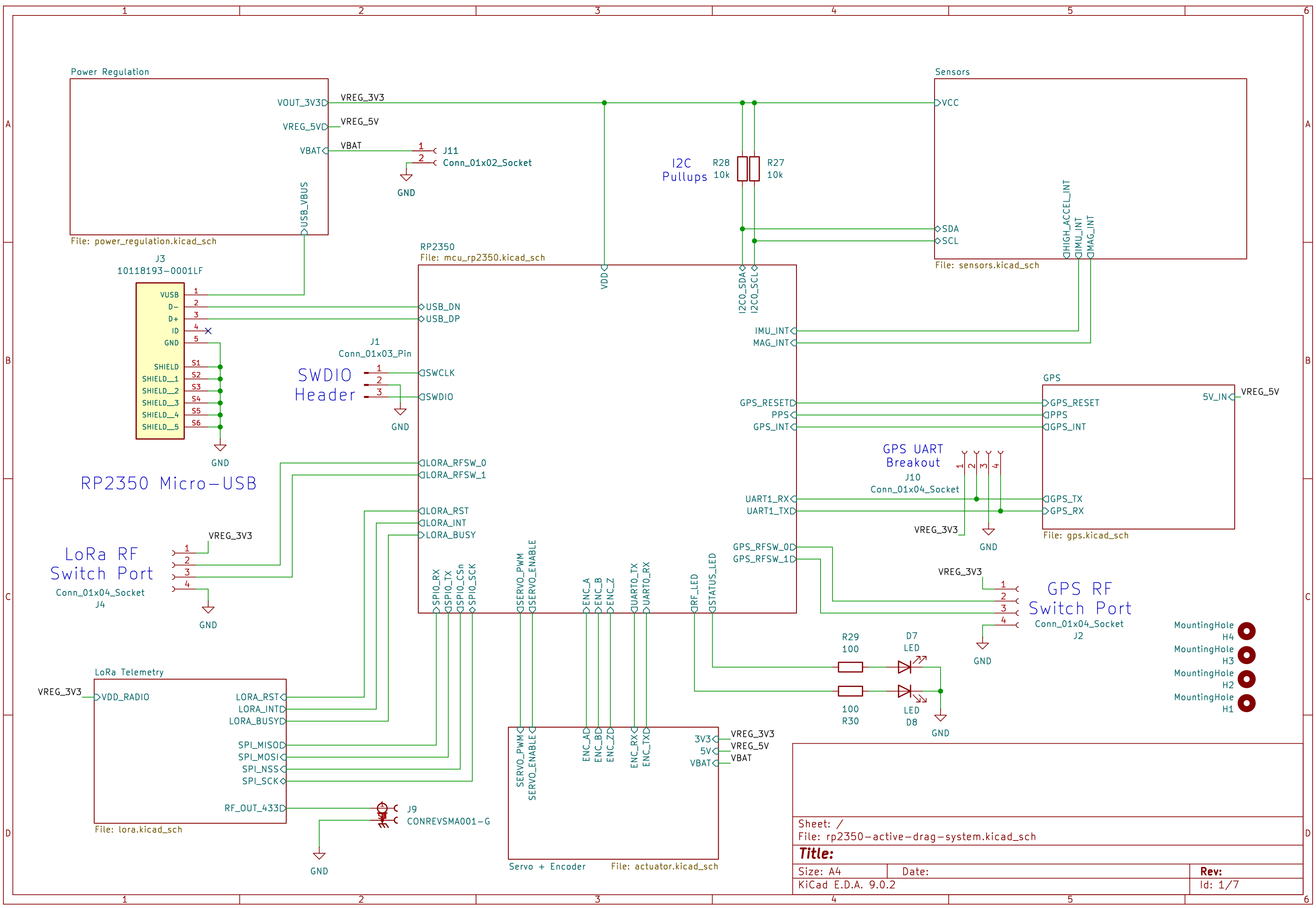
SUBSYSTEM TITLE: ABC 12

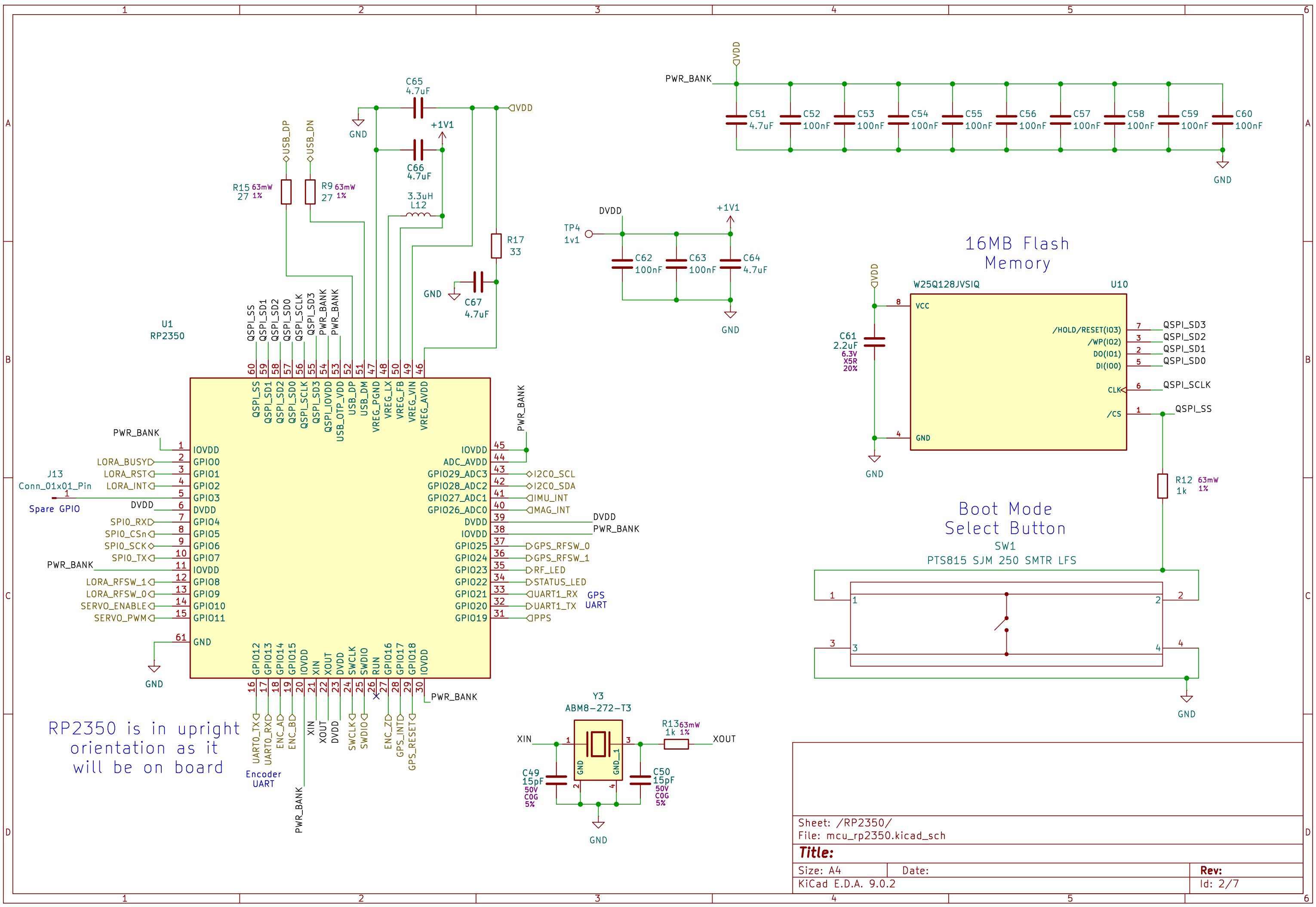
PART TITLE: BATTERY COLUMN

DRAWN BY: ETHAN GEORGE		A3
DATE: 04/29/2026	UNIT: INCHES	
SCALE:1:1	DO NOT SCALE DRAWING	SHEET 1 OF 1

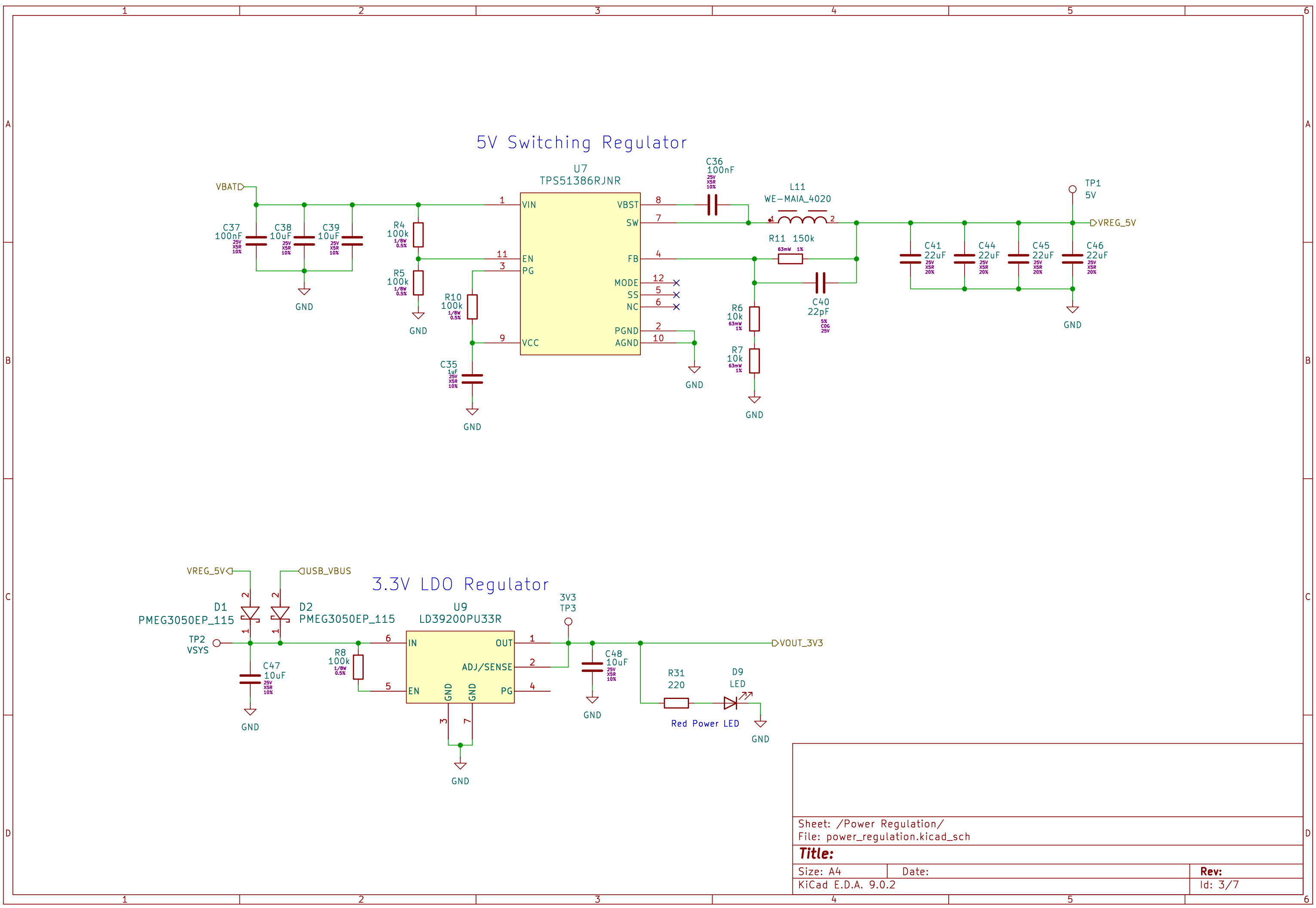
Appendix G: ADS Control/Switchboard PCB Schematics & Testing

RP2350 Control PCB Schematics

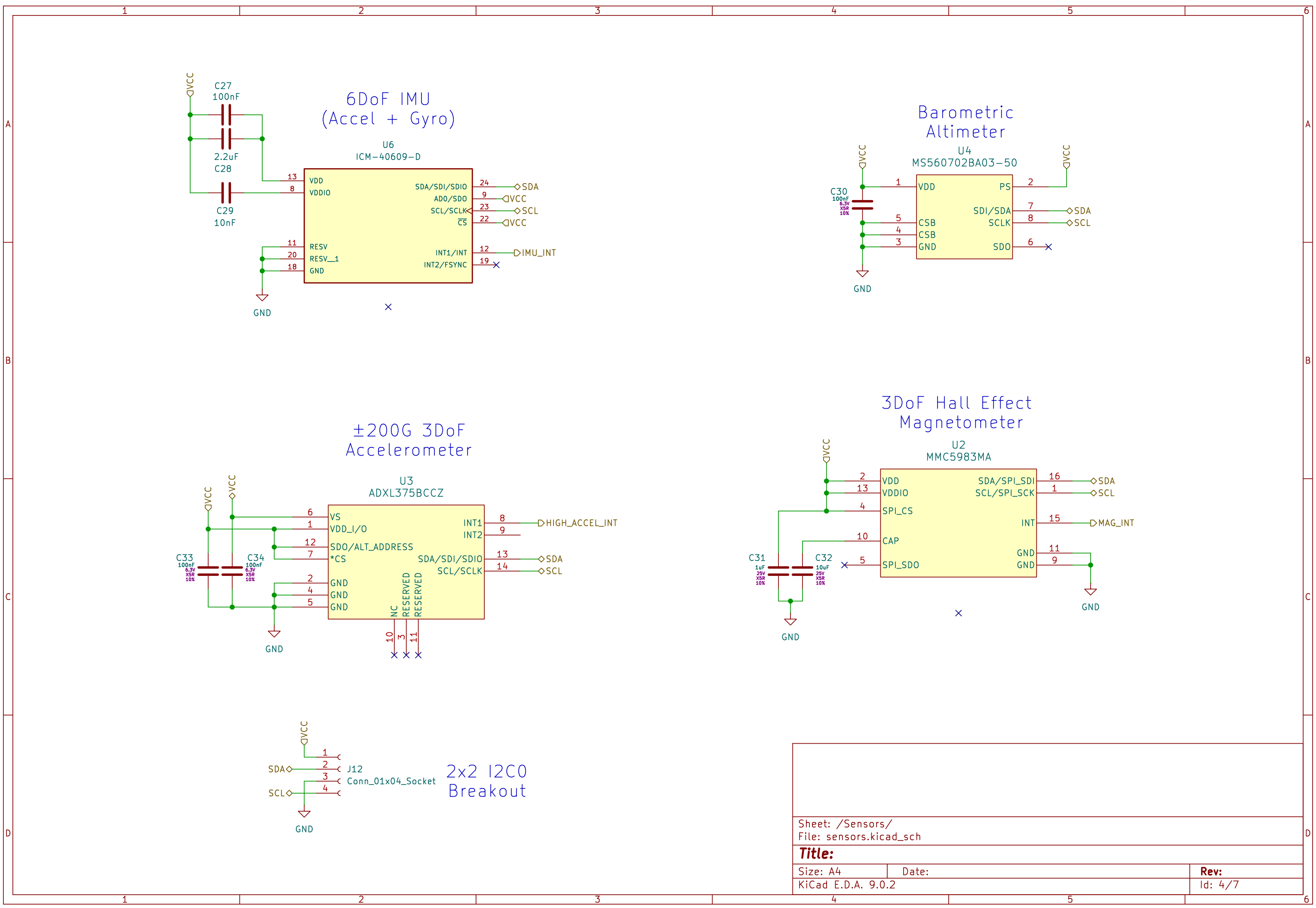

Power Regulation
VOUT_3V3
VREG_5V
VBAT
USB_VBUS
VREG_3V3
VBAT
J11
Conn_01x02_Socket
GND
File: power_regulation.kicad_sch
Sensors
VCC
SDA
SCL
HIGH_ACCEL_INT
IMU_INT
MAG_INT
File: sensors.kicad_sch
I2C
Pullups
R28
10k
R27
10k
RP2350
File: mcu_rp2350.kicad_sch
VDD
I2C0_SDA
I2C0_SCL
J3
10118193-0001LF
VUSB
D-
D+
ID
GND
SHIELD
SHIELD__1
SHIELD__2
SHIELD__3
SHIELD__4
SHIELD__5
USB_DN
USB_DP
IMU_INT
MAG_INT
J1
Conn_01x03_Pin
SWDIO
Header
SWCLK
SWDIO
RP2350 Micro-USB
GPS
GPS_RESET
PPS
GPS_INT
5V_IN
VREG_5V
GPS_TX
GPS_RX
File: gps.kicad_sch
GPS UART
Breakout
J10
Conn_01x04_Socket
UART1_RX
UART1_TX
VREG_3V3
LORA_RFSW_0
LORA_RFSW_1
LORA_RST
LORA_INT
LORA_BUSY
LoRa RF
Switch Port
Conn_01x04_Socket
J4
GPS_RFSW_0
GPS_RFSW_1
GPS RF
Switch Port
Conn_01x04_Socket
J2
SPI0_RX
SPI0_TX
SPI0_CSn
SPI0_SCK
SERVO_PWM
SERVO_ENABLE
ENC_A
ENC_B
ENC_Z
UART0_TX
UART0_RX
RF_LED
STATUS_LED
R29
100
D7
LED
R30
D8
MountingHole
H4
H3
H2
H1
LoRa Telemetry
VDD_RADIO
LORA_RST
LORA_INT
LORA_BUSY
SPI_MISO
SPI_MOSI
SPI_NSS
SPI_SCK
RF_OUT_433
File: lora.kicad_sch
J9
CONREVSMA001-G
ENC_RX
ENC_TX
3V3
5V
VBAT
Servo + Encoder
File: actuator.kicad_sch
Sheet: /
File: rp2350-active-drag-system.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 1/7



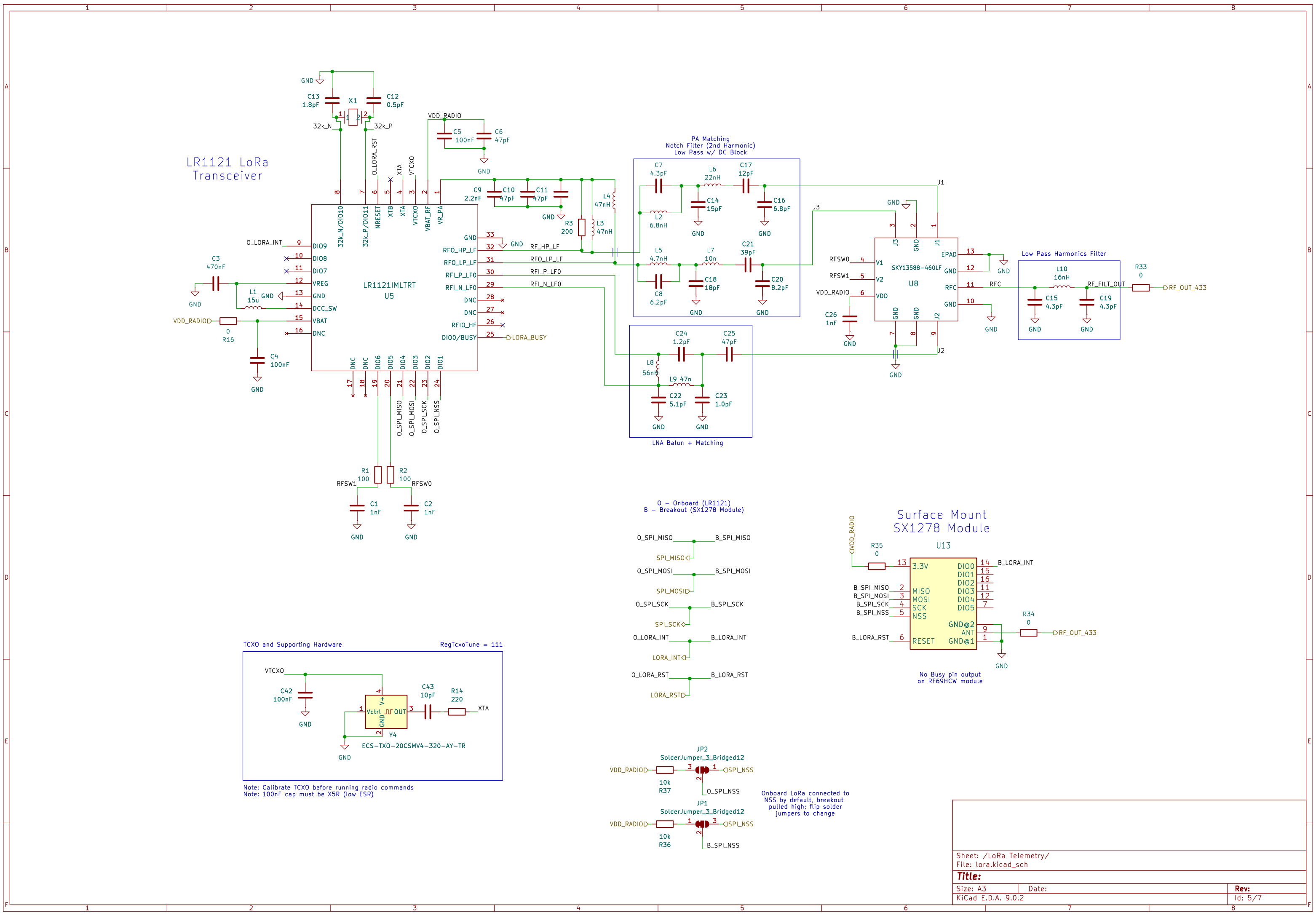
U1
RP2350
16MB Flash
Memory
W25Q128JVSIQ
U10
Boot Mode
Select Button
SW1
PTS815 SJM 250 SMTR LFS
Y3
ABM8-272-T3
J13
Conn_01x01_Pin
Spare GPIO
RP2350 is in upright
orientation as it
will be on board
Encoder
UART
GPS
UART
C65 4.7uF
C66 4.7uF
C67 4.7uF
L12 3.3uH
R15 27 63mW 1%
R9 27 63mW 1%
R17 33
TP4 1v1
C62 100nF
C63 100nF
C64 4.7uF
C51 4.7uF
C52 100nF
C53 100nF
C54 100nF
C55 100nF
C56 100nF
C57 100nF
C58 100nF
C59 100nF
C60 100nF
C61 2.2uF 6.3V X5R 20%
R12 1k 63mW 1%
R13 1k 63mW 1%
C49 15pF 50V C0G 5%
C50 15pF 50V C0G 5%
PWR_BANK
VDD
DVDD
+1V1
GND
USB_DP
USB_DN
QSPI_SS
QSPI_SD0
QSPI_SD1
QSPI_SD2
QSPI_SD3
QSPI_SCLK
LORA_BUSY
LORA_RST
LORA_INT
SPI0_RX
SPI0_CSn
SPI0_SCK
SPI0_TX
LORA_RFSW_1
LORA_RFSW_0
SERVO_ENABLE
SERVO_PWM
I2C0_SCL
I2C0_SDA
IMU_INT
MAG_INT
GPS_RFSW_0
GPS_RFSW_1
RF_LED
STATUS_LED
UART1_RX
UART1_TX
PPS
UART0_TX
UART0_RX
ENC_A
ENC_B
XIN
XOUT
SWCLK
SWDIO
ENC_Z
GPS_INT
GPS_RESET
Sheet: /RP2350/
File: mcu_rp2350.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 2/7

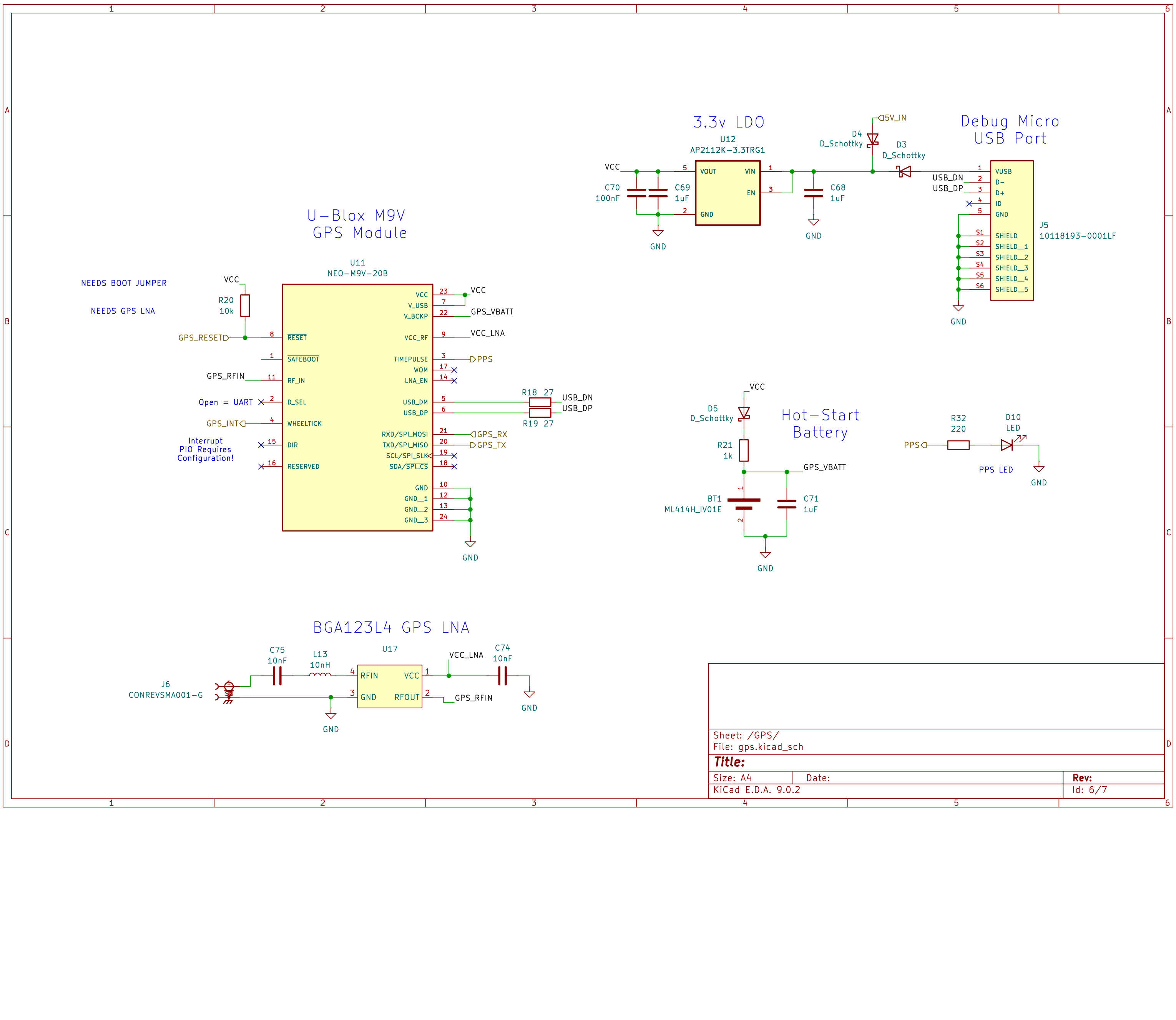


5V Switching Regulator
U7
TPS51386RJNR
VBAT
C37
100nF
C38
10uF
C39
10uF
GND
R4
100k
R5
100k
R10
100k
C35
1uF
VIN
EN
PG
VCC
VBST
SW
FB
MODE
SS
NC
PGND
AGND
C36
100nF
L11
WE-MAIA_4020
R11 150k
C40
22pF
R6
10k
R7
10k
TP1
5V
VREG_5V
C41
22uF
C44
22uF
C45
22uF
C46
22uF
3.3V LDO Regulator
VREG_5V
USB_VBUS
D1
PMEG3050EP_115
D2
PMEG3050EP_115
TP2
VSYS
C47
10uF
R8
100k
U9
LD39200PU33R
IN
EN
OUT
ADJ/SENSE
PG
3V3
TP3
C48
10uF
VOUT_3V3
R31
220
D9
LED
Red Power LED
Sheet: /Power Regulation/
File: power_regulation.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 3/7

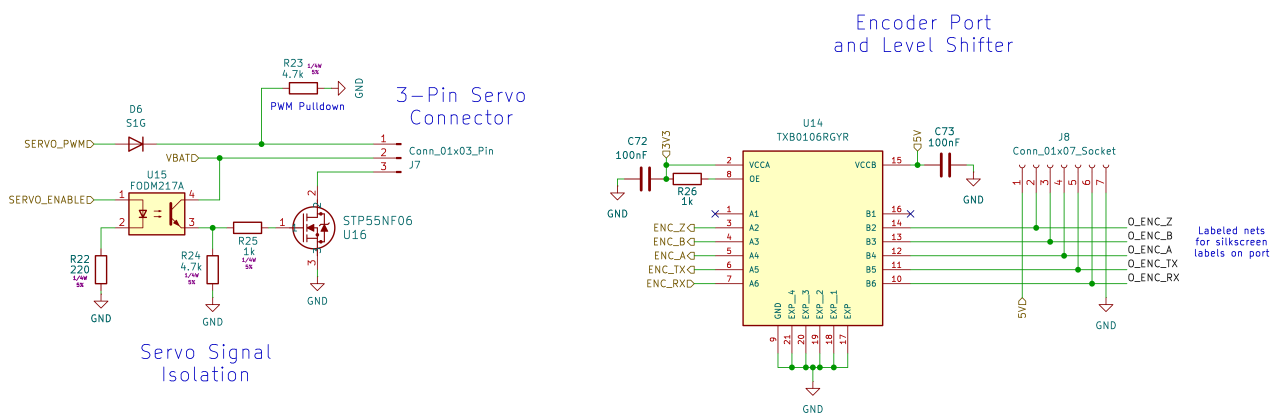


6DoF IMU
(Accel + Gyro)
U6
ICM-40609-D
C27
100nF
2.2uF
C28
C29
10nF
VCC
VDD
VDDIO
RESV
RESV__1
GND
SDA/SDI/SDIO
AD0/SDO
SCL/SCLK
CS
INT1/INT
INT2/FSYNC
SDA
SCL
IMU_INT
GND
Barometric
Altimeter
U4
MS560702BA03-50
C30
100nF
VDD
CSB
CSB
GND
PS
SDI/SDA
SCLK
SDO
±200G 3DoF
Accelerometer
U3
ADXL375BCCZ
C33
C34
100nF
VS
VDD_I/O
SDO/ALT_ADDRESS
*CS
GND
NC
RESERVED
RESERVED
INT1
INT2
SDA/SDI/SDIO
SCL/SCLK
HIGH_ACCEL_INT
3DoF Hall Effect
Magnetometer
U2
MMC5983MA
C31
C32
1uF
10uF
VDD
VDDIO
SPI_CS
CAP
SPI_SDO
SDA/SPI_SDI
SCL/SPI_SCK
INT
MAG_INT
J12
Conn_01x04_Socket
2x2 I2C0
Breakout
Sheet: /Sensors/
File: sensors.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 4/7


LR1121 LoRa
Transceiver
LR1121IMLTRT
U5
PA Matching
Notch Filter (2nd Harmonic)
Low Pass w/ DC Block
LNA Balun + Matching
Low Pass Harmonics Filter
SKY13588-460LF
U8
O - Onboard (LR1121)
B - Breakout (SX1278 Module)
Surface Mount
SX1278 Module
U13
No Busy pin output
on RF69HCW module
TCXO and Supporting Hardware
RegTcxoTune = 111
ECS-TXO-20CSMV4-320-AY-TR
Note: Calibrate TCXO before running radio commands
Note: 100nF cap must be X5R (low ESR)
SolderJumper_3_Bridged12
Onboard LoRa connected to
NSS by default, breakout
pulled high; flip solder
jumpers to change
Sheet: /LoRa Telemetry/
File: lora.kicad_sch
Title:
Size: A3
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 5/7



3.3v LDO
U12
AP2112K-3.3TRG1
VCC
C70
100nF
C69
1uF
VOUT
VIN
EN
GND
C68
1uF
GND
5V_IN
D4
D_Schottky
D3
D_Schottky
Debug Micro
USB Port
USB_DN
USB_DP
VUSB
D-
D+
ID
SHIELD
SHIELD__1
SHIELD__2
SHIELD__3
SHIELD__4
SHIELD__5
J5
10118193-0001LF
U-Blox M9V
GPS Module
U11
NEO-M9V-20B
NEEDS BOOT JUMPER
NEEDS GPS LNA
R20
10k
GPS_RESET
RESET
SAFEBOOT
GPS_RFIN
RF_IN
Open = UART
D_SEL
GPS_INT
WHEELTICK
Interrupt
PIO Requires
Configuration!
DIR
RESERVED
V_USB
V_BCKP
GPS_VBATT
VCC_RF
VCC_LNA
TIMEPULSE
PPS
WOM
LNA_EN
USB_DM
USB_DP
R18 27
R19 27
RXD/SPI_MOSI
GPS_RX
TXD/SPI_MISO
GPS_TX
SCL/SPI_SLK
SDA/SPI_CS
GND__1
GND__2
GND__3
D5
D_Schottky
R21
1k
Hot-Start
Battery
BT1
ML414H_IV01E
C71
1uF
R32
220
D10
LED
PPS LED
BGA123L4 GPS LNA
U17
C75
10nF
L13
10nH
RFIN
RFOUT
C74
10nF
J6
CONREVSMA001-G
Sheet: /GPS/
File: gps.kicad_sch
Title:
Size: A4
Date:
KiCad E.D.A. 9.0.2
Rev:
Id: 6/7



Sheet: /Servo + Encoder/
File: actuator.kicad_sch

Title:

Size: A4	Date:	**Rev:**
KiCad E.D.A. 9.0.2		Id: 7/7

RP2350 Control PCB LoRa Filter Sweeping

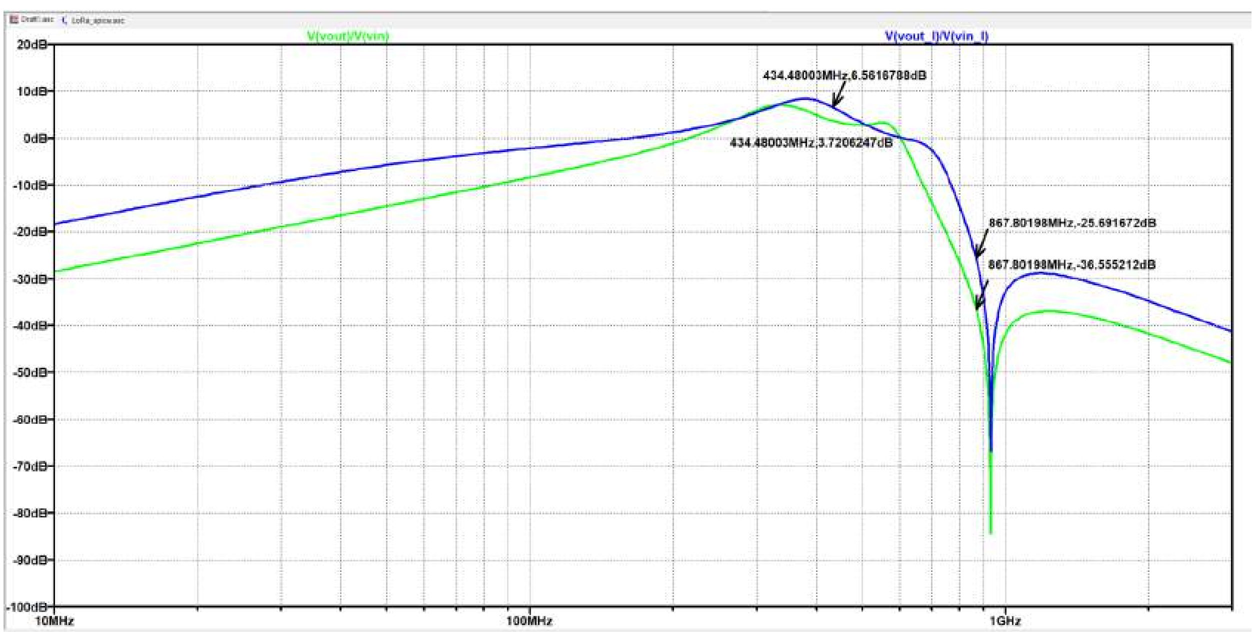
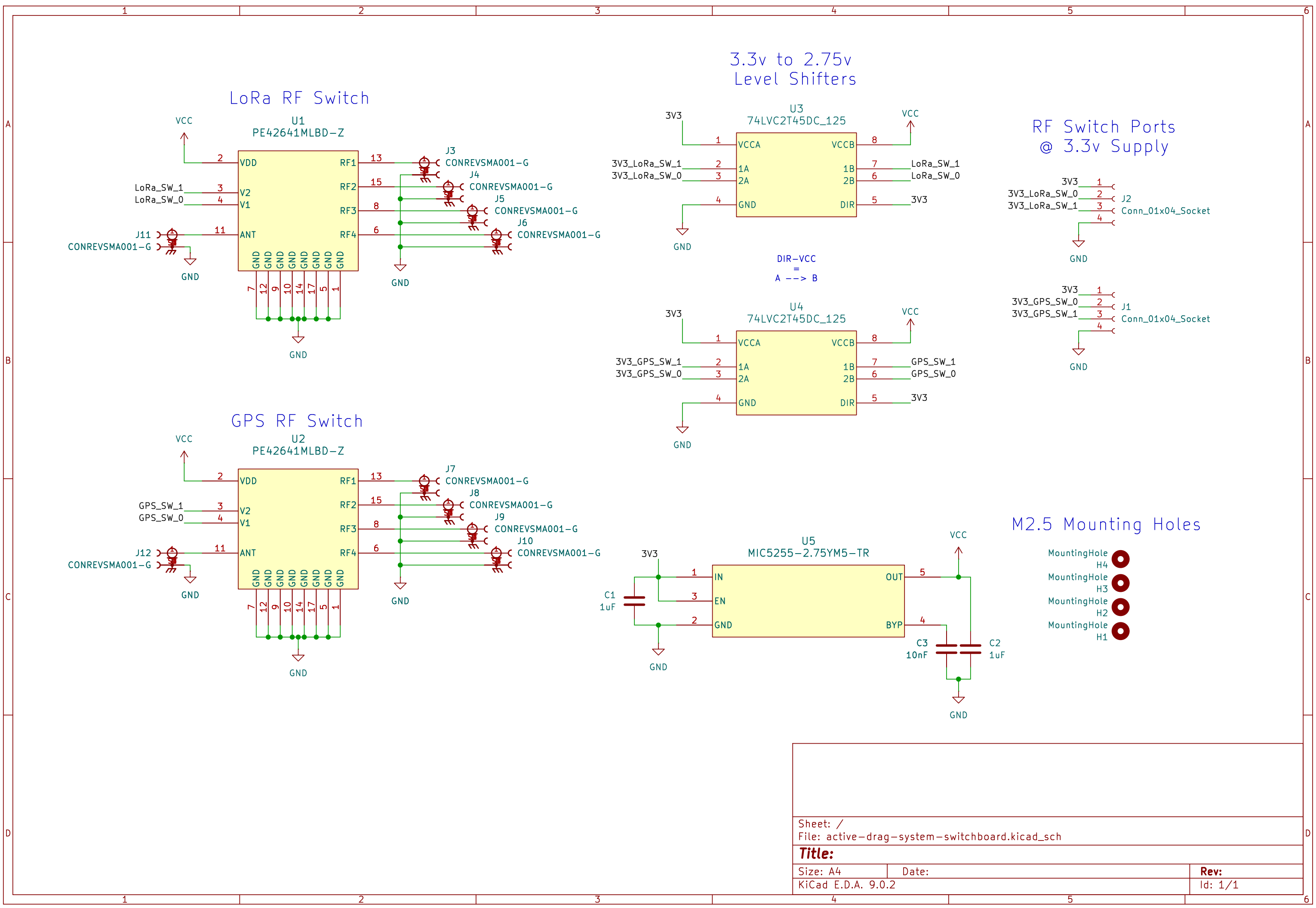


Fig. 23 ADS PCB Filter Network Frequency Sweep Plot

4-Way RF Switch PCB Schematics



LoRa RF Switch
U1
PE42641MLBD-Z
VCC
VDD
LoRa_SW_1
LoRa_SW_0
V2
V1
ANT
RF1
RF2
RF3
RF4
J3
J4
J5
J6
J11
CONREVSMA001-G
GND
GPS RF Switch
U2
PE42641MLBD-Z
GPS_SW_1
GPS_SW_0
J7
J8
J9
J10
J12
3.3v to 2.75v
Level Shifters
U3
74LVC2T45DC_125
3V3
VCCA
VCCB
3V3_LoRa_SW_1
3V3_LoRa_SW_0
1A
2A
1B
2B
DIR
LoRa_SW_1
LoRa_SW_0
DIR-VCC
=
A --> B
U4
74LVC2T45DC_125
3V3_GPS_SW_1
3V3_GPS_SW_0
GPS_SW_1
GPS_SW_0
RF Switch Ports
@ 3.3v Supply
J2
Conn_01x04_Socket
J1
Conn_01x04_Socket
U5
MIC5255-2.75YM5-TR
IN
EN
OUT
BYP
C1
1uF
C3
10nF
C2
1uF
M2.5 Mounting Holes
MountingHole
H4
H3
H2
H1
Sheet: /
File: active-drag-system-switchboard.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.2
Id: 1/1

References

[1] *AeroTech M2400T*. Jan. 1, 2026. URL: https://www.thrustcurve.org/motors/AeroTech/M2400T/ (visited on 01/01/2026).

[2] John K. Bennett. "Fin Flutter Analysis Revisited (Again)". In: *Peak of Flight Newsletter* 615 (Dec. 2023). URL: https://www.apogeerockets.com/education/downloads/Newsletter615.pdf.

[3] *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*. Tech. rep. D3039/D3039M-00. Approved April 10, 2000. West Conshohocken, PA: ASTM International, 2000. DOI: 10.1520/D3039_D3039M-00. URL: https://www.astm.org/d3039_d3039m-00.html.