Capricornus: WPI High Power Rocketry Club

Team 156 Project Technical Report to the 2023 Spaceport America Cup

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Abstract

This report, written by the Worcester Polytechnic Institute (WPI) High Power Rocketry Club (HPRC), details the technical specifications of 2023 Spaceport America Cup project Capricornus. Project Capricornus consists of a 10,000 ft COTS Propulsion sounding rocket and a folding quadcopter payload. The rocket has five major systems which were designed by the team this year. First is our custom threaded aluminum coupler mechanism that replaced standard coupler tubes. Next is our airbrakes mechanism which was developed with an increased emphasis on simulation and flight testing so that we reach as close to 10,000 ft as possible. The other major systems consist of our composite tip-to-tip fin-can, CO2 and black powder ejection systems, and a highly developed electronics package. The payload team developed an air-deployed autonomous quadcopter that is released from a CubeSat retention mechanism. Upon deployment the quadcopter will complete a mission of autonomously deploying small weather station packages throughout the area that will transmit local environmental data to the team's ground station. The goal is to simulate an extraterrestrial planetary exploration mission. The 157-person team has designed, built, and tested these systems throughout the academic year and hope to demonstrate their capabilities at competition in New Mexico. This will be the second year that WPI HPRC has participated in the Spaceport America Cup as we hope to inspire students and push our capabilities.

I. Nomenclature

C_d	=	Coefficient of Drag
d_m	=	Distance in meters
f_{MHz}	=	Frequency in MHz
K_s	=	Equivalent Sand Grain Roughness
K_{rms}	=	Root Mean Square Roughness Height
K_a	=	Roughness Height
S_k	=	Roughness Shape
V	=	Velocity
X	=	Extension of Airbrakes

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II. Introduction

THE Worcester Polytechnic Institute (WPI) High Power Rocketry Club (HPRC) is a 157-member strong club on campus. The team was founded in 2018 as a group of students entering NASA's University Student Launch Initiative (USLI). Prior to 2018, students at WPI had competed in the Battle of The Rockets (BOR). Last year, the team competed in the Spaceport America Cup for the first time. At last year's competition, the vehicle experienced an in-flight failure that resulted in the loss of the vehicle. Despite this, the team left the competition having placed well in many categories such as technical documentation and design quality resulting in a placement of 48th overall. The team also left with the Team Sportsmanship Award for our team's actions during the competition. This year, the team has chosen to continue to compete in the Spaceport America Cup to refine our skills. We intend on remaining a strong and formidable team during this year's events.

Our team is comprised of mostly undergraduate team members. Any member of the WPI community is welcome to join the team as we have no major prerequisites to join. Members of all different majors and backgrounds participate with the majority being Aerospace Engineering majors. A general overview of team composition is seen in Fig. 1.

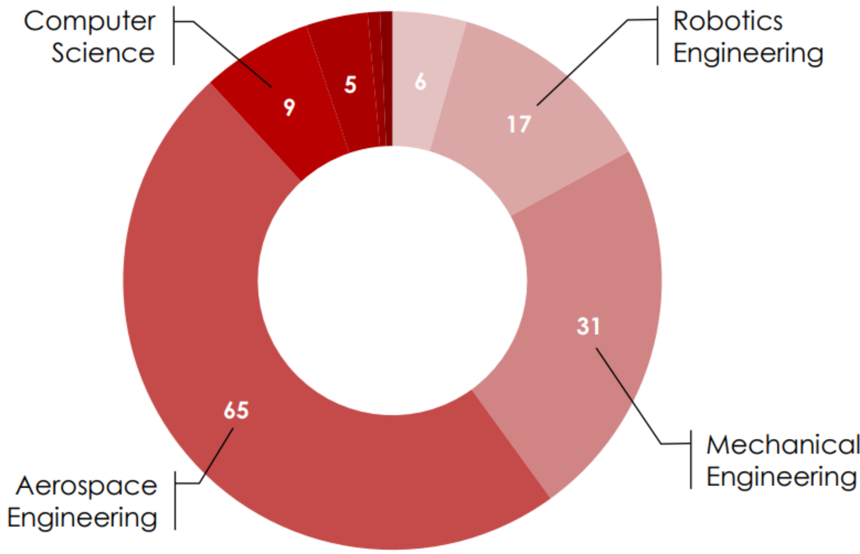


Fig. 1 Team Major Distribution

The team is structured with four executive board members, the Team Captain, Rocket Division Lead, Payload Division Lead, and Electronics and Programming Division Lead. The Team Captain is responsible for all team activities and oversees the team's eleven-person officer board. The officer board consists of the Treasurer, Safety Officer, Logistics Officer, Engagement Officer, Public Relations Officer, Documentation Officer, Sponsorship Officer, and the aforementioned executive board. Each division lead oversees the various subteam leads that manage an individual system. Each subteam lead oversees general team members who complete the design, construction, and testing of each system. The following sections will detail the team's technical systems. The current management structure is seen in Fig. 2.

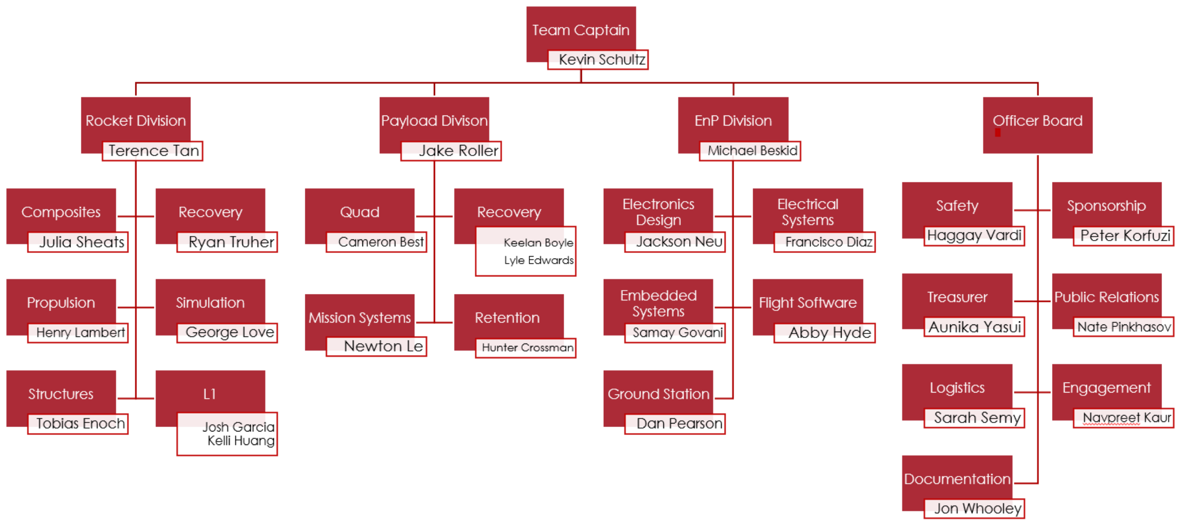


Fig. 2 Team Organizational Structure

The team is not only supported by the efforts of its members, but also through the funding and mentorship of other parties. The primary form of team income comes from the WPI Student Government Association which funds clubs on campus. The next major source of funding is from fundraising events and corporate sponsors. The team has a total of nine sponsors this year. Our Platinum sponsors are Altium, Test Devices by Schenck, and Giving Day Donors. Our Gold sponsors are Ensign-Bickford Aerospace and Defense, Collins Aerospace, EnDAQ and the WPI Tinkerbox Program. Our Silver tier sponsors are Blue Origin and Atomic Machines. The individual and corporate sponsors provide the team with funding, mentorship, and hardware that helps the team complete our mission each year.

The team's developmental cycle closely follows the engineering lifecycle where various milestones are coordinated with design reviews such that designs can be improved and implemented effectively. In October, the team completed a multi-day internal Preliminary Design Review to assess how designs were determined and how they will continue to be developed. In January, the team completed our Critical Design Review where we reassessed current prototypes and considered factors in manufacturing and test validation. Lastly, our team continued design validation following manufacturing with tests and procedures mentioned later in this report. The overview of major milestones is seen in Fig. 3.

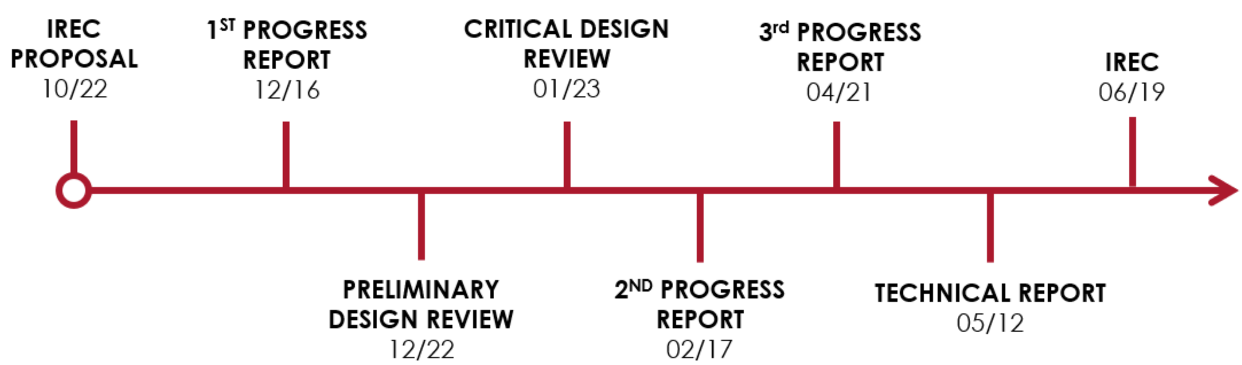


Fig. 3 Major Deliverable Milestones

As our members move from design to rapid prototyping and finally to flight hardware assembly and testing, a strong emphasis is placed on member education. Our team members host a wide range of educational workshops and programs that are designed to give members exposure and build their skillset. These workshops cover everything from basic CAD software to advanced machining and simulation processes.

Lastly, our team continues to grow our community outreach programs. We have partnered with local educational programs and institutions to educate and inspire potential future engineers. Through six separate community outreach events this year, we have dedicated a total of 1058.5 combined hours whilst connecting with hundreds of young students within the Massachusetts area.

III. System Architecture Overview

Capricornus is a solid fueled rocket with a target apogee of 10,000 ft AGL. It has a 6" diameter airframe, stands 143 inches tall, and weighs in at 66.7lbs at liftoff. This vehicle is broken down into 4 main sections: aft bay, electronics bay, parachute bay, and payload bay.

Fig. 4 Livery Design

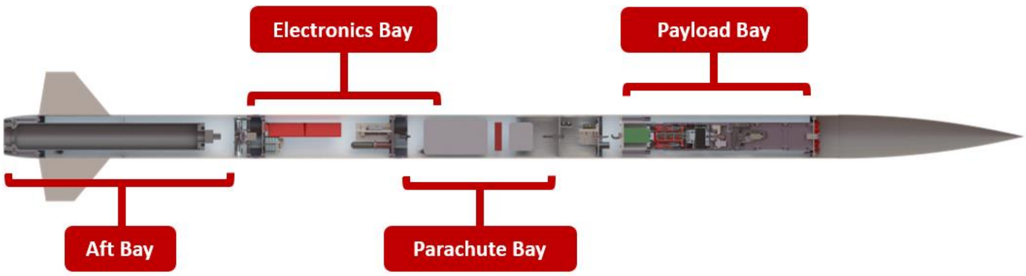


Fig. 5 Cross Section of Capricornus

The aft bay houses the primary thrust structure, motor retention system, custom fiberglass tip-tip layup fin can, and molded tailcone. Next, the electronics bay contains the rocket's recovery electronics, GPS tracker, avionics boards, TX antennas, and airbrakes mechanism. In the parachute bay, there is the main parachute, drogue parachute, and all other associated recovery hardware. Finally, I n the payload bay is the deployable quadcopter payload as well as its associated retention and deployment system. The nosecone houses the payload's adapter structure as well as the secondary GPS tracker.

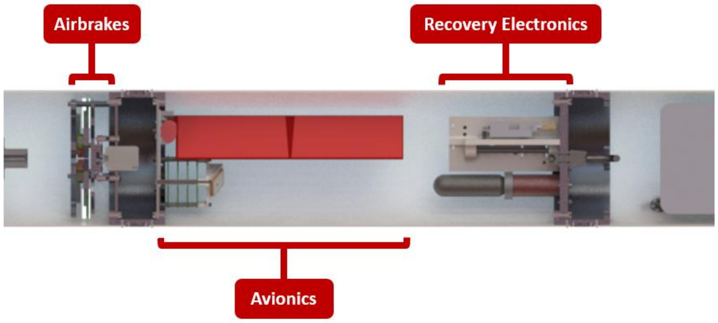


Fig. 6 Cross Section of Electronics Bay

A. Propulsion

1. Motor Selection

The team started off the competition year by creating preliminary mass and size estimates of the subsystems that would be flown on Capricornus. These estimates informed the 1st round of trajectory simulations and narrowed down our selection to motor reloads suitable for the Pro 98mm 4G casing. Even the lower impulse motors out of the available options would be able to deliver the vehicle to 10,000 ft, thus providing us the option to fly heavier rockets on the higher impulse options. Motors were further narrowed down to fulfill proper thrust to weight, off the rail velocity, and static stability requirements. Higher fidelity trajectory simulations determined that the CTI M1800 Blue Streak would be the best fit for the Capricornus launch vehicle.

2. Flight Simulation

Environmental flight conditions were determined based off data from past years at Spaceport America. These conditions included average temperature, pressure, and altitude which is shown in Table 1. On launch day, the vehicle will fly off a standard 1515, 17ft aluminum extrusion rail. Since the last rail guide forward of the center of gravity is 4.8' from the aft end of the vehicle, the effective rail length is 12.2'.

Table 1 Predicted Launch Conditions

Parameter	Value
Windspeed	0-20 mph
Temperature	35 °C
Pressure	14.7 psi
Latitude, Longitude	33 °N, -107 °E
Altitude	4595 ft

OpenRocket 22.02 was used to conduct the vehicle's flight simulations. At a nominal case of 7 mph winds and a 7° launch rail angle, the vehicle is expected to go to 10,502 ft. At worst case flight conditions of 20 mph winds, the vehicle will still reach 10,213 ft. Airbrakes that will induce drag onto the vehicle can reduce the apogee by up to 1000 ft if fully actuated immediately after burn-out for the entirety of the coast. A 200-500' apogee overshoot is well within the capabilities of the airbrakes to bring down the apogee to 10,000'.

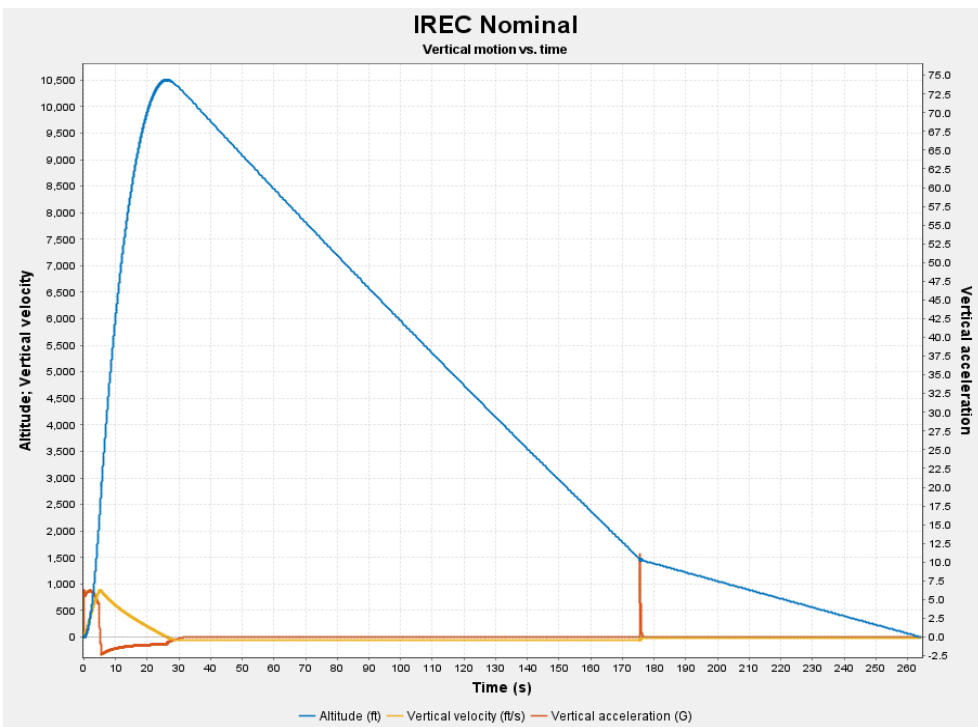


Fig. 7 Nominal Flight Simulation Results

B. Aerostructures

3. Vehicle Loads Analysis

Proper characterization of the loads that the vehicle endures through all phases of flight is used to inform the design and analysis of the vehicle's primary and secondary structures. From data pulled from the OpenRocket simulations and previous launches, a set of worst-case load conditions were compiled along with a minimum design safety factor requirement based on the confidence and thoroughness of the analysis. Vehicle loading during the boost and recovery phases are often the most aggressive load cases throughout the flight profile, so the analysis focuses on the axial and bending loads during those events. Figure 8 showcases the bending moment through the length of the rocket due to wind shear and inertial loads caused by attitude correction in aerodynamically stable flight. It uses lateral acceleration data from several OpenRocket simulations to create this diagram. We assume that the rocket is held between 2 pivots on opposite ends despite the dynamic nature of the rocket trajectory and induce a uniform lateral load on each mass element in the rocket. Since the data received from OpenRocket is a black box and we make static assumptions for a highly dynamic system, a high safety factor requirement of 5 was established for all joints that support the rocket's structural rigidity.

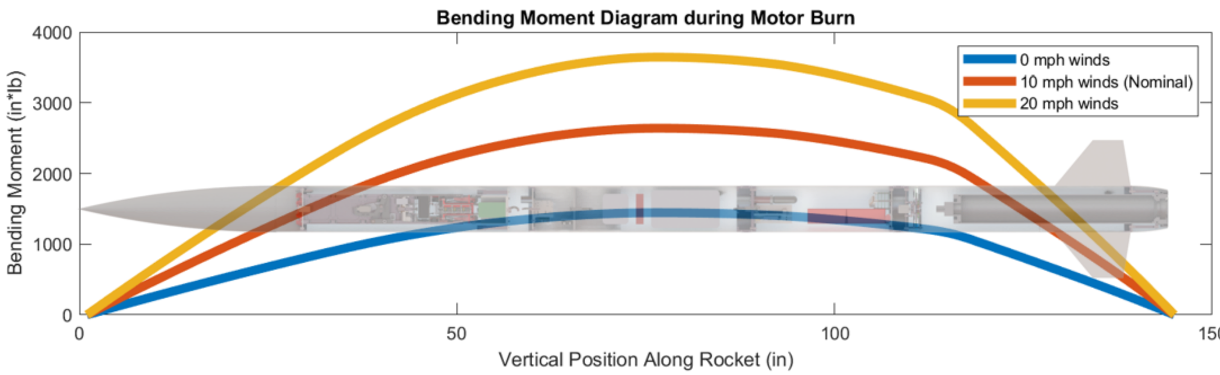


Fig. 8 Max Bending Moment along vehicle during Motor Burn

This bending moment analysis will be later used in the design of our custom aluminum coupler joints. According to OpenRocket, the vehicle will experience a maximum of 6.43 Gs of axial loading during motor burn. On the way down, parachute shock loading during drogue deployment is challenging to accurately quantify. Variables such as angle of attack, wind speeds, and ejection timing all affect the speed of the vehicle during drogue deployment and therefore the force of drogue parachute opening. Based on previous launches, the vehicles of our scale experience an average of 6Gs during drogue opening. We assigned a high safety factor (5) for components withstanding drogue opening forces because of the uncertainly with predicting drogue opening loads. Lastly, we were able to quantify the opening loads of the main parachute opening with a numerical simulation in MATLAB. Due to predictable descent speeds under drogue, we are confident that our predicted main parachute opening loads are fairly accurate and thus assigned a safety factor requirement of 2. Recovery load characterization is further discussed later in the recovery section.

Table 2 Worst Case Loading Conditions

Load Case	Load Value	Design Safety Factor Requirement
Axial Compression during Boost	6.43 G	2
Bending Moment during Boost	2639 in-lbs	5
Drogue Parachute Opening Shock	6 G	5
Main Parachute Opening Shock	15.3G	2

4. Body Tubes

The airframe of the rocket consisted of commercial-off-the-shelf filament wound fiberglass body tubes and couplers. Fiberglass was chosen as the airframe material for its high strength to weight ratio, reasonable cost, and RF transparency. One of the challenges the team faced in previous years was ensuring that the tubes were cut and sanded square to avoid misalignment between the tubes. To address this issue in the current project, the team developed a

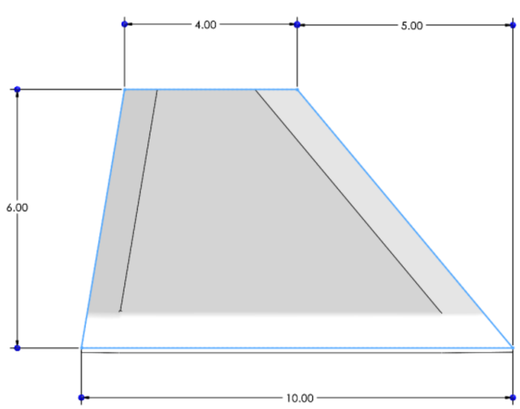
Tube Cutting Jig that interfaced with a Miter saw as shown in Figure 9. The purpose of the jig was to ensure the saw cut a square edge and maintain proper clamping during the cut. Without a jig, the miter saw could only cut a flat, but angled edge. After several iterations, the jig design was selected for its functionality and ability to accommodate varying tube lengths and diameters. The jig consisted of a base and clamp with wheels to secure the tube, while allowing it to be rotated during the cutting process. An adjustable hard stop on rails helped ensure the tube would not travel axially.

Fig. 9 Tube Cutting Jig

To verify that the quality of the tube end cuts, each tube was placed on a surface plate against a square block and examined. Ultimately, the cuts were fairly accurate but required additional hand-sanding to achieve a satisfactory finish. The team determined that future iterations of the Tube Cutting Jig design should consider how to mitigate the deflection of the tube when compressed at one end.

5. Fins

The fin shape and design were determined using OpenRocket software based on the rocket's performance requirements. The team selected a trapezoidal fin shape with a root chord of 10 inches, 6-inch span, and a tip chord of 4 inches. The trapezoidal shape was selected to ensure sufficient span to create a good amount of restoring force and protect the trailing edge of impact damage at the end of its descent. Furthermore, the team selected to have 4 fins mounted 90 degrees apart on the rocket. A 4-fin configuration would be able to achieve the same stability margin as a 3-fin configuration with a shorter span. This decreases the likelihood of mechanical fin failure (flutter and divergence) because the shorter span allows for a smaller moment arm for bending loads. To keep the drag low while maintaining reasonable stability, the team verified the fin shape and quantity selection in OpenRocket by confirming that our static stability falls within the acceptable range.



Fin Dimension (in)	
Root Chord	10.0
Tip Chord	4.0
Span	6.0
Sweep	5.0
Thickness	0.16
Fillet Radius	1.00

Fig. 10 Fin Geometry

The fin core material consisted of 3mm thick G10 custom cut by a vendor. On either side of the fin core is a three-layer fiberglass tip-to-tip layup gradient tapering in thickness from the root chord to the tip. To verify the core selection, the G10 material properties and fin dimensions were inputted into the FinSim simulation software. To ensure the rocket does not surpass fin flutter and divergence velocities, we conducted a series of analyses using the 3D Barrowman method, Classical 2D method, and NACA TN 4197 method in FinSim. The material selected in FinSim was G10 fiberglass, the core material of the fin. The multiple outer layers of S-glass fiberglass sandwiching the core, greatly increasing the stiffness of the fin, signifying that the FinSim analysis provided a conservative approximation. The Classical 2D lift curve slope assumes a 2D airfoil with a lift curve slope of 2π. Based on our input parameters in FinSim, this method indicates both a divergence and flutter failure. The divergence velocity predicted by this method is lower than is allowable, however the 2D airfoil assumption gives the highest possible lift and therefore a low divergence velocity. The actual fin is thick and will therefore have a smaller lift curve slope. The 3D Barrowman method attempts to predict the true lift curve slope, and gives a divergence velocity of 1454 ft/s and a flutter velocity of 2285 ft/s. All safety factors are calculated based off a reference velocity of 904 ft/s which is the maximum velocity of our vehicle towards the end of the boost phase.

Table 3 Fin Failure Mode Calculations

Analysis Model	Lift-Slope	Divergence Velocity (ft/s)	Divergence Safety Factor	Flutter Velocity (ft/s)	Flutter Safety Factor
Classical 2D Lift-Slope	8.8261	719.4	0.79	1130.02	1.25
Barrowman 3D Lift-Slope	**2.1583**	**1454.77**	**1.61**	**2285.16**	**2.53**

To confirm our assumption of the 3D Barrowman lift-slope model, we conducted CFD simulation, using Ansys Fluent, to quantify the lift curve slope of our fins. The simulation included just a singular fin and had an input parameter of angle of attack. The k-omega SST model was used as it is best for external flow when no flow separation occurs, and the linear region of the cl v alpha graph will have no flow separation. Fig. 11 shows the pathlines of the flow coming off the fin colored by the velocity normal to the fin. At the tip of the fin, a wingtip vortex can be seen which causes a large portion of the difference between the 2D and 3D lift-slope.

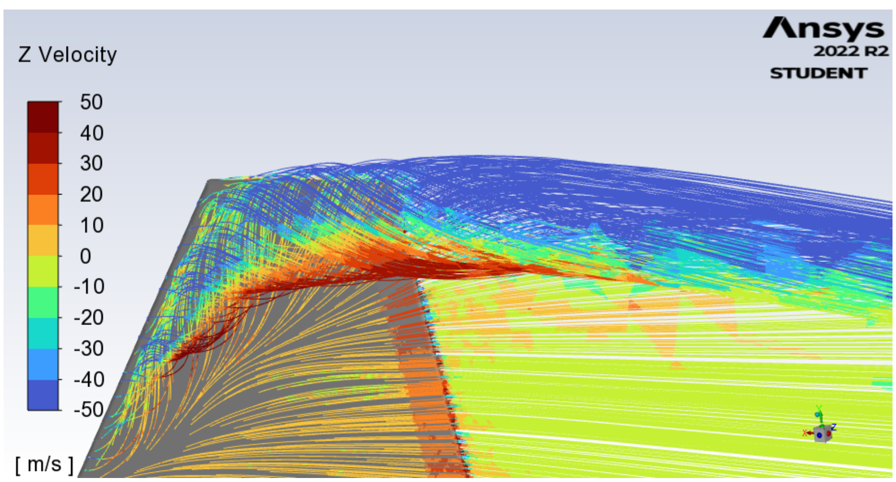


Fig. 11 Pathlines Colored by Normal Velocity

The CFD data can be seen below in Figure 12. The linear lift-slope from the CFD data is 2.0567, which lines up well with the Barrowman 3D lift-slope of 2.1583.

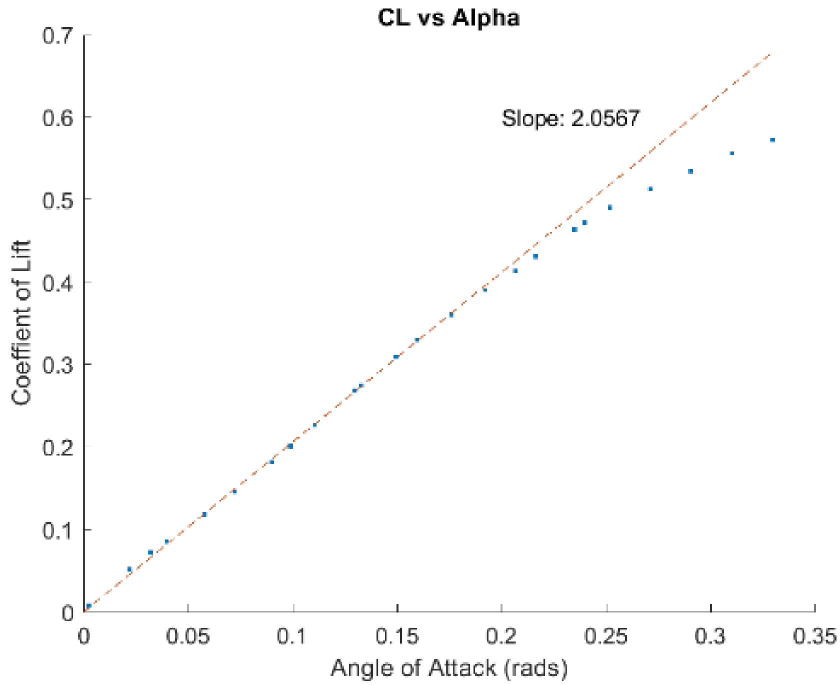


Fig. 12 Coefficient of Lift Versus Angle of Attack for Fin Geometry

To achieve a more accurate mechanical simulation involving the fins in the future, this year the team began material property research for sandwich composites, specifically fiberglass. To develop the sandwich composite testing procedure, standards ASTM C393 [1] and ASTM D7250 [2] were referenced. ASTM C393 goes over the proper way to set up composite coupons and a testing machine to find its core shear properties. ASTM D7250 provides the proper way to calculate core shear modulus and other properties of sandwich materials. The team was able to test three composite coupons in a three-point bending test on an Instron with a 2 kN load cell at WPI. The three types of coupons that were tested included a one-laminate, two-laminate, and three-laminate with G10 core and S-glass wet layup on both sides of the coupons.

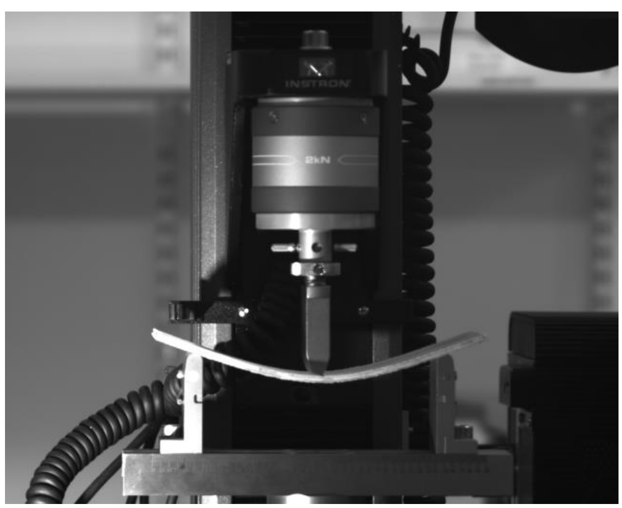


Fig. 13 Three-point Bending Test of Sandwich Composite Coupon

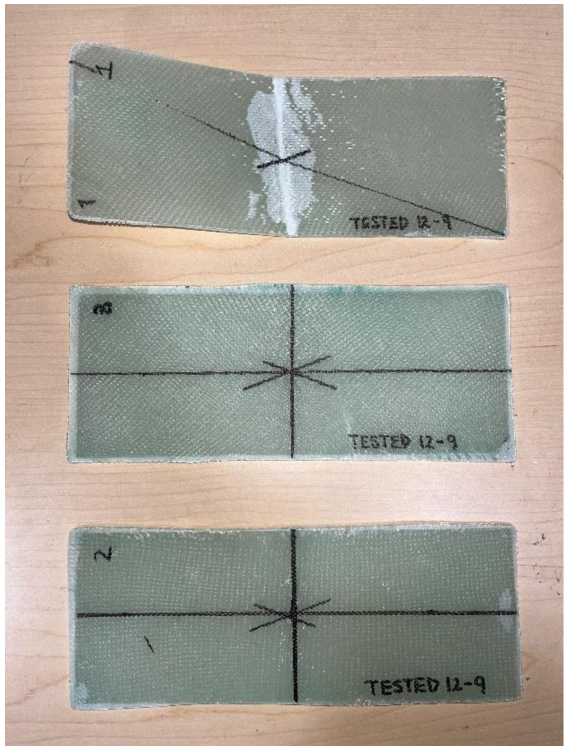


Fig. 14 Fiberglass Coupons: 1-laminate (top), 2-laminate (middle), 3-laminate (bottom)

Table 4 Status of Bending Tests Trials

Type	**Trial 1**	**Trial 2**
One-Laminate	Fractured at around 1.7-1.8 kN	Instron out-of-order, could not complete
Two-Laminate	Severe elastic deformation, no plastic deformation	Instron out-of-order, could not complete
Three-Laminate	Severe elastic deformation, no plastic deformation (failure at 15 mm displacement, 1.8 kN load)	Instron out-of-order, could not complete

From the three-point bending tests, we gathered force-displacement data for each coupon. While we were not able to conduct a second trial because the Instron machine was shut down for maintenance, this data along with future testing to gather information on tensile strength properties will ultimately be used to calculate the bulk modulus of sandwich composite and input the information into future simulation.

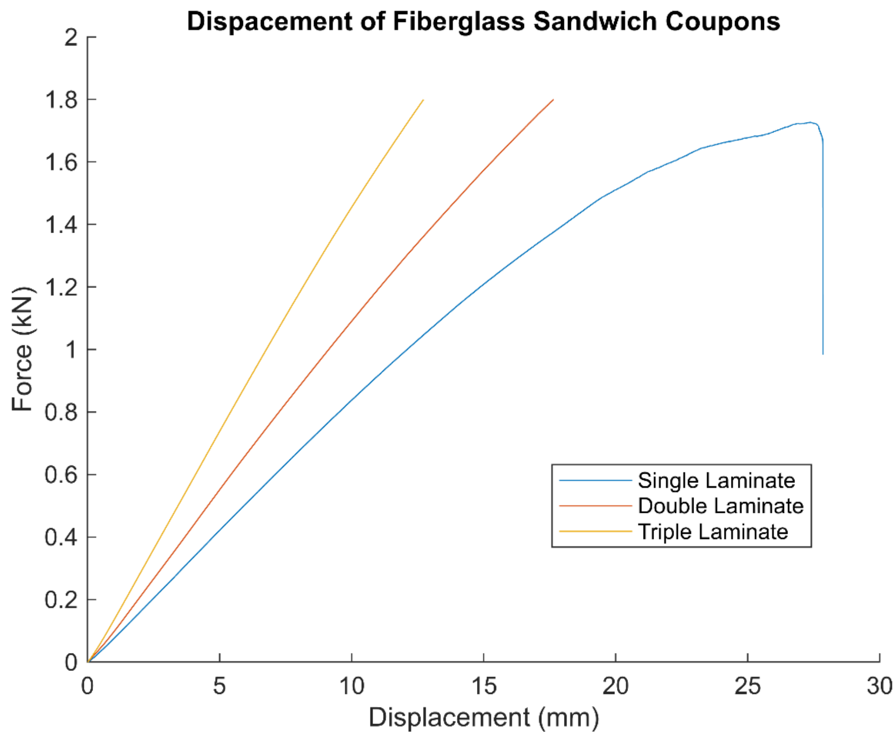


Fig. 15 Displacement-Force Data of Single, Double, and Triple Laminate Bending Test

The team took on a major initiative this year to improve team communication and avoid misunderstandings between different subsystems. To do so, we standardized the x, y, and z axes of the vehicle as illustrated in figure 16. These axes determined the locations of all clocking features, rail buttons, livery, and fins. Before attaching the fins to the rocket, lines were marked along the axes of each tube using a sharpie loaded in the spindle of a 3-axis CNC mill as shown in Figure 17. The purpose of creating these lines was to ensure fins were attached exactly 90 degrees apart from each other and define axis locations.

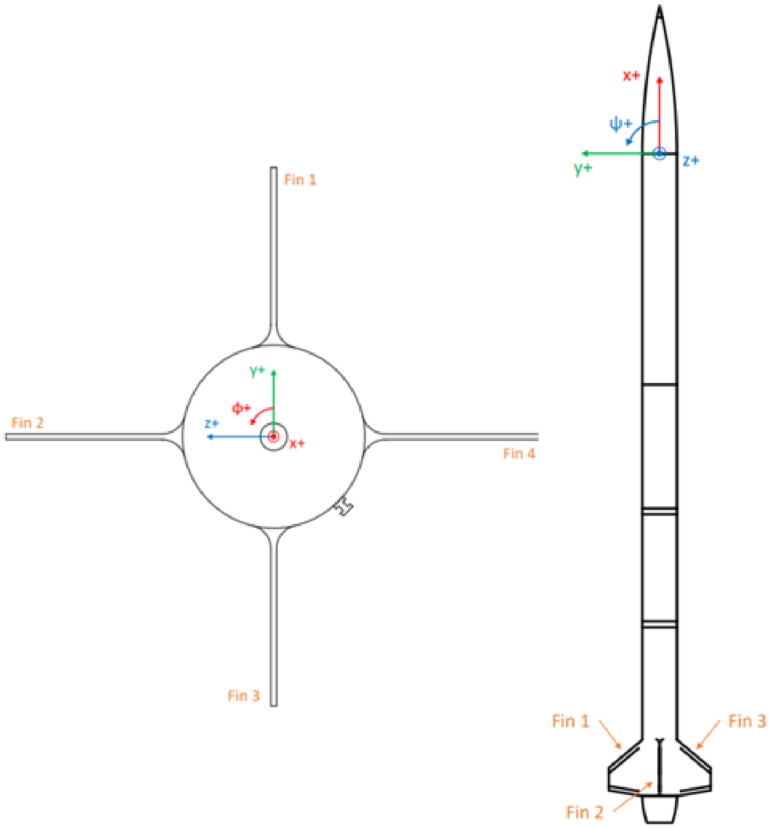


Fig. 16 Vehicle Axis

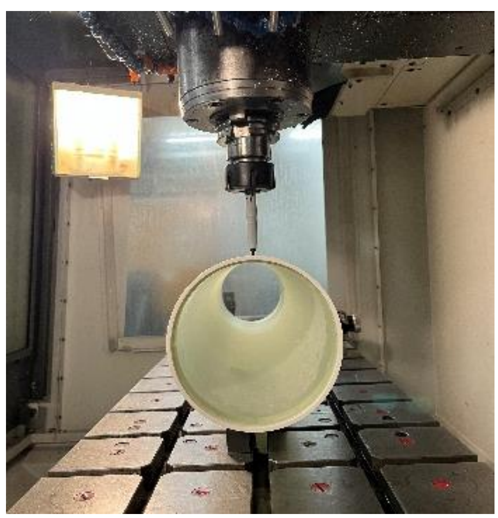


Fig. 17 Marking Vehicle Axes on Tube

A symmetric beveled edge was cut along the leading and trailing edges of each fin to create a hexagonal airfoil. The bevels provide an improvement to the flight performance by reducing pressure and induced drag. A CNC router was utilized along with a beveling fixture for the router bed to achieve a consistent bevel of 3.81 degrees. By implementing this hexagonal airfoil, the vehicle's apogee increased by around 700 feet.

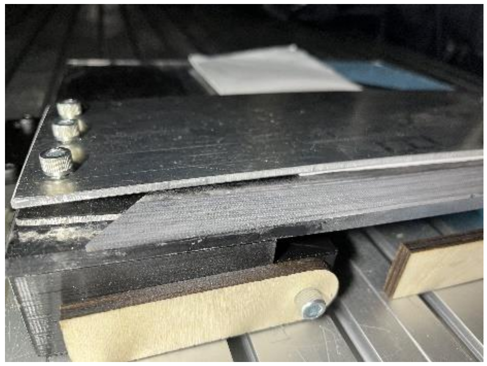


Fig. 18 Fin Beveling Fixture

The team generated several design options for a fin alignment jig. After the numerous iterations and design pivots shown in Table 5, ultimately the team determined the most optimal solution was a combination of a surface plate, ground angle block, and a machined tooling plate with a boss to center the tube and square cutout to align the angle block.

Table 5. Fin Alignment Jig Design Iterations

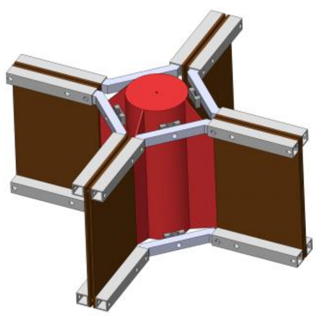
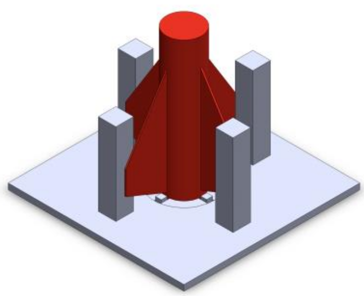
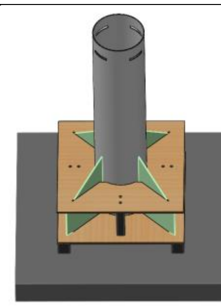
First Iteration	Second Iteration	Third Iteration
		

Fig. 19 Final Fin Alignment Jig

Before tacking, a bead of Rocketpoxy was applied to the root chord of each fin. Once aligned and clamped into position, the fins were tacked into place with super glue. Then, 1” fillets made of Rocketpoxy were applied along the entire length of the root chord on either side of each fin to increase the structural strength of the fin under bending loads, in addition to improving the consistency of the tip-to-tip layup process. To ensure a consistent radius fillet, a small laser cut tool was used to smooth of the epoxy along the root chord.

Fig. 20 Building up Rocketpoxy Fillet along Fin Root

Once the fins were attached, the team mounted the fin can in the 3-axis mill and used a dial indicator to gather positional data, which was then used to calculate the cant of the fins. Determining the actual fin cant of each fin helped inform our Openrocket simulation and ensure that our projected roll rate falls within a reasonable range. The tolerance defined for the fin mounting process was $\pm$ 1°, which the team was able to achieve as shown in Table 6. With the updated actual fin cants in Openrocket, we found that there will be about a 10.5 RPM roll rate based on the measurement results. Thus, these measurements helped us verify the fin mounting positions are within the acceptable tolerance and that the roll rate is reasonably low.

Fig. 21 Utilizing Dial Indicator in a CNC Mill to Measure Positional Data of each Fin

Table 6 Calculated Cant Angles of each Fin

Fin #	Cant Angle (°)
1	+ 0.066
2	- 0.042
3	- 0.150
4	- 0.310

With the fin positions verified, the next step of the manufacturing process was to sand the surface to prepare for a three-layer fiberglass tip-to-tip layup gradient tapering in thickness from the root chord to the tip. A comparison of the various laminating epoxy brands and resin-hardener combinations was conducted to determine the most suitable laminating epoxy for the layup. The team selected the PRO-SET LAM-125/LAM-226 combination for the layups for its good pot life, tensile strength, and cost.

Table 7 Comparison of Lamination Epoxy Options

Brand	Resin	Hardener	Pot Life (min)	Tensile Strength (psi)	Flexural Modulus (psi)	Density (lb/in^3)	Glass Transition Temp (F)	$/Gallon Resin + Hardener Ratio
West System	105	205	12	7846	461000	0.0426	129	$157.37
West System	105	206	21.5	7320	450000	0.0426	126	$157.37
Fiberglast	1000	1025		8567	374930	0.0405	152.3	$139.95
Fiberglast	2000	2060	60	9828	462910	0.0401	196	$179.90
Fiberglast	2000	2020	20	9861	462910	0.0410	180	$179.90
Aeropoxy	PR2032	PH3660	60	9828	462910	0.0420	196	$201.86
Aeropoxy	PR2032	PH3630	30	9867	500883	0.0420	194	$201.86
System 3	A	B	26	7900	420000	0.0385	160	$161.81
PRO-SET	**LAM-125**	**LAM-224**	**13**	**10200**	**453000**	**0.0420**	**193**	**$172.91**
PRO-SET	LAM-135	LAM-224	13	11000	469000	0.0423	216	$172.91
PRO-SET	**LAM-125**	**LAM-226**	**55**	**10200**	**453000**	**0.0420**	**193**	**$140.29**
PRO-SET	LAM-125	LAM-229	90	8850	592000	0.0416	186	
PRO-SET	LAM-125	LAM-237	109	7700	526000	0.0416	184	

Each layer of fiberglass was saturated in epoxy before being applied into a marked position on each quadrant of the fin can. The tip-to-tip layup process provided a small amount of radial taper and a consistent thickness-to length ratio. After applying the fiberglass fabric onto the fin can, one layer of peel ply and one layer of breather fabric was applied on top of the layup. The whole fin can was then vacuum bagged for 6 hours. The bag was attached using yellow sealant tape to the tube above and below the fins. The bag itself was cut was multiple pieces and heat sealed to achieve a sleeve that followed the contours of the fins.

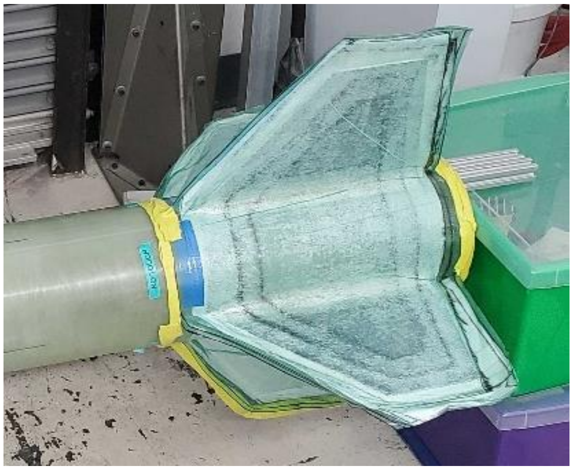


Fig. 22 Vacuum Bagging Fin Can

To fill in any small voids in the fiberglass and provide a more consistent surface finish for applying paint primer, a layer of Bondo Glass was applied to each quadrant of the fin can. The fins were then sanded down to ensure a smoother, consistent finish.

Fig. 23 Applying Bondo Glass to Fin Can

Finally, after completing sufficient surface preparation, we painted the fins and lower airframe with two coats of filler primer, 3 coats of white paint, 2 coats of red paint on the fin edges, 3 coats of glossy topcoat. Painter's tape was applied on the fins before between the coats of white and red paint to achieve a clean edge for the red design on the fins.

Fig. 24 Painted Fin Can

6. Tailcone

The tailcone consists of an ogive shape, mirroring the choice of our ogive nosecone. The team selected an ogive shape due to its low modeling complexity, ability to maintain symmetry with the nosecone, and because other options produce a similar performance at our expected velocities.

Fig. 25 Fiberglass lay-up of Tailcone

Manufacturing the tailcone consisted of conducting a wet hand lay-up of six layers of cylindrical fiberglass sleeve onto a 3d-printed PLA mold covered in mold release. The same laminating epoxy as the fin can layups was used for this layup process. After the fiberglass was cured, the mold was removed, and the appropriate locations were marked for dremeling by mounting the tailcone on a manual lathe. Once the excess fiberglass was cut off, the tailcone was sanded and a fiberglass bulkhead for motor retention mounting was epoxied in using Rocketpoxy.

Fig. 26 Marking Fiberglass Tailcone for Dremeling

7. Aluminum Coupler

Custom aluminum coupler joints were designed and manufactured in replacement of standard coupler tubes because coupler tubes present assembly and mechanical disadvantages. Coupler tubes can be frustrating to assemble, particularly when internal components are mounted inside, as three degrees of alignment are necessary to bolt through the airframe, coupler, and into the internal component. The stiffness of a coupler joint is also highly dependent on the diameter tolerance and length of the tube. A minimum of 1 caliber of coupler tube shall extended into each airframe in order to maintain a stiff mechanical joint, however an aluminum coupler can achieve a greater joint stiffness without being as long. This allows hardware to be packed into the rocket more efficiently and avoid unusually high length to width aspect ratios.

Our aluminum coupler joints separate the 3 lower sections of the rocket: aft bay, electronics bay, and parachute bay. These modular aluminum coupler joints include 2 mounting features for bulkheads to connect to. The airbrakes and avionics computers are mounted to the aft aluminum coupler joint, and the rocket recovery electronics are mounted to the forward aluminum coupler joint.

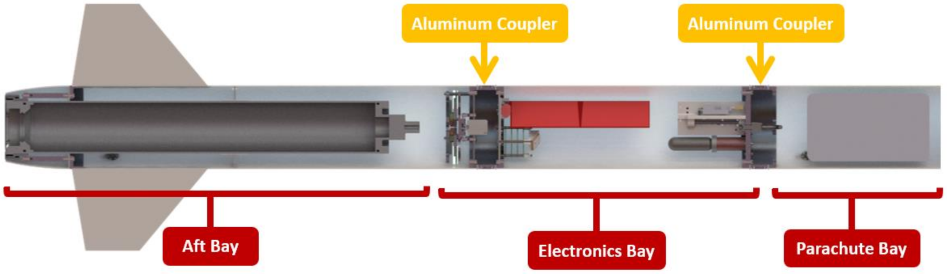


Fig. 27 Cross section of sections coupled by an aluminum coupler

The aluminum couplers operate similarly to the captive nut found on the end of a garden hose, with a freely rotating nut attached to one airframe screwing into a fixed threaded coupling on the opposite airframe. The assembly features 4 primary parts: bare coupling, threaded coupling, rotating nut, and retaining ring. All these parts are machined out of aluminum alloy 6061-T6 except the retaining ring which is made of the 7075-T6 alloy because hand calculations and FEA simulations suggest that this part will have higher bending stresses compared to the other 3 parts.

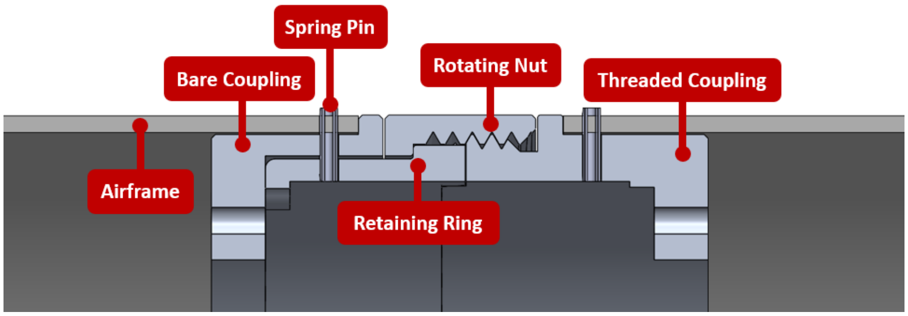


Fig. 28 Detailed view of Aluminum Coupler Joint

This year's design of the aluminum coupler joint focuses on optimizing the wall thickness, thread pitch, and other associated geometry which can be seen in figure 29. Structural hand calculations were re-evaluated with higher fidelity, such that a wider range of failure cases were considered.

Table 8 List of Failure Modes and Corresponding Factors of Safety for Aluminum Couplers

Load Case	Safety Factor
Epoxy Shear on Threaded Coupling	4.14
Thread Shear on Threaded Coupling	57.1
Bending failure on Rotating Nut	23.26
Thread Shear of Rotating Nut	80.61
Bare Coupling to Airframe Epoxy Shear	4.14
Bare Coupling to Retaining Ring Epoxy Shear	**3.14**

From this we were able to make informed modifications of the geometry of the joint such that each part endures similar magnitudes of stresses and fail simultaneously. In addition, the design of the threads was revisited because we experienced minor threading galling which is common in large aluminum threads. To mitigate this, we decreased the TPI (threads per inch) from 12 to 10 in^{-1}. Threads with a lower TPI have weaker bolted joint stiffness and strength, but in return, the likely hood of thread galling and seizing is significantly decreased because of the lower thread engagement. Also, lower thread engagement allowed us to assemble the joint in fewer rotations and ultimately less time. We decided that the tradeoff between weaker bolted joint strength and decreasing the likelihood of galling was in our favor because the bolted joint was proven to not fail first in both simulation and flight test (SAC 2022).

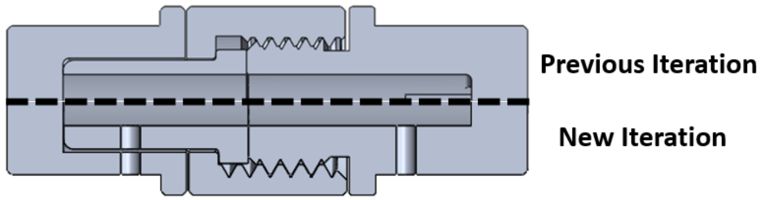


Fig. 29 Geometric Iteration of Bolted Joint

Another area of focus was the bond between the aluminum coupler and airframe as illustrated in figure 30. We use a high strength methyl-methacrylate structural adhesive that has a shear strength of 4,500 psi and peel strength of 50 psi. To ensure proper bonding between surfaces, we performed thorough surface prep on both airframe and aluminum coupler surfaces.

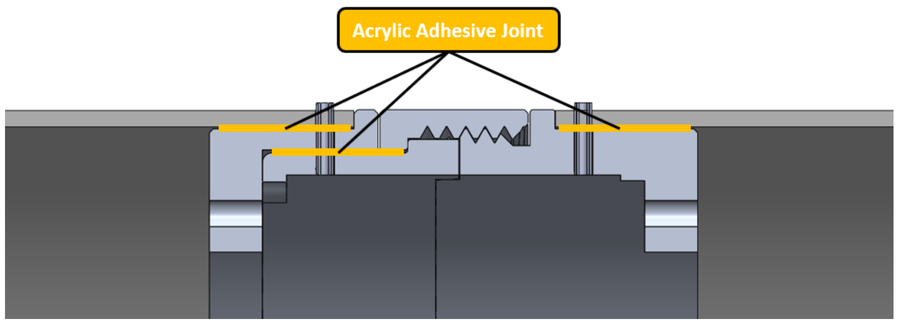


Fig. 30 Acrylic Adhesive Bonds

In our first test launch of the aluminum coupler joint (SAC 2022), the vehicle experienced a rapid unscheduled disassembly due to a premature payload ignition at burnout. The aluminum coupler held up rigidly throughout all of burn but a rapid pitch over at max velocity caused the adhesive joint between the bare coupling and retaining to fail, allowing the rocket to further break apart. The aluminum coupler proved to remain fully stiff during nominal load cases, but the early ejection caused the vehicle to experience bending loads far exceeding the bounds of a nominal flight. This result taught us something important about the complete joint failure mode of the aluminum coupler which was not realized from FEA simulation. The boundary conditions of the simulation had the adhesive joint be infinitely stiff and strong, so an adhesive failure mode was not shown by the simulation regardless of how high of a bending moment was applied. This difference between simulation and real-life testing shows the incredible value of flight tests.

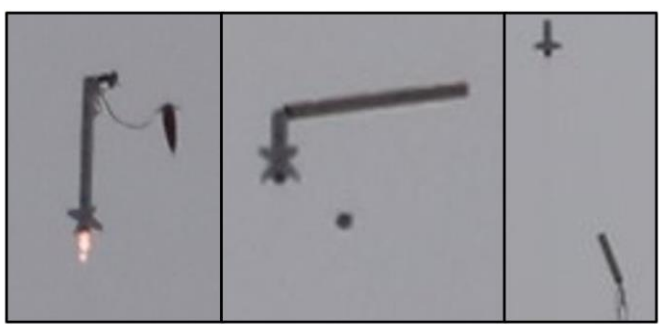


Fig. 31 Fully Destructive Failure of Aluminum Coupler at SAC 2022

The failure of the adhesive joint during SAC 2022 led to the implementation of spring pins into the design. These small but strong steel pins are press fit into the couplings at attachment points to the airframe. The placement of the spring pins had a bonus of further securing the adhesive bond between the retaining ring and the bare coupling. Adhesive lap shear bond calculations performed by the team assumed a perfect bond between both mating surfaces, meaning voids in the epoxy, inconsistent layer thickness, and possible errors in surface preparation are not accounted for. As a result, the spring pin and epoxy joint calculations must both have favorable factors of safety to account for the assumptions made.

Table 9 List of Failure Modes for Aluminum Coupler Spring Pins

Load Case	Safety Factor
Tear Out	41.177
Bearing Failure	62.504
Shear Failure	**7.064**

8. Motor Retention

The motor retention assembly transfers the thrust of the motor to the airframe of the rocket by interfacing with a COTS Aeropack retainer: a part designed to hold the motor securely in the rocket. The assembly also holds the tail cone flush with the airframe via a bulkhead built into the tail cone. This system must transmit the full thrust of the motor into the airframe, and thus why detailed analysis must be conducted.

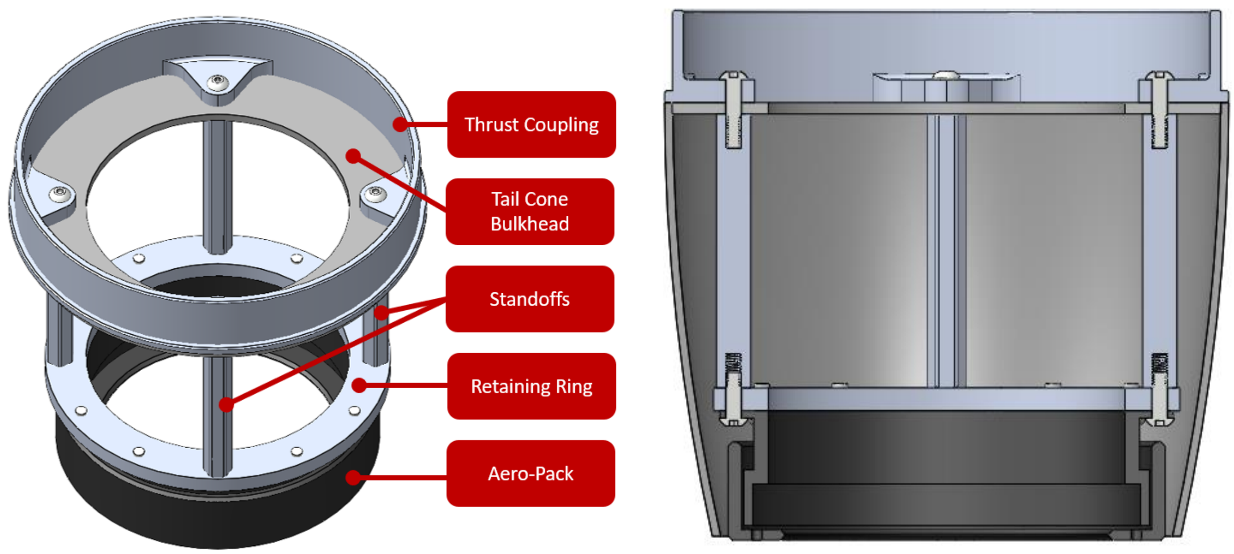


Fig. 32 Motor Retention Assembly

The motor retention assembly begins with an SRAD aluminum thrust plate, referred to as the "thrust coupling" which gets bonded into lower airframe with acrylic adhesive before the tail cone bulkhead and tail cone are installed along with four aluminum standoffs into the thrust coupling's four tabs. The tabs of the thrust coupling line up with four mounting holes on the Aeropack, effectively stepping down the diameter of the rocket. The bottom of the standoffs is bolted to an aluminum retainer plate, which is bolted to the COTS Aeropack. All bolts are the same #8-32 socket or button head to make assembly easy, and a liberal amount of Loctite blue is utilized to ensure that all joints are rigid and strong.

Due to the mission critical status of this subsystem, the team analyzed many different failure modes. The team primarily focuses on how the system would react when the motor produces max thrust and when the shock loading of main parachute deployment occurs. Using static analysis, the safety factors of six primary load cases were determined. The stress experienced at the fillet on the thrust coupling tabs concerned the team, so further analysis was performed on the feature. The team derived the stress concentration factor curves for a rectangular filleted bar exposed to bending; this allowed the team to use height of plate to thickness of tab (H/t) ratios greater than those found in Walter Pilkey and Deborah Pilkey's *Peterson's Stress Concentration Factors* [3]. The "H/t" ratio of "4.0" most accurately models the thrust coupling, so a stress concentration factor on the H/t = 4 line at r/d = 0.24 is selected; the distance from the selected stress concentration factor and the respective value on the H/t =1 line is then used as the final factor to multiply by the theoretical bending stress experienced by the tabs.

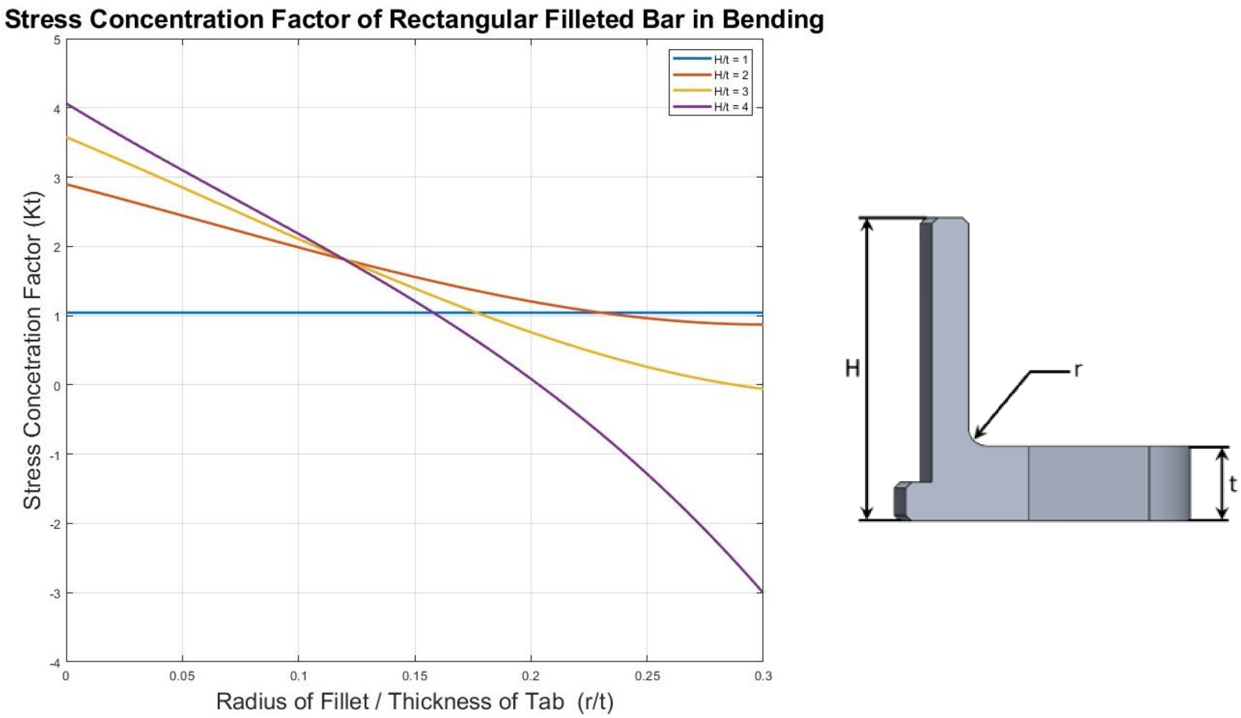


Fig. 33 Graph of Kt Stress Concentration vs the ratio of radius fillet over tab thickness. The change in Kt is measured for structures of height to tab thickness ratios (H/t) ranging from one to four.

Table 10 Primary Load Cases of Motor Retention Assembly during flight.

Load Case	Safety Factor
Buckling of Standoffs During Boost	60.5
Tensile Failure of Standoffs during Parachute Deployment	8.01
Shear of Thrust Coupling Tabs During Boost	82.5
Failure of Thrust Coupling Tabs due to Bending Stress During Boost	6.61
Failure due to Pure Bending Stress on Thrust Coupling Tabs	5.25
Failure due to Stress Concentration between Thrust Coupling Tabs and Body	**2.59**

Table 11 Stress Concentration Calculations

Base of Tab (in)	1.54
Thickness of Tab (in)	0.25
Max Thrust (lbf)	504
Moment Per Tab (in*lb)	65.52
Bending Stress (psi)	4084.36
Radius of Fillet (in)	0.06
Radius of Fillet / Thickness of Tab	0.24
Kt_Factor	2.028
Maximum Stress (psi)	8283.09
Safety Factor	**2.588**

Finite element analysis was performed using SOLIDWORKS Simulation to verify the stress concentration and total resultant stress calculations. FEA analysis yielded a minimum safety factor of 2.4, and considering the assumptions made in hand calculations, this was deemed sufficient to verify the team's previous work.

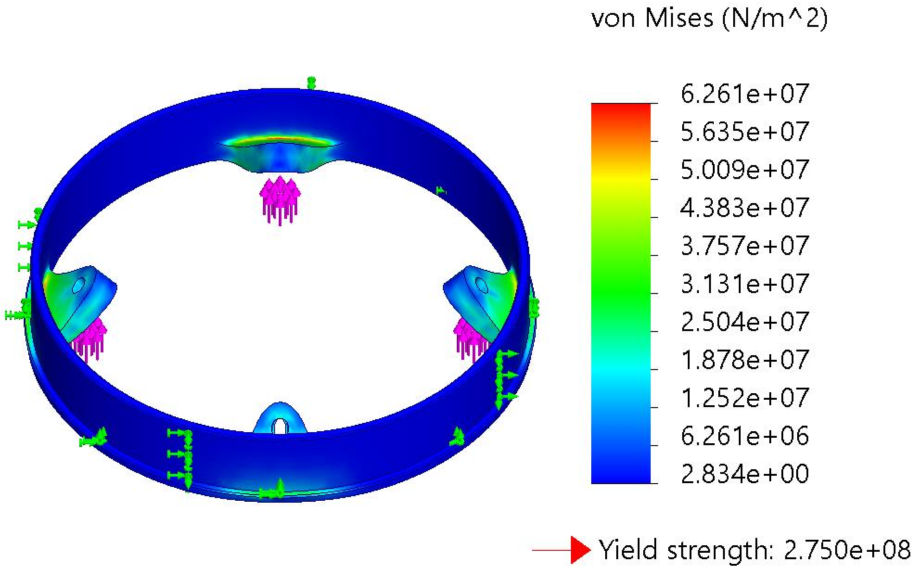


Fig. 34 Thrust Coupling FEA Von Mises Stress Plot

The SRAD components such as the retainer plate and thrust coupling were manufactured in house on CNC milling and turning tools. The thrust coupling in particular utilized a CNC lathe with an additional live-tool spindle and Y-axis. This four-axis machine allowed the team to manufacture the thrust coupling in a single operation, greatly increasing the accuracy of the parts by removing the need to transfer datums between different machines.

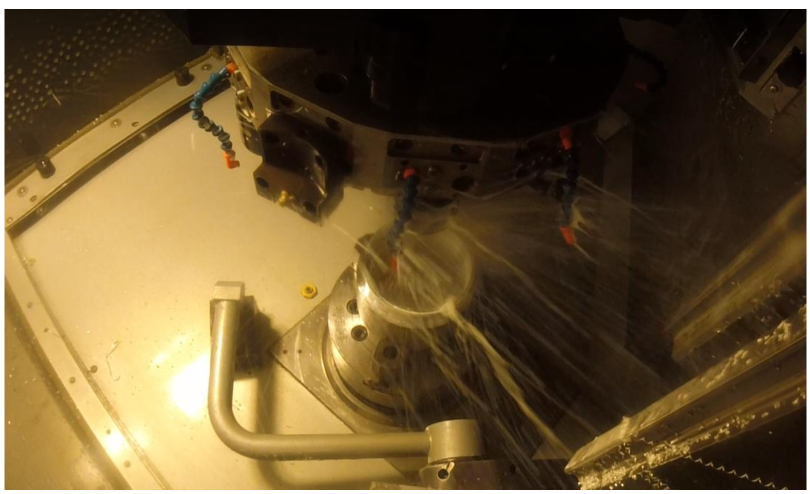


Fig. 35 GoPro Footage of Axial Live Tooling on the Thrust Coupling

C. Recovery

9. Deployment Sequence

The recovery system is responsible for returning the vehicle to the ground safely and ejecting the payload system out of the airframe such that it can begin its mission. Capricornus uses a single end dual deploy recovery system to minimize the number of separation points on the airframe. This separation is achieved with a COTS CO_2 ejection system, and a redundant backup black powder charge. Later in the vehicle's descent, the main parachute is released from inside the airframe from 2 COTS Tender Descender L3s. Once proper descent velocity is sensed by the payload flight computer a pair of steel pins through the nosecone coupler and upper airframe section is retracted such that a series of primary and secondary black power charges pressurizes a deployment piston that ejects the payload.

Table 12 Deployment Event Sequence

Event name	Event type	Event timing
Drogue primary charge	35g CO_2	Apogee
Drogue secondary charge	6g black powder	Apogee + 1 second
Main primary charge	0.25g black powder (Tender Descender)	1500ft AGL
Main secondary charge	0.25g black powder (Tender Descender)	1500ft AGL + 1 second
Pin Retraction	Servo Actuation	1400 ft AGL
Payload deployment primary charge	1g black powder	1250ft AGL
Payload deployment secondary charge	1.5g black powder	1250ft AGL + 1 second

10. Rocket Parachute and Lines

The recovery harness is made of 0.190" braided Kevlar shock cord with an ultimate breaking strength of 5,300lbs. It is 43' length (above 3 times length of rocket recommendation) and uses a combination of 5/16" quick links and 2,500lb rated Kevlar soft link for rigging components to the harness and eye-nuts.

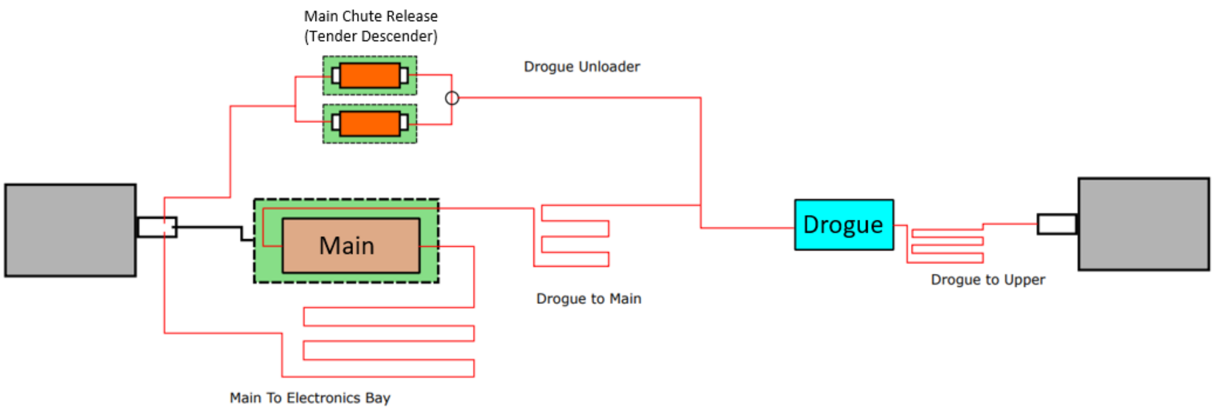


Fig. 36 Vehicle Recovery Lines

The main parachute is a 120-inch toroidal parachute manufactured by Rocketman Parachutes. The drogue parachute is a 36-inch reinforced hemispherical parachute from the same vendor. These parachutes were deemed acceptable based on the descent speeds they were able to achieve. The descent speed under drogue, under main prior to payload deployment, and under main after payload deployment are 98, 16, and 14 ft/s respectively.

11. Main Parachute Release

Last year, the main chute release consisted of 2 Tender Descenders L3 (TD) arranged in series. This configuration was flight proven last year but has several design flaws. Due to the nature of the design, release of the primary TD may cause the e-match for the 2nd TD to break as the main parachute gets pulled out of the airframe. In addition, successful deployment of the main parachute would allow for two ¼" quick links in the TD to be released into the air and lost.

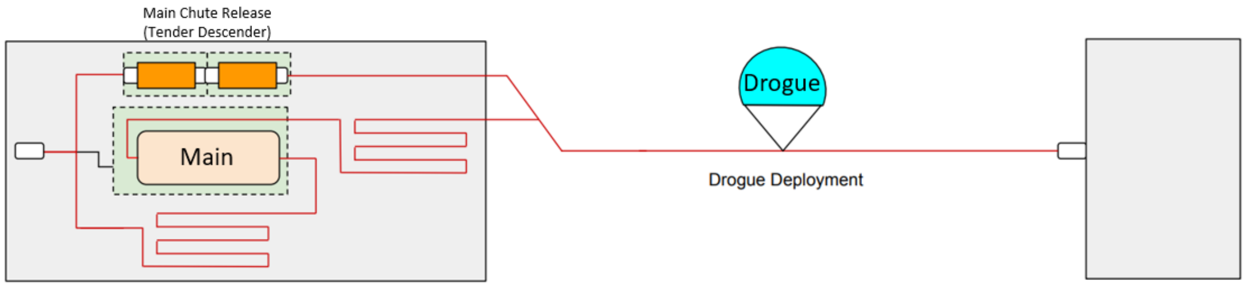


Fig. 37 Lines diagram for Series configuration of Main chute release (last year's design)

This year we set out to design a new configuration that solves these issues. Our first iteration of a new parallel TD configuration utilized a custom "W" shaped hook that is both fully redundant and doesn't lose hardware upon main deployment. This design is redundant because if only 1 TD were to fire, the hook would be able to slide off the unfired TD by rotating around the pin. Despite its strong attributes, we designed not to go with design because the hook was likely to catch on the other recovery hardware such as the parachute bag and shock cord upon release.

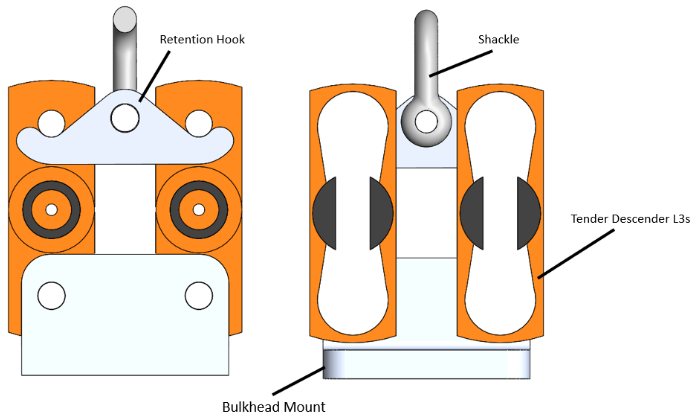


Fig. 38 Rejected Main Chute Release Mechanism

The design that we ultimately decided to use is very similar to the previous iteration, but the "W" hook is replaced with a Kevlar retention line with loops on each end. The ¼" quick link on the top as seen in figure 39 slips of the Kevlar retention links if at least one TD fires. To solve the problem of losing hardware during recovery, a safety line made of a snap clip connects the retention line to the TD bag. This holds the retention line if both TDs were to fire. In the case that only the secondary TD fires, the ¼" quick link will easily break the safety line and allow the drogue unloader to be released. This design has been tested both on-ground and in-flight.

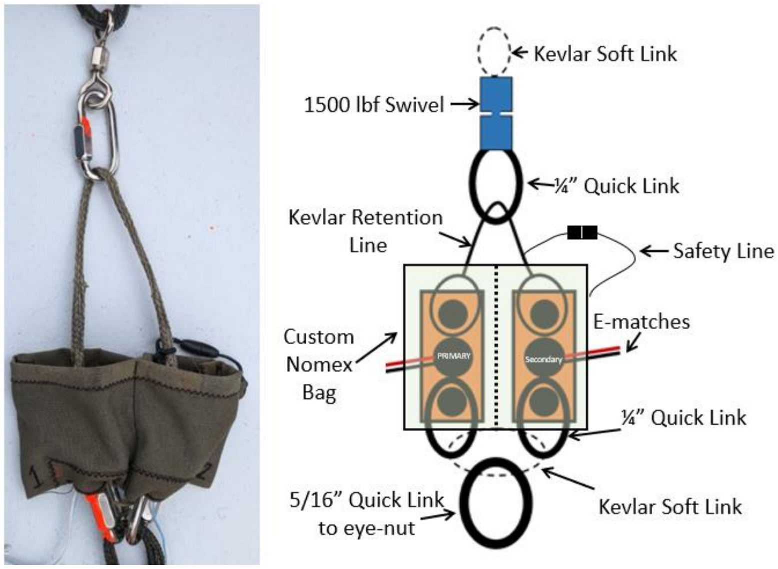


Fig. 39 Final Chute Release Mechanism

12. Payload Parachute, Lines and Ejection Piston

A major challenge that comes with a quadcopter payload is implementing a method for safely ejecting the payload from the airframe. Because our payload is both mechanically complex and constrained to a CubeSat form factor, load transfer from payload ejection was a difficult task. To overcome this challenge, we designed a custom ejection piston that would safely transfer load to the payload assembly by interfacing with the quadcopter arms. The piston contains aluminum standoffs that hold the four arms of the quad and were calculated to have a FOS of 14 with the expected loads from ejection. Once the payload is ejected from the airframe it falls under a 60-inch ultra-light high-performance parachute manufactured by Rocketman Parachutes and has a descent speed of 16 ft/s. This parachute is connected to an eyebolt within the nosecone.

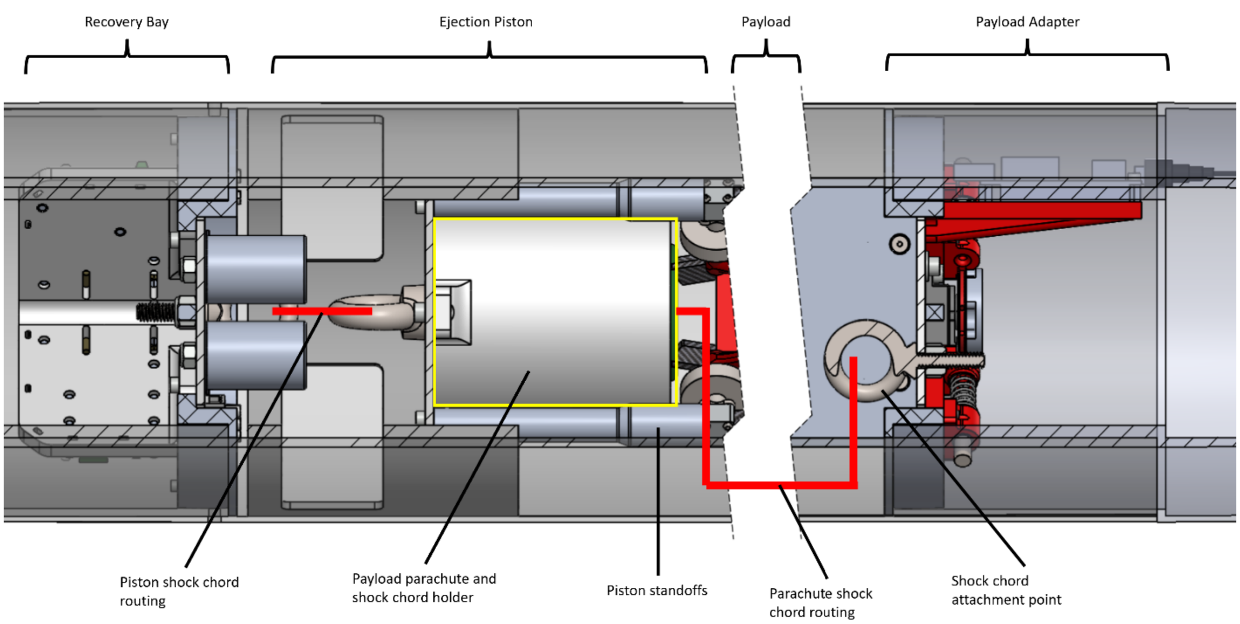
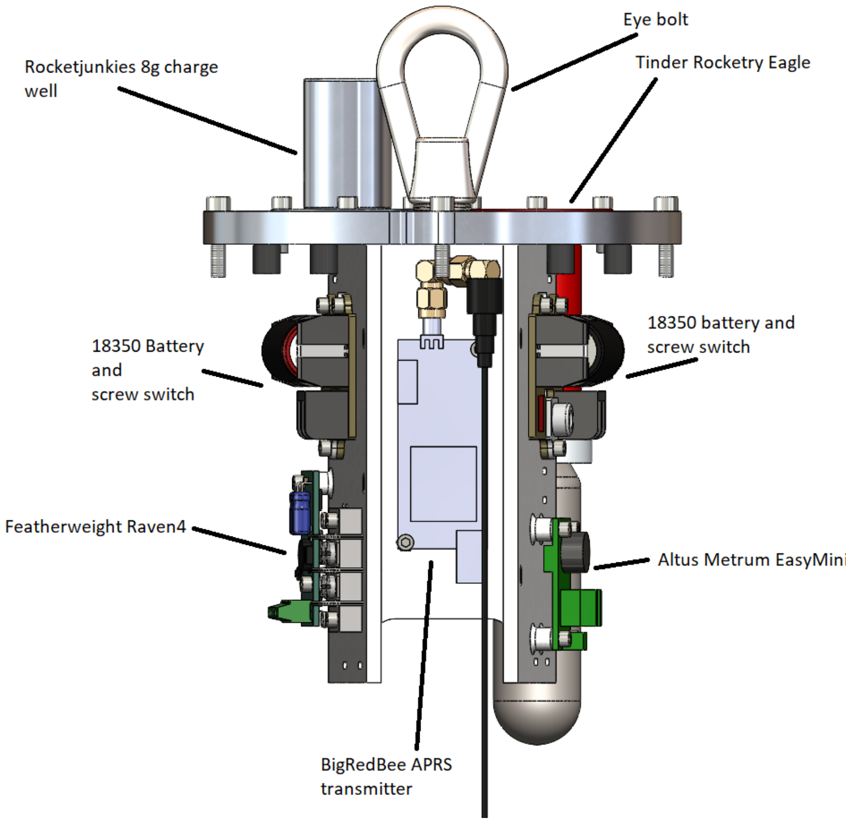


Fig. 40 Payload Ejection Hardware Section

13. Recovery Electronics

The launch vehicle and payload ejection system both use two COTS altimeters for altitude recording and to control recovery events. The primary altimeter is an Altus Metrum EasyMini, with the backup being a Featherweight Raven 4. Dissimilar altimeters were chosen so that a design fault or specific edge case in one of them would not affect the operation of the other. In addition to being manufactured by different companies, the Raven incorporates an accelerometer in addition to the traditional barometer to measure altitude. This further increases the redundancy of the system.

Each altimeter is connected to its own battery and screw switch, which are both mounted on a custom board the team developed. The screw switches are easy to arm from the outside and has been flight tested on several L2 certification flights. Each battery board holds a 4.2v 18350 lithium cell, which can deliver plenty of current to fire the e-matches used to ignite the Tender Descenders, Eagle system, and black powder charges.



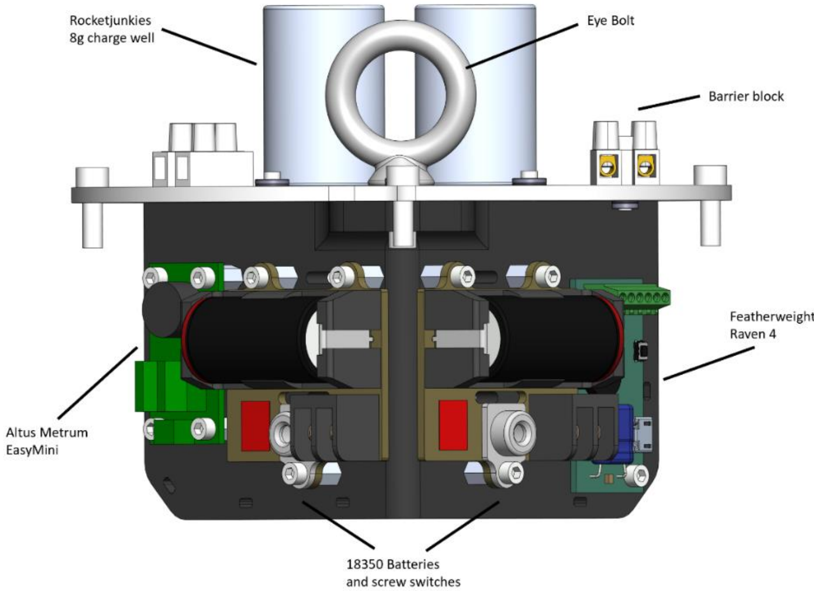
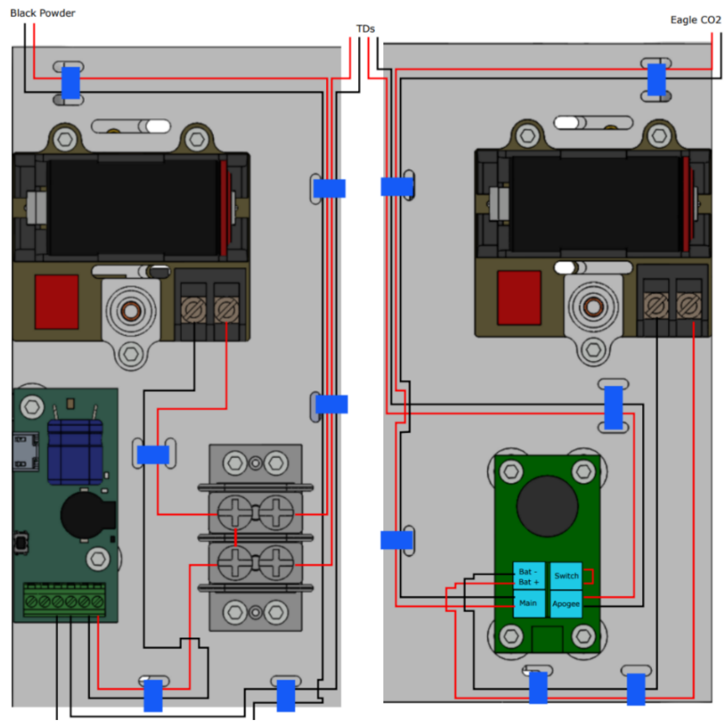


Fig. 41 Vehicle and Payload Ejection Electrical Housing

For the vehicle recovery we chose a combination of black powder and CO_2 systems to try to work towards full dissimilar redundancy. The CO_2 charge fires first, so if everything goes well the most delicate of the recovery hardware is kept away from the corrosive black powder reaction. If that doesn't separate the airframes, the black powder charge has enough energy to do so with a much lower total mass and cost. Both this 6-gram black powder charge and the 35-gram CO_2 charge have been verified in ground ejection testing. On the other hand, the payload recovery bay utilizes only BP charges: 1 and 1.5 grams. These electronics are housed in the recovery bay assemblies, as shown in Figure 41. These electronics sleds are made of polycarbonate for their high heat deflection temperature as needed for a desert environment. Lastly, bulkheads attach to our aluminum couplers, forming a seal and preventing the ejection charges from pressurizing the altimeters.



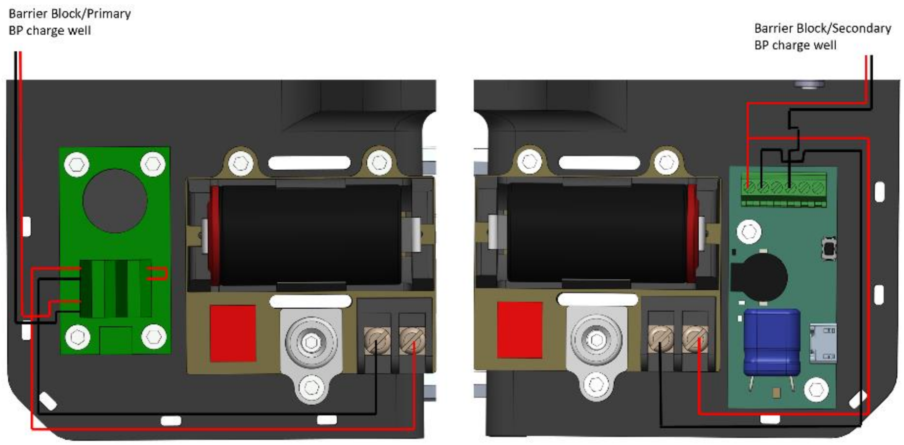


Fig. 42 Recovery Electronics Wire Routing

To confirm sufficient battery life of our chosen batteries, we conducted battery drain testing with the altimeters in the pad mode. From the results of this test, we determined that the EasyMini and Raven 4 altimeters would have a battery capacity of 53 and 13 hours respectively. This is defined by the time it takes the battery to go from full charge (4.2 V) to 3.7 V.

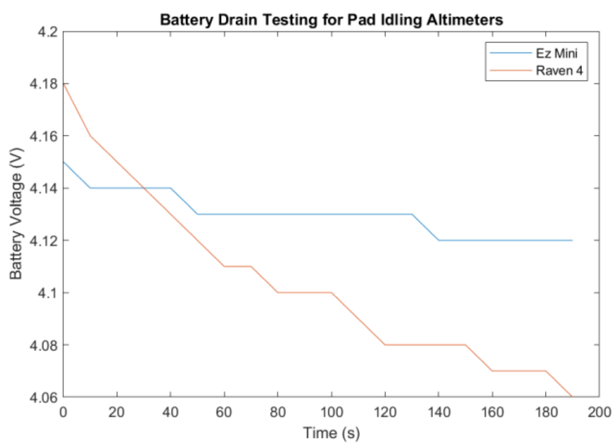


Fig. 43 Battery Drain Test Results

14. Parachute Load Analysis

To properly size our recovery hardware for main parachute opening shock loads, a numerical simulation was created to quantify these loads. These simulations suggest that the vehicle and its internals will experience a shock load of 15.4Gs which equates to 816 lbf on the eye nuts and recovery harness. All recovery hardware is well under the parachute opening load with a minimum safety factor of 2.15 which fulfills our Safety Factor requirement for main parachute loading.

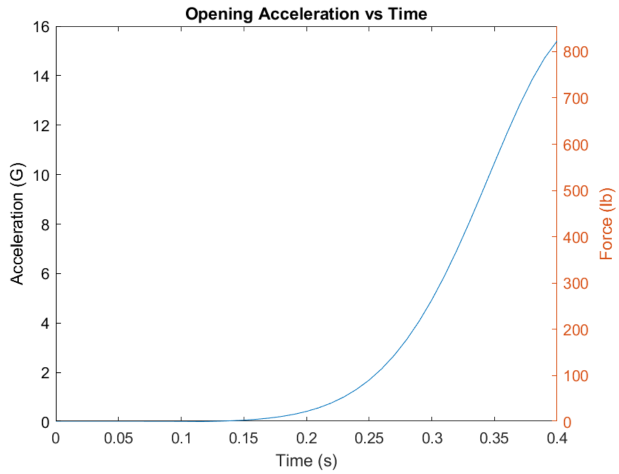


Fig. 44 Open times and Shock Loads of Main Parachute Opening

Based on the numerical simulation from calculations in T.W. Knacke's *Parachute Recovery Systems Design Manual* [4], the recovery bulkhead was analyzed with a worst-case load of 816 lbf. This simulation shows that our factor of safety on the bulkhead is 2.5 and satisfies our safety factor requirements.

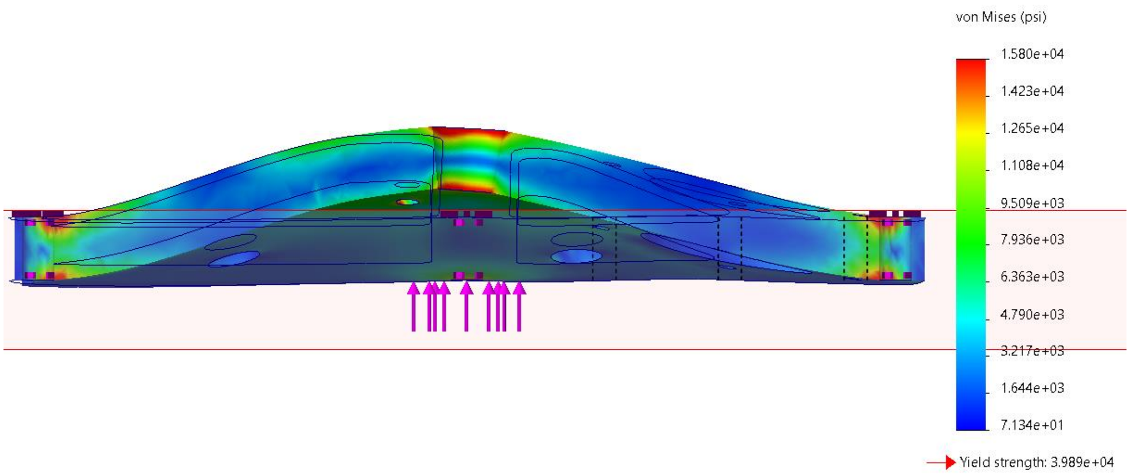


Fig. 45 Static Structural Simulation of Recovery Bulkhead

15. Charge and Shear Pin Sizing

Proper ejection charge and shear pin sizing is critical for a successful vehicle recovery. Since the airbrakes extend shortly after the vehicle reaches its max speed, both drag separation and airbrakes drag force act together to pull the coupler tubes in tension. We found that having 3 4-40 nylon shear spins would be able to withstand a maximum separation force of 81.46 lbf after burnout. Following these we determined the size of our primary ejection charge based on shear pin breaking ability and intuition backed by previous on-ground ejection tests.

Table 13 Charge and Shear Pin Sizing Calculations

Coupler Separation Loads	
Drag Separation Force after Burnout	17.8295 lbf
Airbrakes Induced Drag Force	63.64 lbf
Total Separation Force	81.46 lbf

Shear Pin and Ejection Sizing Calculations	
# of 4-40 Nylon Shear Pins	3
Total Breaking Strength	115 lbf
Separation Safety Factor	1.4
Desired Shear Pin Breaking Safety Factor	4
Ejection Force/Pressure	460 lbf/16.3 psi
BP sizing	4.9 g
Nearest Equivalent CO2 cartridge	35 g

16. Retractable Pins

The payload adapter is where our payload mounts to the nosecone bulkhead. It also houses the payload's COTS GPS tracker and parachute mounting point. Finally, it houses a retractable pin system. This system is responsible for preventing the payload from prematurely ejecting during flight.

During rocket main parachute deployment at 1500ft, the ejection forces from parachute deployment on the nosecone would overcome the forces needed to break the shear pins holding the nosecone in the upper airframe. This would result in an uncontrolled ejection of the payload. We considered the simple solution of adding more shear pins to prevent nosecone separation before ejection. However, we calculated that 8 4-40 nylon shear pins were needed to withstand main parachute opening. With 8 shear pins holding in the payload, we would need 13g of black powder to eject, which would likely damage the piston and airframe in the process. Thus, we decided to use two 0.25-inch diameter steel pins that hold the nosecone in place during flight, and then retract after main parachute deployment. The targeted pin retraction altitude is 1400ft AGL, with payload deployment 150 feet after. These pins are passively pressed into the nosecone and outer airframe with springs and are retracted using a winch system mounted onto the payload adapter bulkhead. This design was ultimately decided on due to its mechanical simplicity and ability to passively hold the pins in place in the case of an actuation failure.

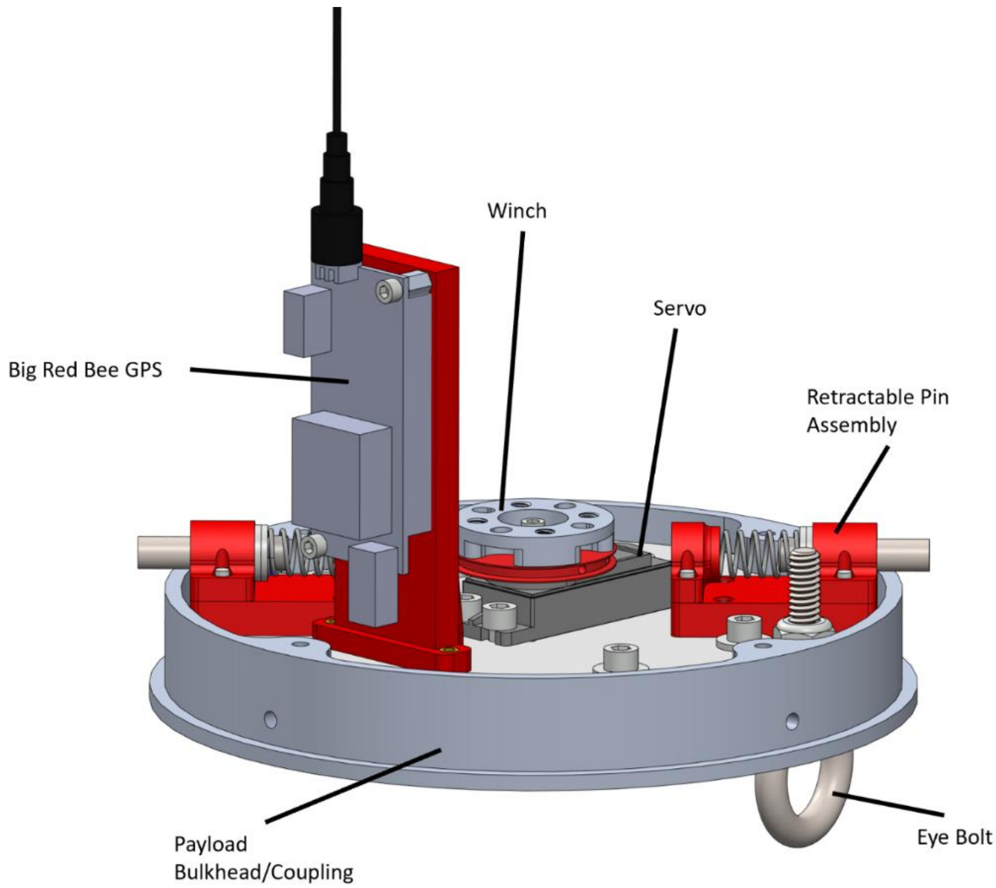


Fig. 46 Payload Adapter Assembly

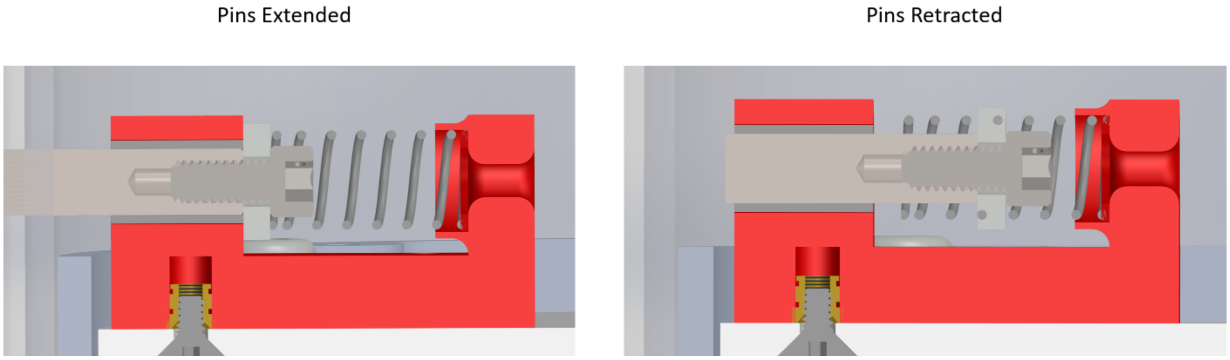


Fig. 47 Retractable Pins

In the event of premature pin retraction, we still have 3 shear pins that will prevent the nosecone from separating during flight until the forces from rocket main parachute opening break them. In the event of a pin retraction failure, the steel pins are strong enough to withstand the ejection forces and the payload mission will be aborted.

D. Flight Dynamics and Controls

17. Airbrakes Mechanical Design

If a launch vehicle were designed with appropriate mass and aerodynamic features to reach an exact apogee, environmental factors such as deviations in cross winds, air pressure, and launch rod angle will prevent that target apogee from being reached without onboard active controls. The airbrakes mechanism allows the vehicle to use data gathered during the flight to actively change the apogee of the rocket based on changing environmental factors.

The current airbrakes design iterates on previous design work with a greater emphasis on model optimization. The airbrakes mechanism relies on a single servo motor to actuate four equally spaced fins towards the outside of the rocket simultaneously, so no net moments are applied to the vehicle.

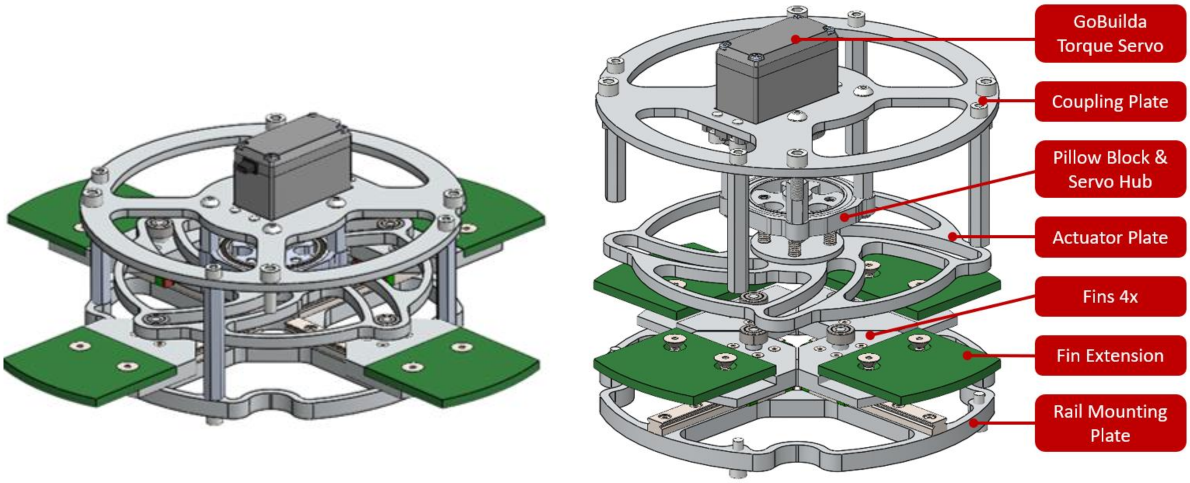


Fig. 48 Airbrakes Assembly

The mechanism itself consists of three primary components: the rail mounting plate holds the linear rails and fins, the actuator plate translates the rotational motion from the servo into the fins during actuation, and the coupling plate mounts the assembly onto an aluminum coupler. The fins are fitted with ball bearings to reduce friction during actuation and provide a smooth travel for the fins. The servo itself extends through a servo hub and pillow block that both prevent unwanted moments from acting on the servo but also helps reduce friction in the mechanism overall.

The limiting factor of the previous iteration of airbrakes was the amount of drag the fins could produce. This year, we added a set of fiberglass fin extensions that would be assembled onto the fin base after the airbrakes assembly were mounted in the aluminum coupler. This required the design to change to smaller size linear rails with lower bending load capacity. To confirm that the linear rails and carriages will not bind and cause the servo to stall, we conducted bending moment calculations. We were able to confirm that the linear rails would still be able to perform under higher drag force and less bending load capacity compared to last year's design.

Table 14 Safety Factors of Linear Rails due to Drag induced Bending Moment

Rail Width	Bending Moment Safety Factor (At Max Fin Extension and Max Q)
9mm (SAC 2022)	5.20
7mm (SAC 2023)	2.01

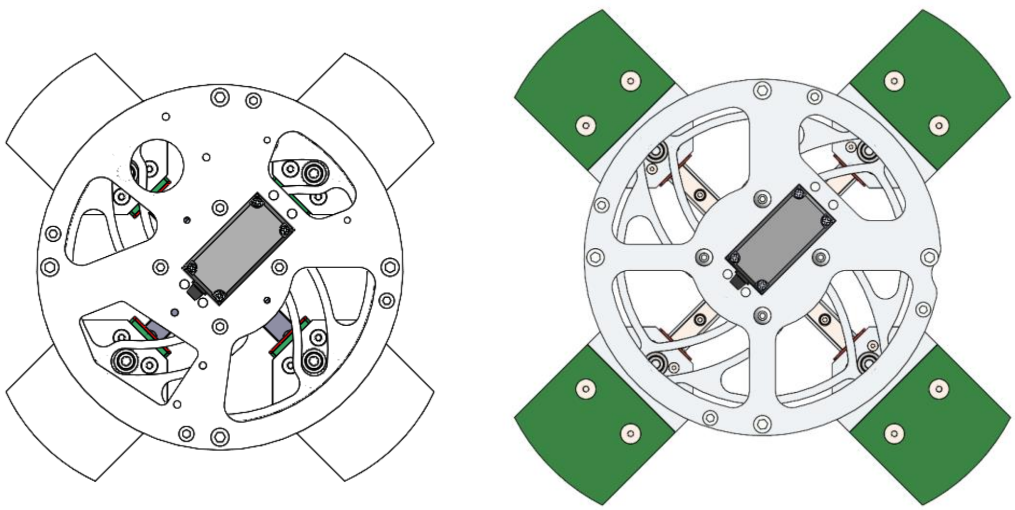


Fig. 49 Comparison of Effective Drag: 2021-22 (left), 2022-23 (right)

Table 15 Drag Produced Per Fin

Fin	Area (in^2)	Max Drag (lbf)
2021-2022	1.28	5.97
2022-2023	2.80	15.91

The drag produced by the airbrakes is a function of fin surface area exposed to the airstream outside the vehicle. With more exposed surface area, the airbrakes gain more control authority over the coast phase. The maximum area required by the airbrakes is determined by considering the maximum reduction in altitude necessary to hit an altitude of 10,000 feet. A more powerful motor must be selected such that the rocket will overshoot the target apogee by some amount, creating a known built in error that the airbrakes can be controlled to correct.

18. CFD Simulation

To properly control the airbrakes on the rocket, a model of the drag produced by the airbrakes is needed. To collect data, an Ansys Fluent CFD model was created with input parameters of velocity and airbrake extension. The Transition SST model was used for turbulence modeling as it uses the base k-omega model, which can accurately model turbulence near walls, as well as additional equations that more accurately model turbulence where flow separation occurs. As the airbrakes are basically a flat plate with a 90° angle of attack, there will be a large region of flow separation below them. As shown in Figure 50, the turbulent region created by the airbrakes encases areas both near walls and in regions where flow separation is expected, this flow then goes on to affect the airflow on the fin can, so it's important to accurately model both regions of turbulence.

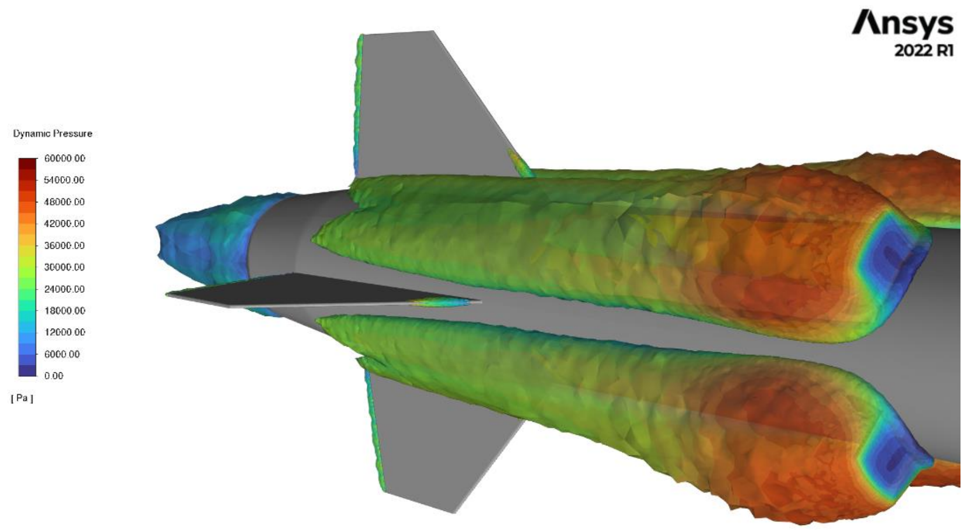


Fig. 50 Contours of Dynamic Pressure on Surface of Turbulent Kinetic Energy = 500 m^2s^{-2}

To increase the accuracy of the surface drag modeling, the surface roughness of Capricornus' outer surfaces where measured. CFD programs take surface roughness inputs of Equivalent Sand Grain Roughness, Ks, a surface parameter that accounts for the height and spacing of surface irregularities. However, this value cannot be directly measured and must be calculated from other surface parameters such as root mean square roughness height (K_{rms}) and roughness shape(S_k). There are several experimentally found equations relating surface parameters to the equivalent sand grain roughness (K_s). For our calculations we used the following equation:

$$K_s = 2.73K_{rms}(2 + S_k)^{-0.45}$$

Equation 1 Equivalent Sand Grain Roughness

To take our surface measurements a GelSight Mobile 0.5X was used. Its mobility allowed us to get direct measurements on-rocket without need for removing a sample. To validate surface roughness values and minimize the effect of outliers, each major surface location (Painted Airframe, Fin Can, Aluminum Coupler, and Airbrake Fin) were measured at least ten times with their surface parameters averaged for use in calculating the equivalent sand grain roughness. Post processing and data analysis was done in MountainsLab Premium 9, where gaussian filters and area extractions were used to remove outliers and macro scale surface deformation such as the inherent bend of the fiberglass airframe. Ultimately, an equivalent sand grain roughness was determined for each surface and fed into our OpenRocket, RasAero, and CFD models.

Table 16 Roughness Measures of Rocket Surfaces

Surface	K_{rms} (Root Mean Square Roughness Height)	S_k (Roughness Shape)	K_s (Sand Grain Roughness)
Painted Airframe	142 µin	-3.94 µin	290 µin
Fin Can	240 µin	-10.0 µin	509 µin
Aluminum Coupler	22.6 µin	-33.7 µin	38.5 µin
Airbrake Fin	25.7 µin	-0.813 µin	51.5 µin

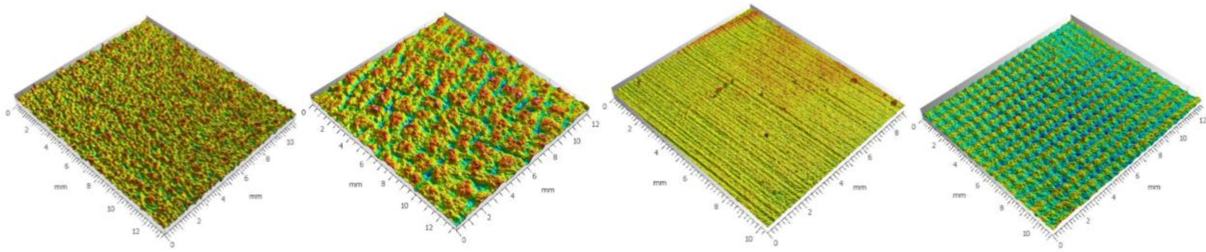


Fig. 51 Surfaces plots of Airframe, Fin Can, Aluminum Coupler, and Airbrakes Fin from left to right

The rocket was split into 1/8th as there are 4 planes of symmetry, and a mesh with about 2 million elements was used. A study was conducted on the effect of the number of elements on the simulated drag force and runtime, the results of which can be seen in Table 17**.** As the decrease of drag force was minimal (0.3%) while the increase in runtime was significant (1220%) between the 2 and 16 million element model, the 2 million element model was chosen for the final model.

Table 17 Mesh Size Effect on Drag and Runtime

Mesh Elements	Drag Force (lbf)	Runtime (Minutes)
431,264	124.3	3.18
2,096,013	124.2	13.28
15,518,901	123.8	162.02

The CFD model was verified with data recording during our test launch in March 2023. The real drag was compared to the drag expended by the model at both minimum and maximum extension at multiple velocities. The real and simulated drag can be seen below in Table 18.

Table 18 Real vs Simulated Drag

Real Drag (lbf)	Simulated Drag (lbf)	Velocity (ft/s)	Extension (%)
26.71	25.56	452	0
35.18	36.78	376	100
21.48	23.37	160	100

With the model set up and verified, the simulations were run for 200 data points with velocity varied from 160 to 850 ft/s and airbrake extension varied from 0 to its maximum, 1.472 in. The minimum velocity of 160 ft/s was chosen as the effect the airbrakes can have on apogee becomes minimal at low speeds. As seen in Table 19, the control of the airbrakes is insignificant compared to the total control, so it was ignored to keep the high-speed estimate more accurate.

Table 19 Maximum Airbrake Control Below Various Velocities

Deploy Velocity (ft/s)	Max Change in Apogee (ft)
160	3.0
330	42.8
490	180.4
660	451.7
850	**900.6**

The data was split into 2 groups randomly. 80% were used as test data set to find the best estimate, and the other 20% was used as verification data set to confirm that the estimate holds up for data not in the test set. The solver feature in Excel was used to find an equation, in the form $z = a + b*x + c*y + d*x^2 + e*y^2 + f*x*y$, that minimized the root mean square error. Initially the GRG Nonlinear method was used to quickly get a close estimate, then the Evolutionary method was employed to find the minimum. This led to the equation:

$$X = -2.12806 + 5.63720V + 3.03284E\text{-}3C_d - 2.15649V^2 - 5.13885E\text{-}6C_d^2 - 1.34280E\text{-}3VF_d$$

Equation 2 Airbrake Drag Estimate

This estimate had a root mean square error of 0.85% for the test data set, and 0.90% for the validation data set. The largest positive error is 2.3% and the largest negative error is -2.2%. The drag estimate can be seen plotted against the CFD data below in Figure 52. The surface shows the drag estimate colored by airbrake extension, and the points are the CFD data colored by the estimate's error to them.

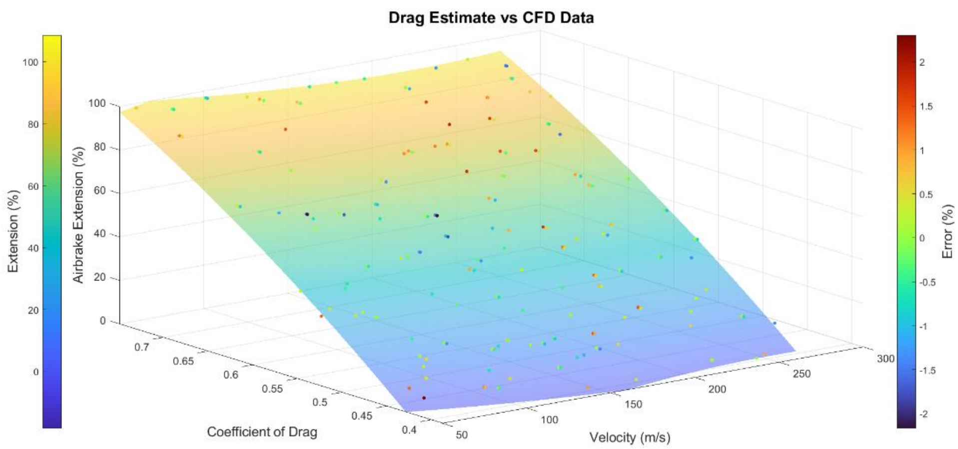


Fig. 52 Drag Estimate vs CFD Data

During the March test launch, the custom electronics experienced a power brownout shortly after motor burnout, causing the system to reboot mid-flight. The most likely cause was determined to be the airbrakes being pulled open or forced closed with enough force to cause the servo to stall. To confirm that there was a significant radial force on the airbrakes, a CFD simulation was run. The simulation used the same base simulation as the airbrakes drag simulation used with only the geometry changed to include a simplified model the internals of the rocket around the airbrakes. The internal rocket was included here as the air flowing into and out of the rocket around the airbrakes would have a large effect of the radial force experienced. Figure 53 below shows the static pressure in the middle of the airbrake fin. A low-pressure region can be seen on the outwards facing faces which causes a significant force pulling the airbrakes out of the rocket.

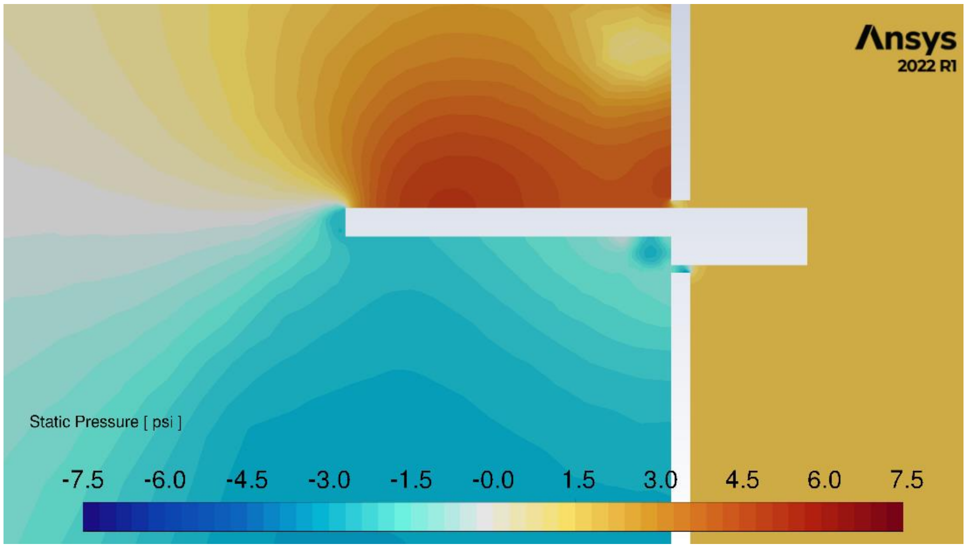


Fig. 53 Static Pressure Distribution in the Middle of an Airbrake

The CFD was able to find that the radial force on the airbrakes would be high enough to cause the motor to stall. The plot of max radial force output of the servo compared to the radial force experienced by the airbrakes at different extensions can be seen below in Figure 54. Using this data, the airbrakes servo was changed from the GoBILDA superspeed servo(5.4 kg*cm @ 7.4V) to the GoBILDA Torque servo(25.2 kg*cm @ 7.4V).

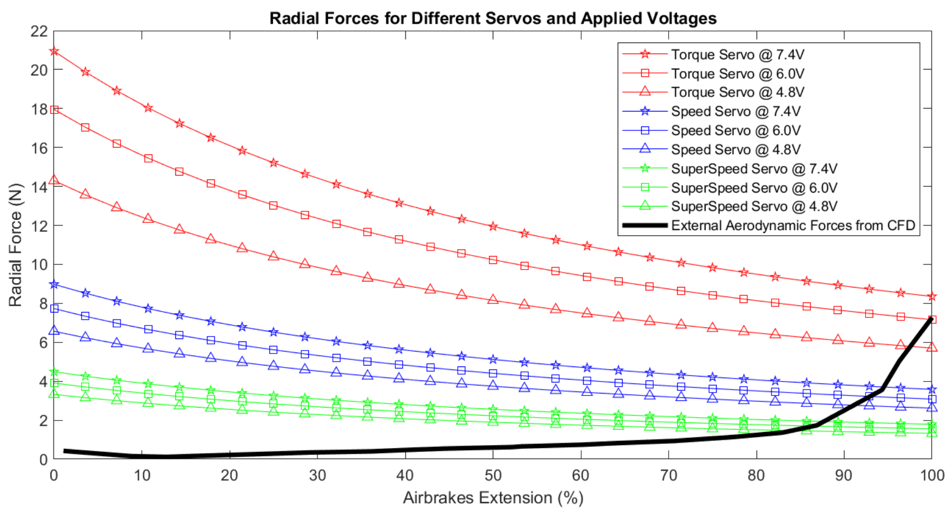


Fig. 54 Airbrakes Applied and Experienced Radial Forces at Max Q

To get proper altitude measurements, barometric pressure was measured. As the pressure measurements are taken from inside the rocket, accurate pressure measurements can't be recorded unless the internal pressure of the rocket is well balanced with the external pressure of the atmosphere. Vent holes were placed along the rocket to balance the pressures, the size of which were determined using a simple fluid dynamics simulation based on altitude data taken from the program RASAero. The simulation ran for gradually larger vent hole sizes until one was found that kept the internal pressure within 0.1% of the external pressure. Figure 55 shows the internal pressure of the electronics bay over time for various vent hole diameters compared to the ambient, external pressure. The chosen vent hole size in red can be seen right on top of the external pressure in black compared to the two smaller vent holes that both lag behind the external pressure a significant amount.

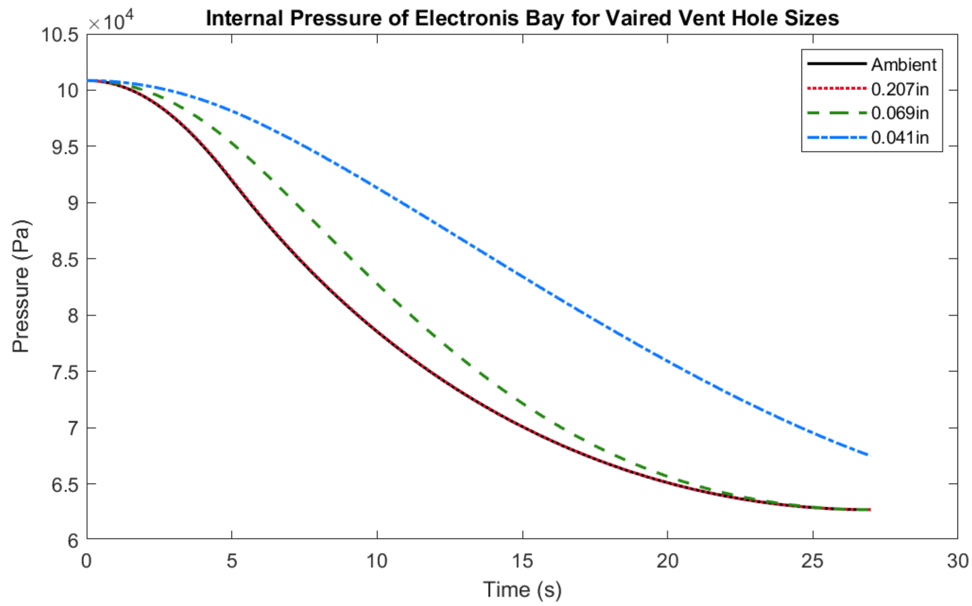


Fig. 55 Internal Static Pressure for Varied Vent Hole Sizes

The minimum vent hole sizing for the various sections of the rocket can be seen below in Table 20.

Table 20 Vent Hole Sizing for Various Airframe Sections

Airframe Section	Vent Hole Diameter (in)
Electronics Bay (Flight Computer + Rocket Recovery Altimeters)	0.207”
Payload Ejection Piston	0.087”
Payload Bay (Quadcopter Flight Computer)	0.243”
Payload Recovery Bay	0.112”

During the April Test Launch, our Polaris flight computer transitioned to the apogee state shortly after burnout and full airbrakes extension due to an increase in pressure inside the electronics bay. The measured altitude vs time for the test launch, with line of detected burnout and apogee, can be seen in Figure 56 below.

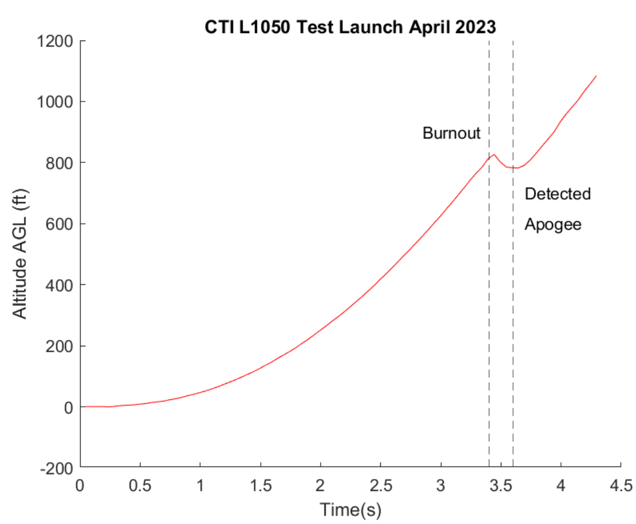


Fig. 56 Measured Altitude vs Time for Test Launch

The pressure increased shortly after burnout, when the airbrakes first deployed, so it was determined the airbrakes created an increase in pressure up the rocket where the electronics bay switch holes are. Using the same airbrakes drag CFD model, data of static pressure along the body of the rocket was collected. The static pressure distributions can be seen below in Figure 57 for three lines up the rocket, 0° is in line with the fins and 45° is in line with the airbrakes.

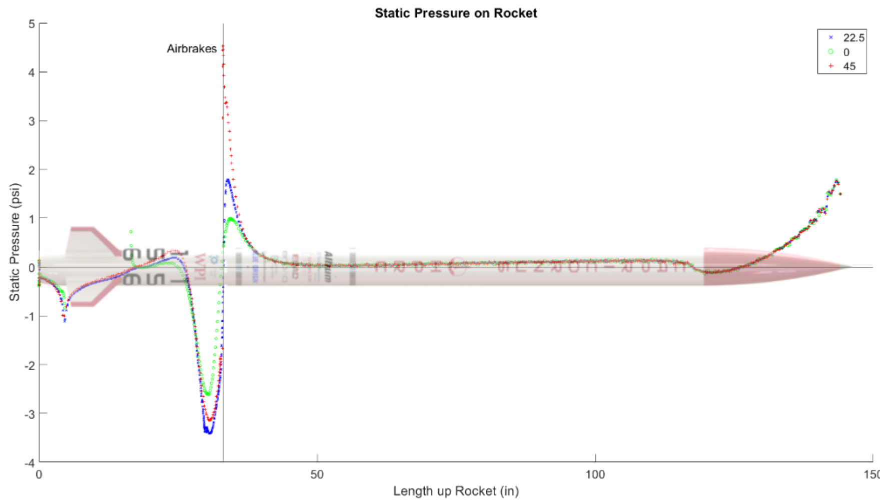


Fig. 57 Static Pressure Distribution Along Lines of 0°, 22.5°, 45°

The electronics bay has two sets of switch holes (they act as vent holes as well), one 2.80 in from the airbrakes and two 19.26 in from the airbrakes. The lower set were well within the region of pressure increase caused by the airbrakes' actuation, with a static pressure increase of 0.913 psi caused by the airbrakes. The upper set is well beyond most of pressure increase, with a static pressure increase of 0.011 psi caused by the airbrakes. From this, we decided to plug the lower switch holes after turning the switch on.

19. Sensing and State Estimation

To effectively control the vehicle's apogee during flight, it's critical to first understand the current state of the vehicle. The apogee achieved by the launch vehicle is ultimately a product of many factors. While some of these factors may be hard to predict such as atmospheric conditions or gusts of wind, onboard sensors can provide vital information to solve this problem. An estimation of the rocket's expected apogee can be computed from the current speed and altitude of the vehicle. This apogee estimate is an integral part of the control algorithm needed to achieve a target altitude.

The rocket features a custom flight computer developed by our team which is housed in the electronics bay. The custom electronics stack consists of a primary flight control board called "Polaris," in addition to a secondary telemetry board. The Polaris board includes a MicroMod Teensy 4.0 processor, a suite of embedded sensors, and a flash memory chip for datalogging. The Telemetry board features a long range (LoRa) radio module that is used for transmitting data packets to the ground station. This system was designed entirely by our team and assembled in our lab space on campus. The onboard sensors include an ICM-42688p inertial measurement unit, an MS5611 barometer, and an MMC5983MA magnetometer. This suite of instruments allows for measurements of the barometric pressure in addition to the acceleration, angular rotation rate, and heading in three axes. The microcontroller communicates with these sensors over the I2C protocol to obtain new readings at a regular interval of 40 times each second.

The raw values from the sensors are insufficient for understanding the vehicle's state with an acceptable degree of accuracy. We must now filter this data to obtain useful information for the flight computer. The raw data is first passed through a low-pass filter to remove high frequency noise from the signals. This is helpful in improving the data, but it cannot completely eliminate variations from the physical quantities, due to random sensor noise and the limited resolution of the instruments. It is for this reason that an individual sensor measurement cannot be trusted absolutely. However, as the variations in measurements from the physical value can be assumed to have a Gaussian error distribution, the reliability of measurements can be improved by combining multiple sensor readings over time to develop a better estimate.

We take advantage of this principle by implementing a running average filter to produce more accurate readings over a small time interval. There is a practical limit to using this technique to observe a dynamic system however, as the underlying assumption is that a constant quantity is being measured. Due to the rapidly changing physical quantities that are being measured, in addition to a phase lag created by the filter, it is best to keep this time interval small. Through experimentation, our team has found that averaging 10 measurements over 0.25 seconds is effective for producing more accurate sensor data without succumbing to these problems. A better solution would be to compare a sensor reading to the expected value as predicted by a physics-based model of the rocket. This can be achieved through an extended Kalman filter (EKF), which our team is investigating and hopes to implement for the next competition year for improved state estimation.

The filtering techniques above are used to produce the most accurate possible data for barometric pressure and acceleration. This filtered data is then used to estimate the state of the vehicle. A standard atmospheric model which makes use of physical constants is used to estimate altitude from the pressure readings. The average temperature and pressure values recorded on the pad before launch are used to calibrate this model and to establish the ground level altitude, such that AGL altitude can be calculated during flight. The altitude estimates can then be used to compute the vehicle's vertical velocity by tracking the change in altitude over time. Similarly, acceleration measurements can be used to estimate the vehicle's total velocity, by integrating acceleration over time given known initial conditions. Combining this with the estimated vertical velocity allows for the calculation of the lateral velocity component as well.

These critical quantities of altitude, vertical velocity, and lateral velocity are exactly what is needed to predict the vehicle's expected apogee. Now that we have developed the best possible estimate of the vehicle's current state, these values can be passed onto a controller for the airbrakes. Combing state information with our pre-run CFD simulations allows for the computation of a control response to command the airbrakes to achieve our target apogee.

All of our avionics flight computers and associated hardware are packaged in our avionics bay as seen in figure 58. This assembly consists of two 18650 batteries, a custom screw switch and battery supply board, SRAD telemetry antenna, and stack of avionics boards.

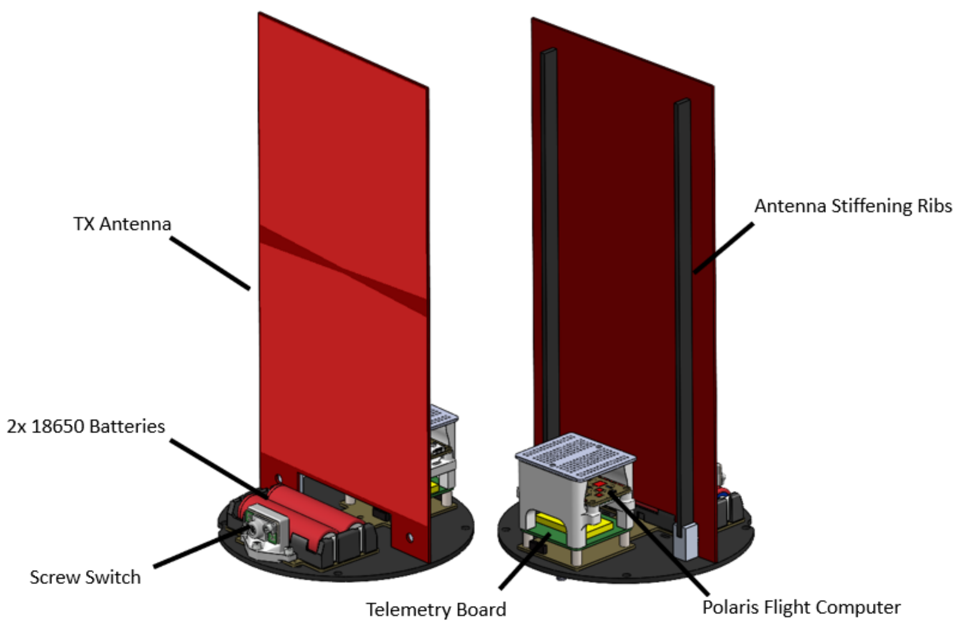


Fig. 58 Avionics Bay Assembly

20. Controls

Using the state data of altitude, vertical velocity, and lateral velocity, the predicted apogee of the rocket can be calculated. A simple 3 degree of freedom flight simulation is run to find the expected apogee with the current coefficient of drag. The Newton-Raphson Method is then used to find the coefficient of drag needed to hit the target apogee. Then the estimate found from the CFD data is used to find the airbrake extension that will lead to the desired coefficient of drag at the current total velocity. This process is repeated every 0.1 seconds between burn out and when apogee is reached. The control loop can be seen below in Figure 59.

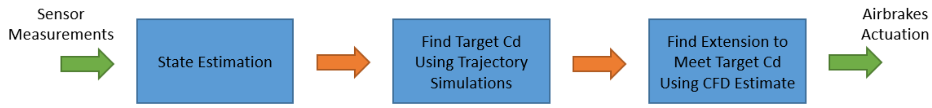


Fig. 59 Airbrake Control Loop

21. Software Implementation

Having developed the theory to support the airbrake controller, it must now be implemented onboard the rocket for effective control during flight. Our team has developed custom C++ flight control software that runs on our own Teensy 4.0 based flight computer as detailed above. The flight computer is responsible for several functions including sensing, state estimation, control, datalogging, and telemetry. Importantly, this functionality is nested within a state machine which progresses through various states during the phases of flight. The general progression through these states includes pre-launch, boost, coast, descent, and post-flight.

Several state transition detection algorithms have been developed and tested to manage the progression through these states. This is done by using sensor data such as acceleration or pressure to detect key events such as liftoff, motor burnout, apogee, and landing. The ability to track the rocket through each phase of flight is important so the flight computer can act appropriately. For example, due to the lengthy on-pad time and limited capacity of the onboard flash memory, the flight computer uses these states to only log data from a few seconds before liftoff until a few seconds after landing. Similarly, it is critical to identify the coast phase, as this is the only time during the flight that the airbrake system may be active.

The airbrakes are intended to operate only during the coast phase in order to actively adjust the vehicle's predicted apogee. Ordinarily, the airbrakes are kept fully retracted so as not to interfere with any aspect of the flight. During a launch, once motor burnout has been detected by the state transition algorithm, the flight computer enters the coast state and airbrakes control is engaged. At this point, the flight software feeds the state estimate into the controller, which then produces a value for airbrake extension as described above. The flight computer then commands the servo to actuate the fins to the desired position. This process repeats throughout the coast phase at 5 Hz. This rate was chosen as it was determined to be reasonably fast for effective control while factoring in the computation time and physical time required to actuate the system. When the flight computer detects apogee, the airbrake fins are once again fully retracted as the rocket enters the descent phase.

In addition to the predefined states for a nominal flight, we must also consider the case of a failure or anomaly. Our team has developed several contingencies to increase the robustness of the system. The first of these measures is a series of timeouts associated with each state to ensure the mission is progressing as anticipated. From the simulations performed, we can be confident in approximately how long each phase of the flight is expected to take. Therefore, if an anticipated state change is not detected within a reasonable amount of time, the flight computer can enter a contingency or abort state. These states exist to save the vehicle and to provide different instructions in the case of an anomalous flight. This is a critical feature which ensures that airbrake deployment will only occur during a nominal flight where everything is behaving as expected. The custom flight control software and state machine discussed in this section have been tested in our two full scale test flights, as well as on several L1 flights in advance of the competition. Our telemetry system and custom ground station application give our team the ability to monitor all of this in real time during launch events. This system is described in more detail in the following section.

E. Telemetry

Capricornus's telemetry system is responsible for all communication between the Rocket and the Ground Station. Throughout each stage of the flight, Capricornus transmits all necessary flight information down to the Capricornus Ground Station at 920MHz using the LoRa[4] data protocol at a transmission rate of 10Hz.

[4] LoRa – Long Range Low Power transmission protocol using spread spectrum technology.

22. Radio

The EByte E32-900T30S radio module was selected for use on Capricornus this year. This module was chosen specifically for its higher power (1W) transmitter, high quality filters, heat dissipation capability and high data rate. At the heart of this module is a Semtech SX1276 LoRa modem capable of multiple data protocols and highly configurable. This module has gone through a series of tests using our custom designed antennas at multiple test launches and performed adequately. The system will go through a series of tests at further distances prior to the competition to 100% verify our simple free space path loss distance calculations. According to these calculations our system is well capable of transmitting at line-of-sight distances greater than 15kM (~49,000ft) which is a significant safety factor for Capricornus' expected apogee, launch pad distance, and maximum expected distance from the ground station.

$$FSPL(dB) = 10log_{10}(d_m) + 20log_{10}(f_{MHz}) - 27.55$$

Equation 3 Free Space Path Loss Distance Calculation

23. Data Protocol

When selecting a data protocol, the most important design requirements that we kept in mind are data rate, transmission rate, bandwidth, and error correction capability. It is incredibly important when designing a data protocol for use in the Amateur Bands/ISM band to consider the free use of others and coordinate your bandwidth to use as much as actually needed. For Capricornus, it was determined that a transmission rate of 10Hz would be ideal to perform later analysis and simulation of the data. For the LoRa data protocol, the configurable parameters are spreading factor[5], sweep rate[6], bandwidth, and bit rate. With a bandwidth of 250KHz and bit rate of 9.6Kbps the transmission rate of 10Hz without overflow[7] is achievable.

24. Antenna Selection

For the transmitter antenna, the team selected a Blade Dipole antenna. This antenna was selected for its low loss when tuned, high gain and radiation pattern. While like a traditional dipole antenna, a blade dipole is conventionally used for wide-banded operation allowing for low SWR high gain operation on the entire 33cm amateur band centered around 920MHz, our requested center frequency, providing Capricornus with a wide selection of operating frequencies to avoid interference as much as possible at competition and elsewhere.

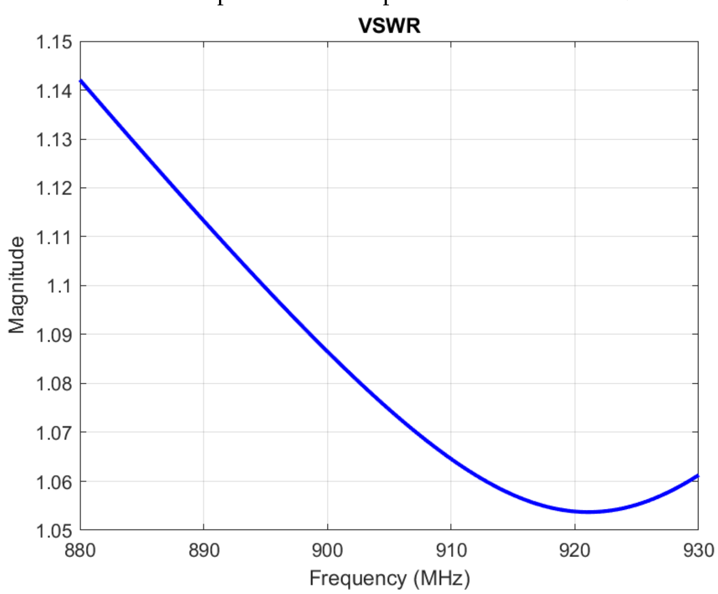


Fig. 60 TX Blade Dipole SWR

[5] Spreading Factor – Ratio relating to the amount of information passed per "chirp" of data.
[6] Sweep Rate - Speed at which the frequency of the transmission is changed to modulate data.
[7] Overflow – Writing of memory when there is no available space in the buffer.

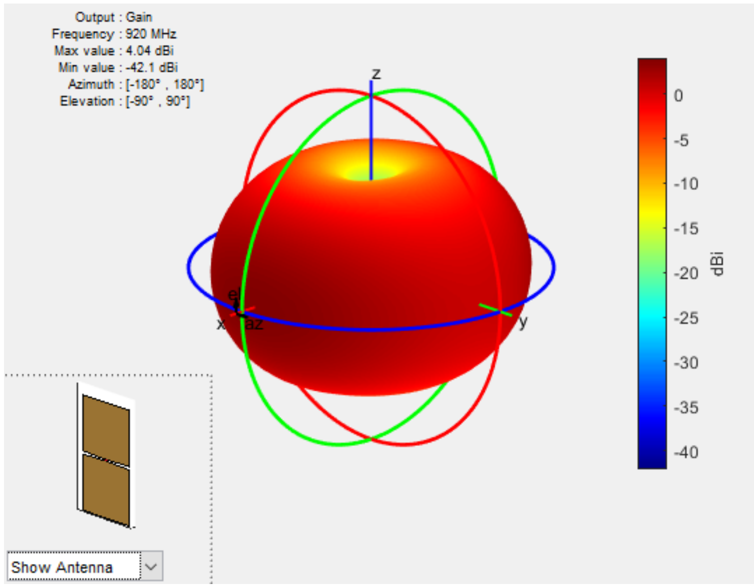


Fig. 61 TX Blade Dipole Radiation Pattern

For the receiver antenna, a QFH (Quadrifiliar Helipticoidal) antenna was selected for its high gain, high elevation and omnidirectional receive pattern. QFH antennas are often used for mobile satellite and spacecraft communications. Many teams opt into an antenna such as a Yagi antenna for its high gain and widespread use, but the main caveat is its directionality. For a Yagi antenna to be effective, a complicated tracking system must be developed to track the rocket. However, since a QFH antenna is circularly polarized and omnidirectional, no human intervention or complicated tracking system is required.

25. Ground Station

The Capricornus Ground Station is an application developed by our team designed to provide the team with necessary information to track the rocket throughout each stage of flight as well as debug issues that may arise. As seen in figure 2, the Ground Station receives and displays all data from our custom flight computers such as acceleration, gyro rotation, altitude, pressure, battery voltage, etc. This data is logged in a csv file created on the user's desktop by a back-end server receiving the rockets data so all flight data can be logged and utilized for later analysis. All graphs and dials are configurable to the users liking including unit selection.

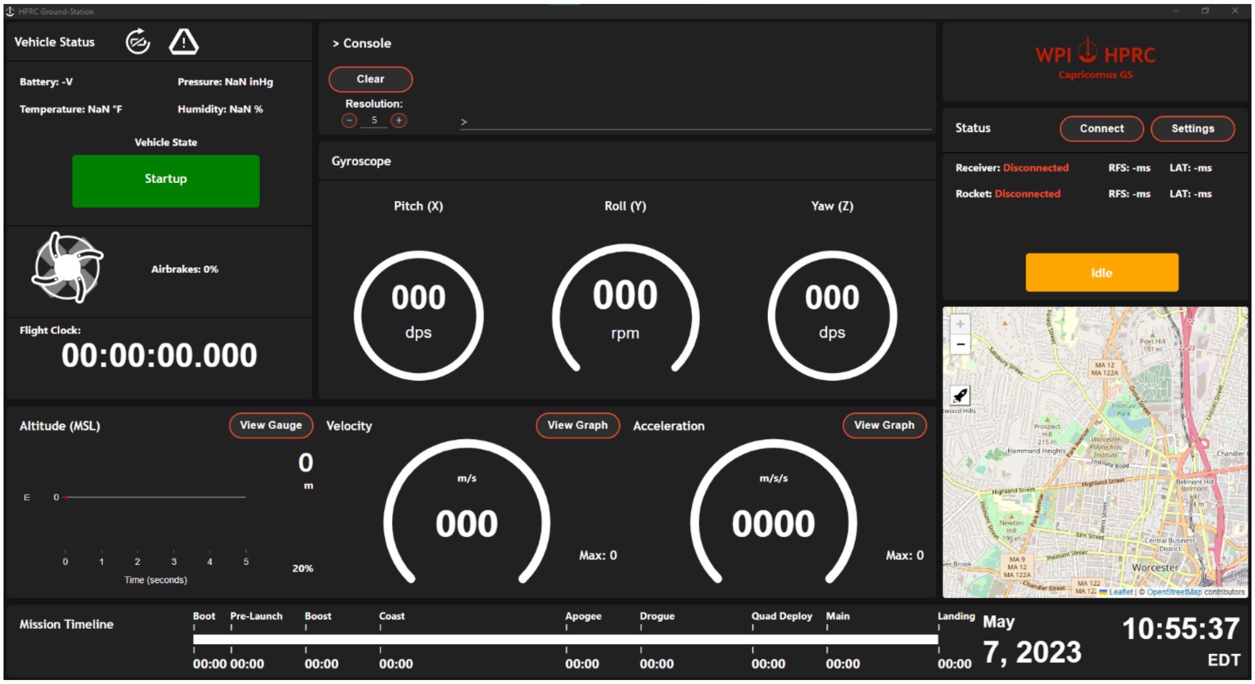


Fig. 62 Ground Station Front End

F. Payload Subsystems

Capricornus's payload is a functional and deployed folding-arm quadcopter designed to complete the mission of autonomously deploying remote weather-station units (cubes) throughout the landing area. The quadcopter is stowed in a retention system attached to the nosecone in the upper airframe of the launch vehicle during ascent and released from the airframe during descent. The entire system fits within the CubeSat formfactor with a length of 23.62 in, or 6U vertically.

Fig. 63 Side View of Integrated Payload Systems

26. Quadcopter

The quadcopter section of the payload consists of the flying vehicle portion of the payload. The structure is primarily made of slotted together carbon fiber plates with aluminum standoffs holding the plates together. The quadcopter arms fold down vertically to stay within the CubeSat form factor. The arms are spring actuated and locked in place with a pin once released. Landing gear is also stored and folded below the quadcopter body and unfolds once the arms are released. Above the landing gear is the quadcopter body, storing most of the electronics. Above the body is the battery, and above the battery an additional plate sandwiching the battery in place, and above that is a screw used to hold the quadcopter in place. Below the body is the cube dropper, a 3D printed part that has three cubes stacked vertically with two servos to stage and drop them when commanded.

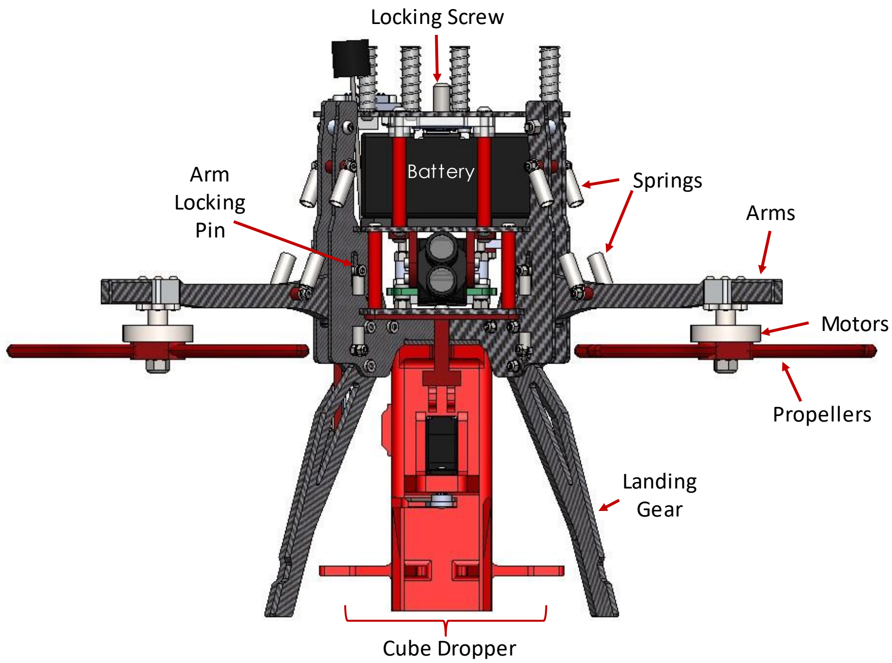


Fig. 64 Quadcopter in Unfolded State

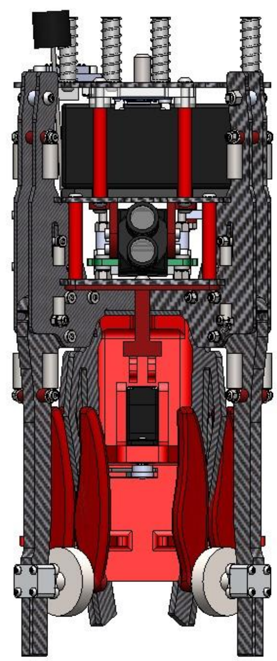


Fig. 65 Quadcopter in Folded State

The quadcopter has a Matek H743 flight controller running ArduPilot firmware. Custom scripts are run on the flight controller giving it additional autonomous flight and retention control capabilities. A custom script controls the release from the retention system and stabilization and another commands the quadcopter to perform the cube mission by flying in a triangle and dropping a cube at each corner. The scripts are activated by specific sensor data which indicates phase of flight. The quadcopter flight controller is the primary controller of the retention system, with the scripts sending commands to control the quadcopter arm retention, pin retraction, camera switching, and final quadcopter deployment.

To connect the quadcopter to the retention system, there is an umbilical connector with POGO pins that the quadcopter pushes up against when it is attached to the retention system. This connector has pins to keep the battery charged and command servos on the retention system when to acuate to properly deploy the quadcopter.

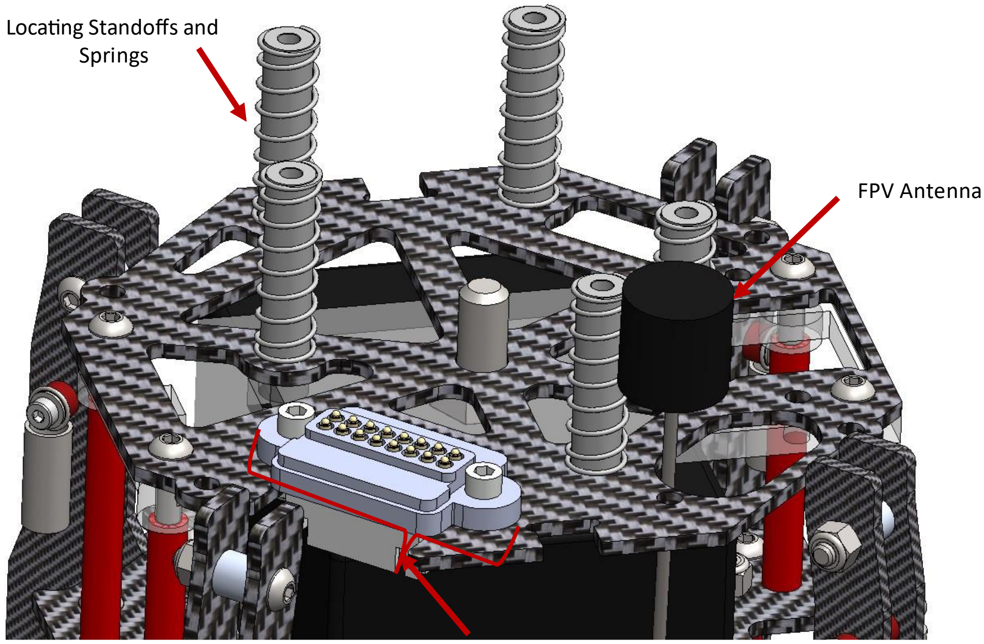


Fig. 66 Top of Quadcopter with Umbilical

27. Mission Systems

The payload's mission systems segment is a crucial component of the quadcopter, as it is accountable for the successful deployment and transmission of weather station packages. These packages are shaped like cubes, with a size of 1.2 inches in length, providing sufficient internal volume to accommodate the necessary sensors and battery. The cube's 3D printed polycarbonate structure is designed to withstand high temperatures during weather data collection. The snap-fit design of the structure allows for easy access to the cube's internal components, while the heat sink ensures the LoRa transmitter remains cooled, resulting in accurate temperature readings. To retain battery life before the weather cubes are deployed from the quadcopter, the structure contains a limit switch that is pressed while the cubes are stowed inside the quadcopter which disconnects the battery.

The cube weather stations are capable of recording humidity, temperature, and pressure data of the outside environment. This functionality is achieved with a compact stack of two custom PCBs. The main control board features an ATMega328p microcontroller with the aforementioned peripheral sensors connected over an I2C bus. This board also includes an onboard flash memory chip for logging data, and a LoRa radio module with antenna for transmitting weather data to the ground station. A secondary PCB is used to regulate the battery voltage to 3.3V and houses the limit switch used for battery disconnect.

Once deployed by the quadcopter and deposited at their observation sites, the weather station cubes will immediately begin collecting and logging sensor data. The weather stations send a data packet to the ground station every 10 seconds, which includes a unique identifier in addition to the temperature, pressure, and humidity data. This identifier is used by the ground station application to parse the data collected by each cube. This data is then displayed on a graphical use interface for observation by the team. This system demonstrates a low cost, air-deployable remote sensing solution which can be applied to gather data about otherwise inaccessible locations.

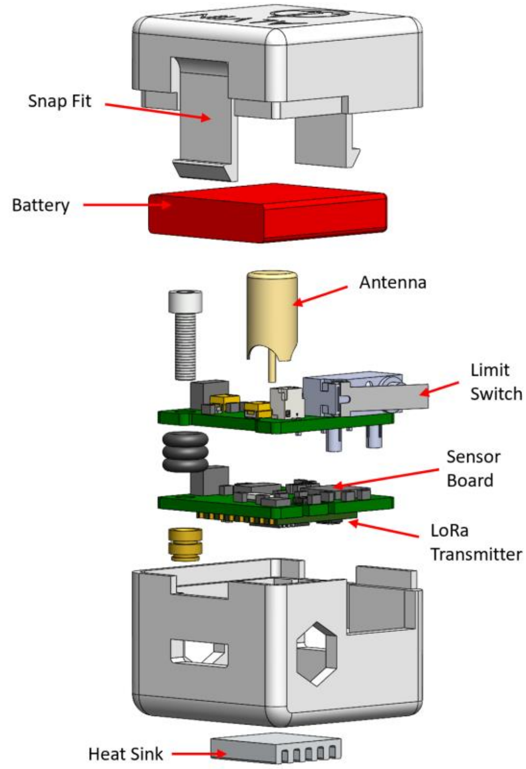


Fig. 67 Weather Station Cube Assembly

28. Retention

The payload retention system is responsible for retaining the quadcopter during the rocket's ascent, and then deploying the quadcopter during the payload's descent, once ejected. The retention system uses two separate mechanical systems, one to retain the quadcopter arms, and the other to retain the quadcopter itself. These two systems are housed inside an aluminum structure that conforms to the CubeSat form factor. Along with the structure and mechanical systems, a series of electrical systems are also present in the retention systems to power and control the mechanical systems, supplement the mechanical systems, and to allow for an umbilical connection between the retention systems and the quadcopter.

The system responsible for retaining the arms of the quadcopter is a linkage-based system that exists above the quadcopter inside the structure and has a long bar, called the vertical extender, that extends down to the arms of the quadcopter. The long bar has a horizontal extrusion, called the horizontal extender, that pushes against the arms of the quadcopter, restraining its motion until the linkage system is released. The system is mechanically locked, with the links being unable to move until actuated vertically by a servo. The servo that releases the links has its own linkage system which pulls the links attached to the locking bar out of their locked state, at which point springs on the system pull the links into the deployed state, moving the long bar and its horizontal extension away from the arms of the quadcopter, allowing the arms to deploy.

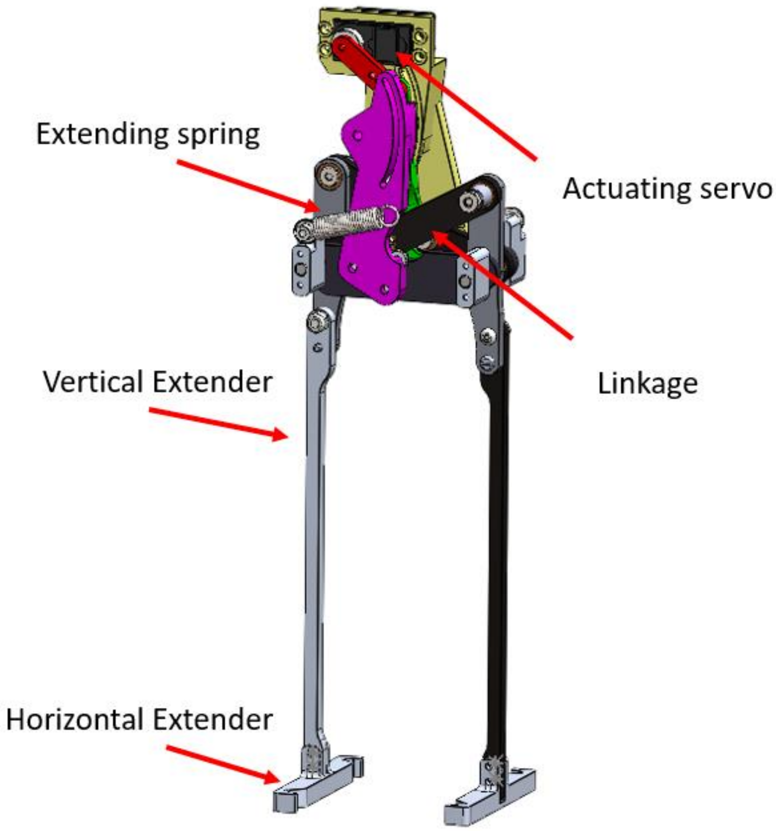


Fig. 68 Overview of Arm Retention System

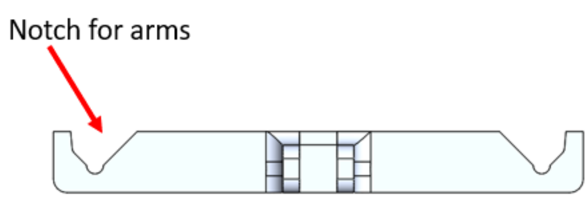


Fig. 69 Top-Down View of Horizontal Extender

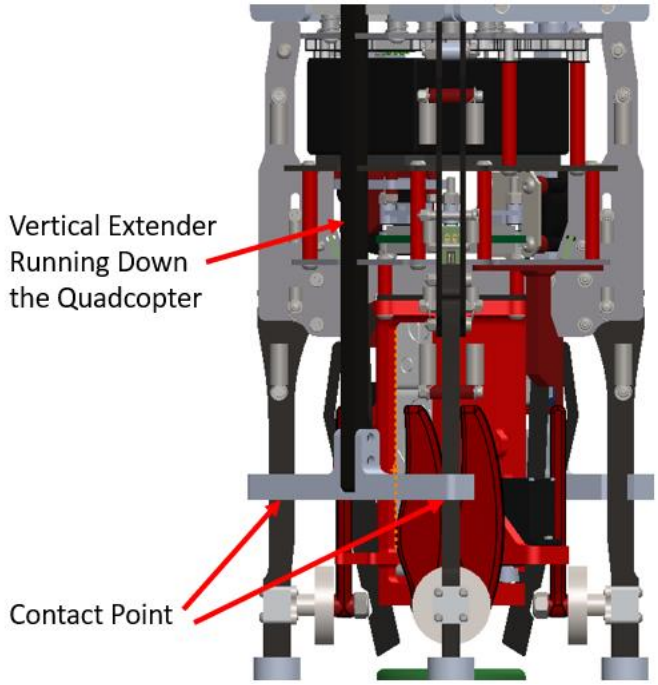


Fig. 70 Arm Retention and Quadcopter Integration

The two leading factors in this design choice were maintaining the CubeSat form factor and allowing for independent arm release and quadcopter release. Due to the quadcopter's cross-sectional geometry being approximately the maximum allowed by the CubeSat form factor, the arm retention system needed to be able to interface with the quadcopter while maintaining a sleek design that did not extend beyond the 10cm x 10cm allowed form factor. This led to the choice of having the mechanical component of the system placed above the quadcopter, and the large bar extended down the side of the quadcopter. The system's actuation method is also independent of the quadcopter retention system's actuation method. This was done for the purpose of safety so that our team can confirm that the arms have been deployed before deploying the quadcopter. The forms of confirmation are twofold: 1. A limit switch on each arm of the quadcopter that signals if the arm is in the deployed state. 2. Two cameras on the retention system are each pointed at two of the arms of the quadcopter that transmit live footage to the ground station.
Once both the limit switches and video footage confirm that the arms have been deployed, a signal will be sent from our ground station to the quadcopter retention system to deploy the quadcopter. The system uses a threaded rex shaft that mates to a bolt on the top of the quadcopter, holding it in place vertically. Bolt shearing equations were used to determine that the system would not fail. To prevent horizontal motion, the quadcopter has five standoffs that interface with cutouts in the bottom plate of the quadcopter retention system, which restrict lateral motion. The rex shaft has a locking piece that rests on the top plate of the system, and that locking piece rotates with the rex shaft. A servo is used to interface with that locking piece using a servo horn that prevents the locking piece, and thus the rex shaft, from rotating until the system is ready to release the quadcopter. When the system is given that signal, that servo will actuate, unlocking the rex shaft, at which point a larger servo will actuate, using two gears to rotate the rex shaft, which unscrews the quadcopter, thus releasing it.

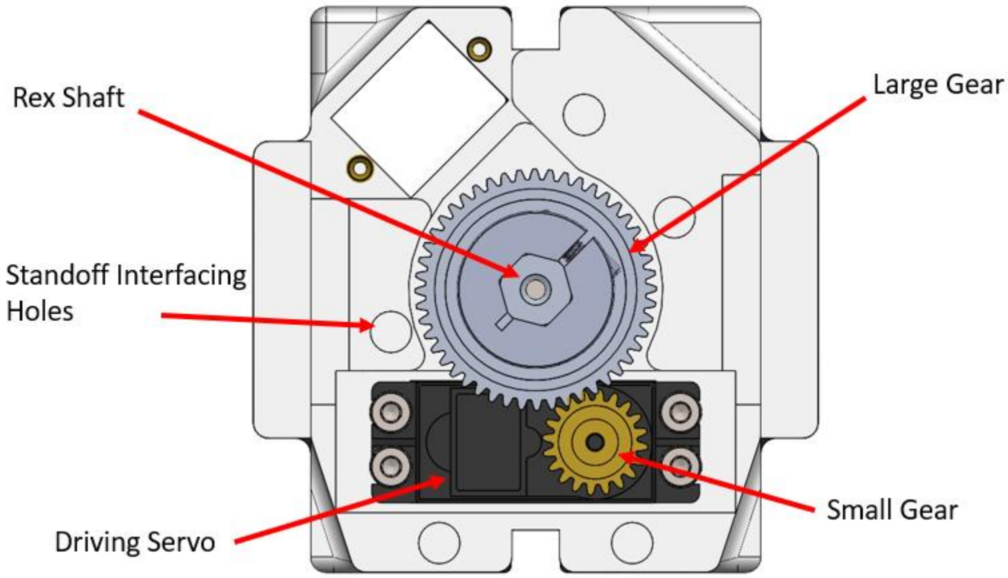


Fig. 71 Bottom View of Quadcopter Retention System

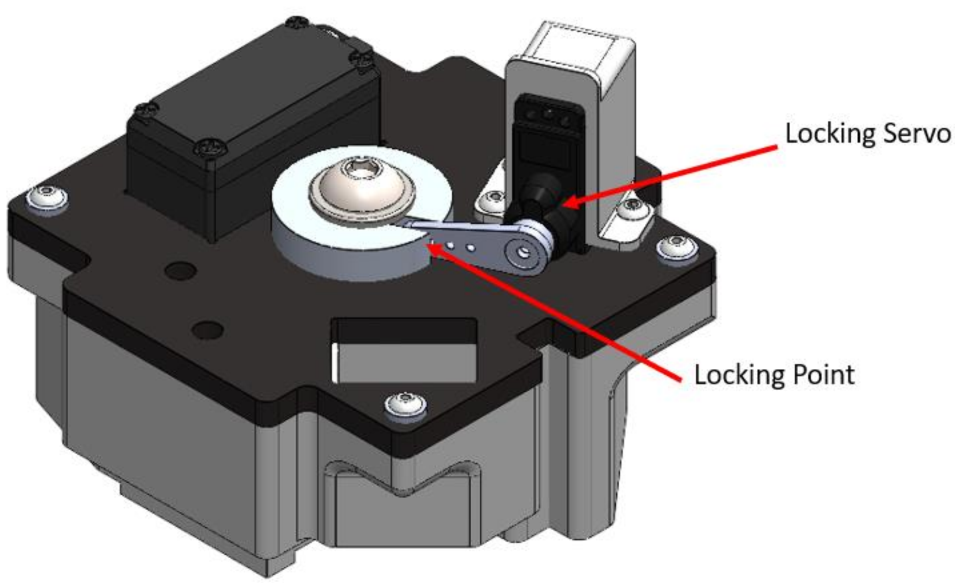


Fig. 72 Quadcopter Retention System Locking System

This system design was chosen to maintain the CubeSat formfactor by placing the retention system above the quadcopter. It also sufficiently retains the quadcopter vertically and laterally, while also enabling independent arm and quadcopter release.

The whole system is powered by eight 18650 batteries, which are housed at the top of the structure.

As mentioned previously, the structure conforms to the CubeSat form factor, and is made of Aluminum 6061 so that it can withstand the ejection load from the rocket. The structure has two large structural pieces that are connected by cross members. The top two cross members are used to mount the structure to the payload adapter, and the middle two cross members are used to mount the battery pack. The structure is covered by panels made of Aluminum 6061 that protects the interior systems from the elements. One of the side panels is replaced by a power board that controls the electronics of the retention system.

The power board holds the electronics needed to power the major electronics from the power supplied by the batteries. This includes two 5V Battery Elimination Circuits and one 12V Battery Elimination Circuit, used to power the servos and various recording equipment housed in the Retention System. The board also distributes power to the Battery Management System, which is used to maintain the batteries on the quadcopter charged until it is deployed. It also holds a microcontroller used to distribute the various signals received from the quadcopter to the major electronics that are not on the board.

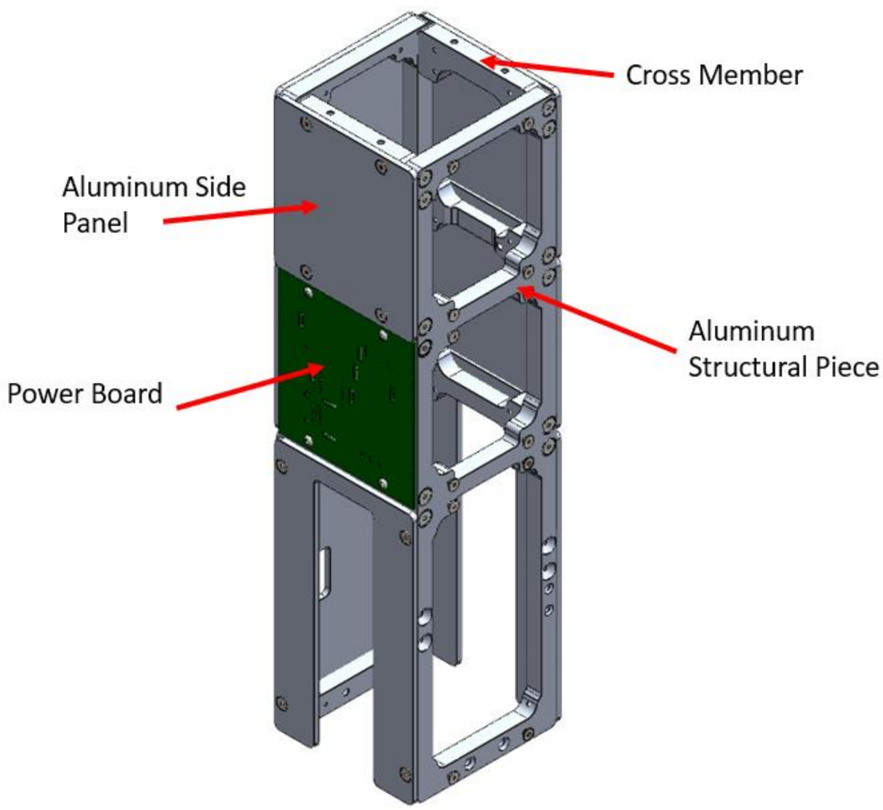


Fig. 73 Retention Structure

IV. Mission Concept of Operations Overview

Capricornus' mission is broken down into 9 different phases as seen in figure 74.

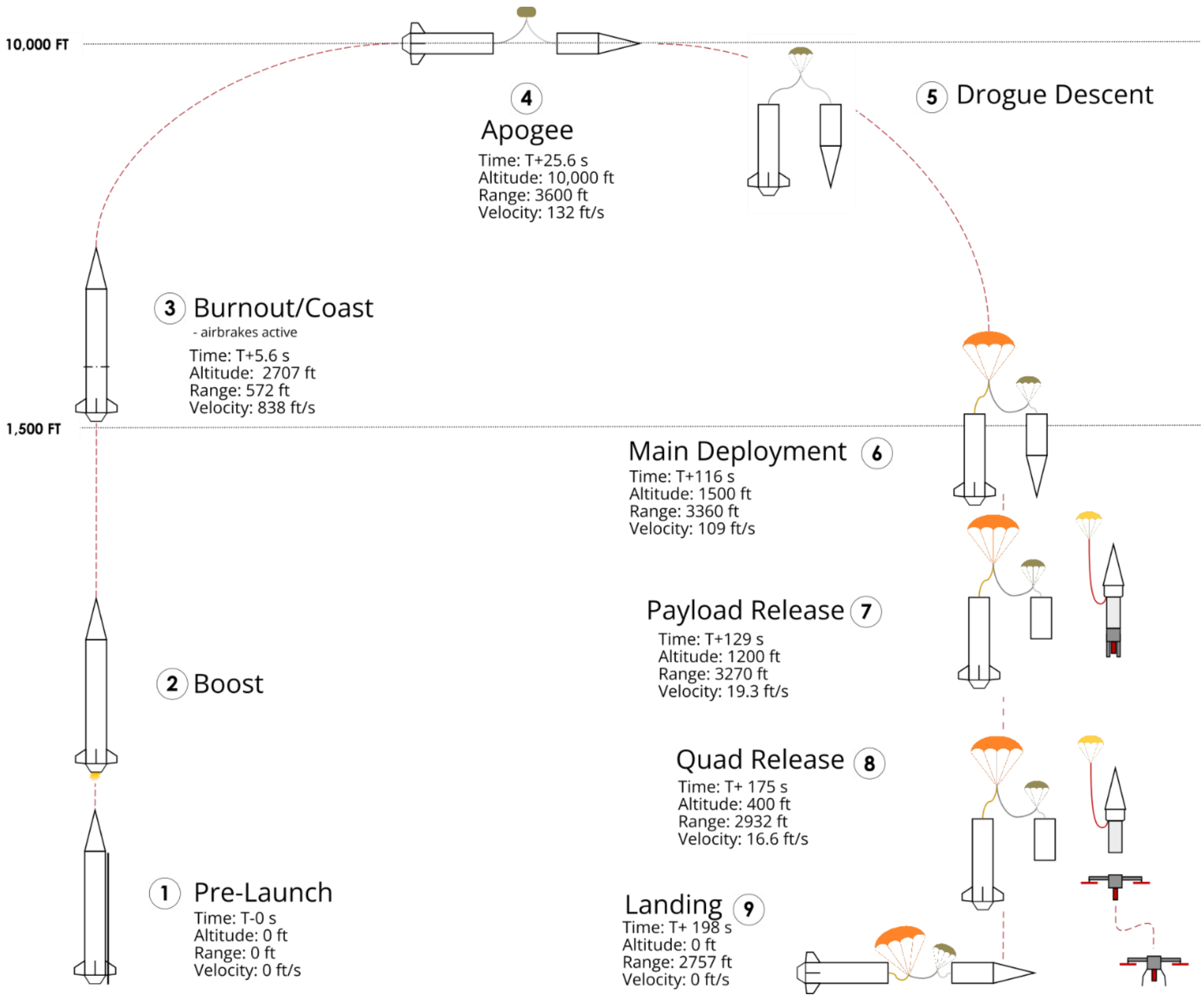


Fig. 74 Flight Profile

Phase 1: In phase 1 the vehicle is on the launch rail before motor ignition. In this phase the avionics system has been activated, the rocket and payload altimeters have been armed, and the ignitor has been installed into the motor and connected. The vehicle is ready for launch.

Phase 2: In phase 2 the motor has been ignited and the vehicle is flying under thrust. This phase will last approximately 5.5 seconds, until the motor burns out. During this time, the altimeters and avionics system will detect launch and begin recording data. The airbrakes will not be activated during this phase.

Phase 3: In phase 3 the motor has burnt out and the vehicle is coasting to apogee. During this phase, the altimeters will continue to record flight data. The avionics system will be analyzing sensor data to estimate the state of the vehicle and use this data to control the airbrakes.

Phase 4: In phase 4 the vehicle has reached apogee and the altimeters have detected apogee. The primary rocket altimeter will fire to separate the vehicle and release the drogue, with the backup altimeter firing 1 second after apogee is detected. The airbrakes will fully retract at this stage to avoid tangling the lines.

Phase 5: In phase 5 the vehicle is descending under drogue parachute. The altimeters are continuing to record data to prepare for main parachute deployment.

Phase 6: At 1500 ft the vehicle reaches phase 6, where the main parachute is deployed. The primary and backup altimeters fire both Tender Descenders with a 1 second delay on the backup to allow the drogue to pull the main parachute from its deployment bag.

Phase 7: At phase 7 and 1400 feet, the retractable pins through the nosecone shoulder and upper airframe retract and at 1250ft the payload altimeters fire to release the payload. The payload and nosecone drop away completely from the rocket.

Phase 8: In phase 8, the rocket and payload are descending separately under their own parachutes. The autonomous quadcopter is released from the payload structure at 400ft.

Phase 9: In phase 9, the rocket will have landed and the payload will conduct its mission deploying weather stations and will land after completing its mission. All altimeters cease data recording and begin reporting apogee using beep codes. Recovery teams will locate the payload and rocket from GPS and return it to the team.

V. Conclusions and Lessons Learned

For knowledge transfer from more experienced members to new team members, the team takes various approaches to continue the education of its members. The first resource team members can use is the team's prior technical documents and technical resources found in the team's shared file system. This file system contains years of competition documents, technical reports, and information that can be used. The team has also created a team wiki where team members have written short posts about the work they have done and the lessons they learned in the process. In the summer, the team runs a series of team workshops based upon team interests. Last summer, the team ran workshops on CAD, CNC, and FEA software. The workshops are multi-day sessions that provide the basic information required to use a desired skill. The team also runs more basic workshops during the beginning of the school year intended to help bring new students up to speed on the team's resources. Additionally, subteam leads--who are usually second year students or older--act as mentors who can help educate newer members.

Our club has undergone incredible growth over the last few years and is now made up of 157 members. However, this growth has led to some obstacles as well. Last year, our subteams were so large that members often felt like there weren't enough tasks to do or opportunities to learn. This year, we addressed this problem by expanding our club structure overall. For example, we added in the Electronics and Programming Division, which contained five new subteams. In addition, we placed an increased emphasis on new member education through our L1 rocketry program. Most onboarding freshmen members started the year in the L1 program where they built and launched their own L1 rocket in teams of 3. Once those were complete, they transitioned to other subteams that were dedicated to working on the vehicle, payload or electrical/programming for the Spaceport America Cup. This has proven to be effective in providing new members with a conceptual framework of rocketry that they can expand on in our many subteams.

Appendices

A. System Weights, Measurements, and Performance Data

Rocket Information:

Number of Stages	1
Vehicle Length [inches]	143
Airframe Diameter [inches]	6.17
Number of Fins	4
Fin Semi-span [inches]	6
Fin Root Chord [inches]	10
Fin Thickness [inches]	0.16
Vehicle Weight [lbs]	48.4
Empty Motor Case/Structure Weight [lbs]	7.8
Propellant Weight [lbs]	10.59
Payload Weight [lbs]	8.8
Liftoff Weight [lbs]	66.7
Center of Pressure [inches]	108
Center of Gravity [inches]	88.175

Propulsion Information:

Propulsion Type	Solid
COTS, SRAD, or Combination	COTS
Propulsion Manufacturer	Cesaroni
COTS Motor – Manufacturer's Designation	Cesaroni 9870M1800-P
Motor Letter Classification	M
Average Thrust [N]	1797.1
Initial Thrust [N]	1951.1
Maximum Thrust [N]	2240.6
Propellant Weight [g]	4802
Total Impulse of all Motors [Ns]	9869.7
Motor Burn Time [s]	5.5

Predicted Flight Data:

Launch Rail	ESRA Provided Rail
Rail Length [ft]	17
Liftoff Thrust-Weight Ratio [X:1]	6.4
Launch Rail Departure Velocity [ft/s]	67.2
Minimum Static Margin During Boost [cal]	3.3
Maximum Acceleration [G]	6.43
Maximum Velocity [ft/s]	904
Target Apogee [ft AGL]	10,000
Predicted Apogee [ft AGL]	10,497

Payload Information:

Deployed or Attached	Deployed
Deployment Altitude [ft]	1300
Main Decent Rate [ft/s]	16
GPS	Big Red Bee 70cm 100mw GPS/APRS Transmitter
Altimeter	Altus Metrum EasyMini Primary

	Featherweight Raven 4 Backup
Ejection System	1g BP Primary 1.5 BP Backup

Rocket Recovery Information:

COTS Altimeter	Altus Metrum EasyMini
Redundant Altimeter	Featherweight Raven 4
Drogue Primary & Backup Deployment Charges [g]	35g CO_2 Cartridge Primary 6g BP Backup
Main Primary & Backup Deployment Charges [g]	0.25g black powder primary 0.25g black powder backup
Drogue Deployment Altitude [ft]	10,000
Drogue Decent Rate [ft/s]	98
Main Deployment Altitude [ft]	1,500
Main Decent Rate [ft/s]	14
Shock Cord	0.190” braided Kevlar
Shock Cord Length [ft]	43
Mechanical Links	5/16” Quick Link (x2) ¼” Quick Link (x2) Braided Kevlar Soft Link (x4)

B. Project Test Reports

1. Main Chute Release Mechanism Test

Date: 1/27/2022

Objective: To determine if the new parallel Tender Descender configuration will release the drogue unloader and allow the main parachute to be released from inside the airframe

Methodology: The Eagle CO_2 is manually triggered causing the rocket to separate between the middle and upper airframes.

Procedure:
1. Assemble either the primary or backup Tender Descender with 0.25g of BP
2. Attach recovery harness to the recovery bulkhead event
3. Rig the drogue unloader to the top of the balcony
4. Feed the ematch to the outside of the airframe and connect to long wires such that you can stand away from the test
5. Fire 1 Tender Descender and watch if the drogue unloader line is released from inside the airframe

Data:
Test #1 (Fire Primary TD): Pass
Test #2 (Fire Backup TD): Pass

Outcome: New main chute release mechanism works on ground. Ready for flight tests.

2. 1st Subscale Flight Test

Date: 3/18/2022

Objective: Launch test rocket built 2 years ago with current airbrakes, avionics system, single end recovery system, and quadcopter payload (not deployed).

Methodology: Utilize air brakes without active controls onboard. Program sweep function for airbrakes servo to collect data and compare to CFD. Confirm proper state changes with updated flight computer state machine. Test that new main chute release mechanism. Test flight computer on quadcopter.

Data:
Airbrakes Deployment Successful
Avionics Board brownout. Lost data logging and telemetry during coast phase
Main Parachute release mechanism successful released the drogue unloader but on the way out the Main Parachute tangled on shock cord and was unable to open
Quadcopter remained on for the entire flight and logged data

Impact: Investigation into avionics and recovery anomaly

3. 2nd Subscale Flight Test

Date: 4/10/2022

Objective: Launch test rocket again with current airbrakes, avionics system, single end recovery system, and weather station cube payload.

Methodology: Utilize air brakes with active controls onboard. Confirm proper state changes with updated flight computer state machine. Test that new main chute release mechanism. Test weather station cube payload and confirm ability to log to flash chip.

Data:
Airbrakes Deployment Successful
Avionics Board brownout. Lost data logging and telemetry during coast phase
Premature transition to apogee phase in flight computer due to pressure increase from airbrakes actuation
Main parachute come out of airframe at apogee due to insufficient packing.
Unable to retrieve data from weather station cube flash chip

Impact: Investigation into avionics, recovery anomaly, and weather station cube data logging

4. Quadcopter Mission Testing

Date: 4/22/2023

Objective: Test quadcopter waypoint mission with dropping cubes.

Methodology: Run the same code that will be dropping cubes at competition but with smaller distance values so we can test it at our local flying field.

Procedure:
1. Load the script for testing the test onto the quadcopter.
2. Boot up quadcopter and wait for initialization.
3. Change quadcopter mode to throw mode. Arm quadcopter and verify successful arm.
4. Throw quadcopter into the air.
5. Wait for script to execute and quadcopter to land autonomously.

Data:
The quadcopter executed the mission successfully when ran three times in a row.

Outcome:
While the test was successful, we may want to increase the speed of the mission in the future so we can travel further to have a larger mission footprint.

5. Quadcopter Drop Test

Date: 5/1/2023

Objective: To determine if the quadcopter is able to successfully recover when dropped from an altitude.

Methodology: The quadcopter was dropped from a large UAV to test successful recovery from a drop.

Procedure:
1. Load the TD-2 Release mechanism with an E-Match. Attach to larger drop UAV and quadcopter
2. Turn on large UAV and quadcopter. Wait until fully initialized. Briefly arm quadcopter to ensure arming successful.
3. Take off larger UAV and climb to an altitude of 60 feet.
4. Arm quadcopter, look for arm message.
5. Command drop of quadcopter.

6. Immediately land larger UAV.
7. Land quadcopter.

Data:

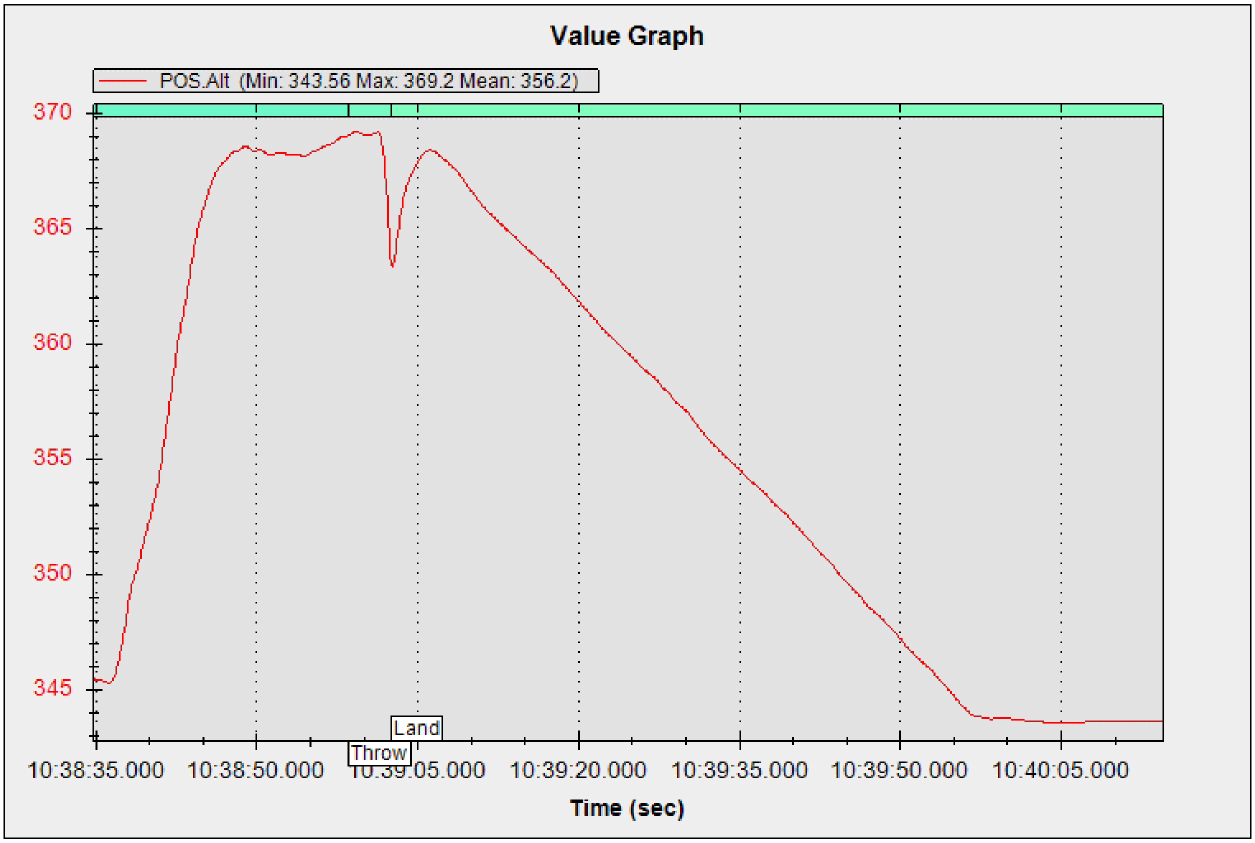


Fig. 75 Altitude Plot from Drop Test

Outcome: The quadcopter was able to successfully recover from the drop. Some of the initial arm attempts were unsuccessful, so more research has to be done on making the arm sequence more reliable.

6. Payload Ejection Test

Date: 5/2/2023

Objective: To determine the amount of black powder necessary to eject the payload from the upper airframe and to stress test the payload with its ejection forces

Methodology: The payload and upper airframe was assembled, and the black powder charge was fired to test the ejection.

Procedure:
1. Assemble payload and nosecone assembly.
2. Assemble 5g black powder charge with E-match.
3. Assemble the payload, nosecone, and upper airframe assembly.
4. Ensuring safety of all present members, fire the E-match.

Data: The payload was ejected about 15 feet. The legs of the quadcopter broke, as did the epoxy joint of the piston.

Outcome: While the payload was able to eject, it severely damaged the quadcopter and the piston. Repairs and additional analysis need to be done before the next test to increase the strength and reduce the black powder used.

C. Hazard Analysis

Hazard Probability Definitions	
Rating	**Description**
A	The condition is probable if it is not mitigated.
B	The condition may occur if it is not mitigated.
C	The condition is unlikely to happen if it is not mitigated.
D	The condition is highly unlikely to happen if it is not mitigated.

Hazard Severity Definitions	
Rating	**Description**
I	The condition may cause death or permanent disability to personnel or loss of the system.
II	The condition may cause major injuries or significant damage to the system.
III	The condition may cause injury or minor damage to the system.
IV	The condition may cause minor injury or negligible damage to the system.

Hazard Analysis	**Severity**			
Probability	**I - Irrecoverable**	**II - Significant**	**III - Minor**	**IV – Negligible**
A – Probable	AI	AII	AIII	AIV
B – May Occur	BI	BII	BIII	BIV
C - Unlikely	CI	CII	CIII	CIV
D – Highly Unlikely	DI	DII	DIII	DIV

Personnel Hazard Analysis						
Section	**Hazard**	**Cause**	**Effect**	**Probability/Severity**	**Mitigation & Controls**	**Verification**
Construction	Hand Tool Injury	Improper training or human error during the use of tools	Injuries include, but are not limited to cuts, scrapes, even amputation or crushing.	CIII	HPRC members will receive proper training and will have access to instructions on how to operate each tool. Members will also wear proper PPE specific to each tool. If an injury does occur, a member will be given proper medical attention.	Safety officer, leads and/or the lab safety monitor is present during the use of potentially dangerous tools to ensure proper usage and PPE.
	Fire	Human error, short circuit amongst any other event that could cause a fire to start.	Burns, inhalation of toxic fumes, and in extreme cases, death.	DII	Fire control tools such as water and fire extinguishers will be present at the construction site. Additionally, members will wear protective equipment and will separate flammable objects from potential fire hazards.	Safety officer and/or leads will be present to ensure proper handling of flammable objects and will verify the existence and availability of a fire extinguishing tool nearby.

	Electric Shock	Member coming in contact with an exposed wire.	Burns, and in extreme cases, death from electrocution.	DII	Members will inspect all wires before working with them and not deal with live wires often, if at all.	HPRC members will perform an analysis of wires.
Chemical	Exposure to epoxy	Improper PPE worn during construction.	Eye and skin irritation; prolonged and reputative skin contact can cause chemical burns.	BIV	During work with epoxy, members will wear proper PPE including safety goggles, gloves, and clothes that protect the skin from encountering the material.	MSDS sheet for epoxy will be consulted and members will be wearing proper PPE.
	Exposure to carbon fiber/ fiberglass dust and debris	Sanding, using a Dremel tool, machining carbon fiber/ fiberglass.	Eye, skin and respiratory tract irritation.	CII	During work with carbon fiber/ fiberglass members will wear proper PPE including safety goggles, gloves, long pants and long sleeve shirt, as well as a mask to protect their lungs.	MSDS sheet for each material will be consulted to make sure members are wearing proper PPE.
	Exposure to black powder	Loading charges for stage separations or any other	Serious eye irritation, an allergic skin reaction; can cause	CIII	Only people who are trained in working with black	Safety officer will ensure that unauthorized members

		contact with black powder.	damage to organs through prolonged and repetitive exposure.		powder will be allowed to handle it. They will wear proper PPE. Clothing that has black powder on it will be washed in special conditions.	do not work with black powder. MSDS sheet for black powder will be consulted to make sure members are wearing proper PPE
	Exposure to LiPo	LiPo battery leakage.	Chemical burns if contacts skin or eyes.	DIII	The battery will not be dismantled and will be checked for leaking before use.	WPI HPRC members will provide analysis of the battery.
	Exposure to APCP	Motor damage.	Eye irritation, skin irritation.	DIII	Only a few select HPRC members handle the motor and will wear proper PPE while doing so.	MSDS sheet for APCP will be consulted to make sure members are wearing proper PPE.
Launch	Injuries due to recovery system failure	Parachute or altimeter failure	The rocket/ parts of the rocket go in freefall and injure personnel and spectators in the area causing bruising and possible death	DI	HPRC members will pack the parachutes correctly, ensure the altimeter will be calibrated correctly, and that the amount of black powder in separation chares are weighed on	HPRC Recovery subteam lead, along with others will oversee this process.

					an electronic scale for accuracy.	
	Injuries due to the motor ejection from launch vehicle	Motor installed and secured improperly.	Motor and other parts of the rocket go in freefall and injure personnel and spectators in the area causing burns and possible death.	DI	The motor will be installed by a certified mentor	Safety officer will ensure that the motor is installed by a certified mentor. Prior to the launch, the rocket will be inspected following a checklist.
	Injuries from premature ignition of separation charges	Improper installation of igniters, stray voltage.	Severe burns.	DI	The battery will be switched off during installation of the igniters, black powder in separation charges will be weighted on an electronic scale.	Safety officer will ensure that all safety procedures are followed during the installation of the charges.
	Injuries due to a premature motor ignition	Improper storage of the motor, damage of the motor or early ignition.	Severe burns.	DI	Motor and igniters will be bought from official suppliers, properly installed by a certified mentor and ignited by the RSO.	Safety officer will ensure that installation of the motor and ignition are done by certified personnel.
	Injuries due to unpredicta	Wind, faulty parachute, or instability in thrust.	If the rocket goes in unexpected areas, it	DI	The rocket will not be launched during	Weather conditions will be assessed,

	ble flight path		could injure personnel or spectators.		strong winds, the rocket design will be tested through simulations to make sure that it is stable during flight.	the rocket will be launched only if the RSO considers the weather safe. Multiple simulations will be run to ensure that the rocket is stable.

D. Risk Assessment

Risk Probability Definitions	
Rating	**Description**
A	The failure is probable if it is not mitigated.
B	The failure may occur if it is not mitigated.
C	The failure is unlikely to happen if it is not mitigated.
D	The failure is highly unlikely to happen if it is not mitigated.

E.

Risk Severity Definitions	
Rating	**Description**
I	Complete loss of the item or system.
II	Significant damage to the item or system. Item requires major repairs or replacement before it can be used again.
III	Damage to the item or system which requires minor repairs or replacement before it can be used again.
IV	Damage is negligible.

F.

Risk Analysis	**Severity**			
Probability	**I - Irrecoverable**	**II - Significant**	**III - Minor**	**IV – Negligible**
A – Probable	AI	AII	AIII	AIV
B – May Occur	BI	BII	BIII	BIV
C - Unlikely	CI	CII	CIII	CIV
D – Highly Unlikely	DI	DII	DIII	DIV

G.

Risk Analysis: Launch Vehicle

Hazard	Cause	Effect	Probability/Severity	Mitigation & Controls	Verification
Vehicle does not separate at apogee	Insufficient ejection charge, altimeter failure	The rocket would descend at a dangerous terminal velocity. If the main parachute deploys at this speed, the airframe will most likely be severely damaged and the payload cannot safely deploy.	BI	Calculate appropriate ejection charge sizing, and ensure the correct quantity of CO_2 is used	Testing of the recovery system. Ground Ejection Test.
Drogue parachute does not inflate	The parachute may not be packed properly, or it might be too tight of a fit in the airframe.	The rocket would descend more rapidly than anticipated velocity. If the main parachute deploys at this speed, the airframe and vehicle will most likely sustain minor damage	BII	The drogue parachute will be properly sized and have a redundant system to deploy it.	Testing of the recovery system using last year's rocket.
Parachute detaches from launch vehicle	Improper installation of the recovery system	This would result in the probable destruction of the rocket and its components upon ground impact as well as failure to complete the payload mission criteria. It could also injure personnel on the ground due to debris upon impact or impact near a person.	DII	Proper installation of the recovery system and select correct sizes of hardware to handle ejection forces.	Testing of recovery system including a ground ejection test and a full-scale test using last year's rocket.
Main parachute does not deploy	The parachute may not be packed properly, or it might be	If the drogue parachute deploys, the rocket would still fall at a	BII	The main parachute will be properly sized and also have multiple	Testing of the recovery system including a full-scale test using

	too tight of a fit in the airframe.	high speed, leading to damage. The significance of the damage being less than if the drogue did not open. Payload could still deploy.		systems to deploy it.	last year's rocket.
Melted or damaged parachute	The parachute bay is not properly sealed, or the parachutes are not packed correctly.	This could prevent the parachutes from slowing the rocket's descent rate, resulting in the possible loss of the rocket and payload.	DII	Proper protection and packing of the parachutes.	Testing of recovery system including a full-scale launch using last year's rocket.
Shock cord tangles	Parachutes are not packed properly	Could decrease the parachutes' effectiveness, resulting in the loss of the rocket and payload upon ground impact.	BII	Properly pack the parachutes	Testing of recovery system including an ejection test, and a full-scale launch using last year's rocket.
Electronics bay is not secured properly	Electronic bay does not fit tightly into the airframe	Potential electronics and recovery failure	DII	Manufacture the electronics bay to fit accurately within the airframe. Design couplings to allow a simple, reliable installation of the electronics bay.	Physical testing of the couplings to ensure tight fit of the airframes with minimal movement of any attachable part.
Motor ejected from launch vehicle	The motor is secured improperly.	The motor could possibly go into freefall during flight. If it is still ignited, it may harm personnel in the vicinity or destroy the launch vehicle. It could also create free falling debris that could cause harm.	DI	The motor will be installed by a certified mentor. The motor retention system will also be inspected prior to launching the rocket. Conduct a thorough Finite Element Analysis of the motor retention system. Combine commercial	No physical testing prior to launch. A thorough analysis and integration of commercial parts raises our factor of safety and ensures a reliable performance.

				retainers with the manufactured parts to increase the safety factor.	
Fins break off during ascent	Large aerodynamic forces or poor fin design	Rocket cannot be relaunched, damage to airframe or internal components	DII	Mount fins properly onto the airframe	Material testing of the fins.
Rail buttons fail during launch	Unexpected forces, damage to attachment components	Rocket does not achieve sufficient stability, possible danger to personnel at large distance	DII	Calculate expected loads on rail buttons & attachment hardware, conduct qualitative “hang” test	Conduct a qualitative “hang” test
Launch rail/tower fails	Poorly maintained equipment, improper setup	Rocket does not safely exit rod, damage to vehicle, danger to personnel at a large distance	DI	Launch tower will be setup and maintained by a responsible person at the launch club, and inspected by the safety officer prior to launch	ERSA equipment, so no prior testing will take place
Airframe separates during ascent	Improper connection of airframe sections; large aerodynamic forces cause the airframe to separate	Rocket cannot be relaunched, damage to airframe or internal components	DI	Couplings are tightened in the airframe using torque wrenches. A thorough analysis ensures its capability to withstand expected loads.	Complete analysis of coupling and material strength testing. Conduct a physical static load test to simulate expected in-flight loads.
Altimeter failure	Loss of power, low battery, disconnected wires, destruction by black powder charge, or burnt by charge detonation	Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload not deploying from rocket.	DI	There will be a backup altimeter with a second power source in case the main altimeter fails. There will also be a set of backup CO2 charges connected to the backup altimeter. Both altimeters will	Altimeter testing included full-scale test of last year’s rocket.

				also be tested before launch.	
Altimeter switch failure	Switch comes loose or disarms during launch or component failure	Incorrect altitude readings and altitude deployment; can result in potential loss of rocket and payload not deploying from rocket	DI	Test switches before launch	Altimeter testing included in full-scale testing of last year's rocket
Recovery electronics bay failure	Loss of power, disconnected wires, destruction by black powder or CO2 charge, or burnt by charge detonation	Altimeter or recovery system failure	DII	Test the electronic bay and altimeter before launch	Full-scale test of electronics on last-year's rocket.
Descent too fast	Parachute is too small	Potential damage or loss of rocket and payload depending on speed of descent	DII	Properly size parachute; test recovery system before launch	Testing of recovery system in a full-scale launch of last year's rocket.
Motor Misfire	Damaged motor or damage to ignitor prior to launch.	Significant to unrepairable damage to the rocket and possibility of harm to personnel	DI	The motor is only handled by a certified team mentor. If there is a misfire, the team will wait at least 60 seconds before approaching the launch vehicle and will follow the instructions of the RSO.	There will be no prior verifications or testing.
Premature motor ignition	Damaged motor or accidental early ignition.	Possibility to harm personnel in vicinity during ignition.	DII	The motor will be replaced. It will be properly installed by a certified mentor and inspected by the RSO.	There will be no prior verifications or testing.
Motor fails to ignite	Ground support equipment failure, faulty or damaged motor	Launch vehicle cannot launch. Could possibly result in disqualification of team	DIII	The ground support equipment will be maintained by responsible persons from the launch site club. The motor	Ignitors testing in launch site.

				will be stored according to specified guidelines.	
Premature ejection charge detonation	Inadvertent arming, recovery electronics failure	Minor damage to vehicle and harm to personnel in vicinity	DII	Arming switches will be locking, and detailed instructions will be kept and followed pertaining to the arming process.	Full scale testing
Shock cord is severed	Faulty shock cord, weak cord from repeated testing, destruction by black powder charge, or burnt by charge detonation	The parachutes would detach from the rocket, leading to the loss of the rocket. Payload could potentially still deploy.	DI	The shock cord will be properly sized to handle ejection loads. It will also be inspected before the parachutes are packed. A Nomex blanket will protect the shock cord from fire damage and the black powder charges will be measured carefully.	Testing of recovery system including a full-scale test using last year's rocket.
Fins do not keep the rocket stable	Damaged fins, improper fin sizing	Predicted apogee is not reached, vehicle sustains minor damage.	CII	Use OpenRocket simulations to make sure the fin design will keep the rocket stable	Will not test before launch. Fins shape and sizing will be verified by both Rocket and Aerostructure team leads.
Fins break off during landing	High impact during landing; point stresses on fins	Rocket cannot be relaunched	CII	Avoid fin designs with weak points and test fins with forces of final descent velocity	Material testing of the fins.
Descent too slow	Parachute is too large	Landing outside of landing range.	CIII	Properly size parachute; test recovery system before launch.	Testing of the recovery system including a full-scale test using last year's rocket.
Pressure not equalized inside airframe	Vent holes are too small	Altimeters do not register accurate altitude	DII	The vent holes will be drilled according to recommendation	Inspection and verification by Rocket and

				s determined by external testing	Aerostructure team leads.
Airbrakes fail to deploy or deploy incorrectly	Electrical or software failure, mechanical parts become stuck	Vehicle over or undershoots expected apogee	BIV	The airbrake system will be tested prior to launch using simulated flight data, and hardware in the loop testing. Mechanical actuation will be attempted with expected loads	Airbrakes performance will not be verified prior to the competition, and will be tested for the first time during launch
Airbrakes deploy asymmetrically	Driving plate or fin pins fail in one section but not others	Vehicle experiences unexpected loads and flight forces, causing an unpredictable trajectory or damage to other components	DII	Conduct analysis of part mechanical strength. Airbrake system is designed to force all fins to deploy evenly when there is no damage to parts	Airbrakes performance will not be verified prior to the competition, and will be tested for the first time during launch
Rocket Catches on Fire	High temperatures, short circuits, physical damage	Significant damage to vehicle, danger to personnel in vicinity due to energetics or harmful gases	DII	Temperature monitored during launches, components tested independently, electronics protected from damage.	No way to verify, but will be monitored and safety precautions will be taken as necessary
Avionics systems fail	Damaged components, faulty power system	Vehicle overshoots expected apogee, flight data is not recorded. GPS positions are not transmitted, causing possible loss of vehicle	CIII	Test avionics systems before launch, verify functionality	Avionics systems testing and full-scale testing using last year's rocket
Payload comes loose in payload bay	Damaged components, improperly designed retention system	Minor damage to vehicle, alteration of flight path	CIII	Perform analysis of payload retention system under expected flight loads, and test strength prior to launch	Independent payload testing

Risk Analysis: Payload					
Hazard	**Cause**	**Effect**	**Probability /Severity**	**Mitigation & Controls**	**Verification**
Payload retention failure	Incorrect programming of the altimeters, or severe damage to the upper airframe and retention pins	Payload deploys prior to apogee	DI	Inspection of upper airframe and retention pins prior to flight. Verification of the altimeter programming by team leads	WPI HPRC will create a payload inspection checklist
Retention system becomes insecure	Damage to retention pins	Payload rattles within upper airframe and causes damage to itself	DII	Inspection of upper airframe and retention pins prior to flight	WPI HPRC will create a payload inspection checklist
Payload Ejection failure	Incomplete separation of upper airframe	Potential launch vehicle tumbling that could affect proper decent	DI	Inspection of CO2 charges and wiring and reduce friction between payload and upper airframe	Payload ejection test using expected CO2 charges.
Payload becomes damaged during ejection process	Excessive forces on shock cord during deployment	Payload is damaged	DII	Inspection of shock cord and computed simulations.	Recovery system full-scale test using last year's rocket
Battery catches fire	Overheating of the internals of the payload during launch or outside temperature, faulty battery, incorrect wiring leading to an ignition, ignition within rocket that impacts the security of the payload	The rocket catches on fire and burns during launch, the rocket becomes ballistic and could hurt the environment or people in the crowd, the drone is destroyed and unable to complete its mission	DI	WPI HPRC will design the quadcopter and retention system to be well ventilated to prevent overheating. The payload recovery bay and GPS will be the only batteries turned on during launch to minimalize overheating possibilities	The quadcopter will be run at acceptable levels to not overexert the battery's

H. Assembly, Pre-Flight, Launch and Recovery Checklists

Day Before Launch Checklists

System	Primary	Secondary	Assembler	Division Lead
a) Airbrakes	Tobias Enoch	Julia Sheats	Kate Lindsay	Terence Tan
b) Avionics Bay	Francisco Diaz	Kelli Huang	Jackson Neu	Michael Beskid
c) Rocket Recovery	Ryan Truher	Kate Lindsay	Emma Pollak Rayden Morley	Terence Tan
d) Payload Recovery	Keelan Boyle	Henry Lambert	Daniel Willins	Jake Roller
e) Payload Adapter	Keelan Boyle	Henry Lambert	Lyle Edwards	Jake Roller
f) Ground Station	Daniel Pearson	Abby Hyde	Max Friedman	Michael Beskid
g) Quadcopter	Cameron Best	Dylan Dsilva	Nikhil Gangaram	Jake Roller
h) Mission Systems	Newton Le	Logan Frandsen	Dylan Dsilva	Jake Roller
i) Payload Retention	Newton Le	Francisco Diaz	Hunter Crossman	Jake Roller
j) Payload Final Assembly	Cameron Best	Hunter Crossman	Lyle Edwards Newton Le	Jake Roller
k) Rocket Final Assembly	Tobias Enoch	Cameron McAfee	Niko Gerakaris Kelli Huang	Terence Tan

2023 IREC Day Before Checklist

a) **Airbrakes**

Assembler: Kate Lindsay

#	Instructions	Primary Tobias E.	Secondary Julia S.	Division Lead Terence T.
1	Visually inspect the airbrakes assembly for possible damage from transportation.			X
2	Manually airbrake deployment before installation into lower airframe.			X
3	Tape up servo wire to avoid interference during installation.			X
4	Install airbrake assembly into lower airframe. Insert into the AFT coupling and attach via 4 #8-32 bolts (3/8" long).			X
5	Attach fin extensions and ensure they are screwed down as flush as possible (to avoid catching on airframe).			X
6	Work with Avionics Bay team to test airbrake actuation from flight Polaris board.			

Notes/Variances

2023 IREC Day Before Checklist

b) **Avionics Bay**

Assembler: Jackson Neu

#	**Instructions**	Primary Francisco D.	Secondary Kelli Huang	Division Lead Michael B.
1	Verify that 4x 18650 battery cells marked "flight" are fully charged to 4.0V – 4.2V.			X
2	Ensure that all bolts are securely fastened, and wiring is neat and tidy.			X
3	Check that servo wire connector is connected in the proper orientation and secured with red clip.			X
4	Ensure that SMA cable is fully secured to the TX antenna and to the Telemetry Board.			X
5	Connect the Polaris board to a computer via USB-C.			X
6	Erase the flash chip on the Polaris board. Open the Avionics_Computer23-Release repository on the HPRC GitHub and select the Main branch. Navigate to FlashOps/FlashSetupOp/src/main.cpp. Upload the program to the board.			X
7	Upload the flight code to the Polaris board. Navigate to Polaris/src/main.cpp. Upload the program to the board. After the startup sequence, watch for the yellow LED heartbeat to indicate that the main loop is running correctly.			
8	Coordinate with the Airbrakes team to test airbrake actuation from the Polaris board. Install 2x 18650 battery cells into the battery holder. Press and hold the push button on the proto board while powering on the system via the screw switch. Verify successful full extension of the airbrakes within acceptable limits.			
9	Coordinate with the Ground Station team to power up the avionics system and check for flight readiness. Confirm good telemetry link and expected sensor readings.			
10	Remove batteries from battery holder. Place the avionics bay assembly in the container labeled "Avionics + Airbrakes."			X

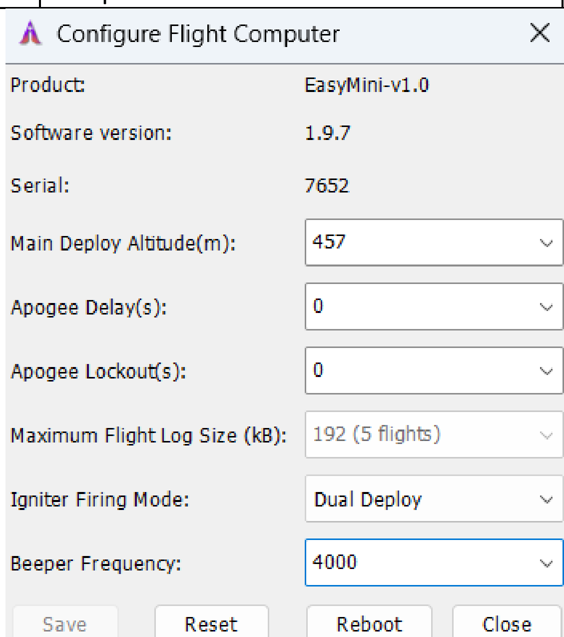
Notes/Variances

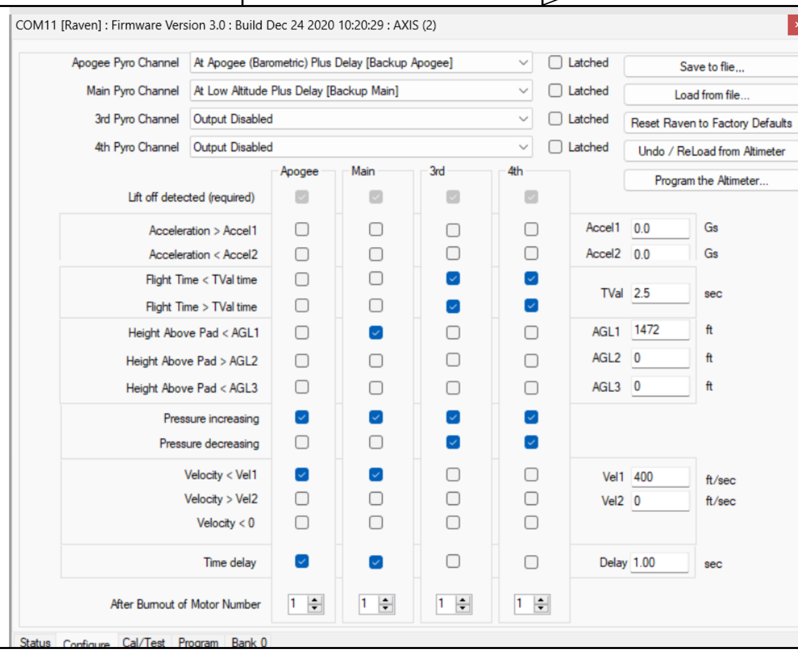
2023 IREC Day Before Checklist

c) **Rocket Recovery**

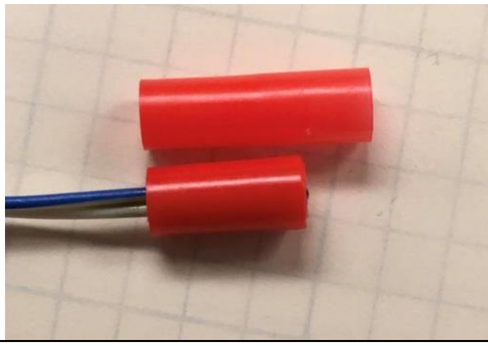
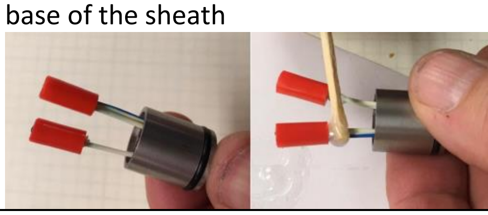
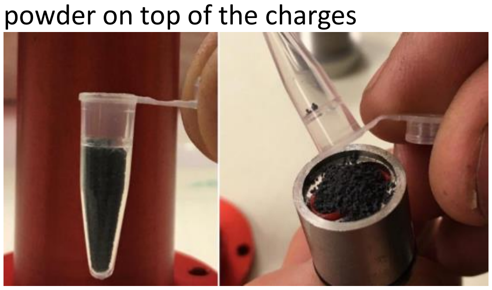
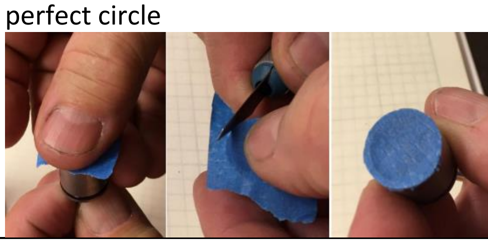
Assemblers: Emma Pollak, Rayden Morley

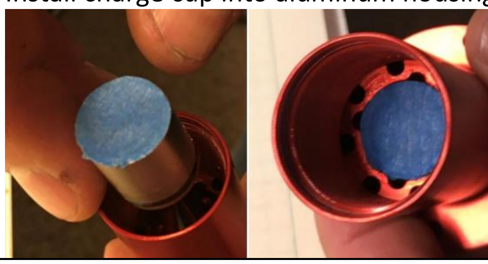
#	Instructions	Primary Ryan T.	Secondary Kate L.	Division Lead Terence T.
1	Open Easy mini settings in Altus Metrum App **on 2 separate laptops**. Take close out photo			
2	Open Raven4 settings in Featherweight App **on 2 separate laptops**. Take close out photos			

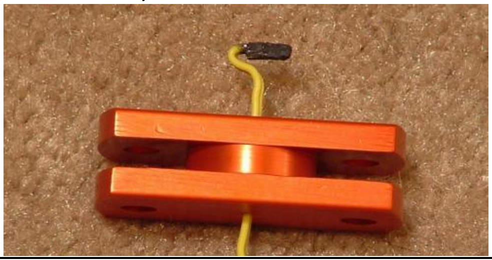


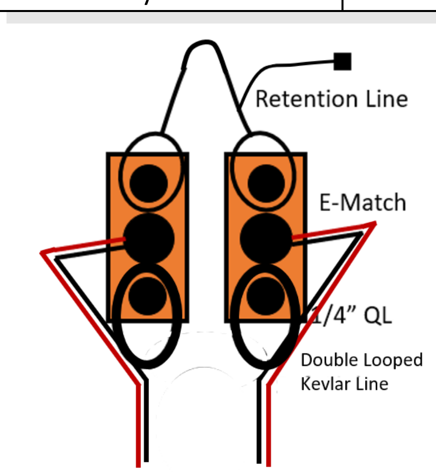


#	Instructions	Primary Ryan T.	Secondary Kate L.	Division Lead Terence T.
3	Put on safety goggles and clear area of all non-assembly, recovery, and checklist people. Provide Safety Officer with a brief overview what charges you will be prepping.	Safety Officer Sign-off		
Eagle Assembly: Gather eagle kit with aluminum housing, charge cup, puncture piston, lube, q-tips, epoxy blanks, etc				
4	Inspect cleanliness and condition of each component.			

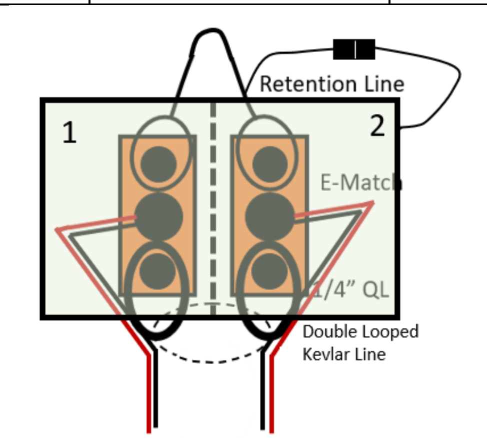
5	Remove around 1/3 off the sheath of the e-match 			
6	Apply lube to inside the charge cups and insert an epoxy blank into one of the charge cups. 			
7	Feed the exposed end of the e-match through the charge cup and epoxy the base of the sheath 			
8	Once fully cured, pull the ematch fully through the charge cup and pour black powder on top of the charges  *Measure BP to line in vial(inside kit)			
9	Apply blue tape onto the top of the charge cup and trim excess until it's a perfect circle 			

10	Lube o-ring on the charge cup 			
11	Install charge cup into aluminum housing 			
12	Lube o-ring on the puncture piston and install into aluminum housing with spring  *TIP: use a pencil			
14	Screw on aluminum adaptor closure (NOT THE PLASTIC ONE)  Store in Ammo Can until launch day			
15	Label terminal end of e-match with “Easy Mini, Apo”			
TD assembly: Gather ematch, TDs and drogue unloader assembly				
16	Inspect cleanliness and condition of each component.			
17	Loop ematch through the bore side of the TD and bend tip accordingly (twice			

	for each TD) 			
18	Tape the back end of the TD to cover the center hole (twice for each TD) 			
19	Pour 0.33g of BP or 1 BP vial's worth of BP into the top of the TD (twice for each TD			
20	One TD at a time, attach the bike chain into the TD with a ¼" quick link on one side and 1 loop of the retention line on each side.			
21	Insert both TDs into the bag with e-match first. Connect safety-line.			



Outside Bag



Inside Bag

22	Connect the 2 lower quick links with a double looped Kevlar line. Torque both quick links. Store in ammo can till launch day			
23	Label terminal end of e-matchs with "Easy Mini, Main" for TD in slot 1 and "Raven, Main for TD in slot 2			

BP charge assembly: Gather glove tip, BP, electrical tape, and e-match

24	Mass 6g of BP on a scale and carefully pour into a glove tip			
25	Check continuity on e-match with multimeter			
26	Insert e-match into glove tip and wrap tightly with electrical tap			
27	Label terminal end of e-match with "Raven, Apo"			
28	Confirm that the (x2) 18350 batteries and BRB APRS Battery have a voltage of >4.0 V			

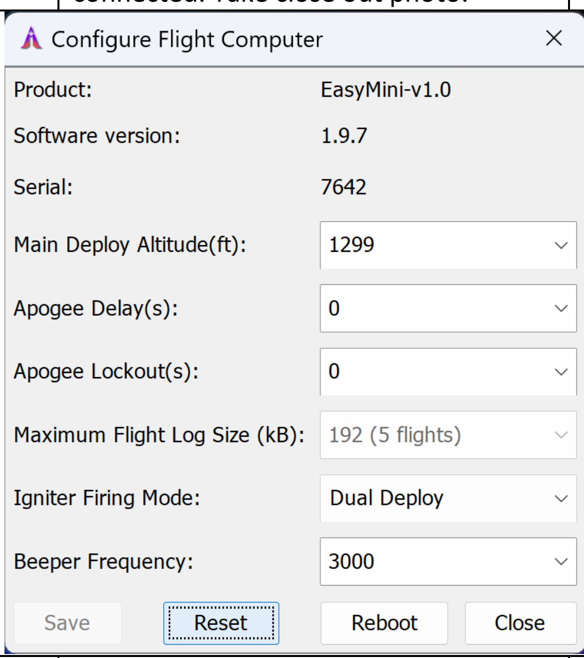
Notes/Variances

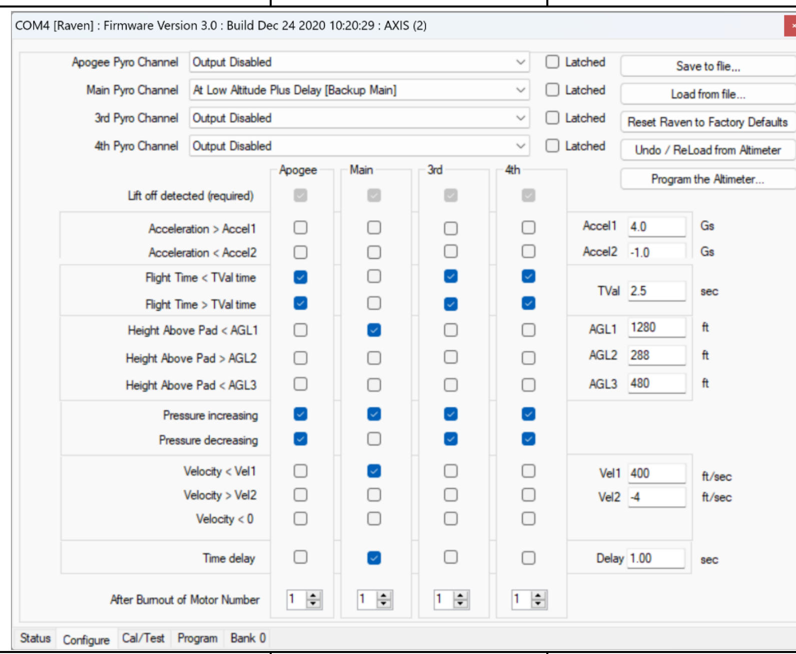
2023 IREC Day Before Checklist

d) Payload Recovery

Assembler: Daniel Willins

#	Instructions	Primary Keelan B.	Secondary Henry L.	Division Lead Jake R.
1	Ensure that each (x2) 18350 battery is fully charged using a multimeter. The voltage should be 4.0 – 4.2V.			
2	Open Easy mini settings in Altus Metrum App on **two** separate laptops. Verify programming. Remove flights. Verify that switch terminals are connected. Take close out photo.			





#	Instructions	Primary	Secondary	Division Lead
3	Open Raven 4 settings in Featherweight App on two separate laptops. Verify programming. Remove flights. Calibrate the Raven. Take close out photo.			
4	Put on safety goggles and clear area of all non-assembly, recovery, and checklist people. Provide Safety Officer with a brief overview what charges you will be prepping.	Safety officer sign-off		
	BP charge assembly: Gather glove tip, BP, electrical tape, and e-match			
5	Check continuity on e-matches with multimeter			

6	Mass 5g of BP on a scale and carefully pour into a glove tip			
7	Insert 1 e-match into glove tip and wrap tightly with electrical tape			
8	Label terminal end of e-match with "EasyMini - Primary"			
9	Mass 6g of BP on a scale and carefully pour into a glove tip			
10	Insert 1 e-match into glove tip and wrap tightly with electrical tape			
11	Label terminal end of e-match with "Raven - Secondary"			

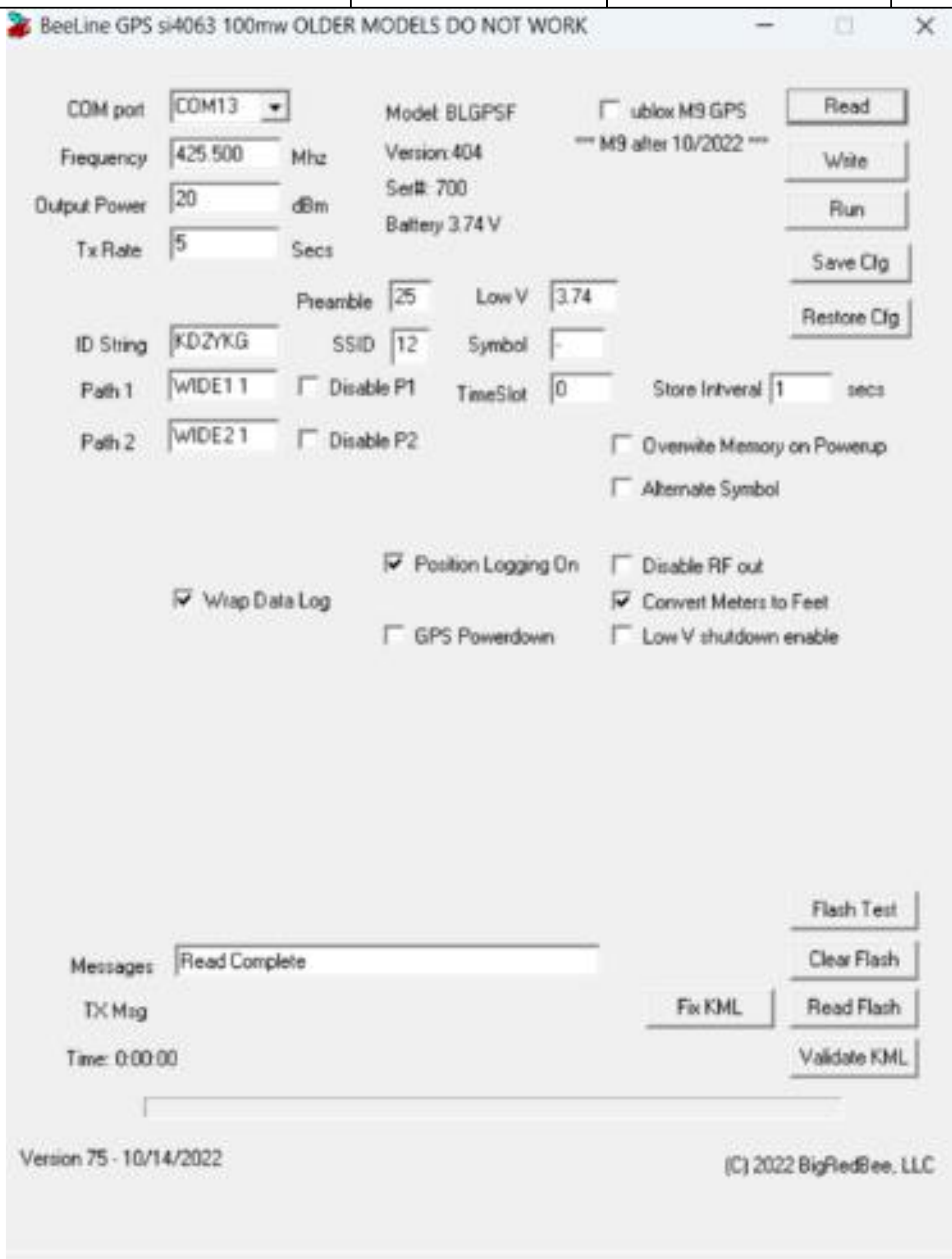
Notes/Variances

2023 IREC Day Before Checklist

e) Payload Adapter

Assembler: Lyle Edwards

#	Instructions	Primary Keelan Boyle	Secondary Henry L.	Division Lead Jake R.
1	Ensure BRB is charged and battery reads voltage > 4.0 V. Check with multimeter.			
2	Verify programming on BRB			



3	Take off the servo hub, torque the screws that are below the winch.			
4	Test that servo functions with programming, replace servo hub.			
5	Ensure that the paracord is taught.			

Notes/Variances

2023 IREC Day Before Checklist

f) Quadcopter

Assembler: Nikhil Gangaram

#	**Instructions**	Primary: Cameron B	Secondary: Dylan D	Division Lead: Jake R		
1	Fully charge all 3 LiPo batteries			X		
2	Fully charge goggle internal batteries			X		
3	Fully charge goggle external batteries			X		
4	Fully charge transmitter battery			X		
5	Fully charge monitor battery			X		
				Check ELRS TX output power is 1 watt		X
6	Check all springs and bolts			X		
7	Check prop rotations and tightness			X		
8	Wipe Runcam and Quad SD card. Wipe quad SD card through mission planner (so the lua script isn't deleted).			X		
9				Verify that the Lua script is the most up to date version		X
10				Double check quad parameters for throw mode. 1. Throw_nextmode = 4 2. Throw_type = 1		X
11				Check flight modes are 1. Stabilize		X

			2. Position hold 3. Acro for acrobatic			
12	Power on quad to verify GPS lock, compass, datalogging, runcam recording, and FPV frequency and power 1. Goggles should be on R-8 Purple light on transmitter for power					
13	Briefly arm quad in GPS mode					
14	Hover and verify proper functionality					
15	Check that the proper lua script messages are being shown					
16	Verify logs are good					
17			Replace Battery and ziptie FPV transmitting antenna			
18			Take off quad arm unfolding springs			
19			Carefully pack the quad and all batteries inside the black pelican case			
20			Verify that all necessary components are present in the case			

Notes/Variances

2023 IREC Day Before Checklist

g) Payload Retention

Assembler: Hunter Crossman

#	Instructions	Primary Newton L.	Secondary Francisco D.	Division Lead Jake R.
	Arm Locking (T-Bar) Assembly			
1	Visually inspect the preassembled system for damage or loose hardware. In this state, the vertical and horizontal extenders should not be attached.			
2	With the springs detached, actuate the inverter by hand to put the system in the locked state. Verify that the system is locked by applying outward force to the vertical extenders (no linkages should move)			
3	Actuate the inverter by hand to unlock the system. Verify that the system is unlocked by applying rotating the vertical extenders outward			
	Quad Locking (Screw) Assembly			
4	Visually inspect the preassembled system for damaged or loose hardware			
5	Verify that the locking servo and its servo horn are securely fastened			X
6	Verify that the driving servo and its brass gear are securely fastened			X
7	Verify that the shaft collar is tightened and that its bottom face is above the bottom face of the REX shaft			X
8	Verify that the large screw on the top of the REX shaft is tightened, and that Loctite has been applied			X
9	(somehow) Test the driving servo by rotating it such that the locking slot is aligned with the servo horn			X
10	(somehow) Test the locking servo by rotating the servo horn to the locked position			X
11	Verify the lock functionality. The driving servo shouldn’t be able to be backdriven by the REX shaft			X
12	Actuate the locking servo to the unlocked position			X
	Battery Pack Assembly			

13	Check that the metal contacts are properly attached to each lid.			
14	Check that the wires on each metal contact are properly soldered.			
15	Insert the batteries into the pack, alternating the orientation of each battery cell.			
14	Screw the battery pack lids onto the battery pack and check that it is properly fastened.			
15	Screw the DVR boards onto the battery pack.			
16	Screw the BMS into larger standoffs on the battery pack.			
Structure & Arm Locking Integration				
17	Verify all cross members are fastened to one ladder structure piece in their correct locations: - Top 2: adapter - Middle 2: battery - Bottom 2: regular			
18	On the arm locking assembly, attach mounting blocks to the rotary shafts with the bolt side facing outward and upward on the side opposite the spring mount			
19	Mount the system into the ladder structure with T-Bars on the open sides of the structure			
20	Pull the two springs over their respective bolts on the mounting blocks			
Structure & Quad Locking Integration				
21	Install the quad locking assembly into the ladder structure piece and fasten with 4x 6-32 flathead bolts			
Structure & Battery Integration				
22	Install the battery pack into the battery cross member using 2x 6-32 flathead bolts. Make sure the system is properly fastened.			
Structure & Camera Integration				
23	Check that the camera is properly mounted to the camera mount.			
24	Mount each camera mount to each ladder structure using 2x 4-40 0.5” flathead screws for each mount. Check that they are both properly mounted.			
Final Structure Integration				

25	Screw the second ladder structure piece into the cross members.			
26	Attach the second set of screws to the T-bar mounting blocks so that the system is fully installed.			
27	Attach the second set of screws to the locking screw mounting threads so that the system is fully installed.			
28	Mount the power board to the ladder structure on the same side as the driving servo for the locking screw system.			
29	Plug the solenoid into the power board.			
30	Plug the locking servo and driving servo into the power board.			
31	Attach the T-bar vertical extenders to the linkage system with the cutouts in the horizontal extenders facing inwards.			
Final Prep				
32	Install what panels we can (so we don't need to do them all on launch day)			

Notes/Variances

Pre-Launch Checklists

System	Primary	Secondary	Assembler	Division Lead
a) Airbrakes	Tobias Enoch	Julia Sheats	Kate Lindsay	Terence Tan
b) Avionics Bay	Francisco Diaz	Kelli Huang	Jackson Neu	Michael Beskid
c) Rocket Recovery	Ryan Truher	Kate Lindsay	Emma Pollak Rayden Morley	Terence Tan
d) Payload Recovery	Keelan Boyle	Henry Lambert	Daniel Willins	Jake Roller
e) Payload Adapter	Keelan Boyle	Henry Lambert	Lyle Edwards	Jake Roller
f) Ground Station	Daniel Pearson	Abby Hyde	Max Friedman	Michael Beskid
g) Quadcopter	Cameron Best	Dylan Dsilva	Nikhil Gangaram	Jake Roller
h) Mission Systems	Newton Le	Logan Frandsen	Dylan Dsilva	Jake Roller
i) Payload Retention	Newton Le	Francisco Diaz	Hunter Crossman	Jake Roller
j) Payload Final Assembly	Cameron Best	Hunter Crossman	Lyle Edwards	Jake Roller
k) Rocket Final Assembly	Tobias Enoch	Cameron McAfee	Niko Gerakaris Kelli Huang	Terence Tan

2023 IREC Launch Assembly Checklist

a) **Airbrakes**

Assembler: Kate Lindsay

#	Instructions	Primary Tobias E.	Secondary Julia S.	Division Lead Terence T.
1	Visual inspection focused on moving parts (smooth actuation, carriages binding, deformed hardware).			X
2	Confirm that the airbrakes assembly is inserted in the AFT coupling and attached via 4 #8-32 bolts			X
3	Confirm that the fin extensions are flush with the outside of the airframe when retracted.			X
4	Extend the airbrakes fins with their extensions to confirm that there is no obstruction/binding.			X

Notes/Variances

2023 IREC Launch Assembly Checklist

b) **Avionics Bay**

Assembler: Jackson Neu

#	**Instructions**	Primary Francisco D.	Secondary Kelli H.	Division Lead Michael B.
1	Tug firmly on TX Antenna SMA connector to confirm it is fastened properly. Ensure that the U.FL connector is securely fastened to the Polaris board and hot glued for security.			X
2	Tug firmly on all other wires to confirm they are properly connected and completely secure.			X
3	Install 2x 18650 battery cells into the battery holder. Take care to ensure that correct polarity is correct. The flat end indicates the negative electrode, and the end with the protruded boss indicated the positive electrode.			X
4	Check that the combined voltage of the 2 battery cells exceeds 8.0V with a digital multimeter. Measured battery voltage: __________ V			
5	Strap down the batteries with 2 red zip ties. Cut any excess length with flush cutters.			X
6	Turn the screw switch CW with a 5/64" Allen key until the Polaris Board receives power as indicated by the red power LED. **Confirm telemetry with Ground Station team before proceeding.**			
7	Turn the screw switch CCW to turn off power to the avionics. Ensure that the screw is turned until encountering resistance from the backout cover to prevent accidental arming.			X
8	Take close out photos of the Avionics Bay assembly. Be sure to capture battery holder/screw switch, Polaris board, and all wire connections.			X
9	Install Avionics Bay bulkhead on top of the aft-coupler tube. Fasten 4x #8-32 bolts.			
10	Confirm "Avionics" arming switch sticker is placed on the airframe covering the access hole.			X

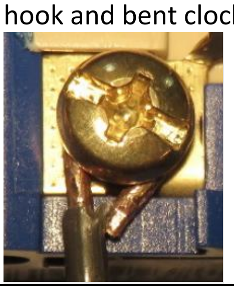
Notes/Variances

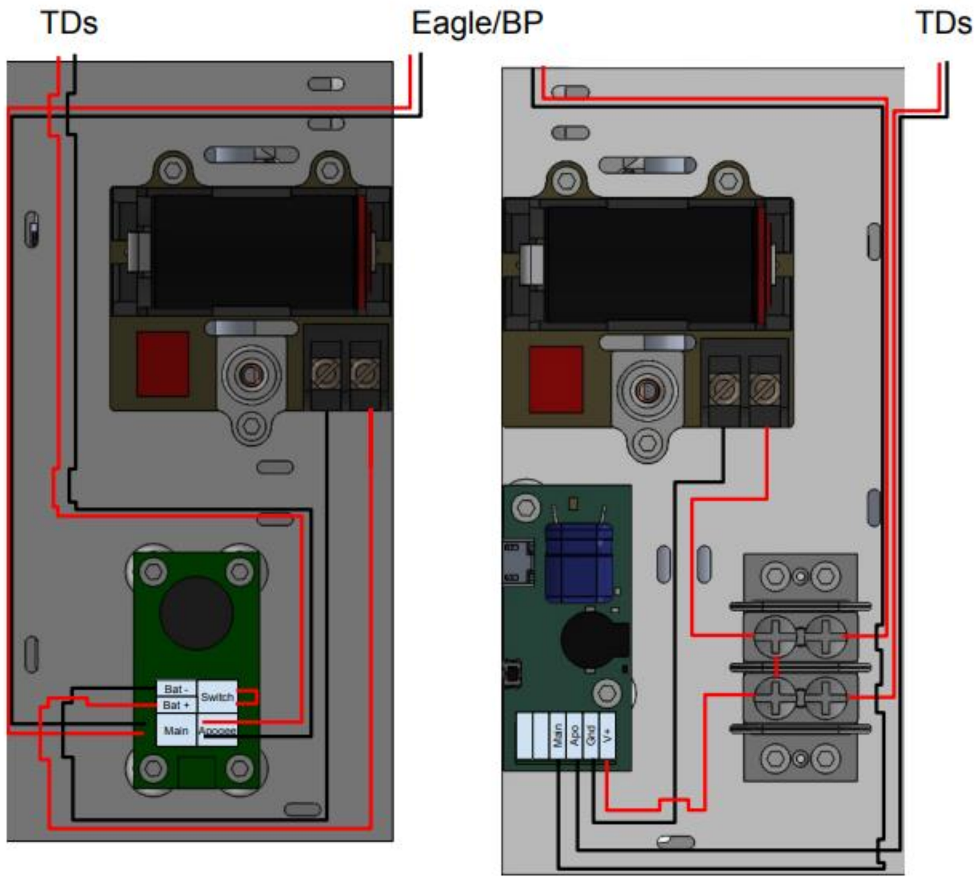
2023 IREC Launch Assembly Checklist

c) **Recovery Bay Assembly**

Assemblers: Emma Pollak, Rayden Morley

#	Instructions	Primary Ryan T.	Secondary Kate L.	Division Lead Terence T.
1	Open Easy mini settings in Altus Metrum App. Take close out photo			
2	Open Raven4 settings in Featherweight App. Take close out photos			
3	Ensure that each (x2) 18350 battery is fully charged using a multimeter The voltage should be 4.0 – 4.2V.			X
4	Install the batteries onto either side of the electronics sled. POLARITY!! Strap down the batteries using zipties and cut flush. *RED zipties are in rocket box			X
5	Before connecting any ejection charges, turn on the switch for the EasyMini (Primary) altimeter. Verify these beeps: 1. Battery Voltage (4.0 – 4.2V) 2. brap (no continuity on both charges) brap = long dissonant tone ** Turn off when done			X
6	Turn on the switch for the Raven4 (Secondary) altimeter. Verify these Beeps: 1. Battery Voltage, round down to nearest volt (4V) 2. 1 low beep every 2 seconds (no charges or not vertical or voltage <3.85V) ** Turn off when done			X
7	Layout recovery harnessing out on the ground. "S" MAIN shroud lines and neatly place into MAIN parachute bag.			
8	Attach main swivel to main line with soft link Take close out photo			
9	Install hair band onto MAIN parachute bag around 1-2 inches from the top of the bag. Take close out photo			

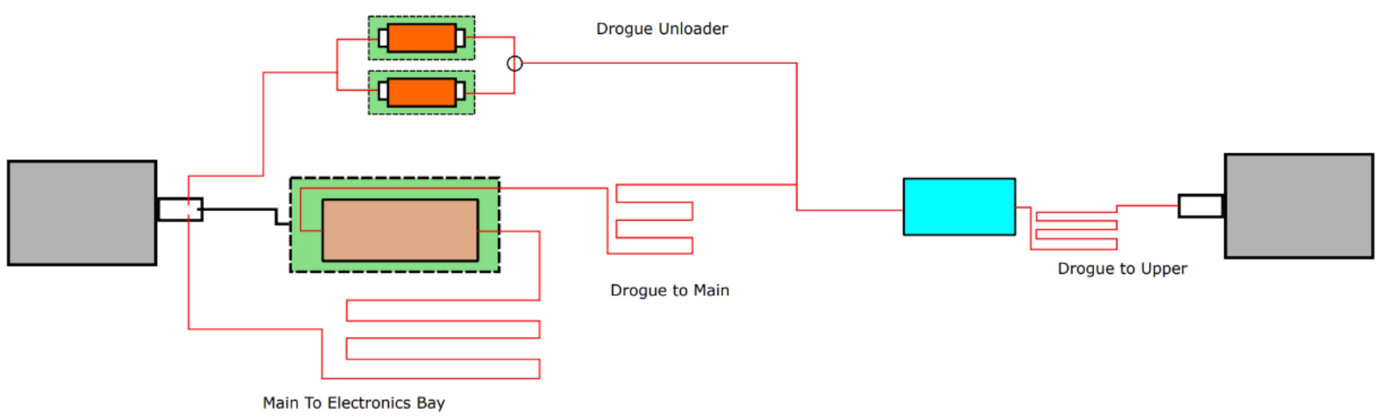
10	Pack Drogue parachute into Nomex blanket with the Nomex blanket on the soft-link			
11	Confirm that all soft links are double looped and tug to confirm.			
12	Put on safety goggles and clear area of all non-assembly, recovery, and checklist people	Safety Officer Sign-off		
13	Install the eagle assembly. Remove the aluminum closure, insert the eagle into the top of the bulkhead and install 4 #8-32 bolts			
14	Screw on the aluminum closure and then the 23g CO_2 cartridge			
15	Install 6g BP charge into the charge well and secure with electrical tape			
16	Feed ematches through the bulkhead and seal with well nut			
17	Easymini – Connect the ematch to the **APO** terminals			
18	Raven – Connect one end of the ematch into the **APO** terminal of the altimeter and the other end into one of the screw terminals. The end on the screw terminal shall make at least a 180 deg hook and bent clockwise 			
19	Install the drogue unloader assembly. Connect the double looped Kevlar line to the lower eyebolt with the 5/16" quick link.			
20	Feed both e-matches through the bulkhead and seal with well nut.			
21	Easymini – Connect the ematch into the **MAIN** (+) and (-) terminal			
22	Raven – Connect one end of the ematch into the **MAIN** terminal of the altimeter and the other end into one of the screw terminals. The end on the screw terminal shall make at least a 180 deg hook and bent clockwise			



Primary: Easy Mini   Secondary: Raven

23	Secure all e-match wires with zipties.			
24	Tug on all e-match wires to confirm that terminals are properly tightened down Close out photo			
25	Check again that all e-matches are connected to the correct terminals and confirm continuity of all e-matches Take close out photo			
26	Plug in BigRedBee APRS battery. Confirm GPS lock from the ground station team.			
27	Install the recovery bay into the coupling with clocking feature aligned. Install 4 #8-32 bolts into the coupling and tighten.			
28	Loop the main bag, drogue unloader and main line throughmiddle airframe (from the top - down). Followed by the rest of the harnessing.			
29	Connect drogue unloader quick link to the TD retention link. Torque QL			

30	Connect Main parachute bag and main line to the lower eye bolt. There should be 3 loops on the lower QL now. Take close out photo			
Hand over to Structures team to assemble FWD coupling joint				
Acquire Payload Coupler tube +upper airframe from the Payload recovery team				
31	Connect forward 5/16” quick link to upper eye bolt. Torque quick link. Take close out photo.			
32	Insert coupler tube into the middle airframe and align diamond clocking feature			
33	Install 4 #2-56 nylon shear pins through the middle airframe and coupler tube. Take close out photo			



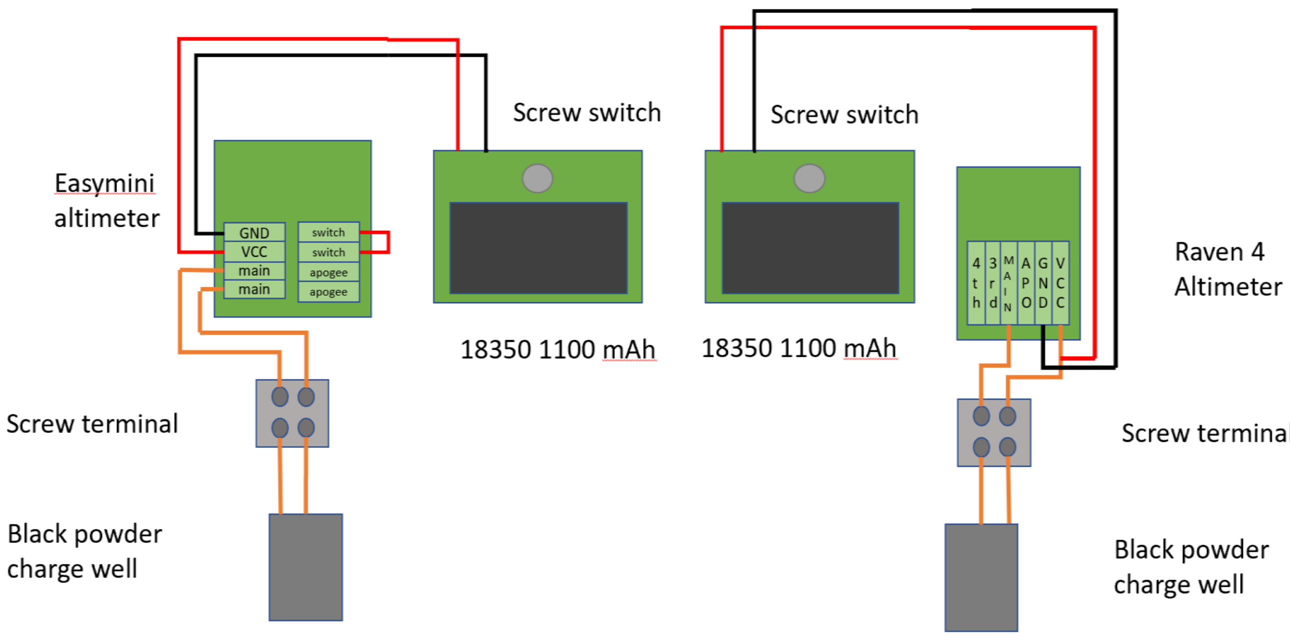
Notes/Variances

2023 IREC Launch Assembly Checklist

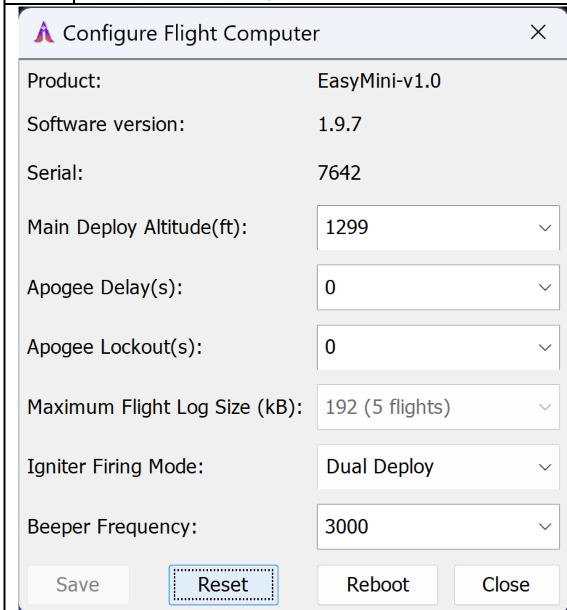
d) **Payload Recovery Bay/Piston Assembly**

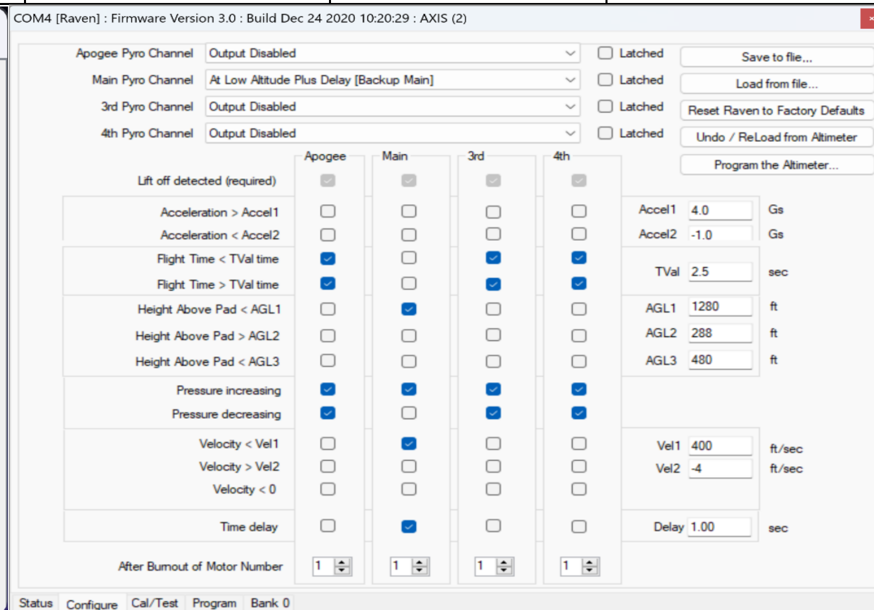
Assembler: Daniel Willins

#	Instructions	Primary Keelan B.	Secondary Henry L.	Division Lead Jake R.
1	Ensure that each (x2) 18350 battery is fully charged using a multimeter. The voltage should be 4.0 – 4.2V.			
2	Ensure that the pull tape is attached to the battery. Install the batteries onto both sides of the electronics sled. Ensure that the polarity is correct. Ensure that pullout tab does not block the screw switch. Secure the batteries with zip ties  			

3	Ensure correct wiring and pull test all wires entering the altimeters and the battery boards			
				
4	Turn on the switch for the Raven4 (Secondary) altimeter. Verify these Beeps: 1. Battery Voltage, round down to nearest volt (4V) 2. 1 low beep every 2 seconds (no charges or not vertical or voltage <3.85V) ** Turn off when done			
5	turn on the switch for the EasyMini (Primary) altimeter. Verify these beeps: 1. Battery Voltage (~4–4.2V) 2. brap (no continuity on both charges) brap = long dissonant tone ** Turn off when done			

6	Open Easy mini settings in Altus Metrum App. Verify programming. Power cycle and re-verify the programming. Verify that switch terminals are connected. Take close out photo.			





7	Open Raven 4 settings in Featherweight App. Verify programming. Power cycle and re-verify the programming. Calibrate the Raven. Take close out photo.			
8	Turn off the Raven and EasyMini screw switches and verify no beeps			
9	Put on safety goggles and clear area of all non-assembly, recovery, and checklist people	Safety officer sign-off		
10	Verify that primary charge is 5g and secondary charge is 6g			
11	Verify continuity of charge and ensure that it is tightly packed. Put 5g black powder charges into primary charge well. Secure tightly with electrical tape.			
12	Verify continuity of charge and ensure that it is tightly packed. Put 6g black powder charges into secondary charge well. Secure tightly with electrical tape.			
13	Connect Primary charge to Primary terminal			
14	Connect secondary charge to Secondary terminal			
15	Tug on all e-match wires to confirm that terminals are properly tightened down **Close out photo**			

16	Use a multimeter to confirm continuity of all e-matches and **take close out photo**			
17	After camera is installed: Insert recovery bay into coupling and secure with screws **Close out photo**			

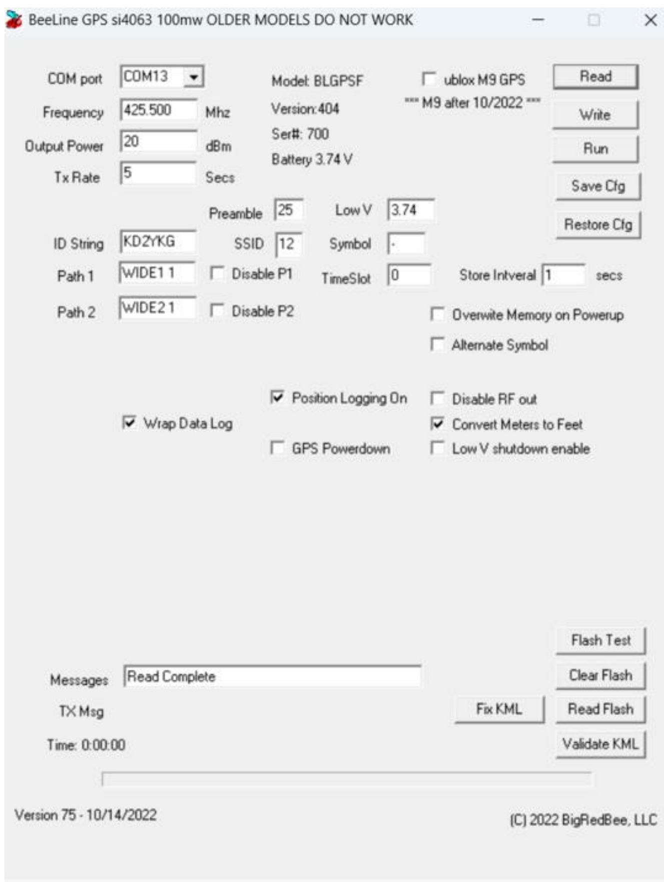
Notes/Variances

2023 IREC Launch Assembly Checklist

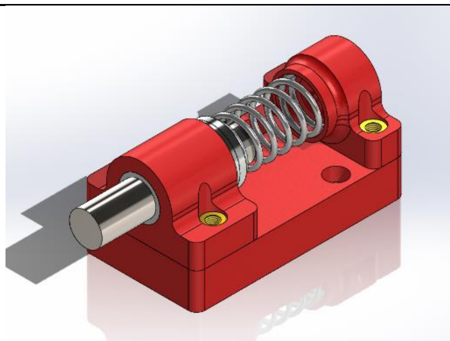
e) **Payload Adapter Assembly**

Assembler: Lyle Edwards

#	Instructions	Primary Keelan B.	Secondary Henry L.	Division Lead Jake R.
1	Ensure BRB is charged and battery reads voltage > 4.0 V. Check with multimeter.			
2	Verify programming on BRB			



#	Instructions	Primary Keelan B.	Secondary Henry L.	Division Lead Jake R.
3	Check with Ground Station that the BRB is transmitting.			
4	Ensure that each paracord enters the winch in the green hole and exits through the black hole.			
5	Ensure the pin assemblies are assembled properly. Make sure the springs are flat in the backing and on the washers, wrapped around the bolt.			X

				
6	Ensure that the paracord on the screws is attached to the pins with safety wire correctly.			
7				
8				
9	Check that the knots are done correctly (4 square knots over each other)			
10	Ensure that the paracord is taught. Cut off excess paracord.			
11	Check all screws are torqued. 1. Top of the servo hub (x1) Hold on to the servo hub when torquing this screw. 2. Pin Assembly screws (x6) 3. Big Red Bee Backing screws (x3) 4. Big Red Bee screws (x2) Eye-Bolt / nut (x1)			
Wait until the payload is weighed in by the judges.				
12	Connect servo to quadcopter power.			
13	Place Adapter onto Structure, the Eye-Bolt should be on the same side as the Quadcopter's GPS. Attach structure to bulkhead, one washer between each screw-head and bulkhead. The screws are 8-32 Socket Heads, 0.375" Take a closeout photo.			
14	Run the servo program to retract the pins and insert assembly into nosecone, bolt down.			

15	Extend pins once inserted.			
16	Torque the coupling bolts. Take a picture once it is bolted into the coupling. Including pictures of each of the four bolts.			

Notes/Variances

2023 IREC Launch Assembly Checklist

f) **Ground Station**

Assembler: Max Friedman

#	Instructions	Primary Dan P.	Secondary Abby H.	Division Lead Michael B.
1	Setup foldable table for ground station.			X
2	Pull out RX antenna and inspect for physical damage to structure.			X
3	Inspect solder joints at top and bottom and perform a tug test on the coax cable.			X
4	Open tripod, extend to highest setting, and secure antenna properly to the top of the pole.			X
5	Plug ground station laptop into power bank and power on.			X
6	Plug Polaris/receiver into ground station laptop.			X
7	Connect receive computer to RX antenna and check for solid connection.			X
8	Open ground station back-end software by running “java -jar gs-backend.jar” and select the correct COM port for the receive computer.			X
9	Check if csv file is created in same directory as jar file.			X
10	Check for back-end connection and verify all graphs and dials are functioning.			
11	Confirm good telemetry signal from rocket with Avionics Bay team.			

Notes/Variances

2023 IREC Launch Assembly Checklist

g) **Quadcopter Assembly**

Assembler: Nikhil Gangaram

#	**Instructions**	Primary Cameron Best	Secondary Dylan Dysilva	Division Lead Jake R.
1	Inspect the quad's springs and screws			
2	Check Battery Voltage 1. 2. 3. 4. 5. 6. All cells should be between 4.15V - 4.25V			
3	Verify that TX sticks and switches are in their start positions (sticks up, sliders down, buttons depressed)			
4	Power on the ELRS TX			
5	Power on both goggles and start recording			
6	Power on the quad			
7	Verify the FPV signal and these messages: 1. "REC" text in the top right 2. Look for any abnormal bootup messages			
8	Verify the quad's control link using RSSI on OSD			
9	Hold the quad still for GPS lock until 8 sats have been locked onto and home has stopped flashing.			
10	Verify the artificial horizon			
11	Wait for the quad to fully initialize (a home icon will be displayed on the OSD).			
12	Switch the quad to PosHold. Arm the quad briefly to verify all propellers are spinning and quad arms successfully, then disarm.			
13	Fold the quad and place the strap around the arms			
14	Verify that the landing gear legs are in their slots and that the jig has been mounted onto the legs			
15	Hand off to Payload Retention and ensure that the quad has been securely mounted with the rest of the retention assembly			
16	Verify that the umbilical has proper connection between the quad and retention assembly 1. Verify that the quad's battery is increasing/ not decreasing 2. Verify signal from all 3 cameras Verify that we have control over the retention assembly's servos			

17	Double check that all prior checks are valid: 1. FPV signal 2. SATS Battery Voltage:			
18	Start the Lua Script and ensure that the proper messages are being displayed			
19	Hand off the assembly to Rocket			
Hand over the assembly for final assembly				

Notes/Variances

2023 Launch Assembly Checklist

h) **Mission Systems Assembly**

Assembler: Dylan Dsilva

#	Instructions	Primary Newton L.	Secondary Cameron B.	Division Lead Jake R.
1	Charged the 290 mAh Lipo to 4.2 V			
2	Zip tied the 290 mAh Lipo to the labeled side of the cube with 2 zip ties			
3	Made sure that two cube boards are on the cube stack			
4	Made sure that there are three o rings between the two boards in the cube stack			
5	Boards are bolted down onto the cube using a 4-40 3/8” socket head bolt			
6	Power board connected with battery			
7	Verify that the cube boards are transmitting data (humidity, pressure, temperature) and that the limit switch is capable of turning cubes on and off			
8	Cubes are enclosed with no gaps			
9	Made sure that the cubes are loaded into the tower correctly according to instruction sheet (Instructions for Loading Cubes into Tower.docx)			
10	Verify that all the servo horns are operating and spinning correctly			
11	Tower bolted down to the quad with 4 M3 10mm screws			
12	All wires on cube retention tower are zip tied down			
13	BEC Connector is plugged in to the quad			

Notes/Variances

2023 IREC Launch Assembly Checklist

i) **Payload Retention Assembly**

Assembler: Hunter Crossman

#	Instructions	Primary Newton L.	Secondary Francisco D.	Division Lead Jake R.
1	Visually inspect all preassembled systems for damage or loose fasteners			
2	Check battery pack voltage using a multimeter - Each cell >4.0V - Total pack voltage >32V			
3	Connect battery leads to BMS			
4	With the arm locking assembly deployed, locate the standoffs on the top of the quadcopter with their respective holes on the quad locking assembly. Insert the quadcopter until the screw is touching the REX shaft and actuate the locking servo to secure the quadcopter.			
5	Verify that the umbilical is making proper connection between the quadcopter and retention system using the cameras and switching the FPV feeds			
6	Return the arm locking assembly to its stowed position by pushing them, then push down the inverter/solenoid by hand, locking the quadcopter arms in placed			
7	Install remaining panels			
Payload is now ready for weigh-in with judges				

Notes/Variances

2023 IREC Launch Assembly Checklist

j) **Payload Final Assembly**

Assembler: Lyle Edwards

#	Instructions	Primary Cameron B.	Secondary Hunter C.	Division Lead Jake R.
1	Inspect piston and make sure all screws are torqued down			
2	Fold parachute and place into parachute holder			
4	Attach shock chord to parachute and place shock chord into holder, leaving enough loose to attach to eye bolt.			
5	Integrate quad with piston by aligning quad arms with piston standoffs.			
6	Attach remailing loose shock chord to payload adapter eye bolt with a soft link. (Insert photo of how to use soft link here) Take close out photo			
7	Tape over holder with blue tape, leaving a gap near the edge to let lose shock chord through.			
8	Pull shock chord taut and use blue tape to secure it to the side of the retention assembly. If the shock chord is too long, make figure 8's and tape that to the side of retention structure. (INSERT PHOTO HERE)			
9	Holding the piston and payload together, horizontally slide the assembly into the upper airframe from the top until the nosecone is flush with the upper airframe. Make sure axes are aligned.			
10	Reach into the airframe and attach piston shock chord to the eye nut of the piston with a soft link. Take close out photo.			
11	Attach the other side of shock chord to payload recovery bay eye bolt with a soft link. Take close out photo.			
12	Pull all three soft links and ensure they are installed correctly.			

13	Insert payload recovery bay into the upper airframe from the bottom, and screw into place.			

Notes/Variances

2023 IREC Launch Assembly Checklist

k) **Final Vehicle Assembly**

Assemblers: Niko Gerakaris, Kelli Huang

#	Instructions	Primary Tobias E.	Secondary Cameron M.	Division Lead Terence T.
1	Connect airbrakes servo wires to avionics boards. Install red servo wire clip.			X
2	Connect the lower airframe and ebay together via coupling joint. Torque rating:			
3	Clear all non- safety, non-checklist, non-assembly members from the assembly area and put on googles	Safety Officer Checkoff:		
3	Connect the ebay and middle airframe together via coupling joint. Torque rating:			
4	Insert Upper airframe into the payload coupler tube. Install 4 #8-32 bolts through the airframes and into the payload recovery coupling			X
5	Install motor into Aeropack retainer			X
6	Tighten Aeropack retainer with white 3D printed tool			X
7	Confirm that all switch puncture stickers are installed and covering the appropriate switch hole. 1. Rocket Primary 2. Rocket Secondary 3. Payload Primary 4. Payload Secondary 5. Avionics 6. Camera			X
8	Check continuity with motor ignitor			X
9	Final inspection + go from division leads and safety officer	Rocket Lead	Payload Lead	EnP Lead

Notes/Variances

2023 IREC Launch Ground Station Pad Checklist

#	**Instructions**	Ground Station Lead
1	After receiving confirmation that the rocket is armed from the pad team: check each graph, dial, and interface on front-end for proper data.	
2	As data flows, check for change in CSV file size.	
3	Check for data from both BigRedBee APRS transmitters and confirm signal and frequency over handheld radio.	

Notes/Variances

2023 IREC Launch Pad Checklist

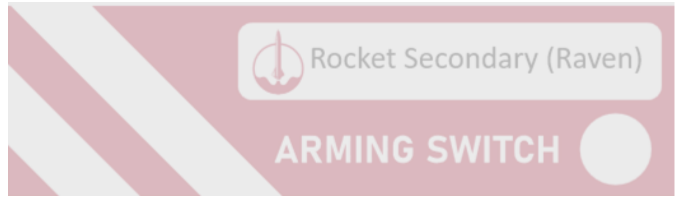
#	Instructions	Division Lead
1	The launch vehicle should be installed on the rail and vertical before beginning this checklist.	
2	All vent holes and airframes should be inspected for damage	
3	Record anemometer, launch angle, air temp.	
4	Activate the avionics system via the screw switch on the avionics bay. Verify these beeps: 1. Startup beeps on power up 2. After a pause, “Crazy Frog” plays to indicate entering main loop	
5	The pad team should confirm with the ground station team that telemetry is being received from the GPS tracker and avionics board.	
6	Turn on cameras via screw switch on the bottom of the upper airframe	
At this point only the rocket division lead and 1 other person shall be next to the pad. Everyone else should step away.		
7	ROCKET: Turn on the switch for the EasyMini (Primary) altimeter. Verify these beeps: 1. Battery Voltage (4.0-4.2V) 2. Dit dit dit (continuity on both charges)	
8	ROCKET: Turn on the switch for the Raven (Secondary) altimeter. Verify these Beeps: 1. Battery Voltage (4V) 2. High high low low (continuity on both charges)	
9	Payload: Turn on the switch for the EasyMini (Primary) altimeter. Verify these beeps: 3. Battery Voltage (4.0-4.2V) 4. Dit dit (continuity on main)	
	Payload: Turn on the switch for the Raven (Secondary) altimeter. Verify these Beeps: 1. Battery Voltage (4V) 2. Low high low low (continuity on main)	

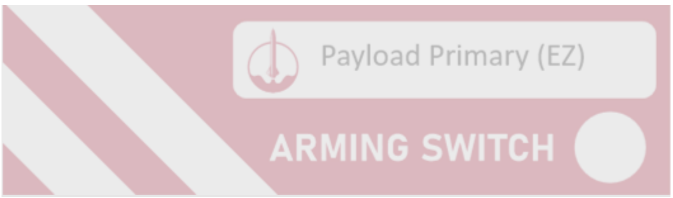
8	Confirm that all 6 switch stickers are punctured and placed on the checklist below.	
9	Verify that the launch system is inactive.	
10	Install the ignitor into the motor.	
11	Connect the ignitor to the launch system and confirm continuity.	

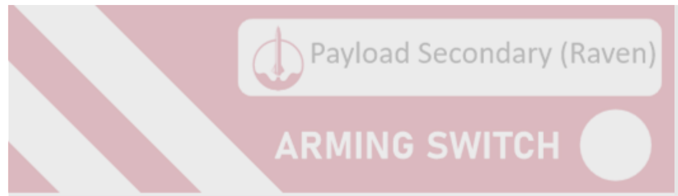
Wind Speed (mph)	
Air Temp (F)	
Launch Angle (deg)	Direction #1
	Direction #2
Time Electronics were turned on	
Time of Launch	

Notes/Variances

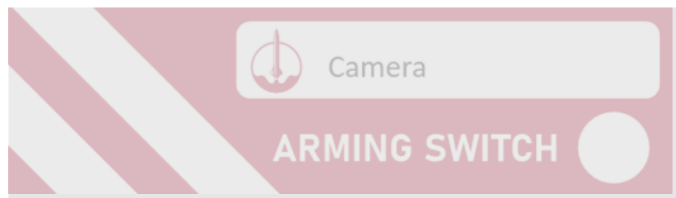

Rocket Primary (EZ)
ARMING SWITCH


Rocket Secondary (Raven)
ARMING SWITCH

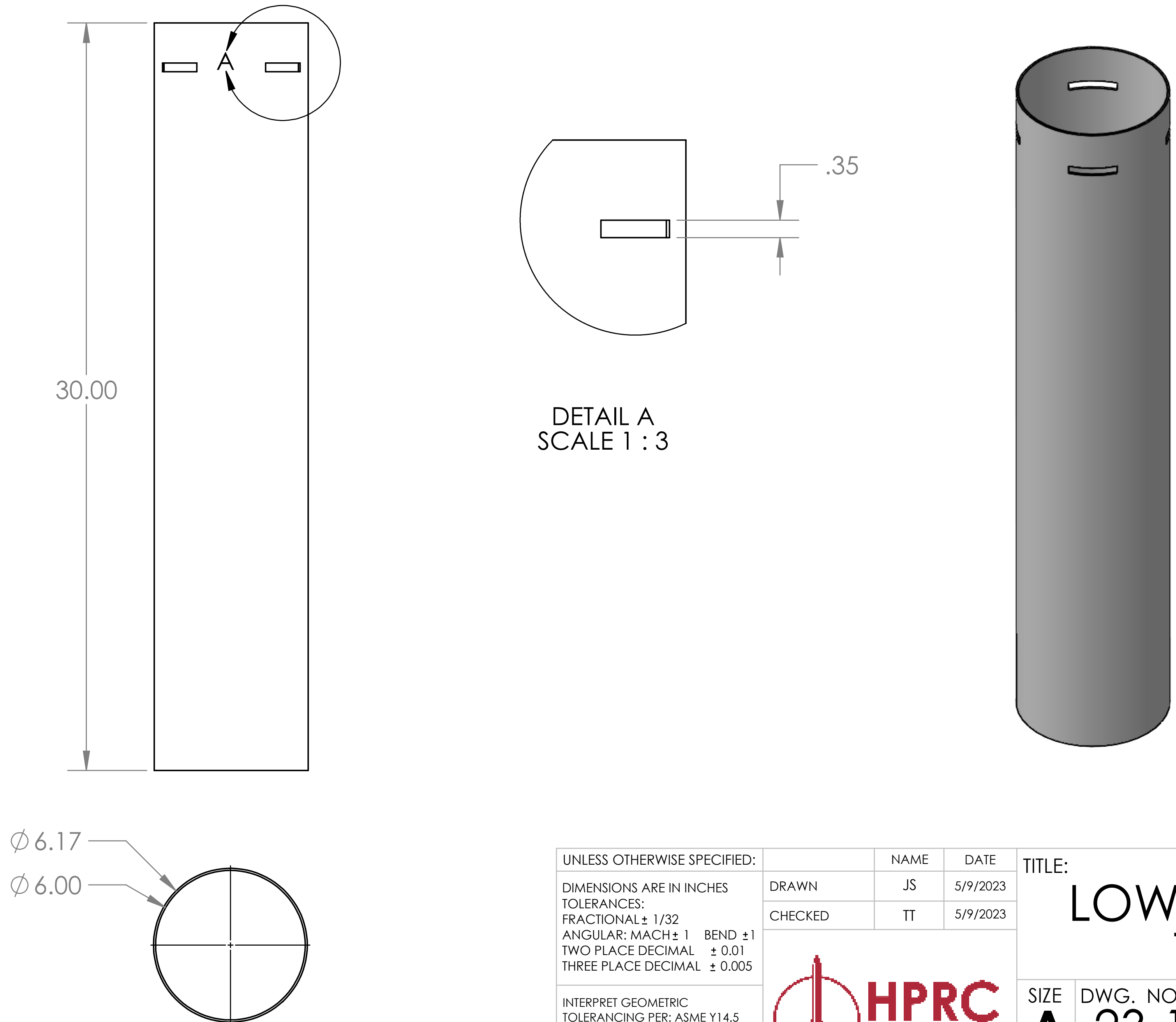

Payload Primary (EZ)
ARMING SWITCH


Payload Secondary (Raven)
ARMING SWITCH


Avionics
ARMING SWITCH


Camera
ARMING SWITCH

I. Engineering Drawings



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
G12 Fiberglass

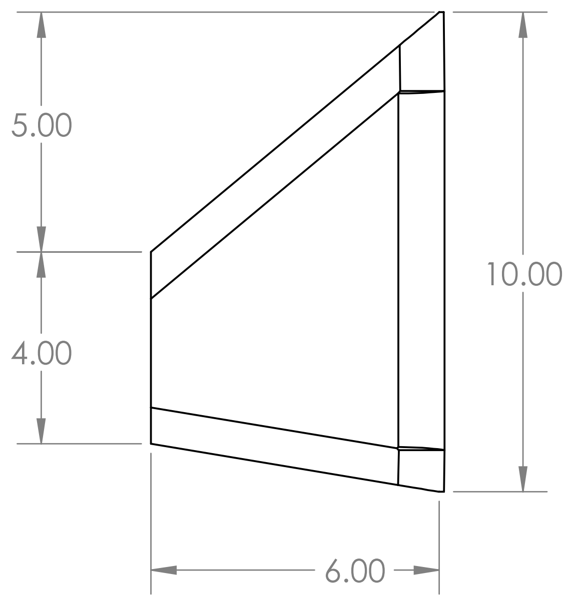
	NAME	DATE
DRAWN	JS	5/9/2023
CHECKED	TT	5/9/2023

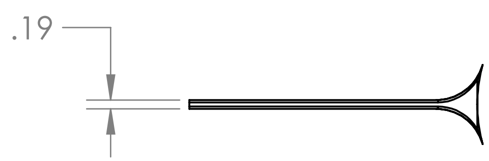
HPRC
WPI AIAA

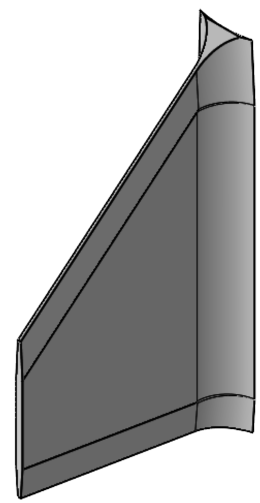
TITLE:
LOWER BODY TUBE

SIZE	DWG. NO.	REV
A	23-1-1-001	

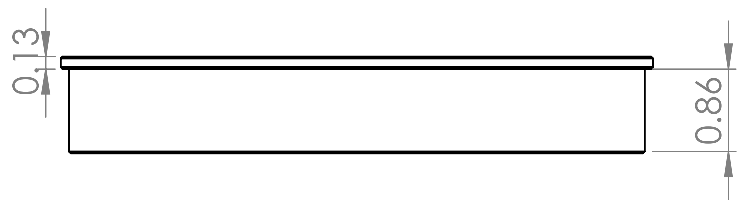
SCALE: 1:6 WEIGHT: SHEET 1 OF 1

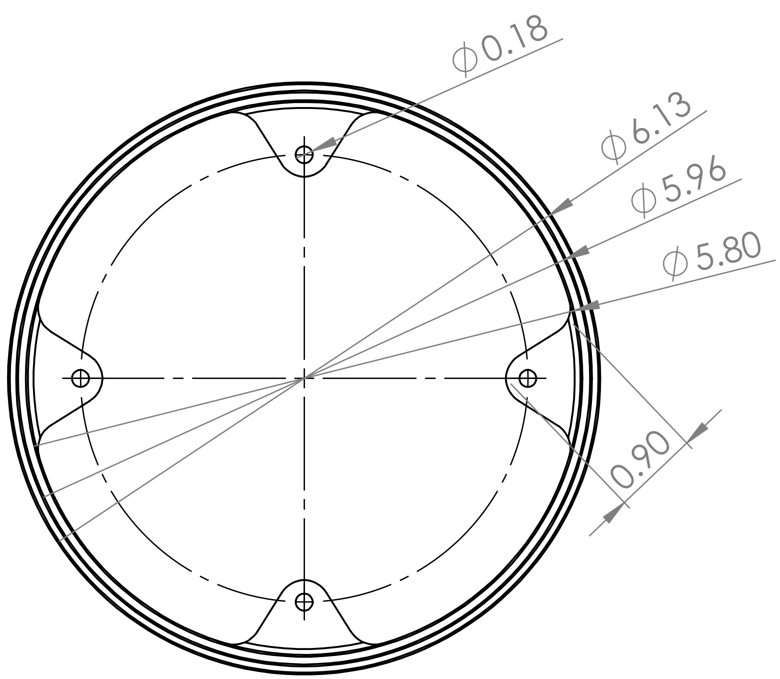


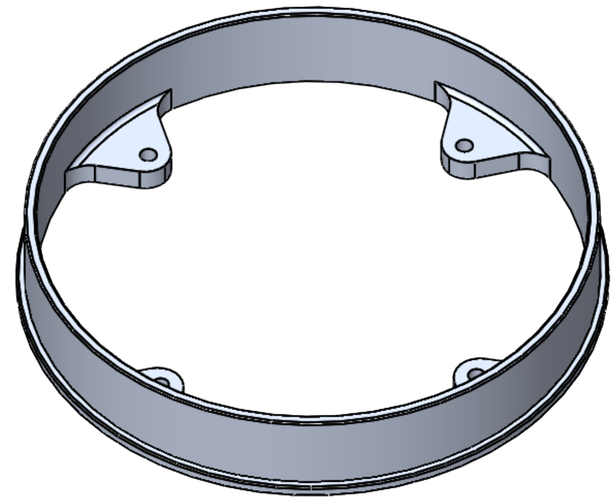




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023	FIN
	CHECKED	TT	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A DWG. NO. 23-1-1-002 REV
MATERIAL G10 Fiberglass				SCALE: 1:4 WEIGHT: SHEET 1 OF 1







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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

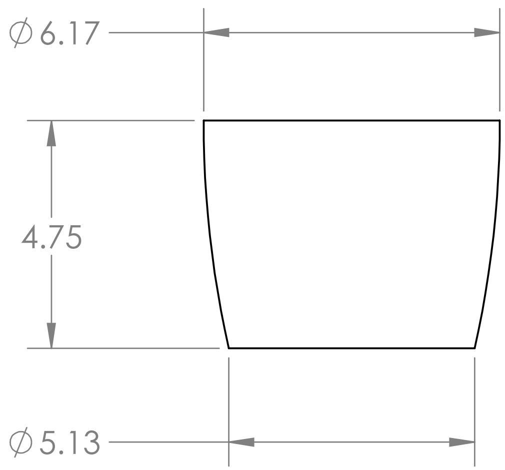
MATERIAL
Aluminum 6061 T6

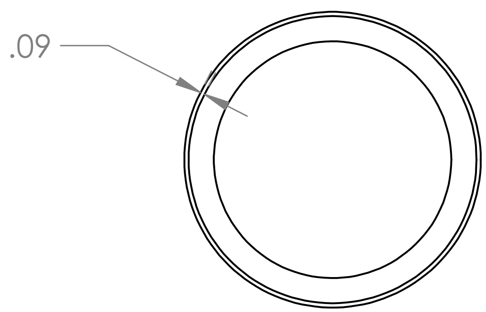
	NAME	DATE
DRAWN	NE	5/10/23
CHECKED		

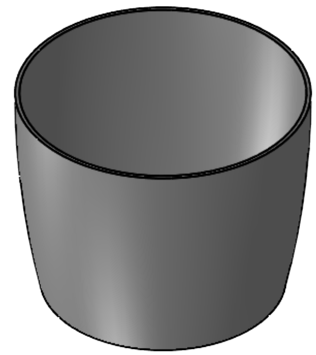
TITLE:
THRUST COUPLING

SIZE	DWG. NO.	REV
A	U23-1-1-101	

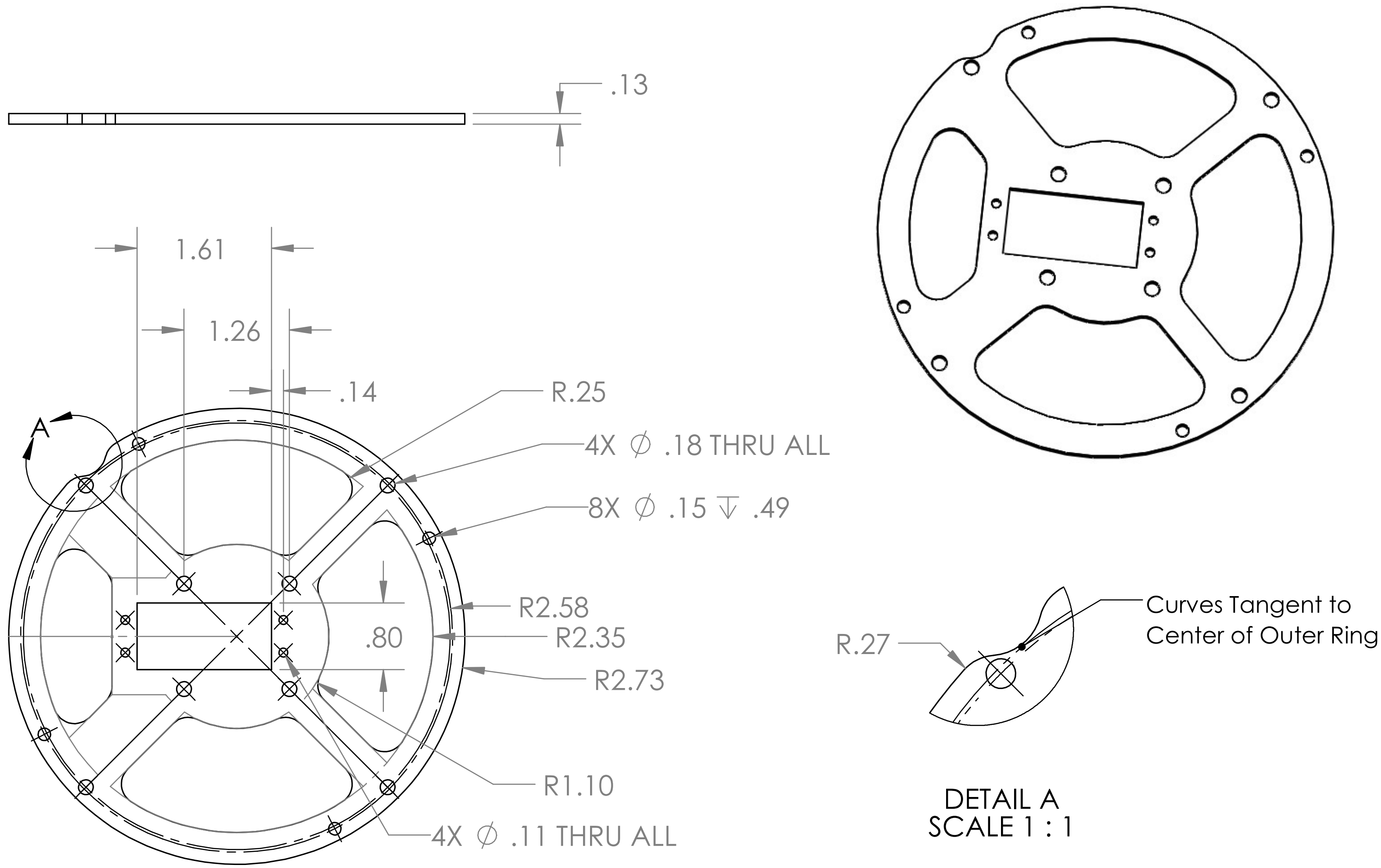
SCALE: 1:2 | WEIGHT: 0.345 lb | SHEET 1 OF 1







UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: TAILCONE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023	
	CHECKED	TT	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-1-1-103 · REV
MATERIAL S-GLASS FIBERGLASS				SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1



DETAIL A
SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 0.005
ANGULAR: MACH ± na
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL : Aluminum 6061 T6

	NAME	DATE
DRAWN	Tobias Enoch	5/10/23
CHECKED		

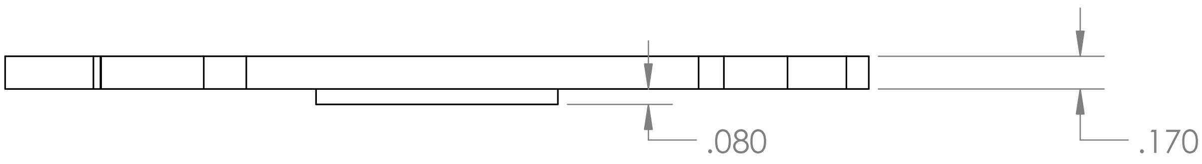
HPRC WPI AIAA

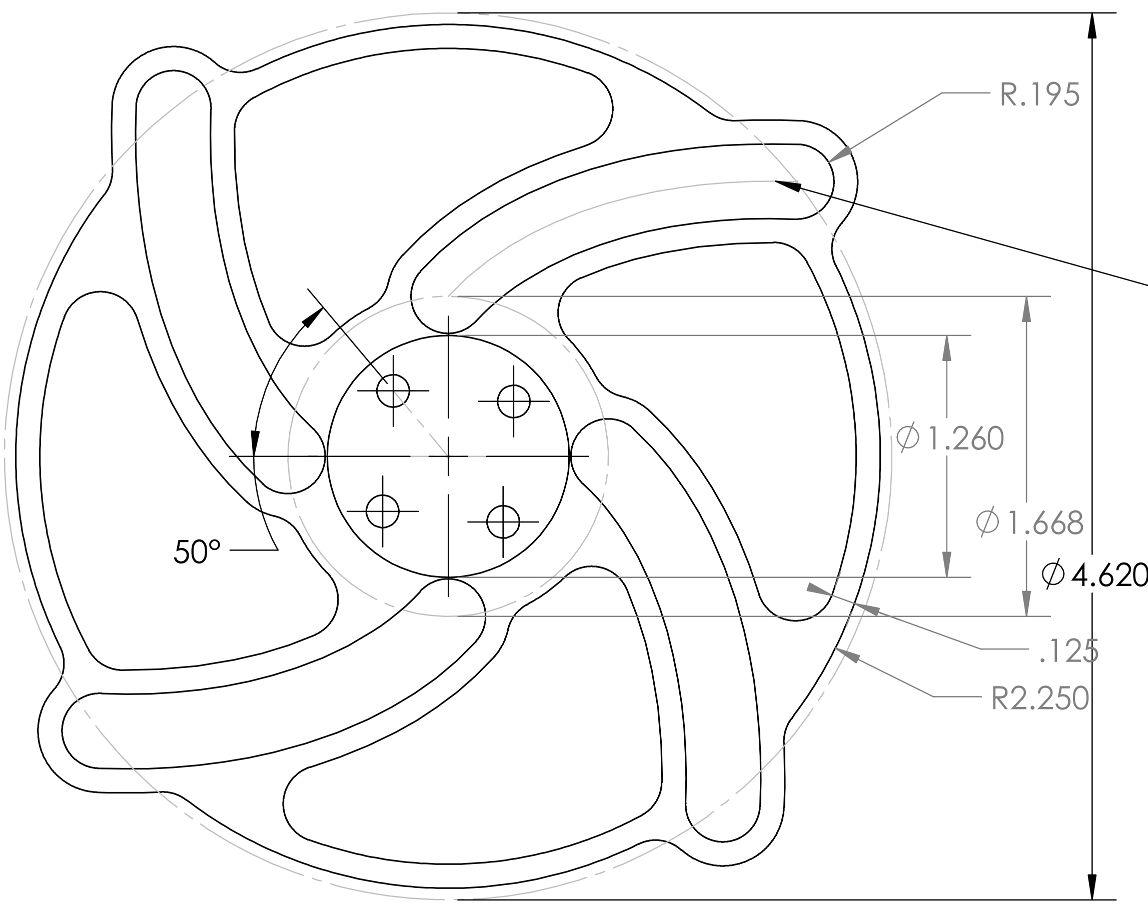
TITLE:

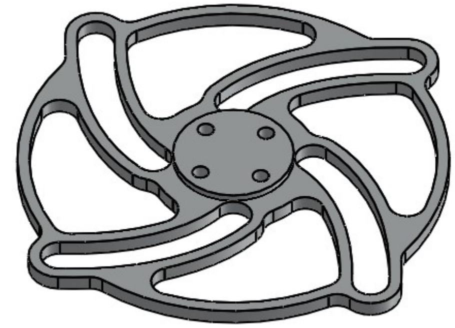
COUPLING MOUNTING PLATE

SIZE	DWG. NO.	REV
A	23-1-1-201	1

SCALE: 1:2 WEIGHT: 0.141lbs SHEET 1 OF 1







Slot is Defined By Parametric Equation
0.777*exp(1.25052*t)*cos(t)
0.777*exp(1.25052*t)*sin(t)
t0 = 0
tf = 0.87266

Slot Tolerances are +0.003 -0.000

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.005
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061 T6

	NAME	DATE
DRAWN	Tobias Enoch	5/10/2023
CHECKED		

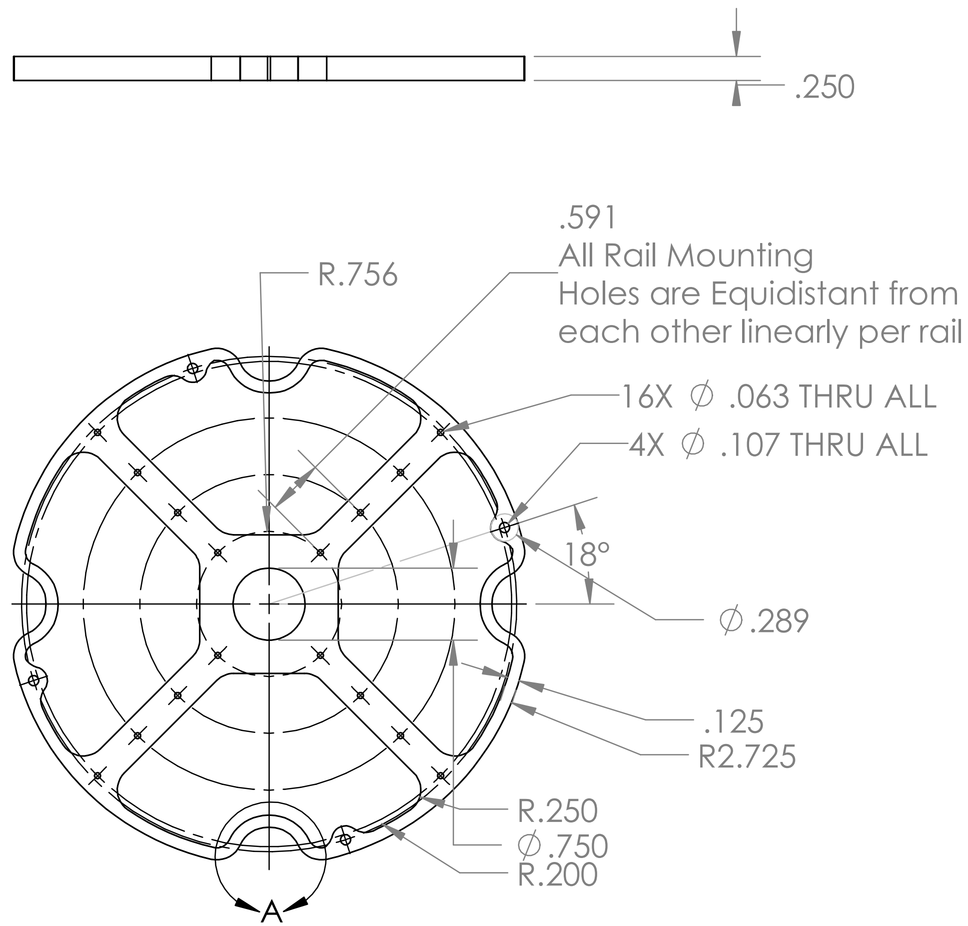
HPRC WPI AIAA

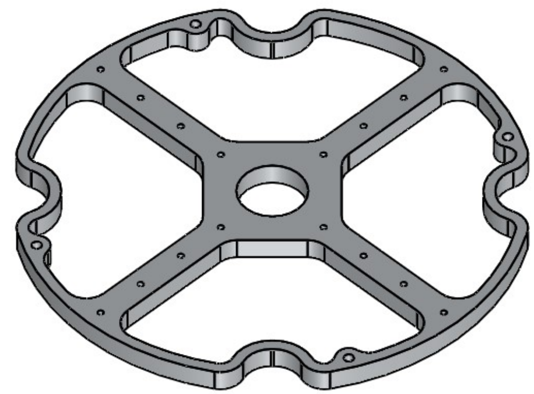
TITLE:

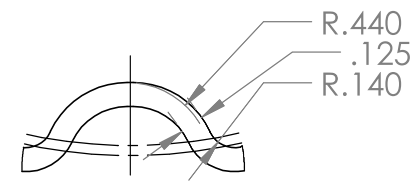
ACTUATOR PLATE

SIZE	DWG. NO.	REV
A	23-1-1-203	1

SCALE: 1:1 WEIGHT: 0.109lb SHEET 1 OF 1







DETAIL A
SCALE 1 : 1

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.005
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061 T6

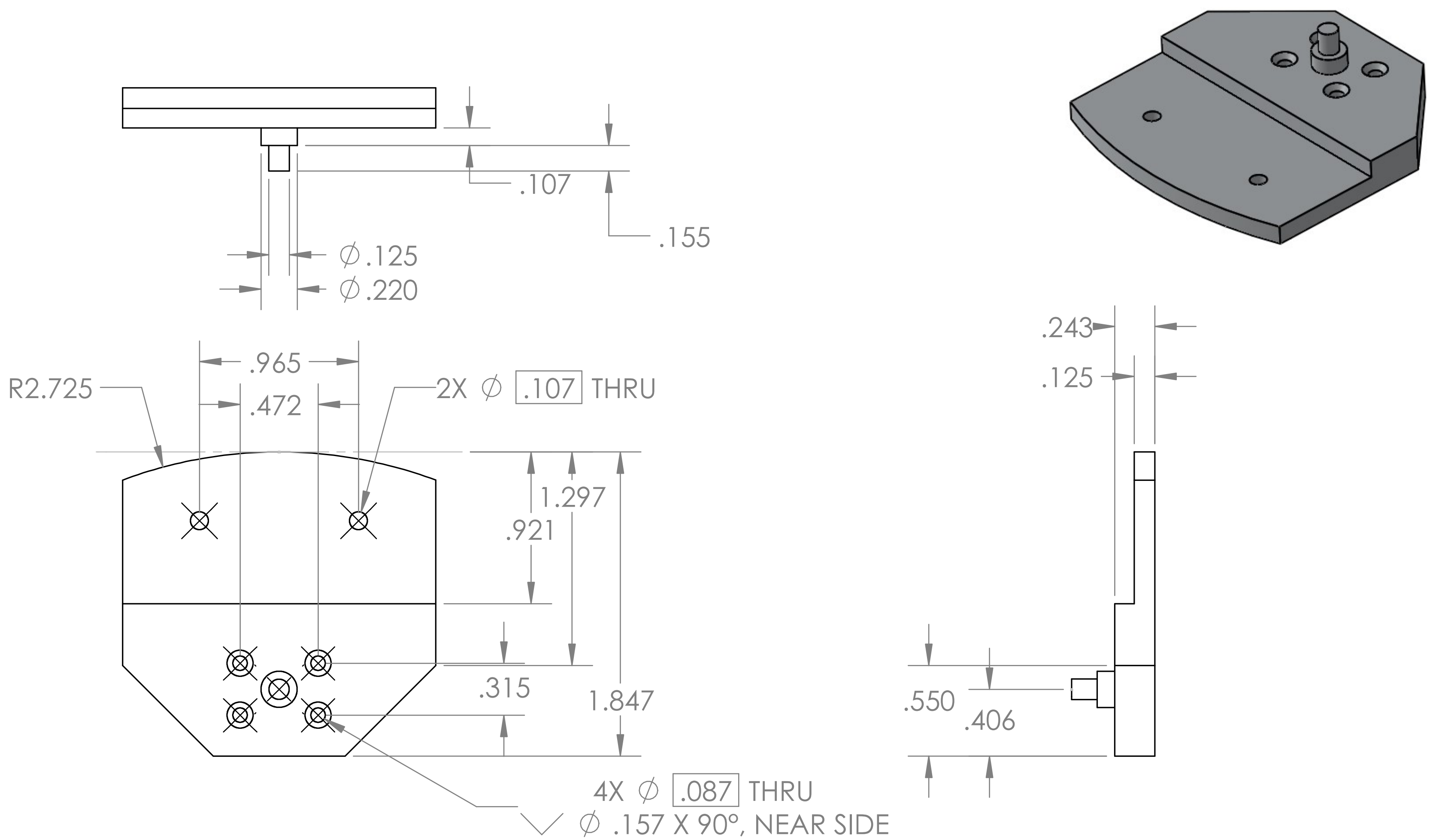
	NAME	DATE
DRAWN	Tobias Enoch	5/10/2023
CHECKED		

HPRC
WPI AIAA

TITLE:
RAIL MOUNTING PLATE

SIZE	DWG. NO.	REV
A	23-1-1-204	1

SCALE: 1:2 WEIGHT: 0.157lb SHEET 1 OF 1



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TOLERANCES:
FRACTIONAL ±0.005
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061 T6

	NAME	DATE
DRAWN	Tobias Enoch	5/10/2023
CHECKED		

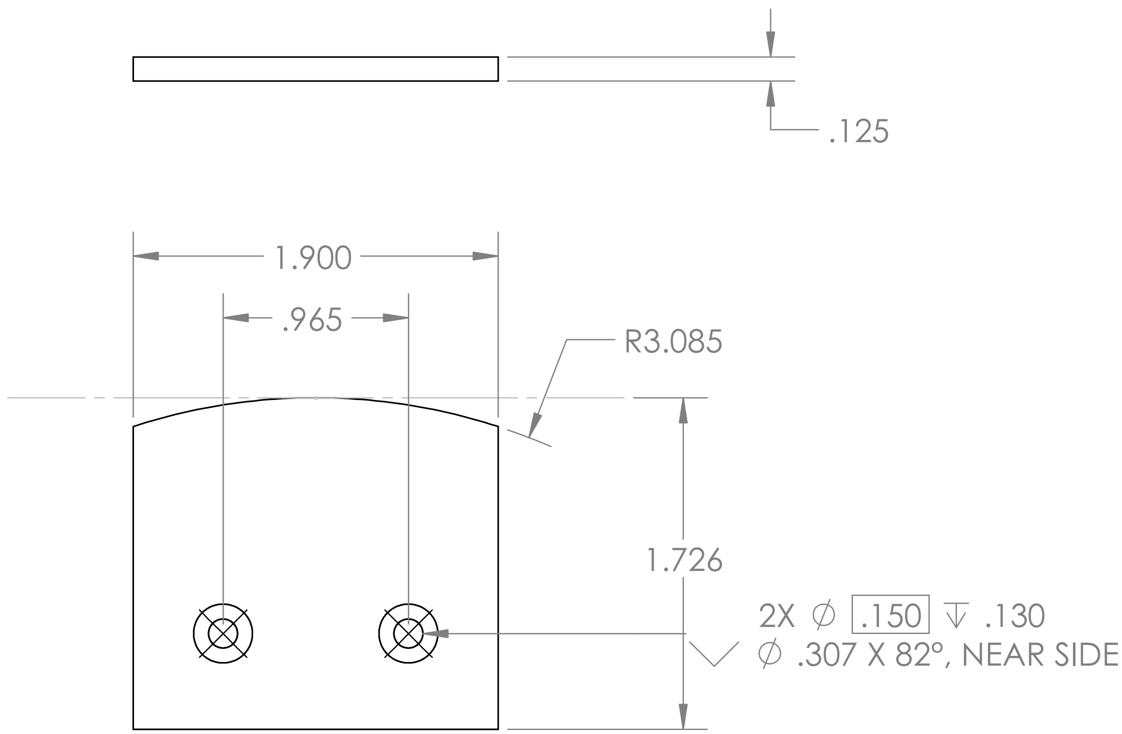
HPRC WPI AIAA

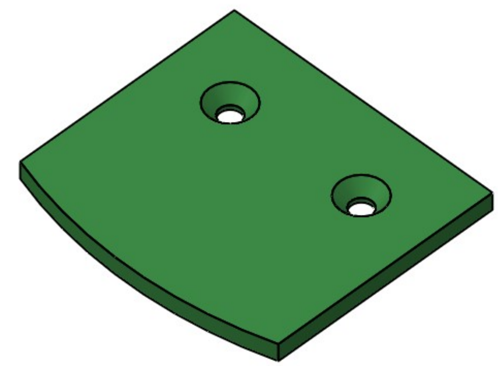
TITLE:

AIRBRAKE FIN

SIZE	DWG. NO.	REV
A	23-1-1-205	1

SCALE: 1:1 WEIGHT: 0.057lb SHEET 1 OF 1





PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.005
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061 T6

	NAME	DATE
DRAWN	Tobias Enoch	5/10/2023
CHECKED		

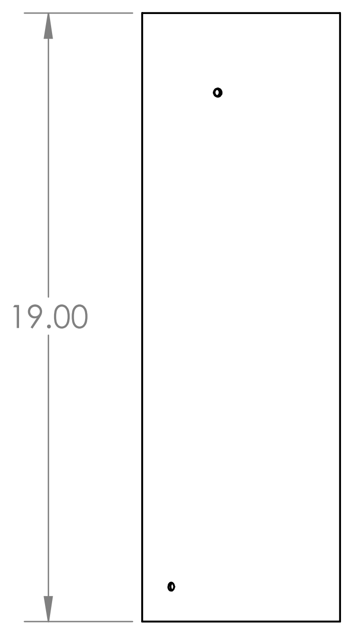
HPRC WPI AIAA

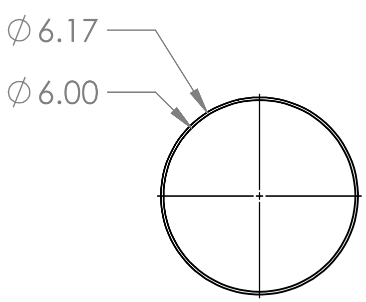
TITLE:

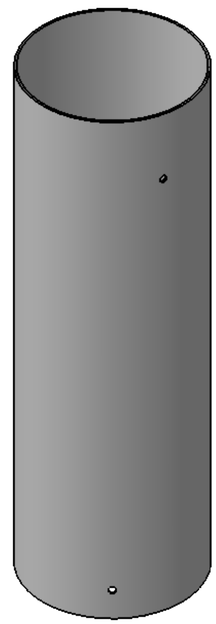
FIN EXTENSION

SIZE	DWG. NO.	REV
A	23-1-1-206	1

SCALE: 1:1 WEIGHT: 0.027lb SHEET 1 OF 1







UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023
	CHECKED	TT	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G12 Fiberglass			

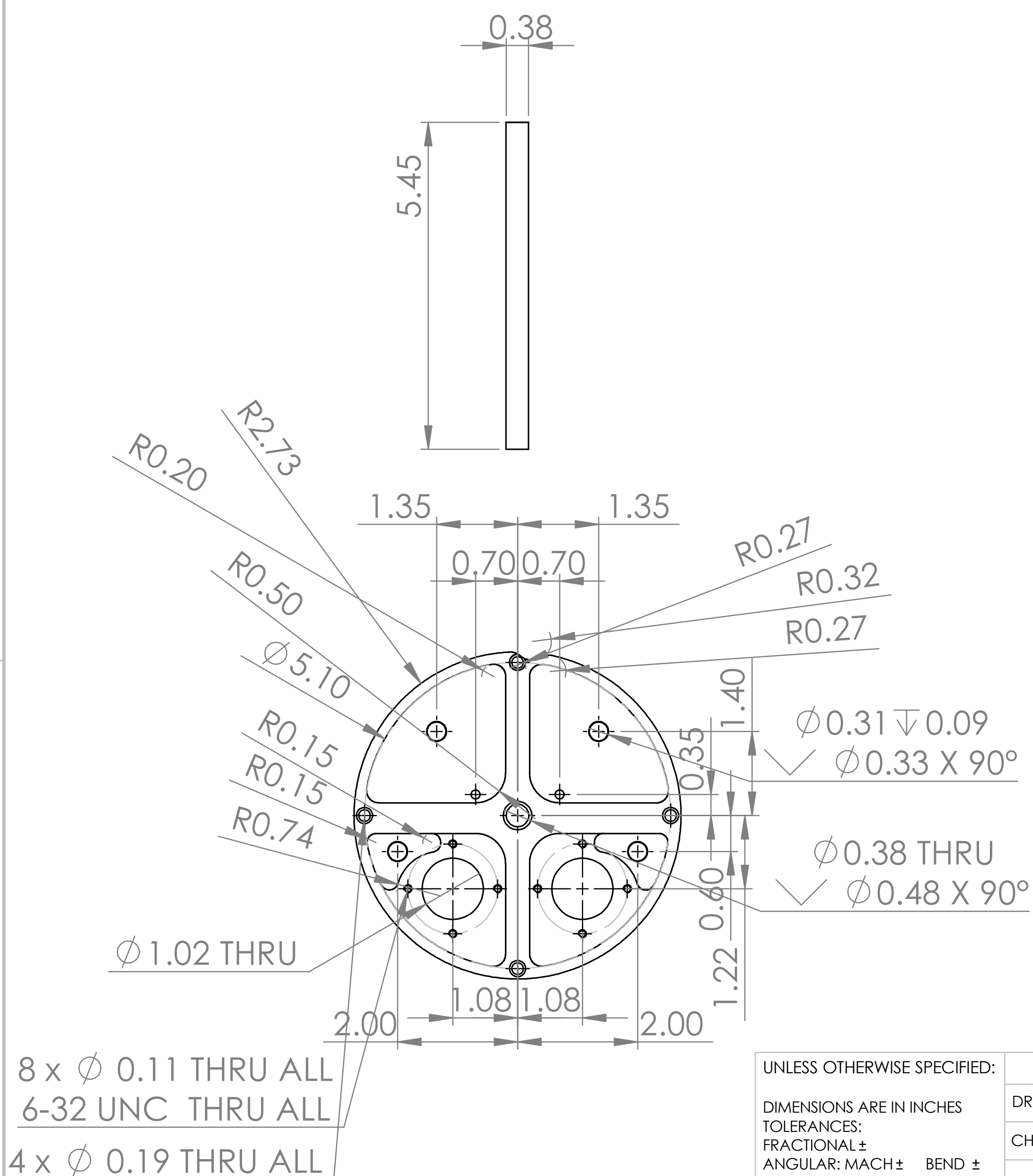
HPRC WPI AIAA

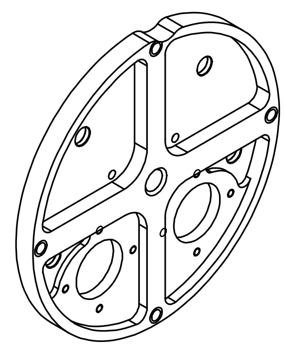
TITLE:

ELECTRONICS BAY TUBE

SIZE	DWG. NO.	REV
A	23-1-2-001	

SCALE: 1:6 WEIGHT: SHEET 1 OF 1





PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

	NAME	DATE
DRAWN		
CHECKED		

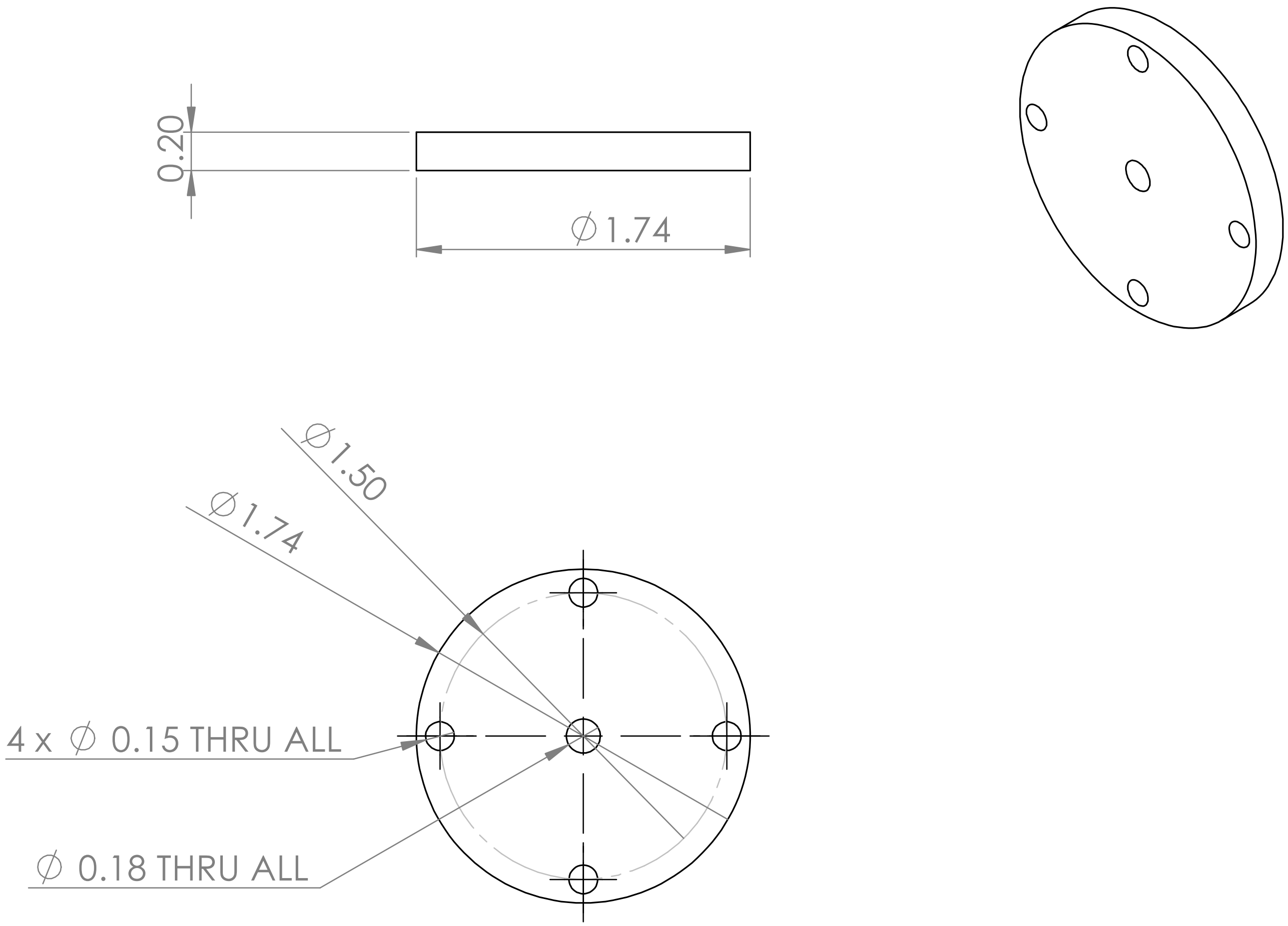
HPRC
WPI AIAA

TITLE:

23-1-2-101 (RECOVERY BAY BULKHE

SIZE	DWG. NO.	REV
A		

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

	NAME	DATE
DRAWN		
CHECKED		

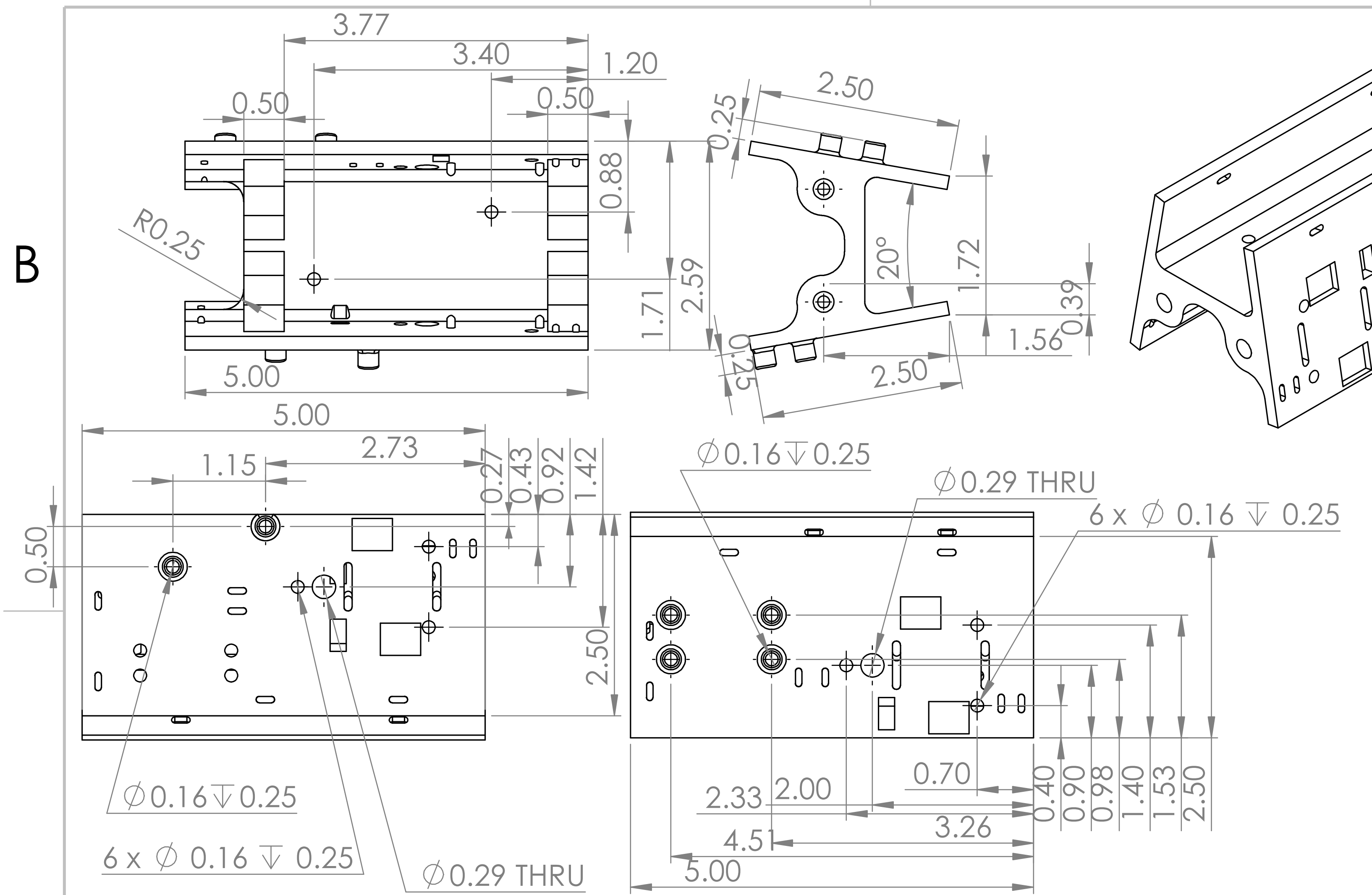
HPRC WPI AIAA

TITLE:

23-1-2-105 (CHARGE WELL PLATE)

SIZE	DWG. NO.	REV
A		

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

	NAME	DATE
DRAWN		
CHECKED		

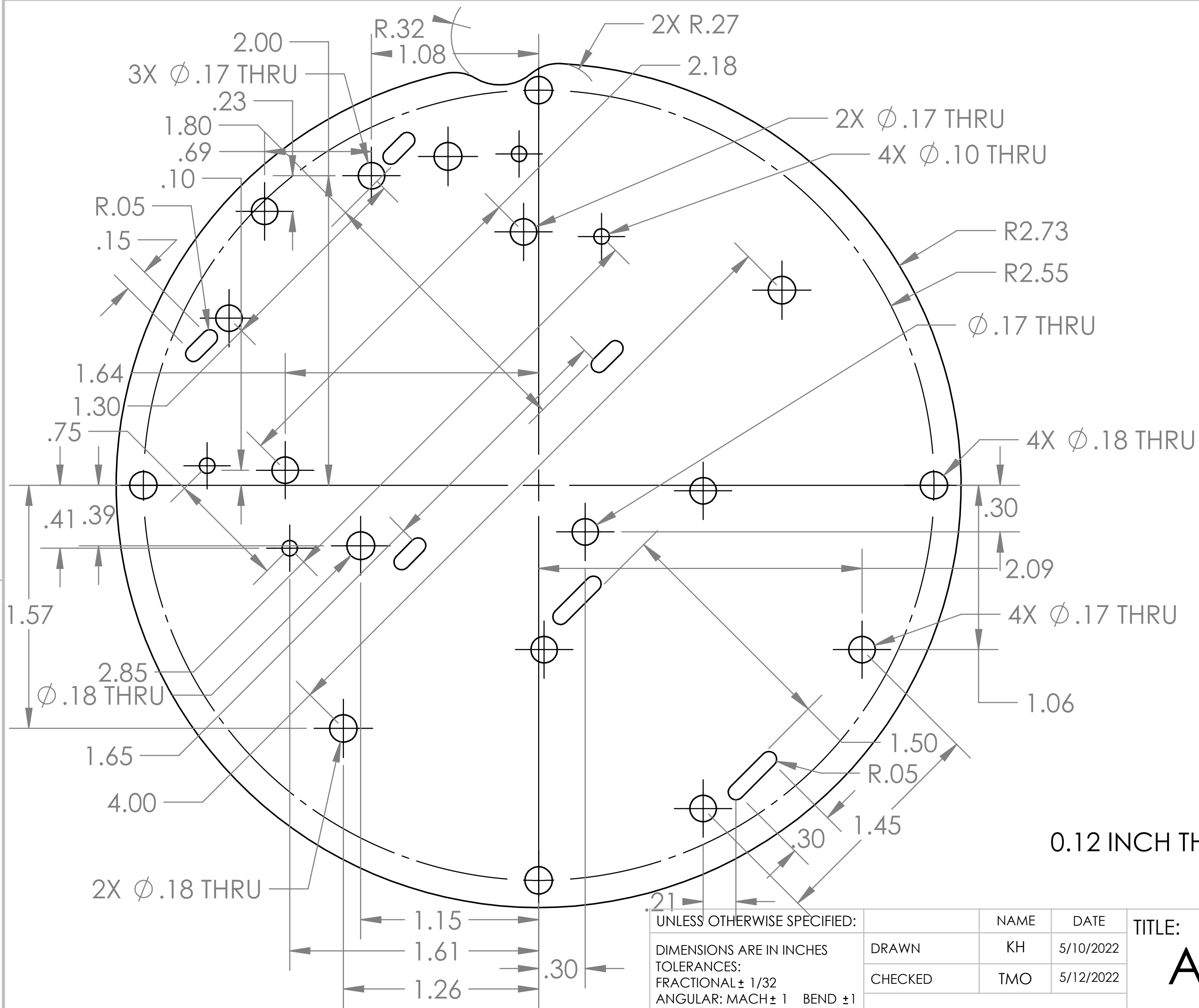
HPRC WPI AIAA

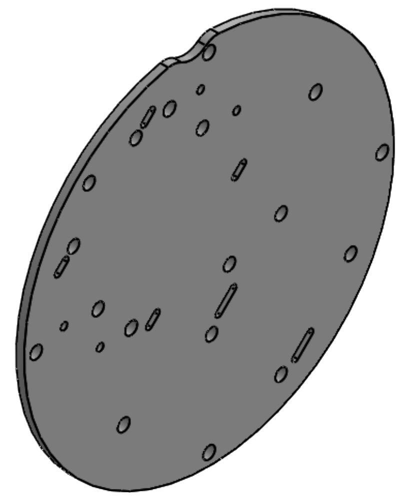
TITLE:

23-1-2-111 (RECOVERY BAY SLED)

SIZE	DWG. NO.	REV
A		

SCALE: 1:2 WEIGHT: SHEET 1 OF 1





0.12 INCH THICKNESS

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KH	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G10 FIBERGLASS			

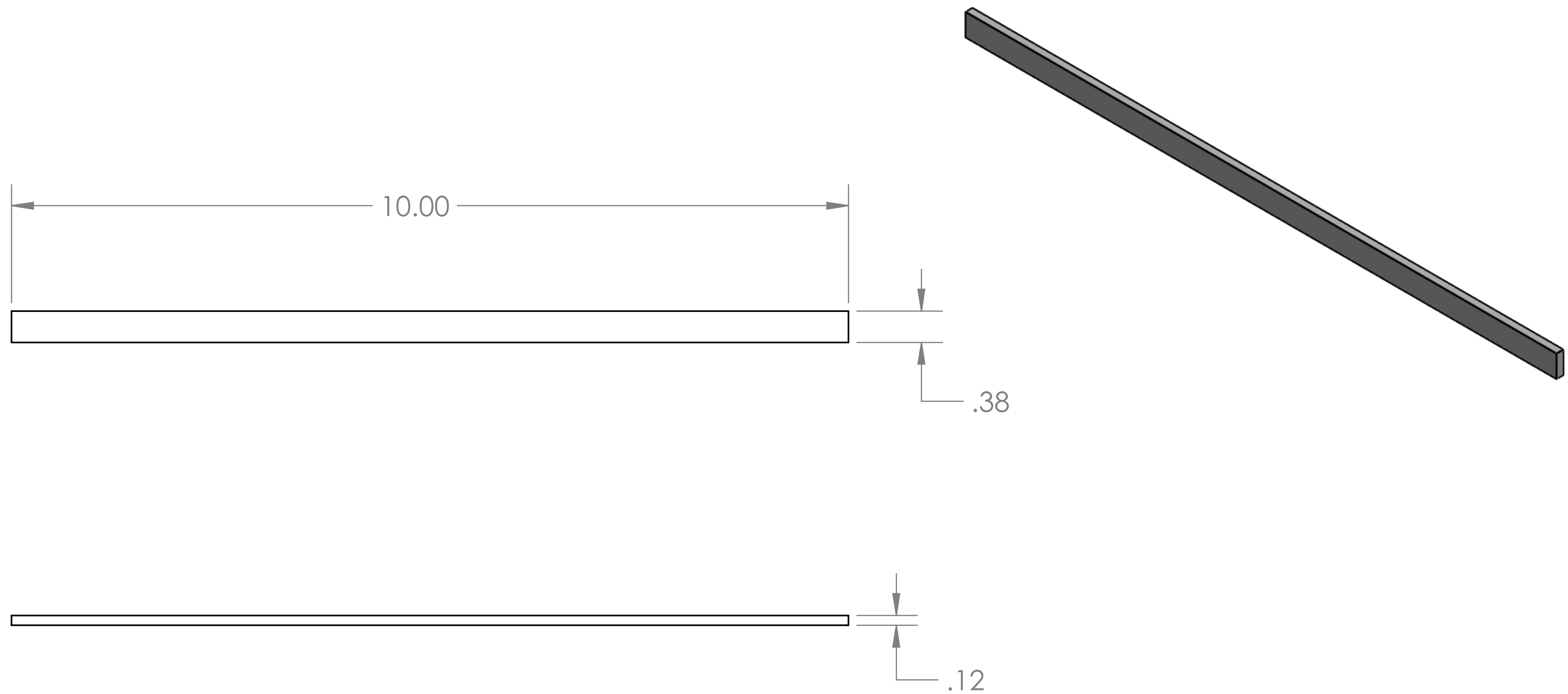
HPRC WPI AIAA

TITLE:

AVIONICS BAY BULKHEAD

SIZE	DWG. NO.	REV
A	23-1-2-201	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
G10 FIBERGLASS

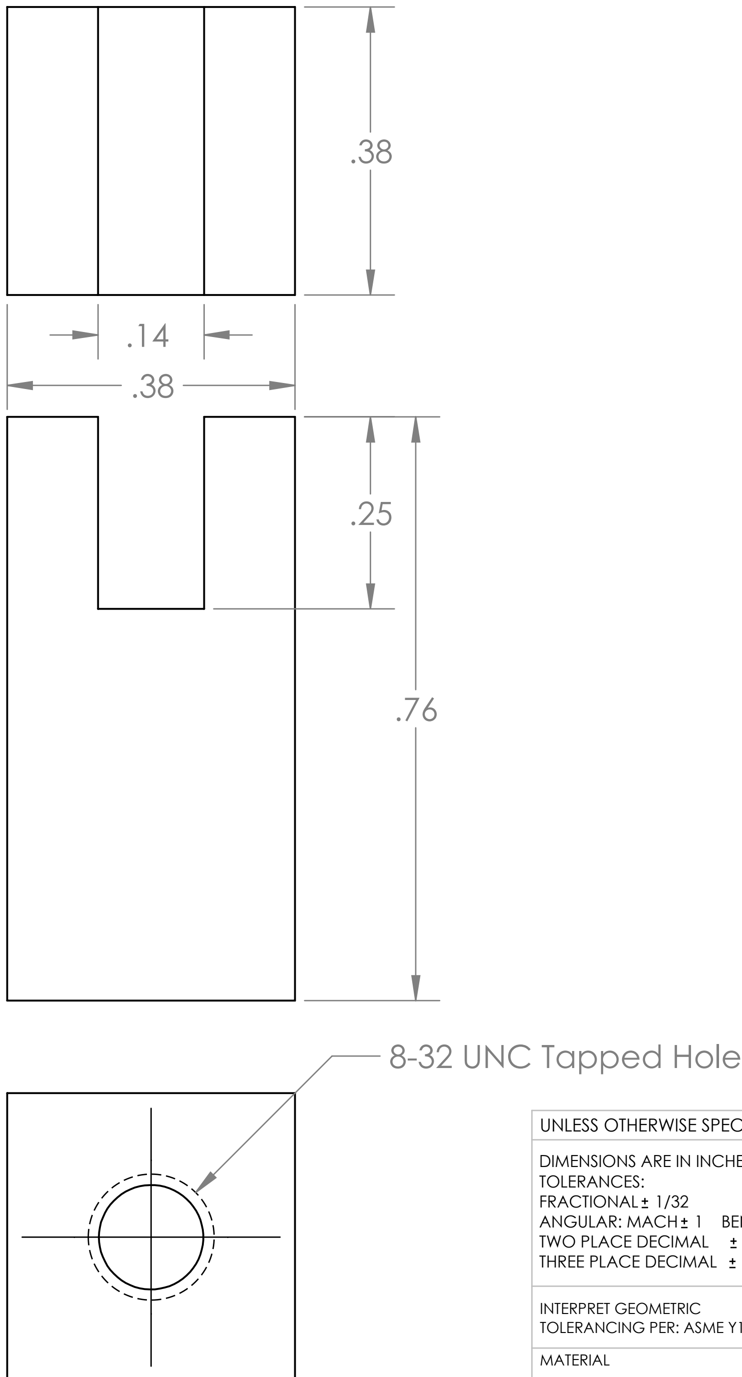
	NAME	DATE
DRAWN	KH	5/10/2022
CHECKED	TMO	5/12/2022

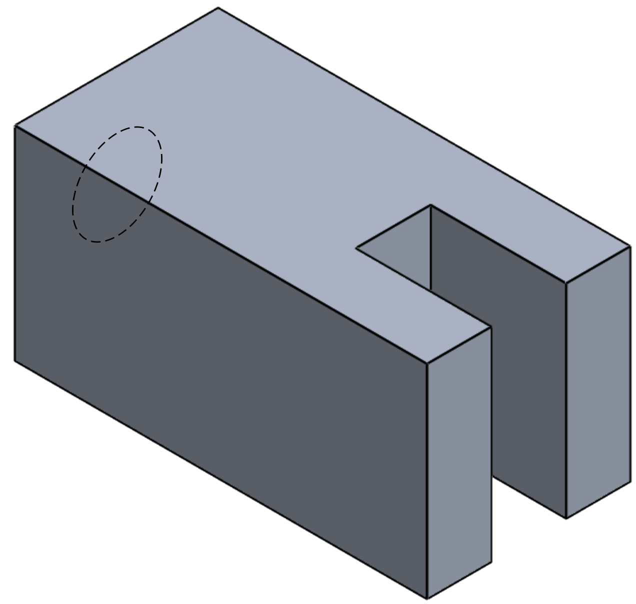
HPRC
WPI AIAA

TITLE:
ANTENNA RIB

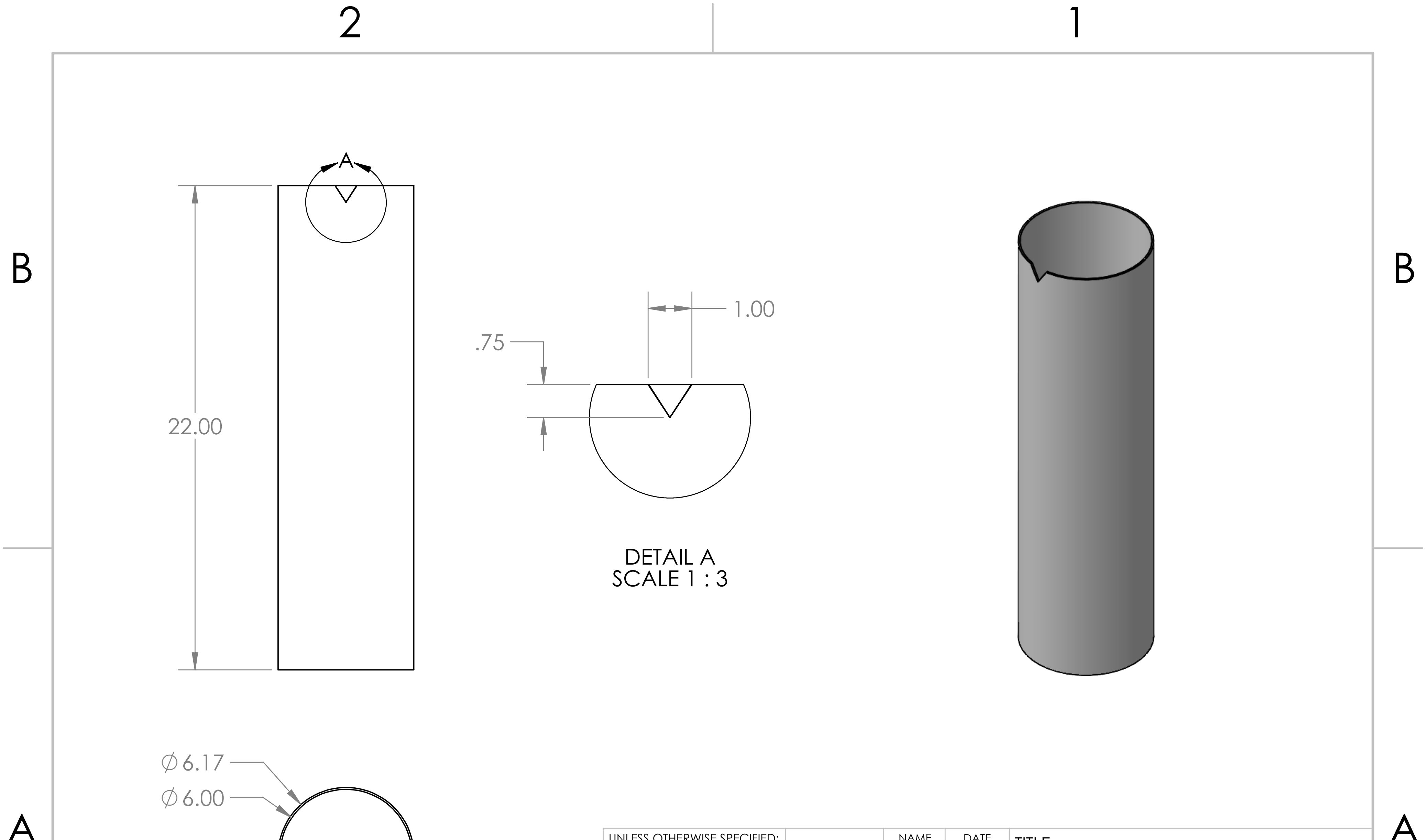
SIZE	DWG. NO.	REV
A	23-1-2-203	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1





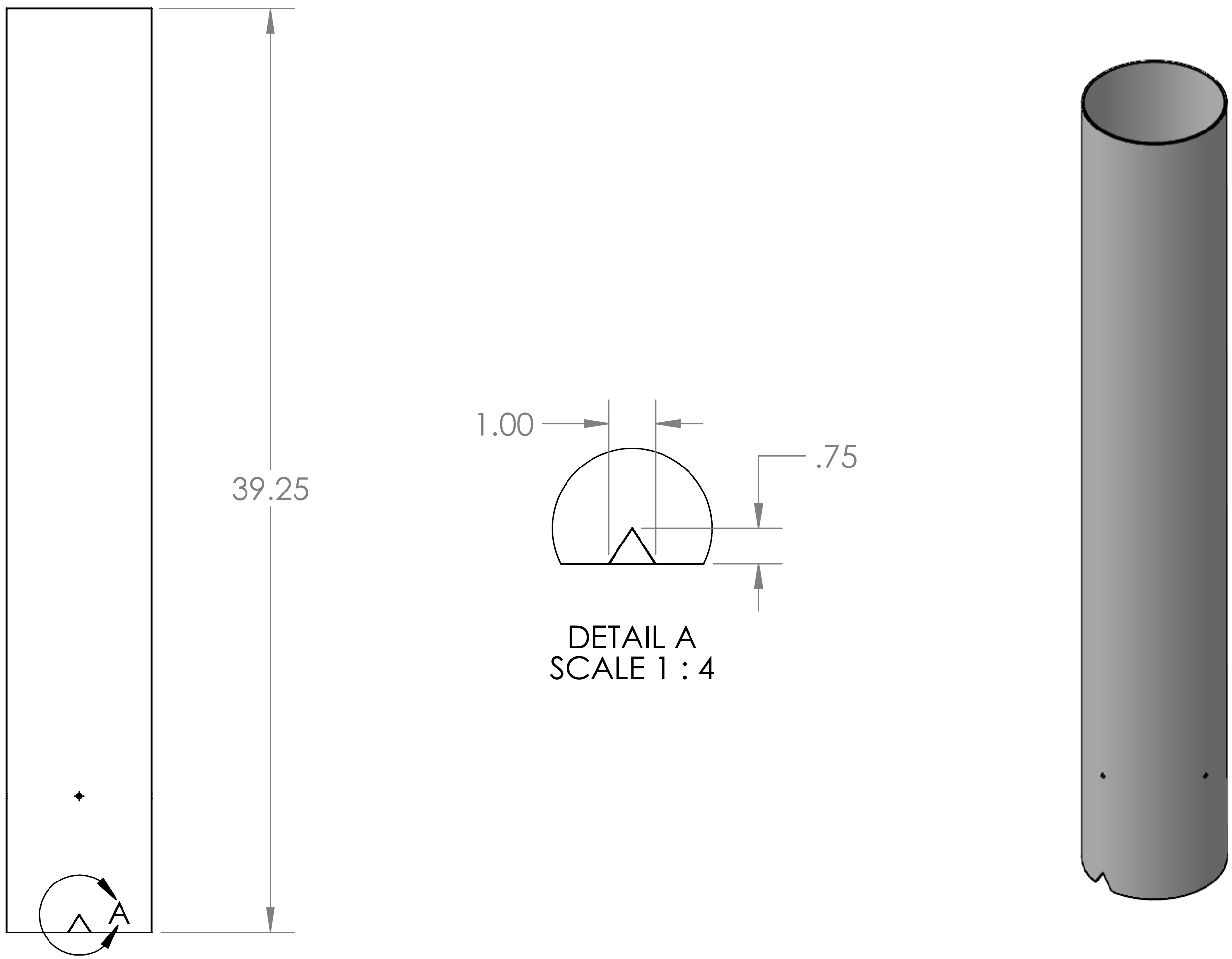
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KH	5/10/2022	ANTENNA MOUNT
	CHECKED	TMO	5/12/2022	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-1-2-204 · REV
MATERIAL ALUMINUM 6061				SCALE: 4:1 · WEIGHT: · SHEET 1 OF 1

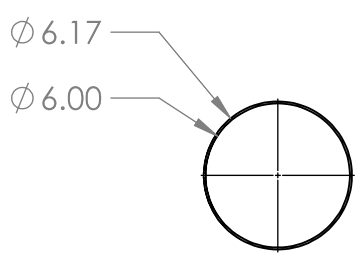


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023
	CHECKED	TT	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G12 Fiberglass			

TITLE:
MIDDLE BODY TUBE

SIZE	DWG. NO.	REV
A	23-1-3-001	
SCALE: 1:6	WEIGHT:	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G12 Fiberglass

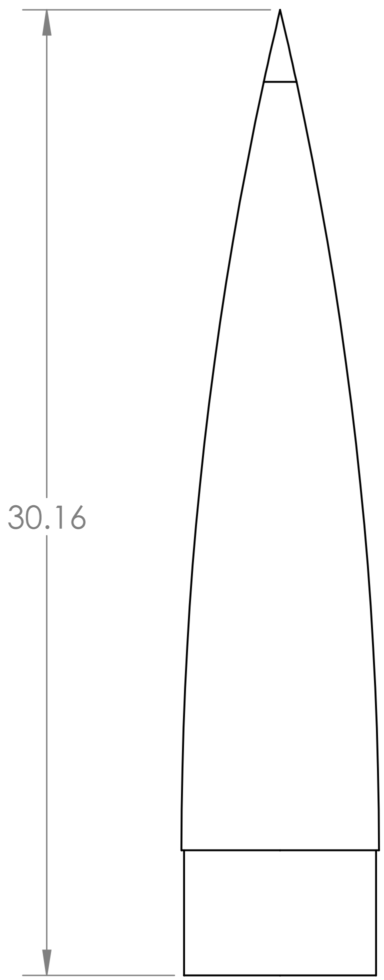
	NAME	DATE
DRAWN	JS	5/9/2023
CHECKED	TT	5/9/2023

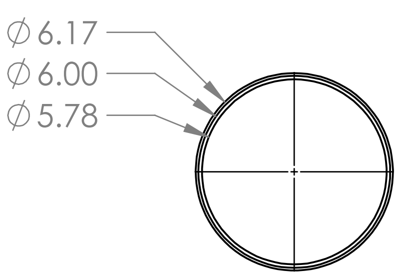
HPRC WPI AIAA

TITLE:
UPPER BODY TUBE

SIZE A | DWG. NO. 23-1-4-001 | REV

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1



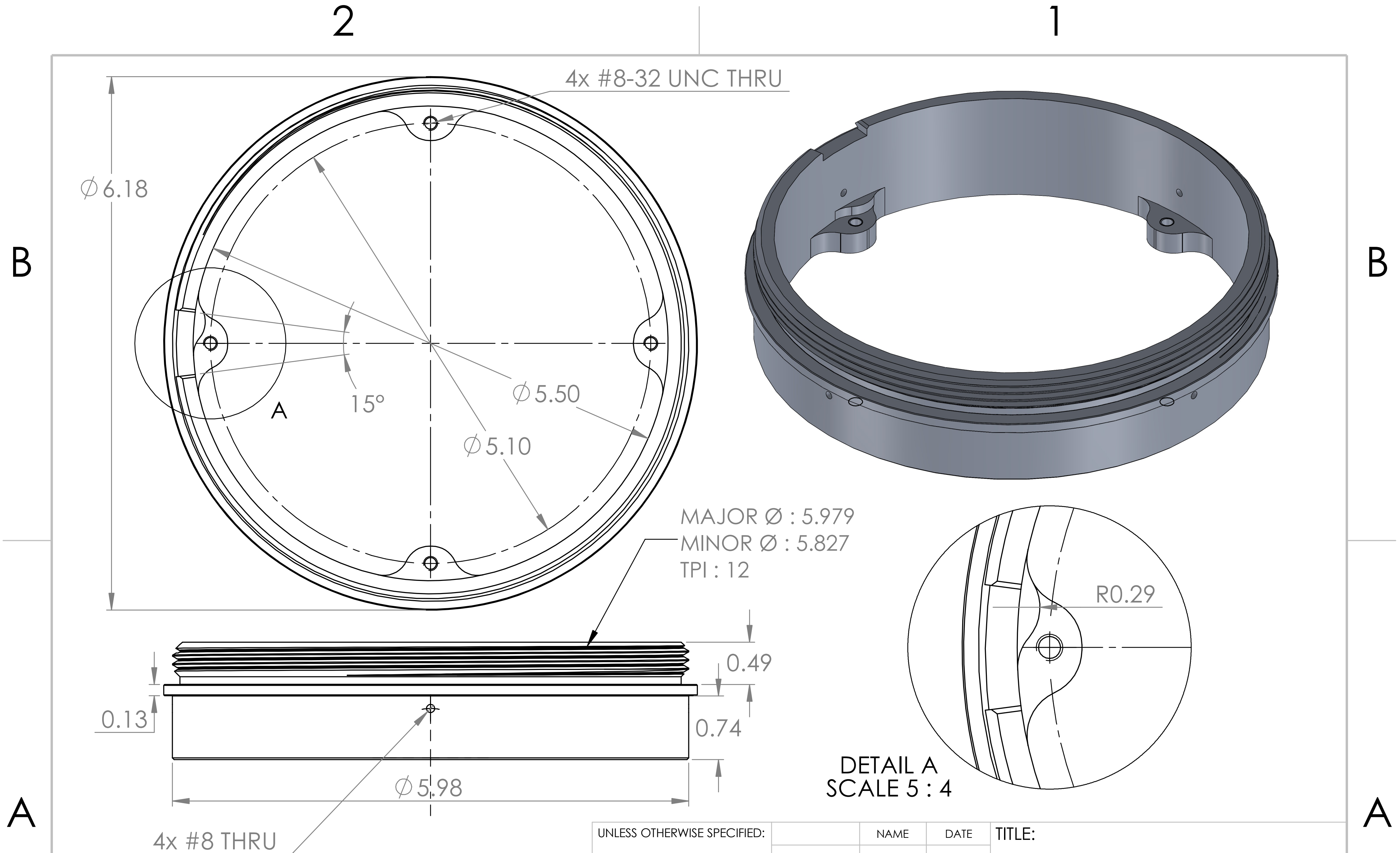


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023
	CHECKED	TT	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G12 Fiberglass			

TITLE:

NOSECONE

SIZE	DWG. NO.	REV
A	23-1-4-001	
SCALE: 1:6	WEIGHT:	SHEET 1 OF 1



	NAME	DATE
DRAWN	DAN JARVIS	5/11/2023
CHECKED		

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±0.005
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

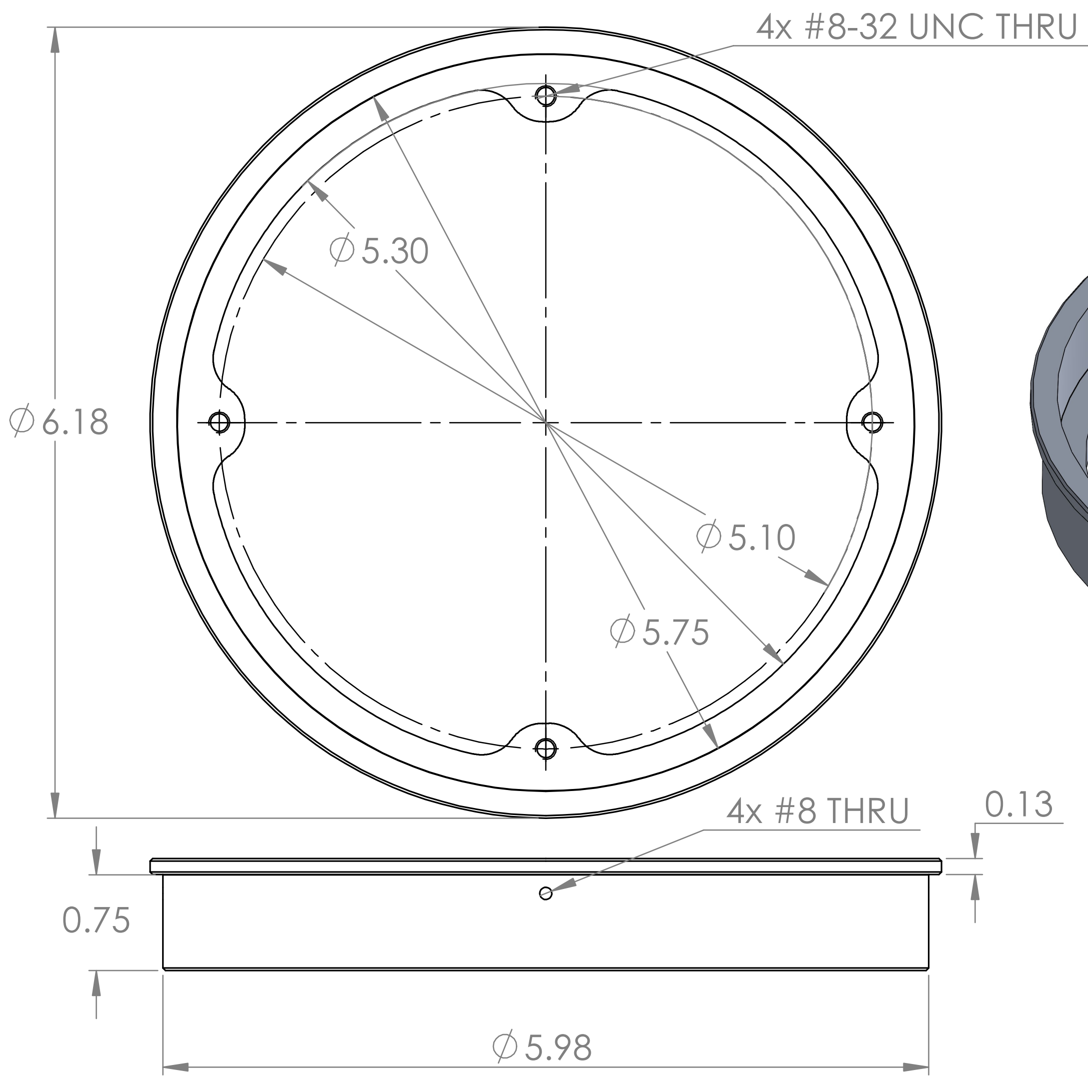
MATERIAL
ALLUMINIM 6061

HPRC
WPI AIAA

TITLE:

THREADED COUPLING

SIZE	DWG. NO.	REV
A	23-1-5-001	
SCALE: 2:3	WEIGHT:	SHEET 1 OF 1



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UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
ALLUMINIM 6061

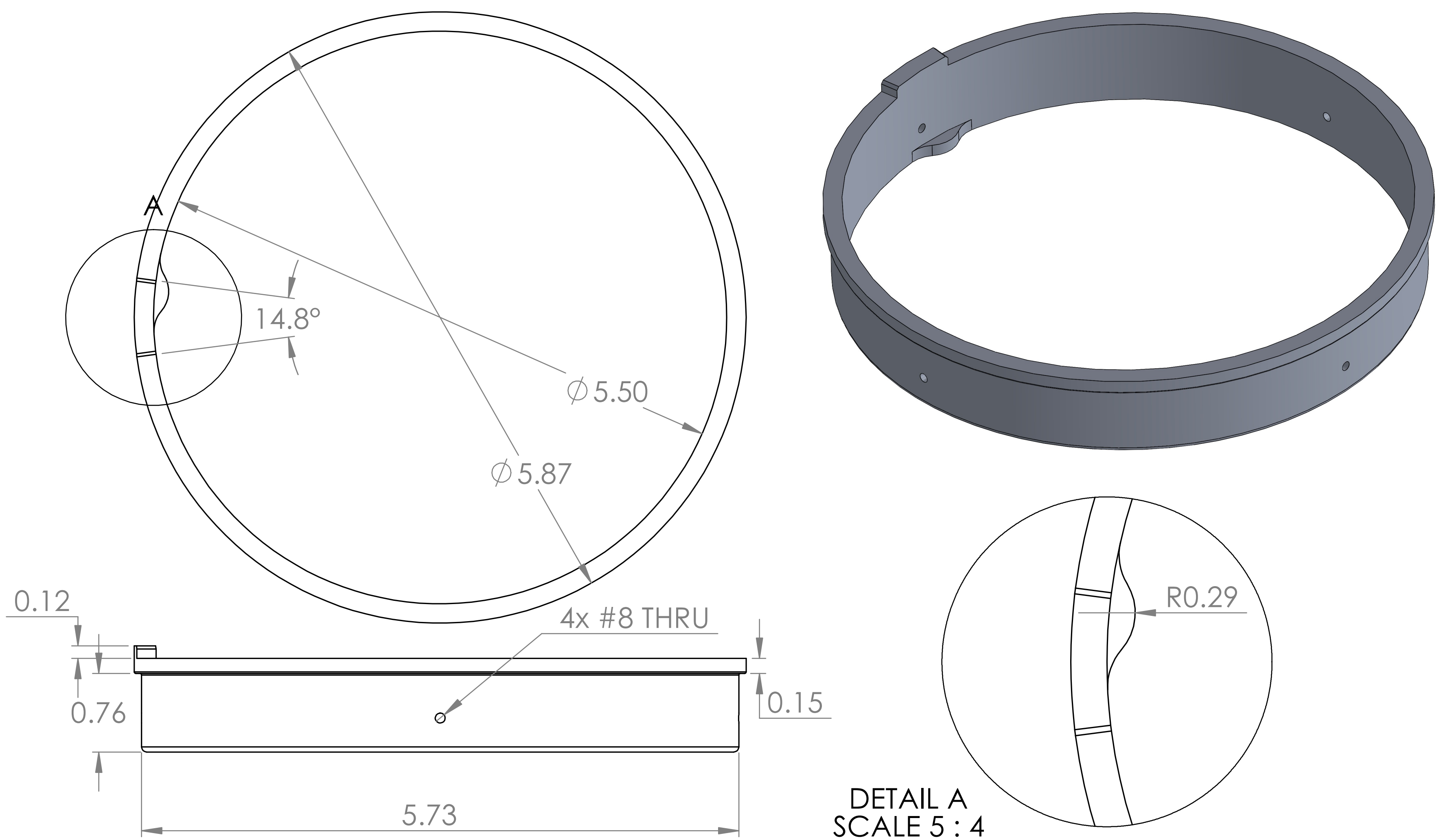
	NAME	DATE
DRAWN	DAN JARVIS	5/11/2023
CHECKED		

HPRC WPI AIAA

TITLE:
BARE COUPLING

SIZE	DWG. NO.	REV
A	23-1-5-002	

SCALE: 2:3 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DAN JARVIS	5/11/2023
	CHECKED		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL ALLUMINIM 7075			

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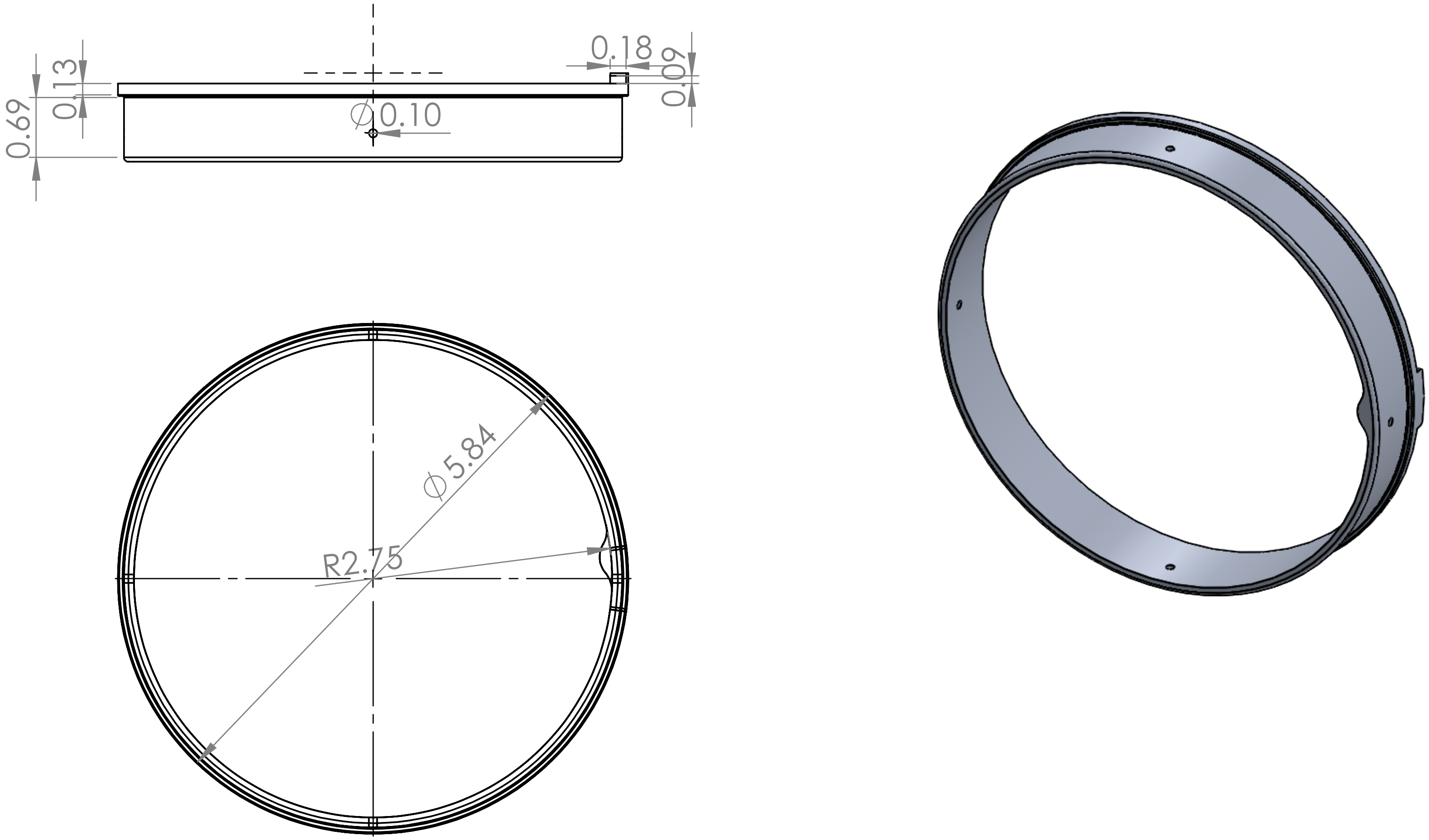
HPRC WPI AIAA

TITLE:

RETAINING RING

SIZE	DWG. NO.	REV
A	23-1-5-003	
SCALE: 2:3	WEIGHT:	SHEET 1 OF 1



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TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061 T6

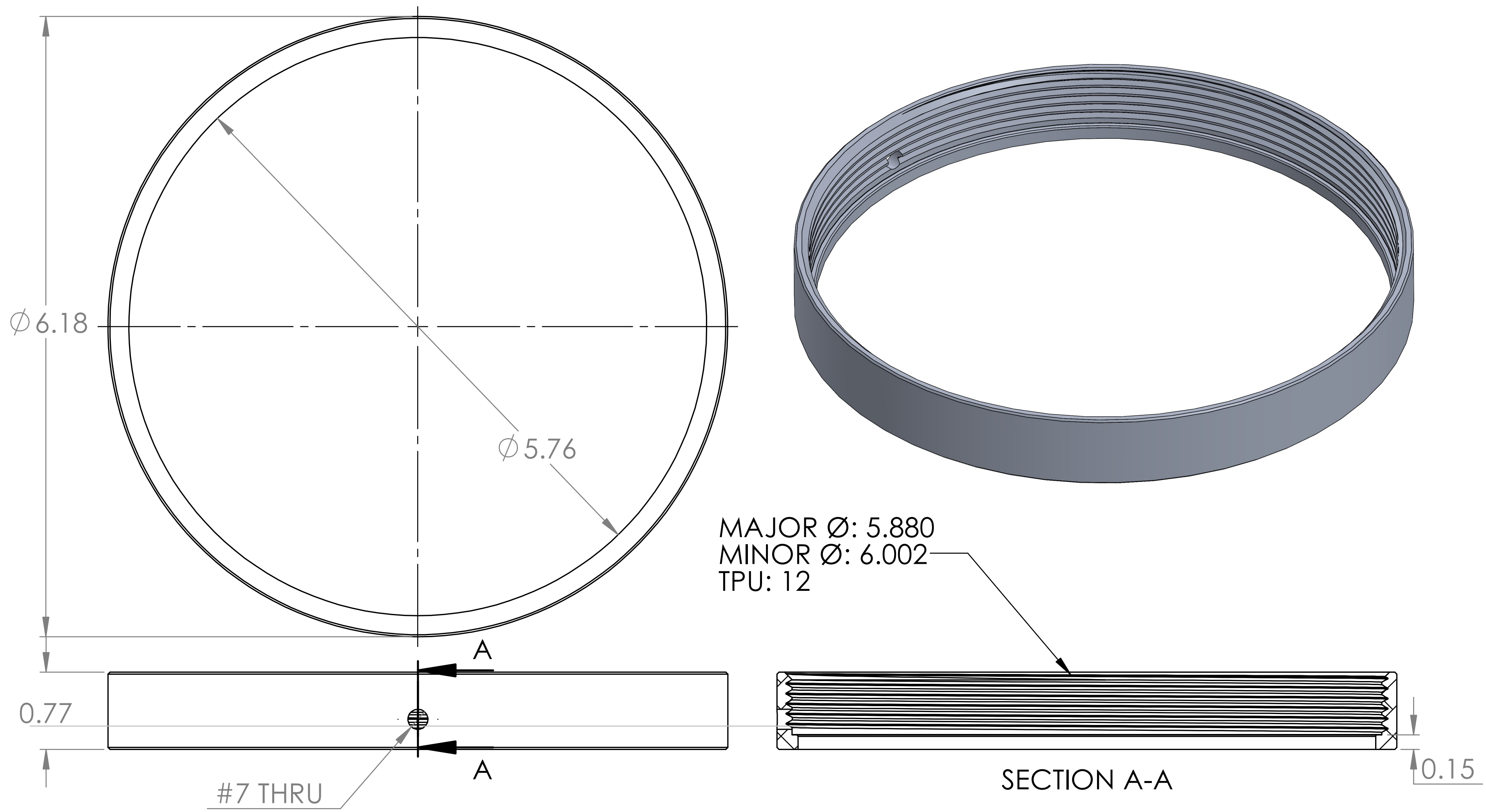
	NAME	DATE
DRAWN	NE	5/10/23
CHECKED		

HPRC WPI AIAA

TITLE:
RETAINING RING

SIZE	DWG. NO.	REV
A	U23-1-5-003	

SCALE: 1:2 | WEIGHT: 0.204 lb | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	DAN JARVIS	5/11/2023
	CHECKED		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL ALLUMINIM 6061			

HPRC WPI AIAA

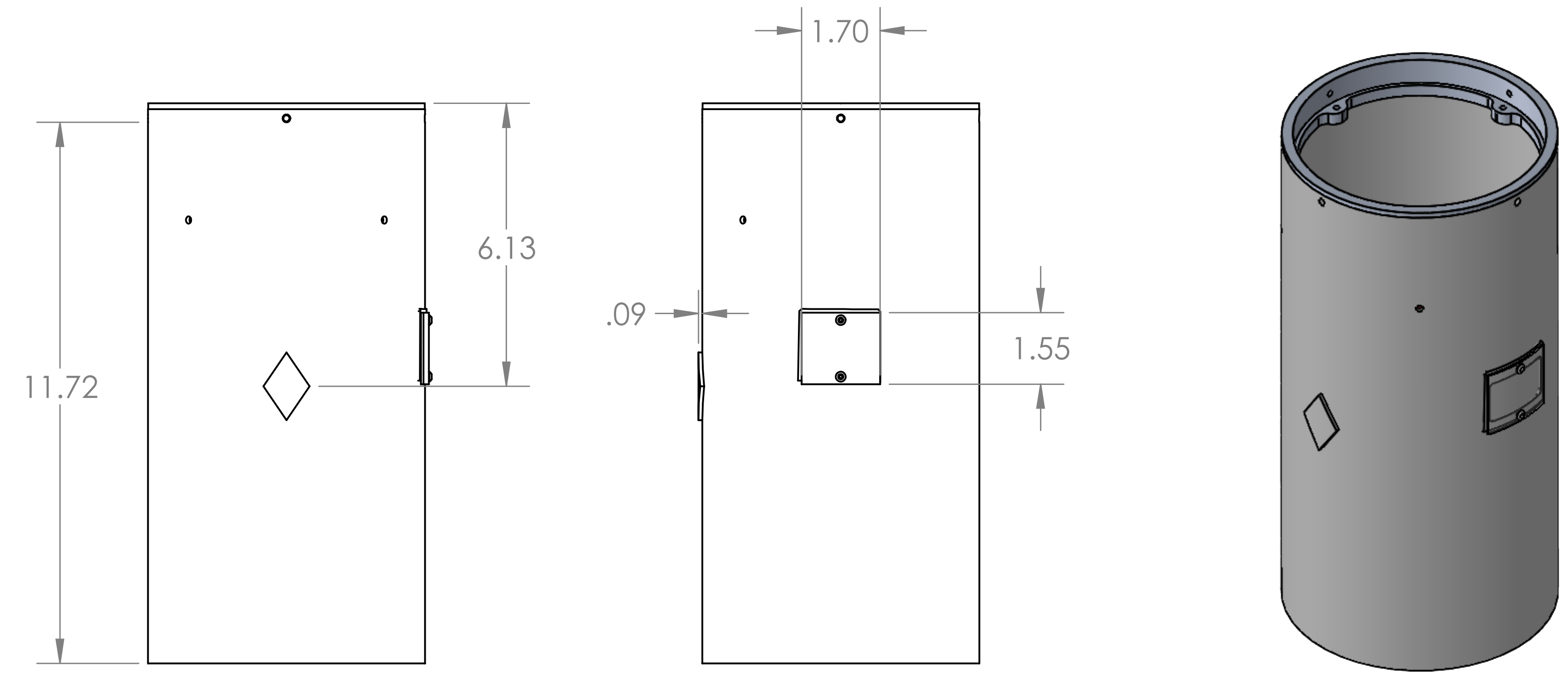
PROPRIETARY AND CONFIDENTIAL

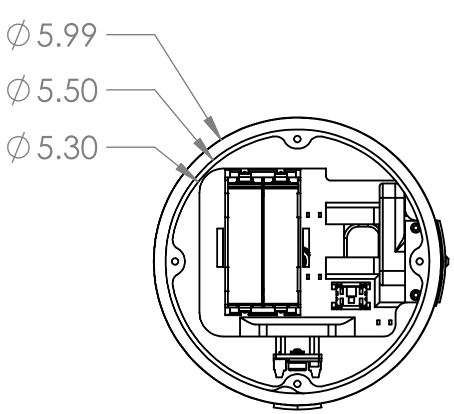
TITLE:

ROTATING NUT

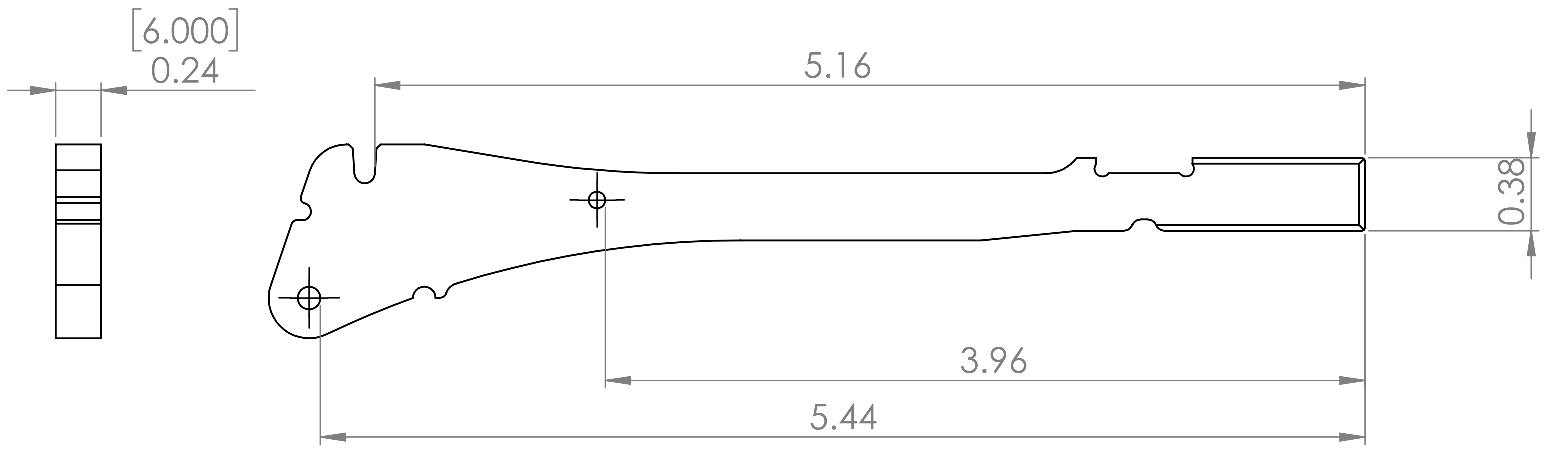
SIZE	DWG. NO.	REV
A	23-1-5-004	

SCALE: 2:3 | WEIGHT: | SHEET 1 OF 1



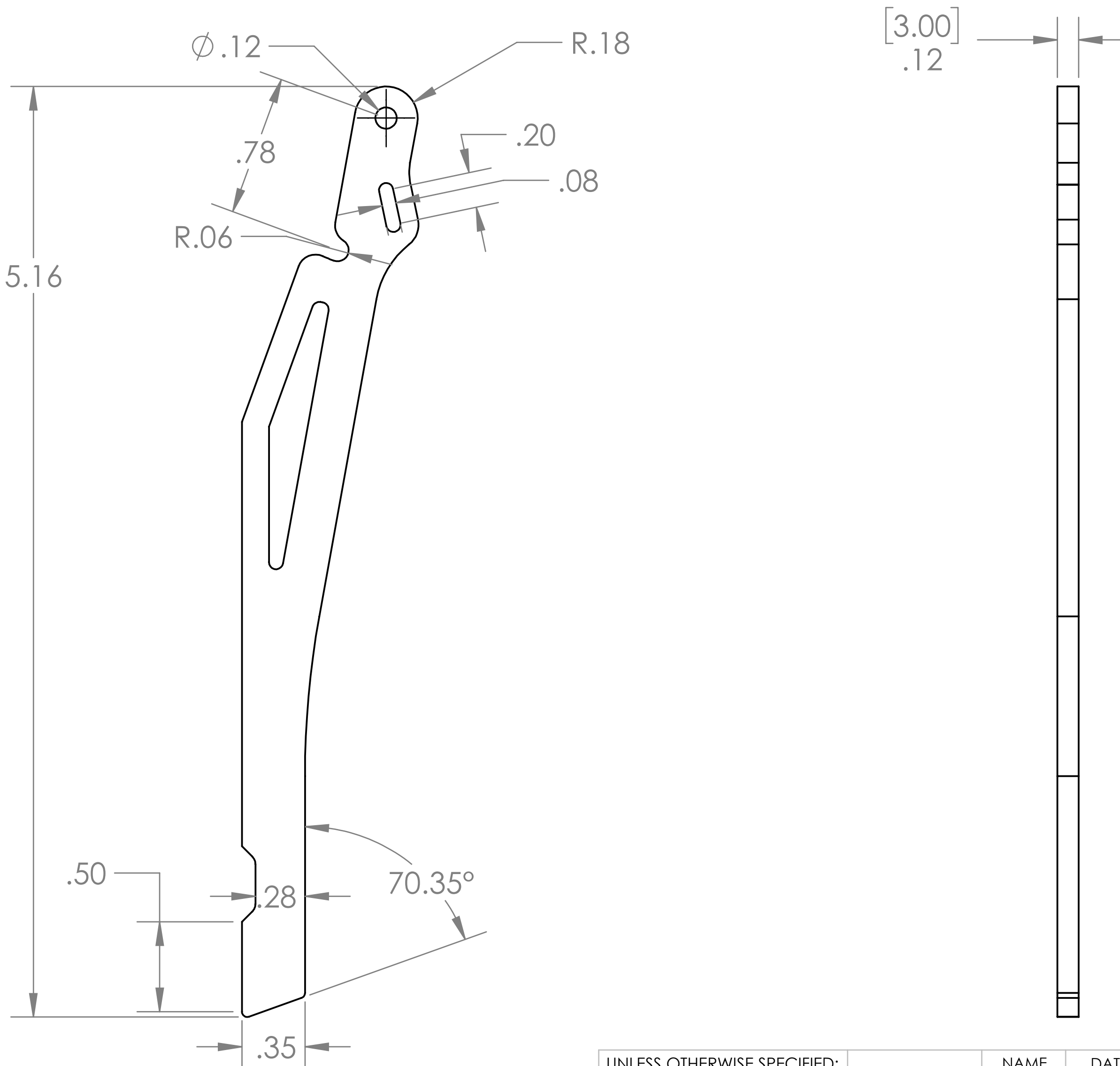


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JS	5/9/2023	COUPLER TUBE ASSEMBLY
	CHECKED	TT	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A DWG. NO. 23-1-6-000 REV
MATERIAL FIBERGLASS				SCALE: 1:4 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023	Arm
	CHECKED	JR	5/10/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A DWG. NO. 23-2-1-001 REV
MATERIAL Carbon Fiber				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

2 | 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

HPRC WPI AIAA

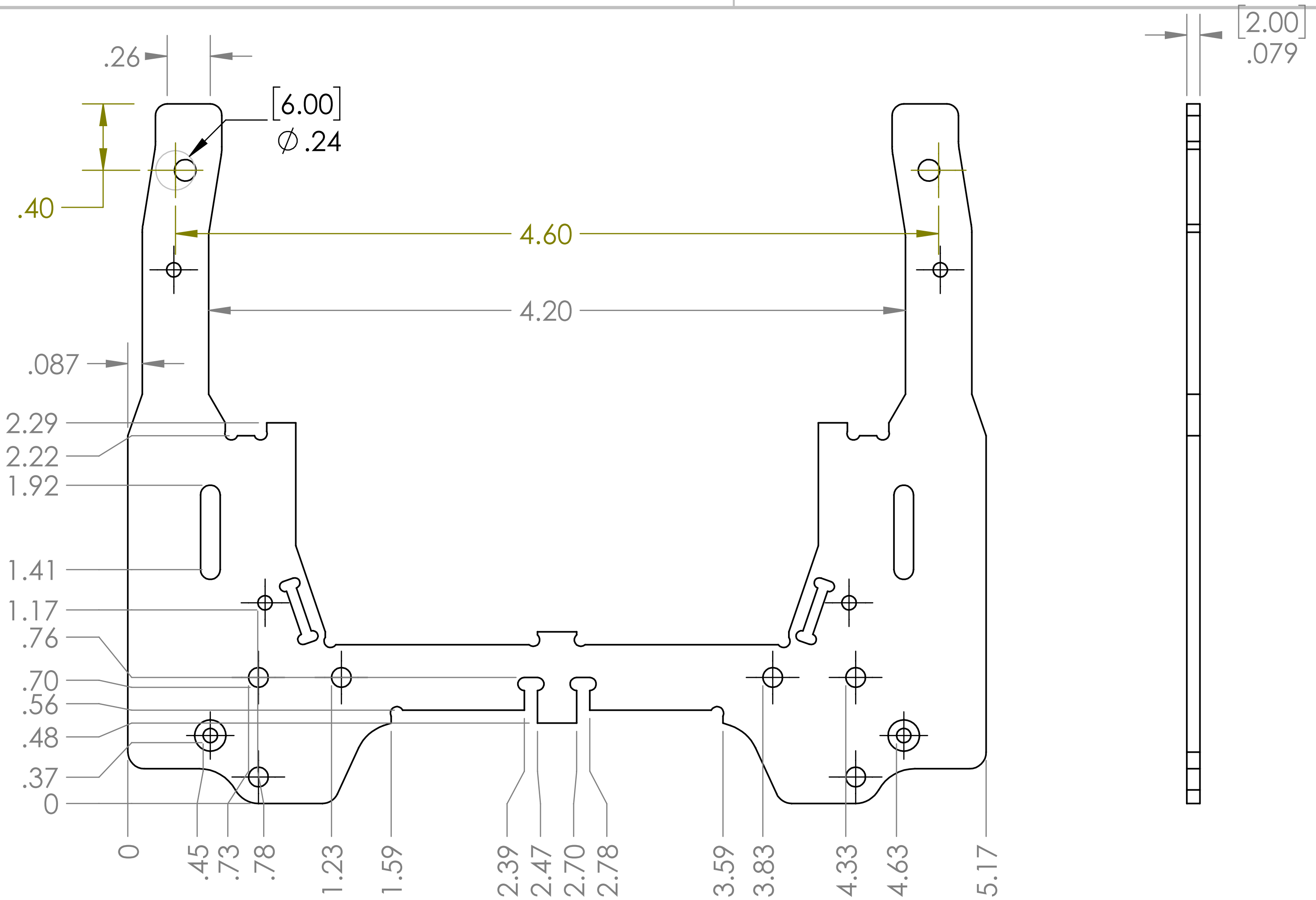
TITLE:

Landing Leg

SIZE	DWG. NO.	REV
A	23-2-1-002	

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

2 | 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

HPRC WPI AIAA

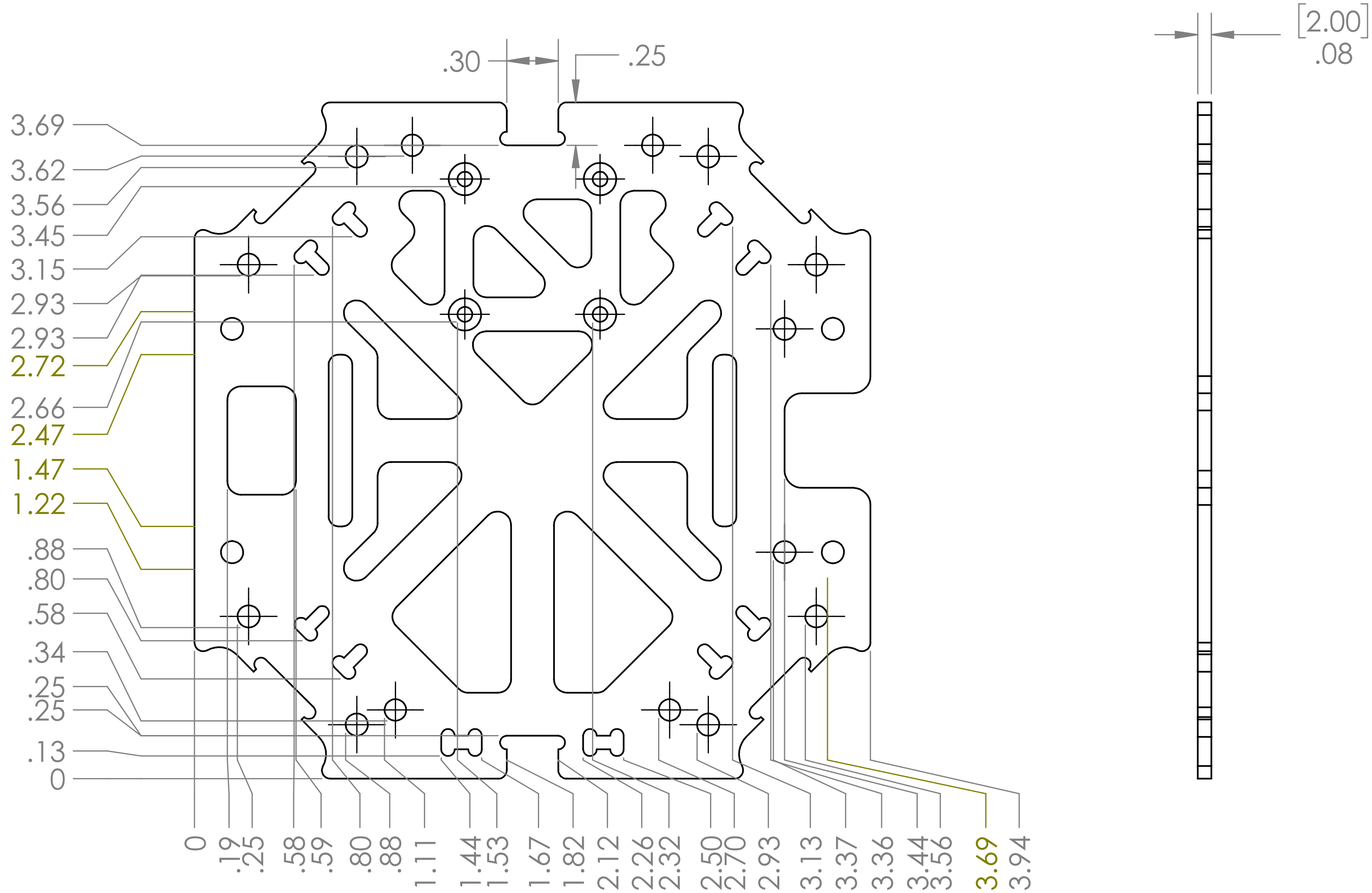
TITLE:

Side Plate

SIZE	DWG. NO.	REV
A	23-2-1-003	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

HPRC
WPI AIAA

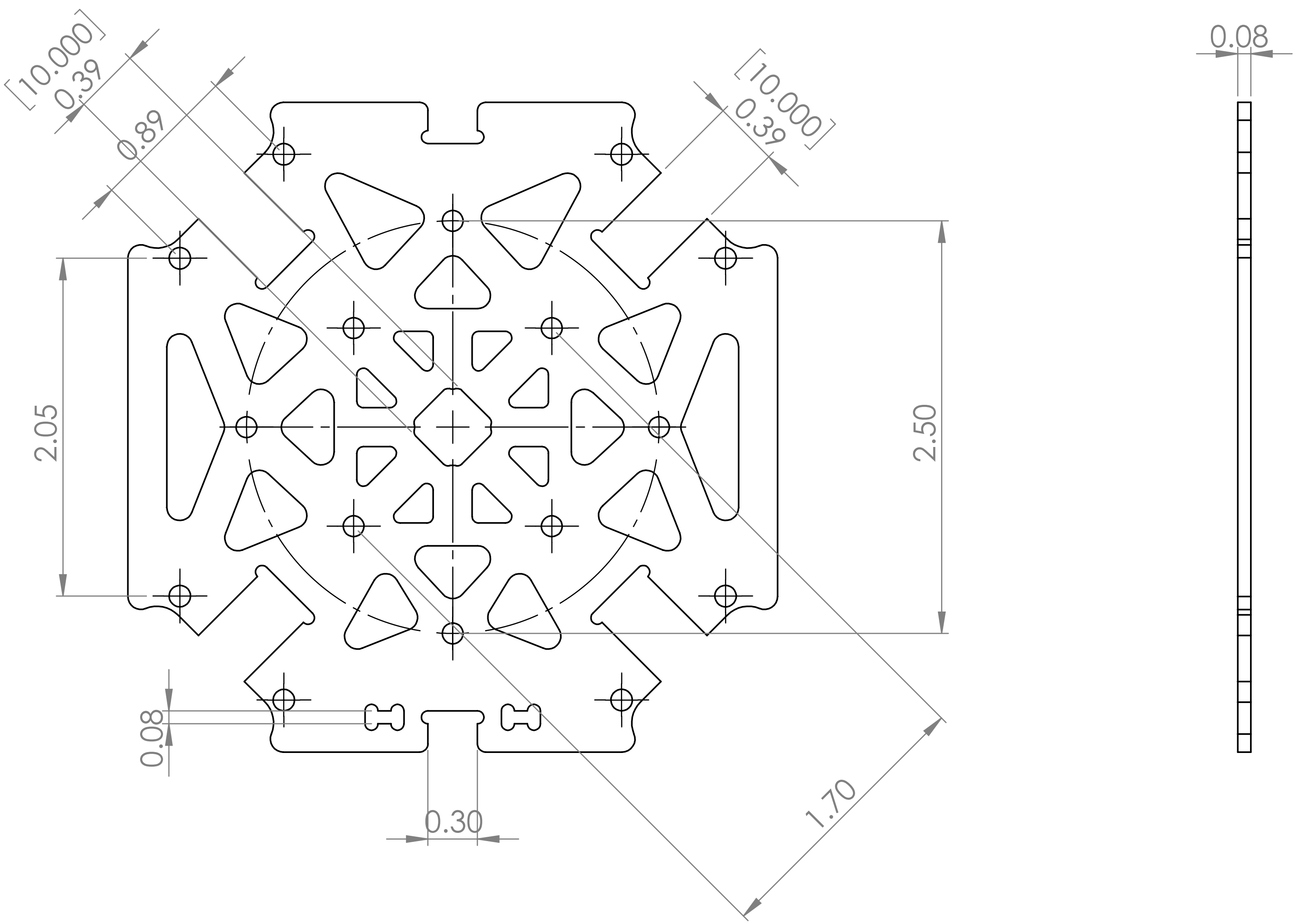
TITLE:

Top Plate

SIZE **A** DWG. NO. 23-2-1-004 REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
Carbon Fiber

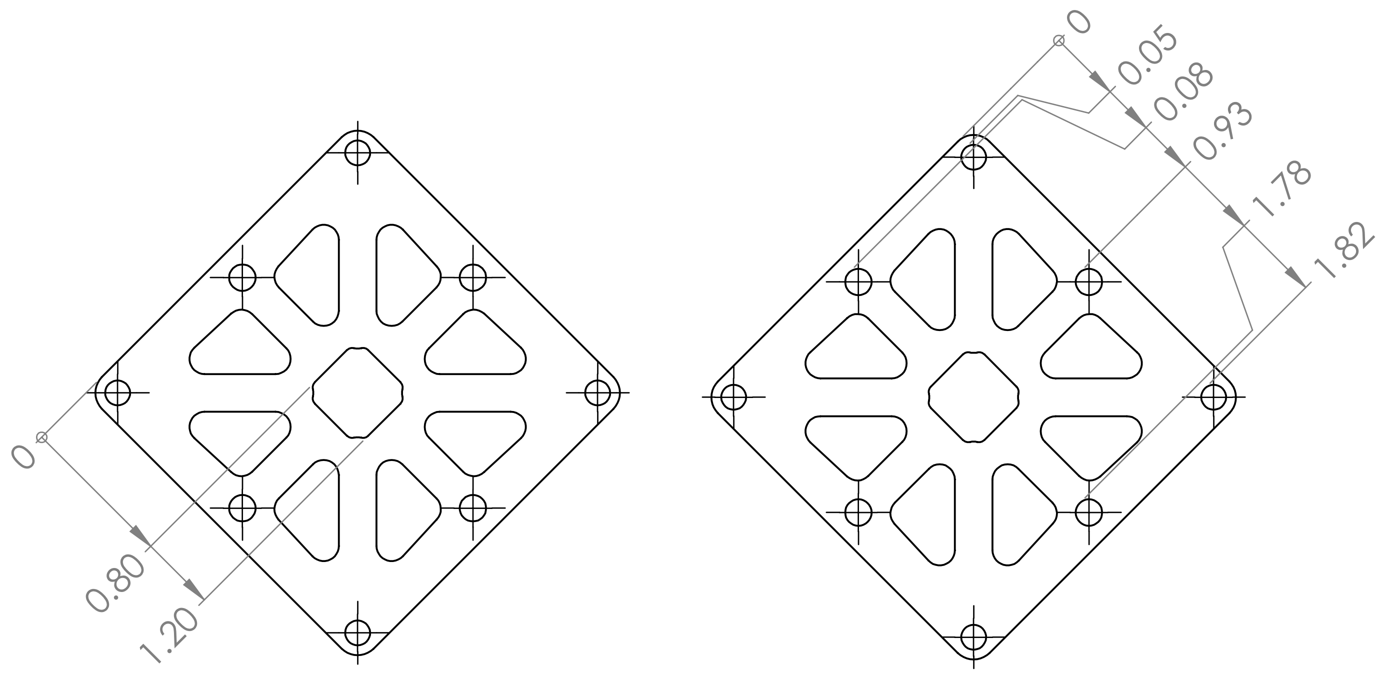
	NAME	DATE
DRAWN	NG	5/9/2023
CHECKED	JR	5/10/2023

HPRC WPI AIAA

TITLE:
Middle Plate

SIZE	DWG. NO.	REV
A	23-2-1-005	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

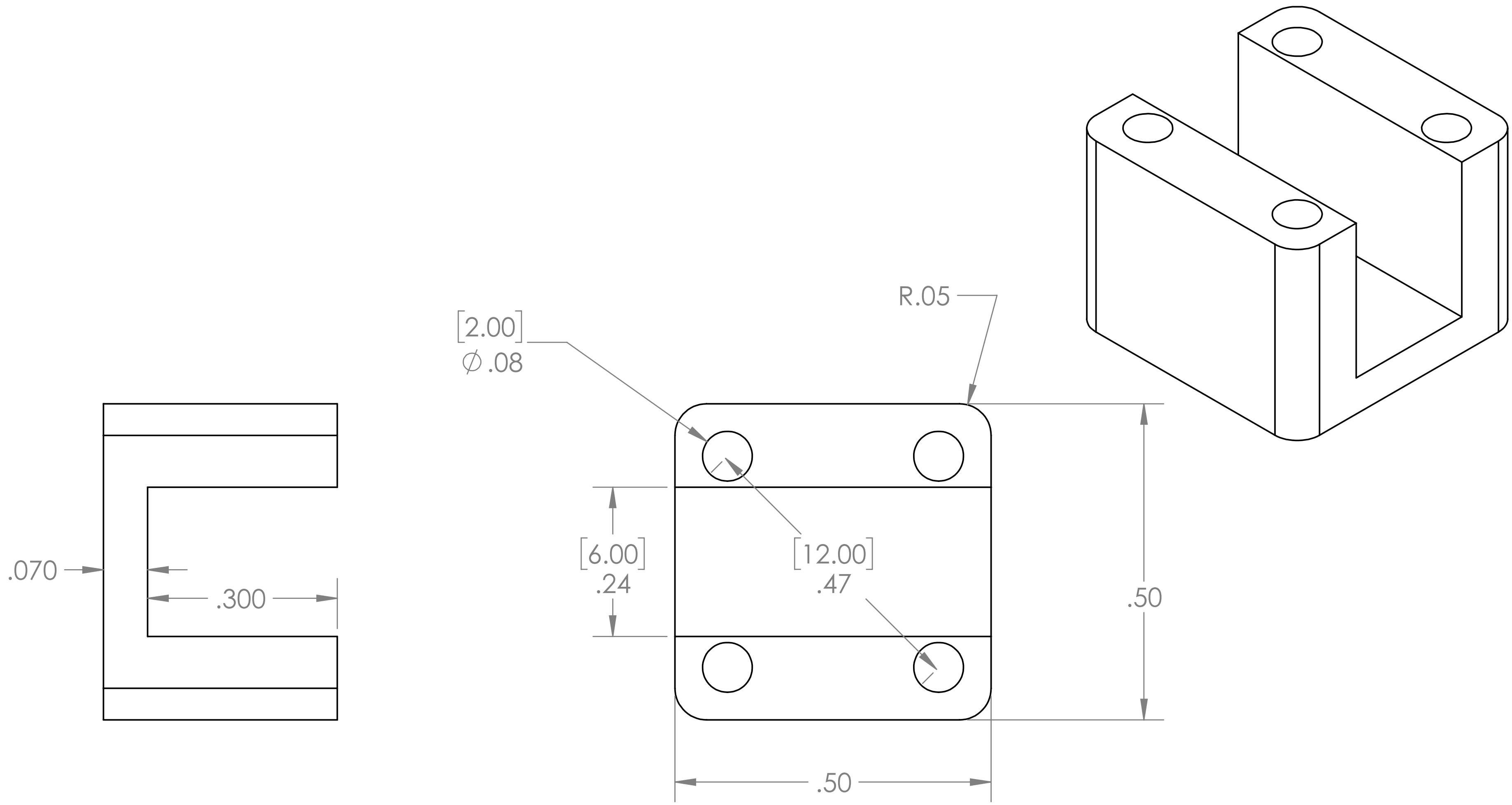
HPRC WPI AIAA

TITLE:

Bottom Plate

SIZE	DWG. NO.	REV
A	23-2-1-006	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



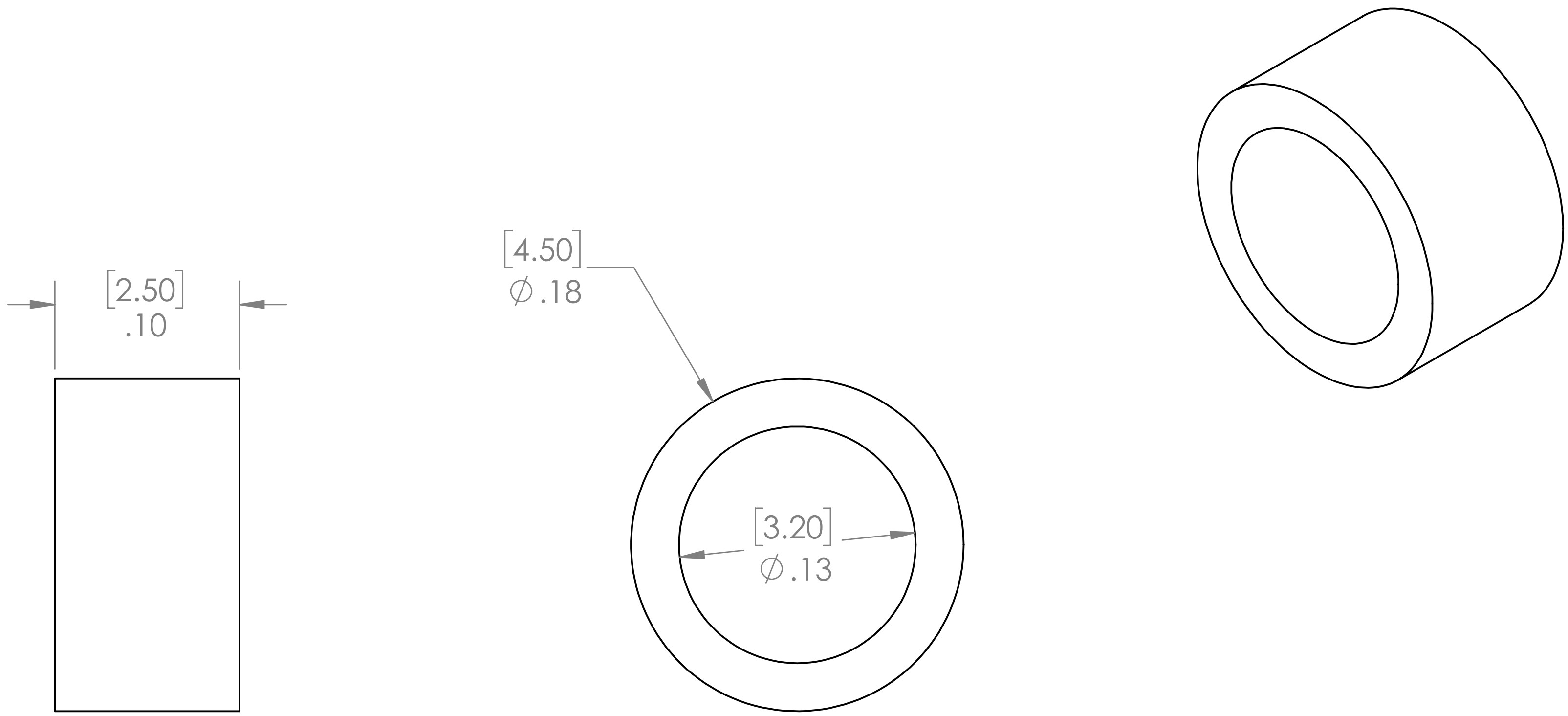
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL 6061 Aluminum			

HPRC
WPI AIAA

TITLE:
Motor Mount

SIZE	DWG. NO.	REV
A	23-2-1-007	

SCALE: 4:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

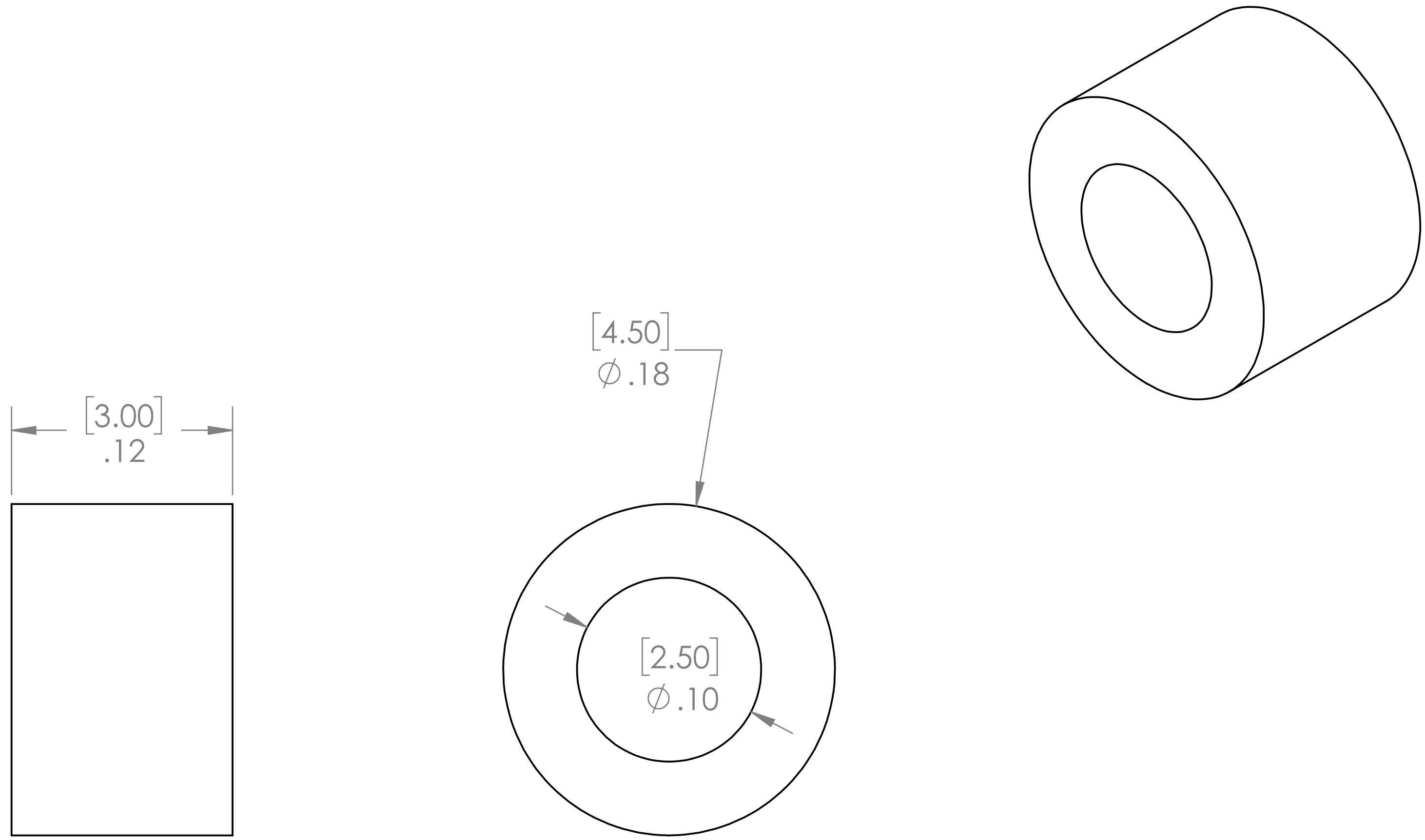
HPRC
WPI AIAA

TITLE:

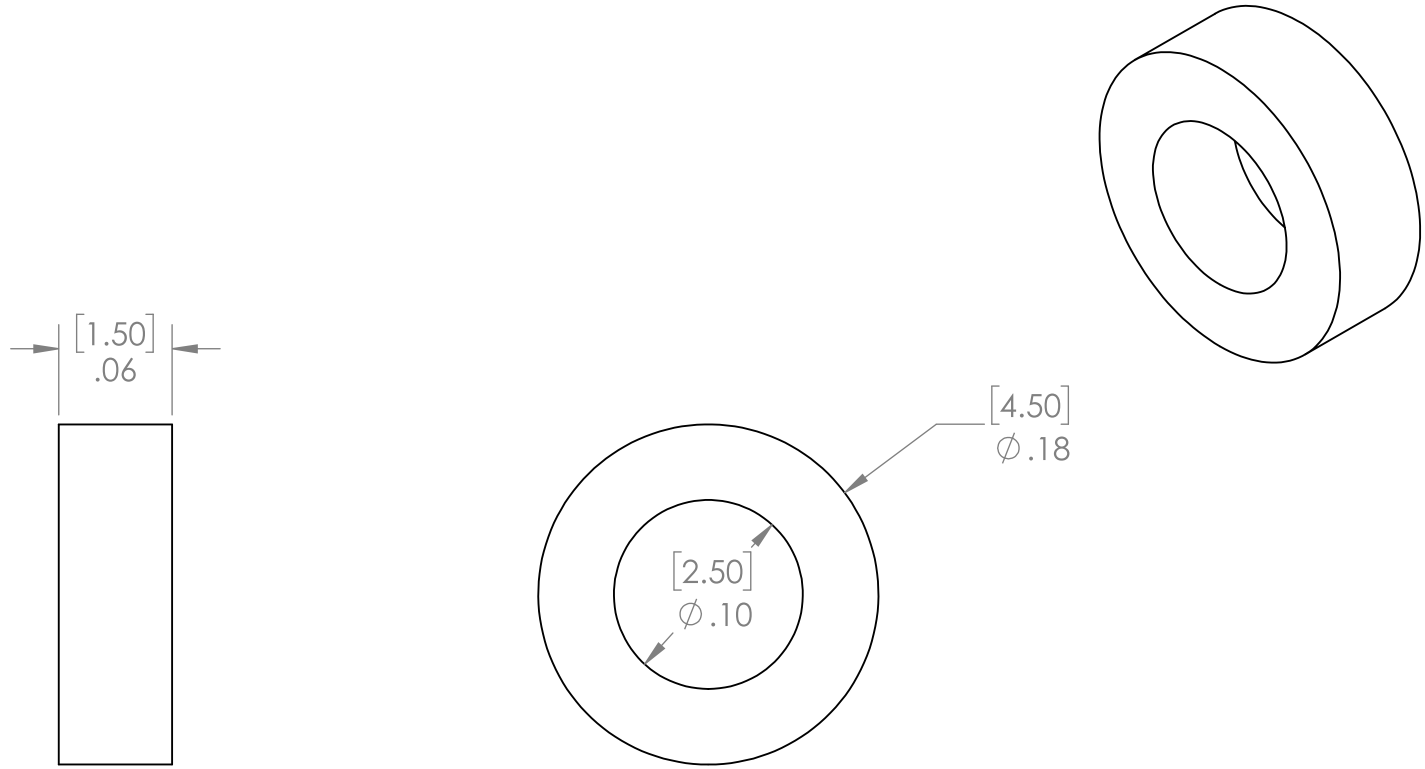
M3 2.5mm Spacer

SIZE	DWG. NO.	REV
A	23-2-1-008	

SCALE: 10:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/11/2023	M2 3mm Spacer
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-1-009 · REV
MATERIAL Polycarbonate				SCALE: 10:1 · WEIGHT: · SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC
WPI AIAA

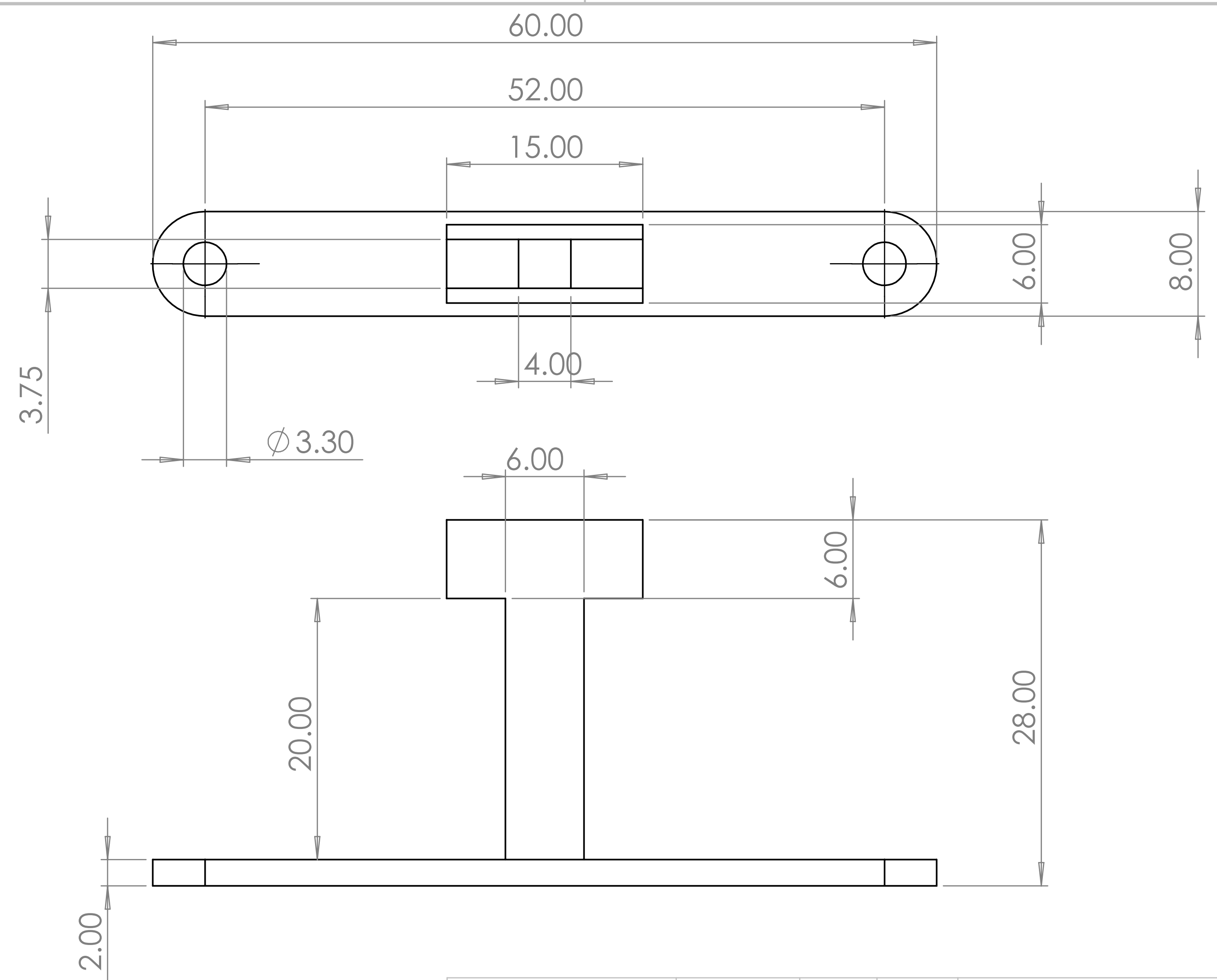
TITLE:
M2 2mm Spacer

SIZE	DWG. NO.	REV
A	23-2-1-010	
SCALE: 10:1	WEIGHT:	SHEET 1 OF 1

2 1

B B

A A



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

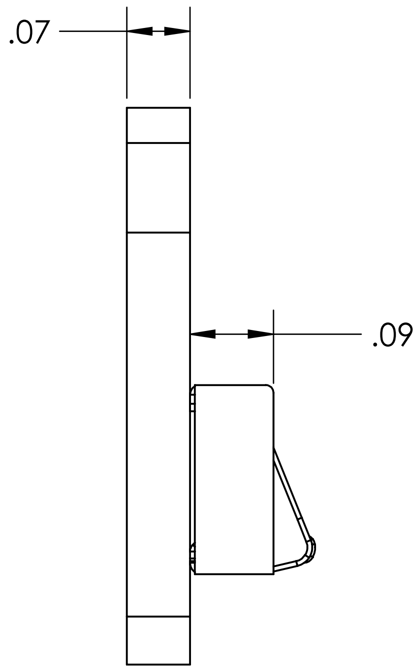
TITLE:
Reciever Mount

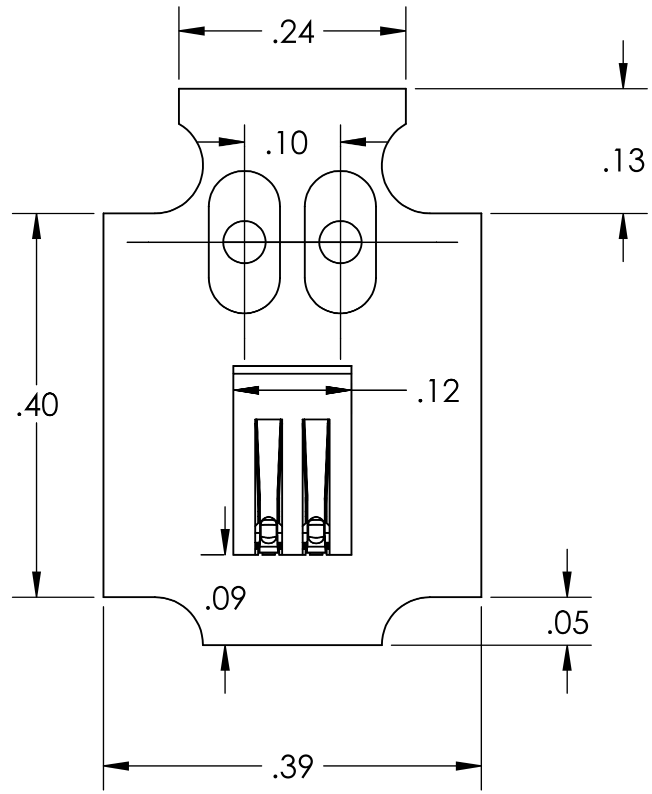
SIZE	DWG. NO.	REV
A	23-2-1-011	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

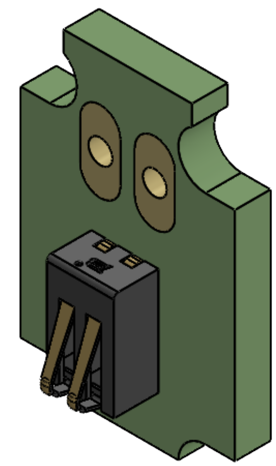
2 1

2 | 1

B | B







A | A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA		
MATERIAL Fiberglass PCB			

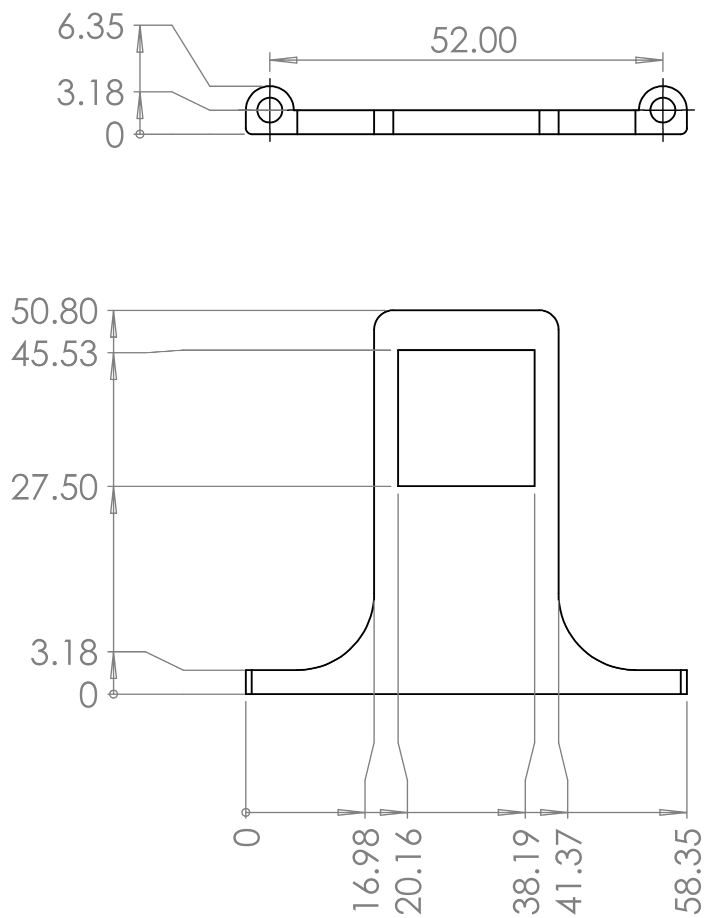
TITLE:

Limit Switch

SIZE	DWG. NO.	REV
A	23-2-1-014	

SCALE: 5:1	WEIGHT:	SHEET 1 OF 1

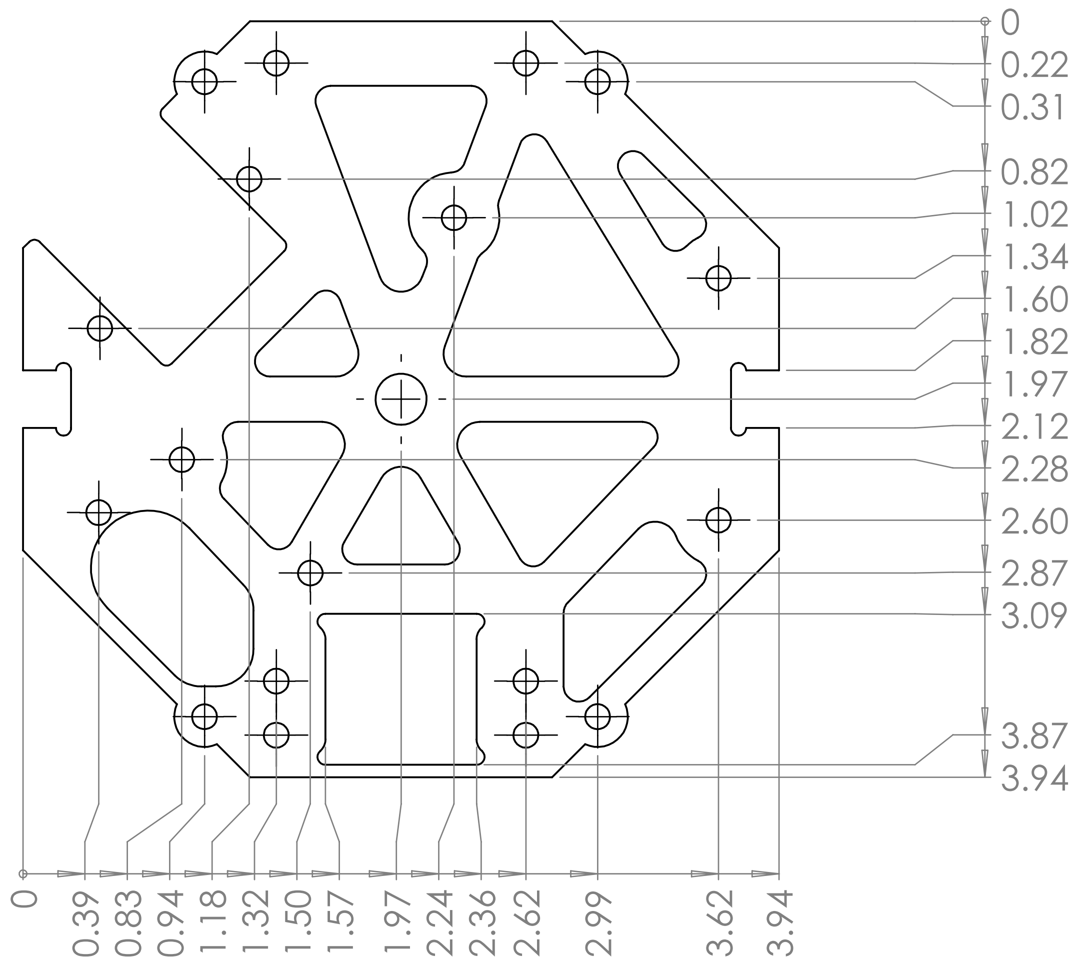
2 | 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Secondary GPS Mount
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023	
	CHECKED	JR	5/10/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-1-015 · REV
MATERIAL Polycarbonate				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

2 1

B B



A A

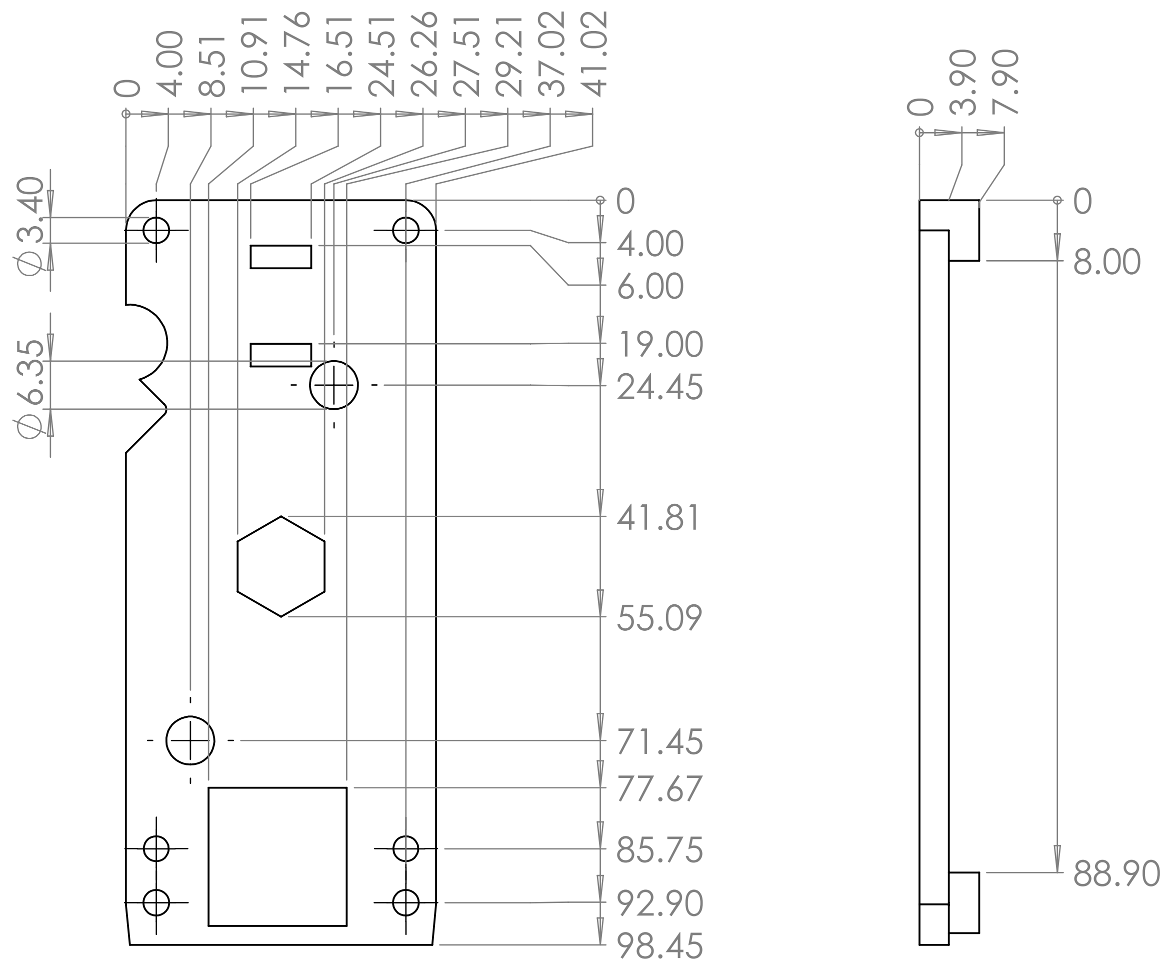
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

HPRC
WPI AIAA

TITLE:
Upper Battery Plate

SIZE	DWG. NO.	REV
A	23-2-1-016	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

2 1



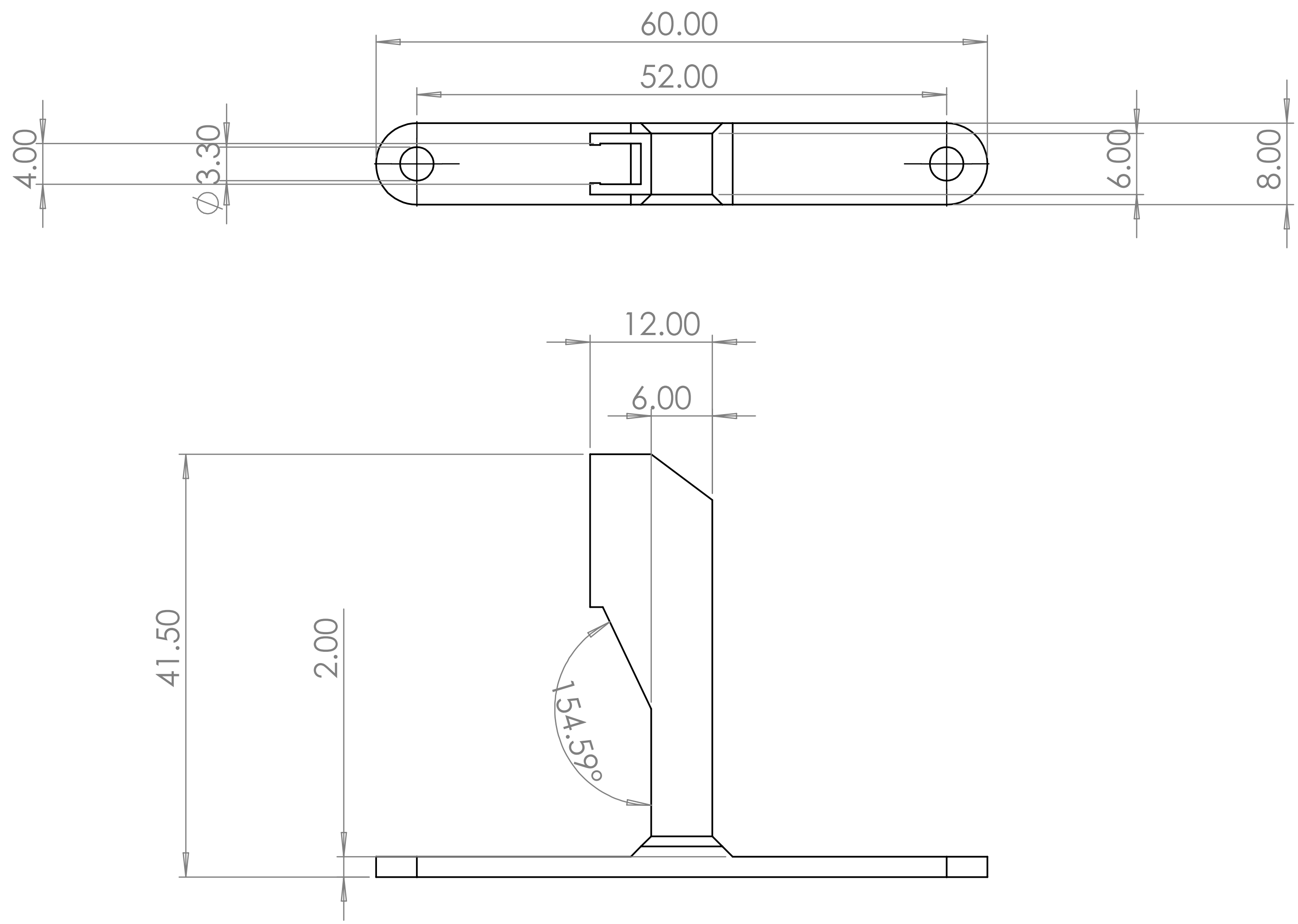
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC
WPI AIAA

TITLE:
Sub Upper Plate

SIZE	DWG. NO.	REV
A	23-2-1-017	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



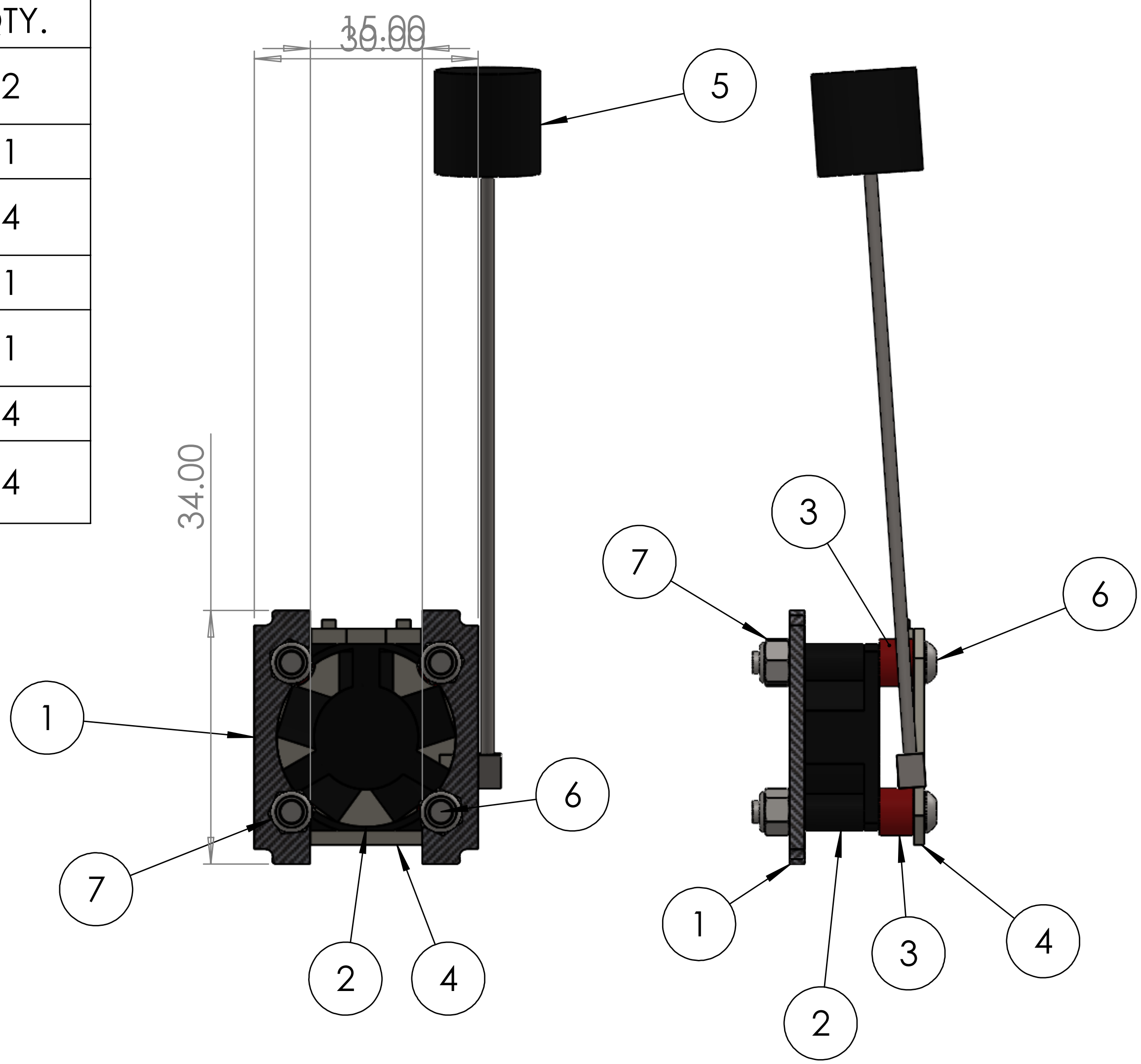
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC
WPI AIAA

TITLE:
Reciever Mount Angled

SIZE	DWG. NO.	REV
A	23-2-1-018	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	23-2-1-102 (FAN MOUNT)	2
2	25X25X10 DC fan	1
3	23-2-1-101 (M3 VTX SPACER)	4
4	Lux 20mm VTx	1
5	Lumenier Micro AXII 2	1
6	91306A725	4
7	90576A102	4



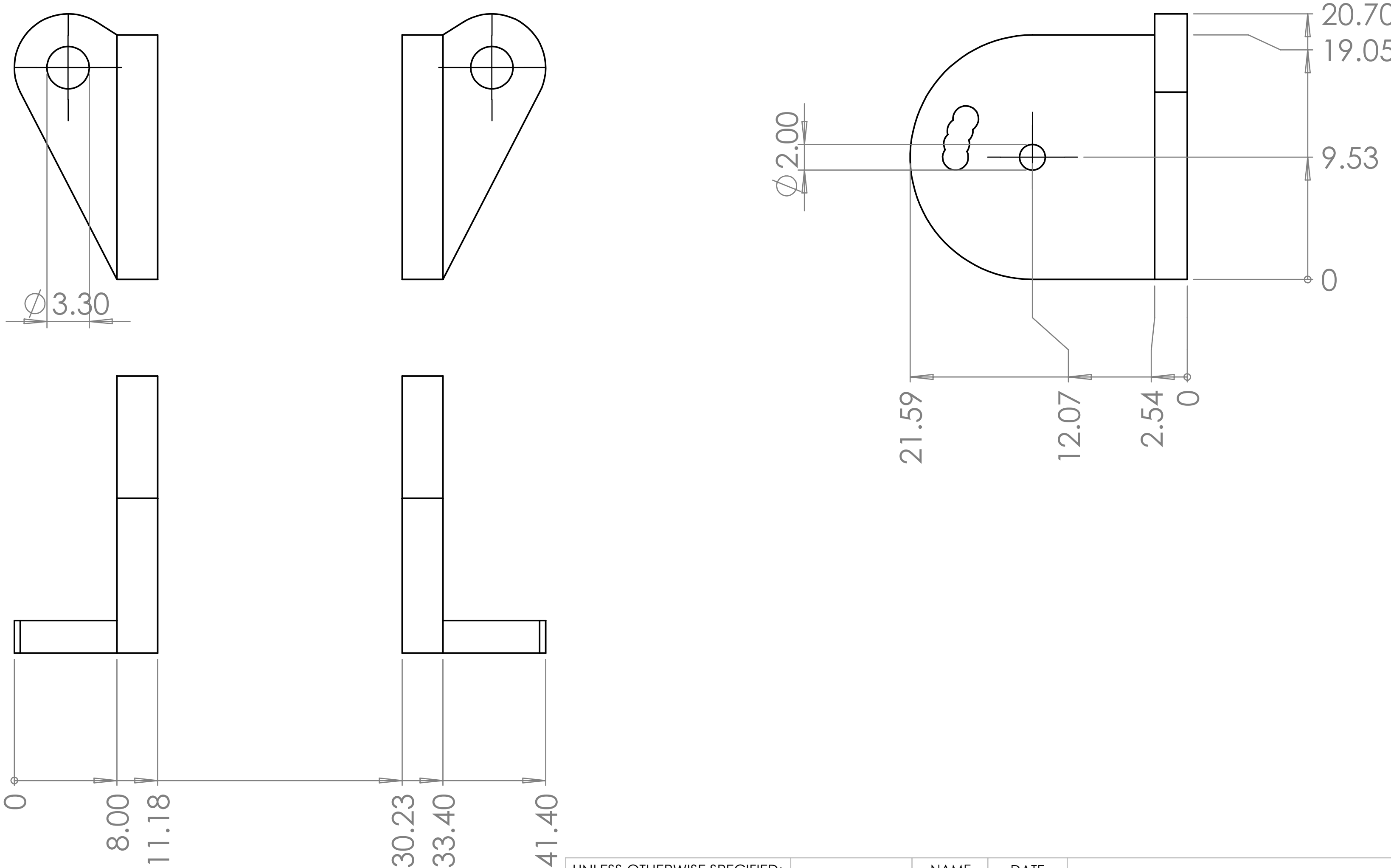
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± 1/32 ANGULAR: MACH± 1 BEND ±1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	CB	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL			

HPRC WPI AIAA

TITLE:

VTX Assembly

SIZE	DWG. NO.	REV
A	23-2-1-100	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycabonate			

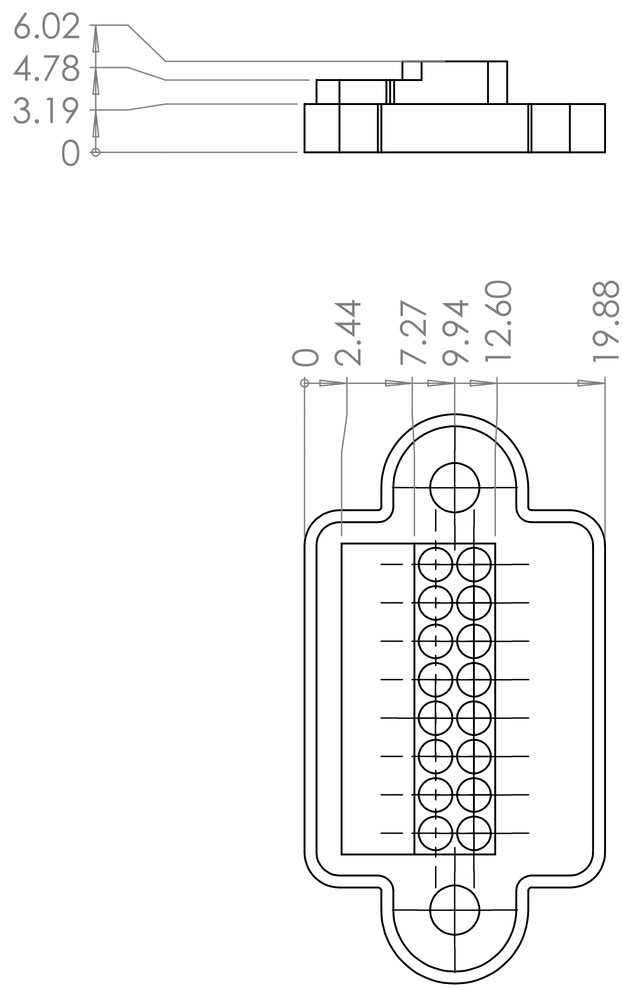
HPRC
WPI AIAA

TITLE:
Runcam Mount

SIZE	DWG. NO.	REV
A	23-2-1-201	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	NG	5/9/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

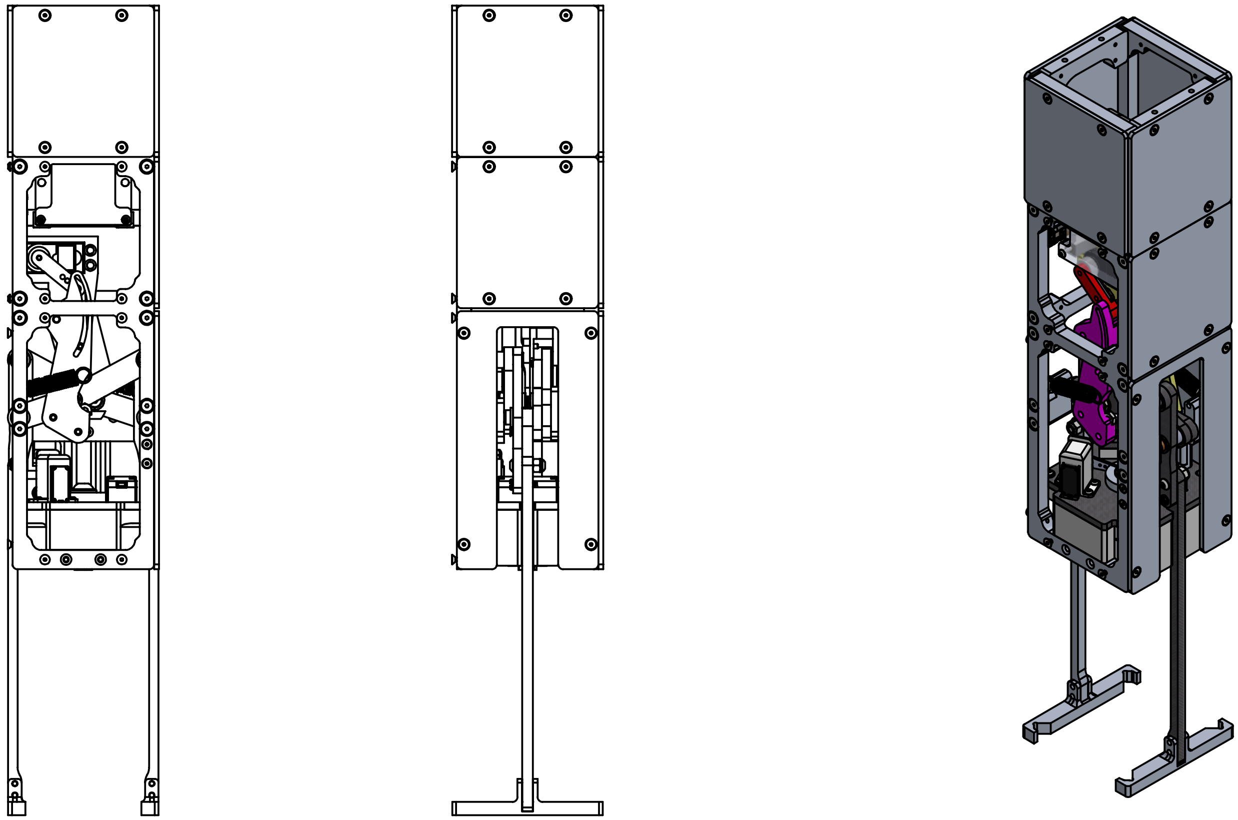
TITLE:

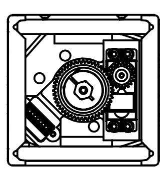
Quadcopter Umbilical Housing

SIZE	DWG. NO.	REV
A	23-2-1-402	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

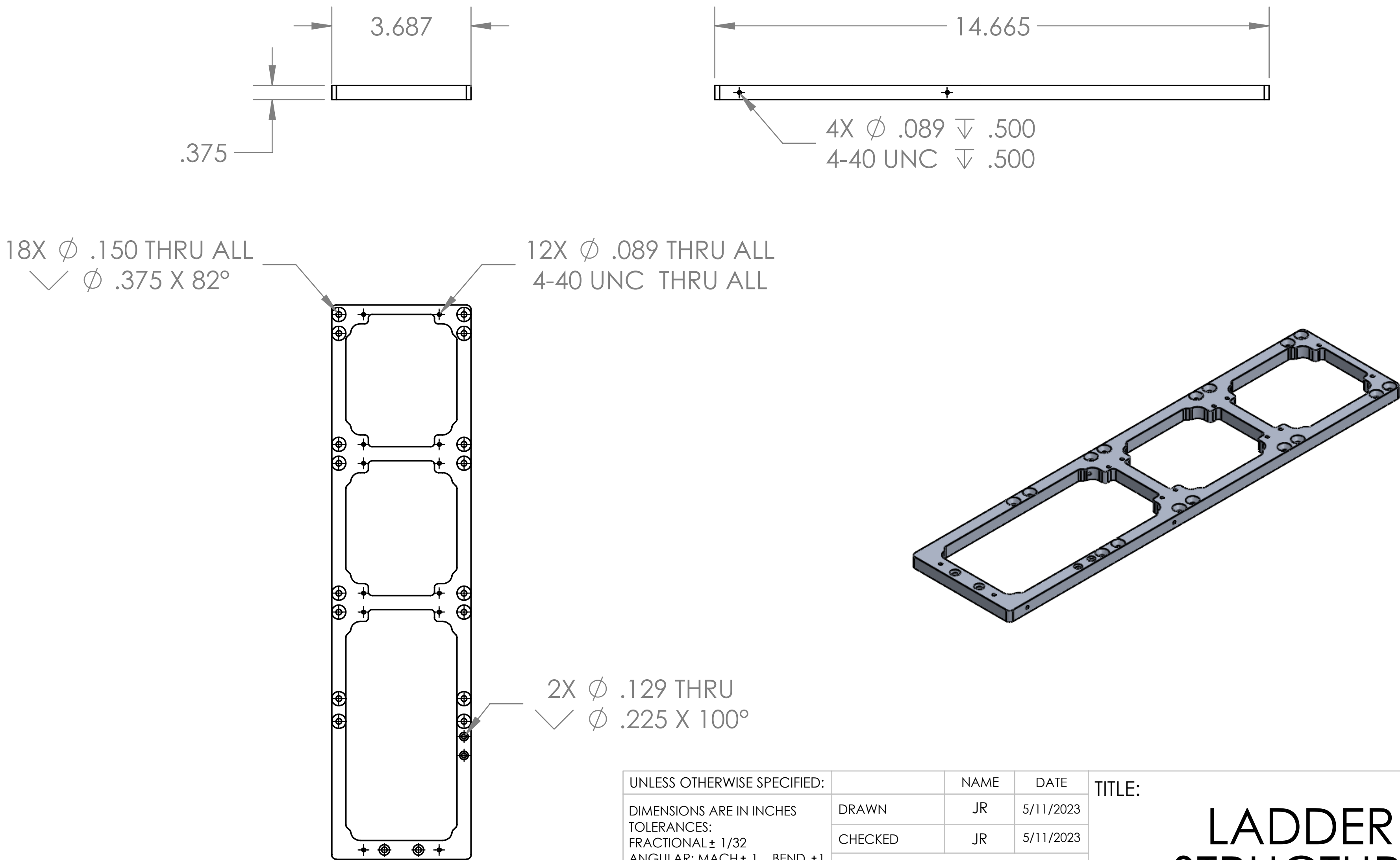
2 1



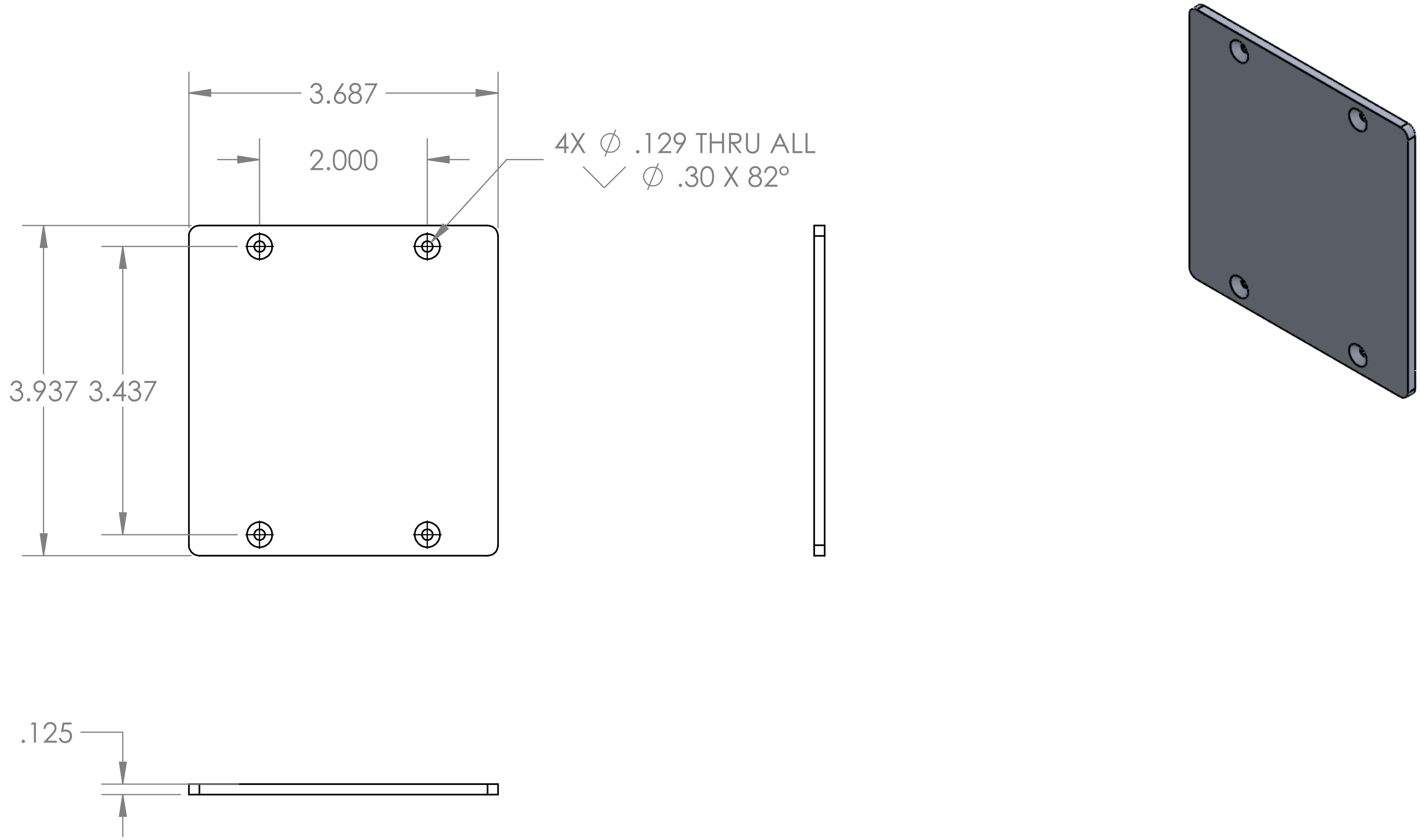


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL **INSERT MATERIAL**			

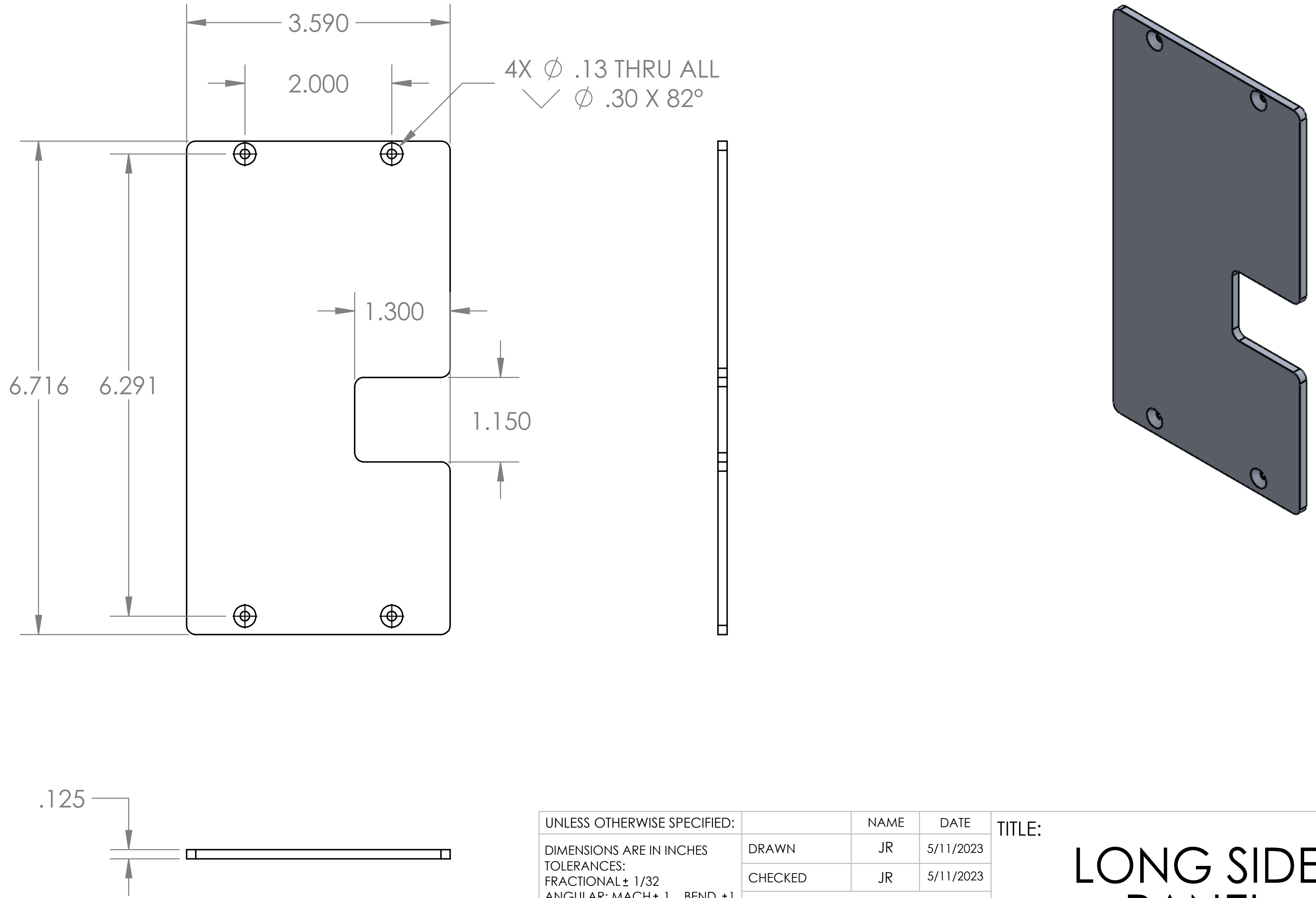
TITLE: RETENTION ASSEMBLY		
SIZE A	DWG. NO. 23-2-2-000	REV
SCALE: 1:5	WEIGHT: 6.335 lb	



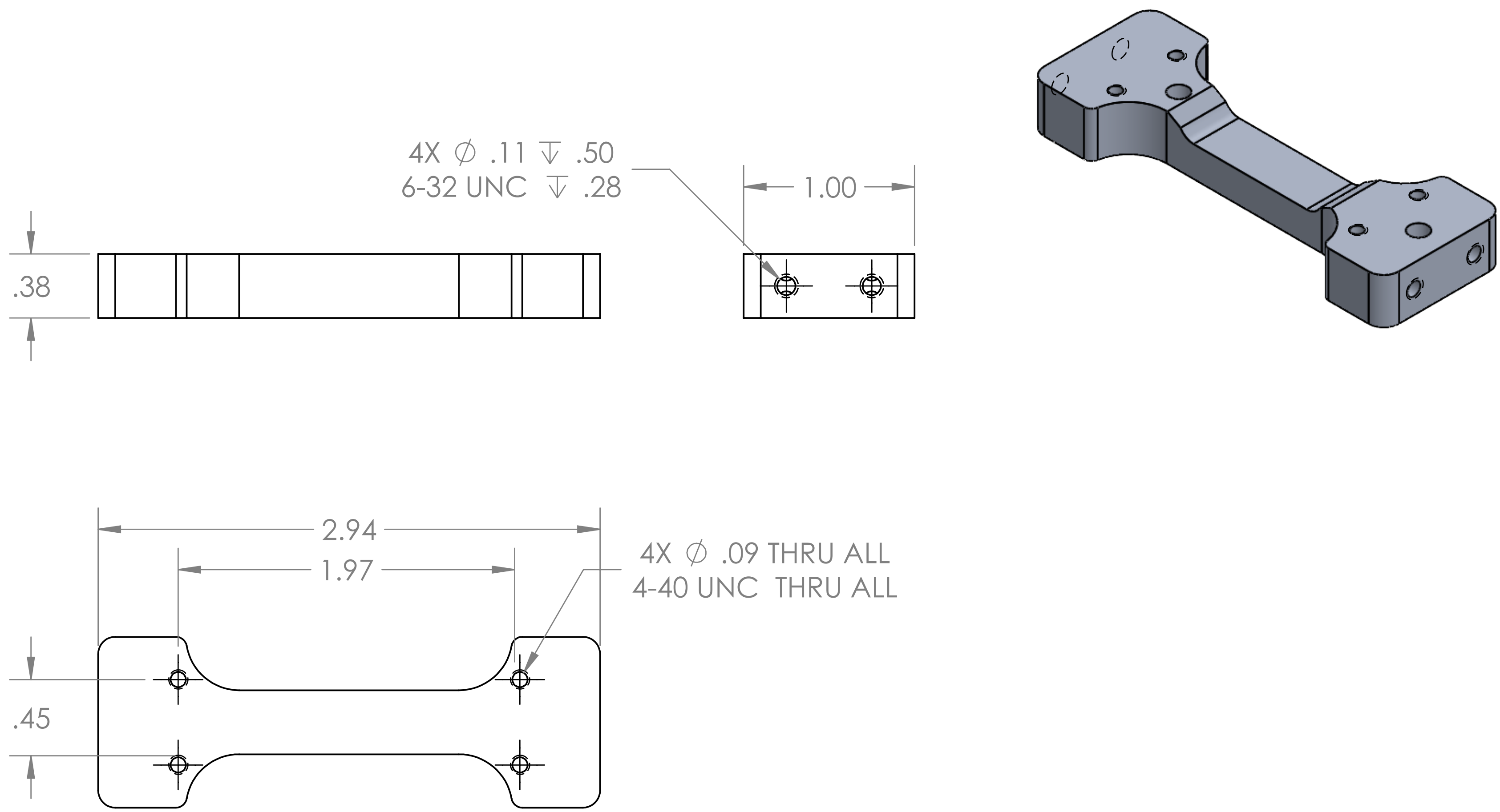
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023	LADDER STRUCTURE
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-2-101 — REV
MATERIAL AL 6061-T6				SCALE: 1:4 — WEIGHT: — SHEET 1 OF 1



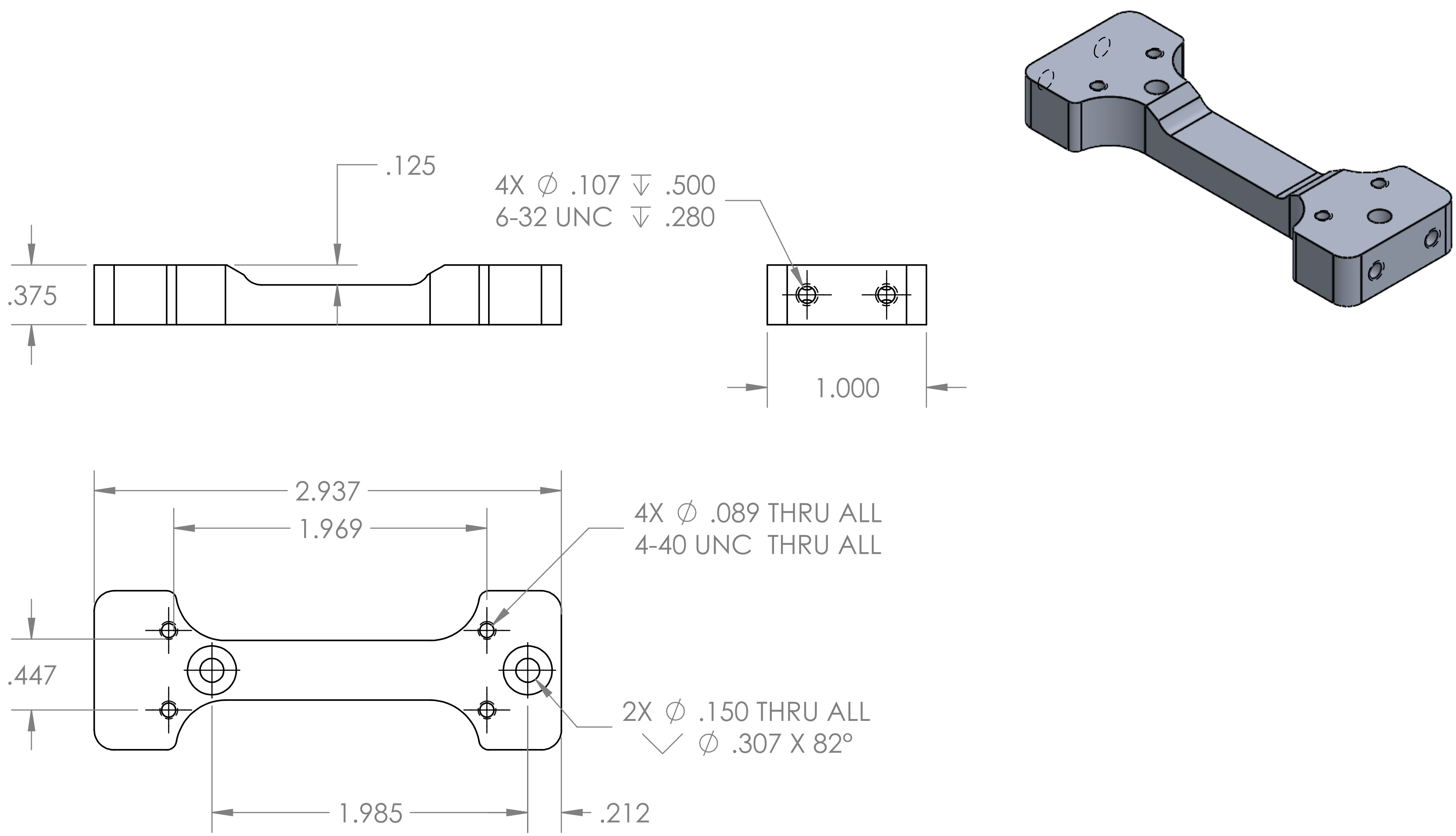
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: 10CM SIDE PANEL			
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023				
	CHECKED	JR	5/11/2023				
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A	DWG. NO. 23-2-2-102		REV
MATERIAL AL 6061-T6				SCALE: 1:2	WEIGHT:	SHEET 1 OF 1	



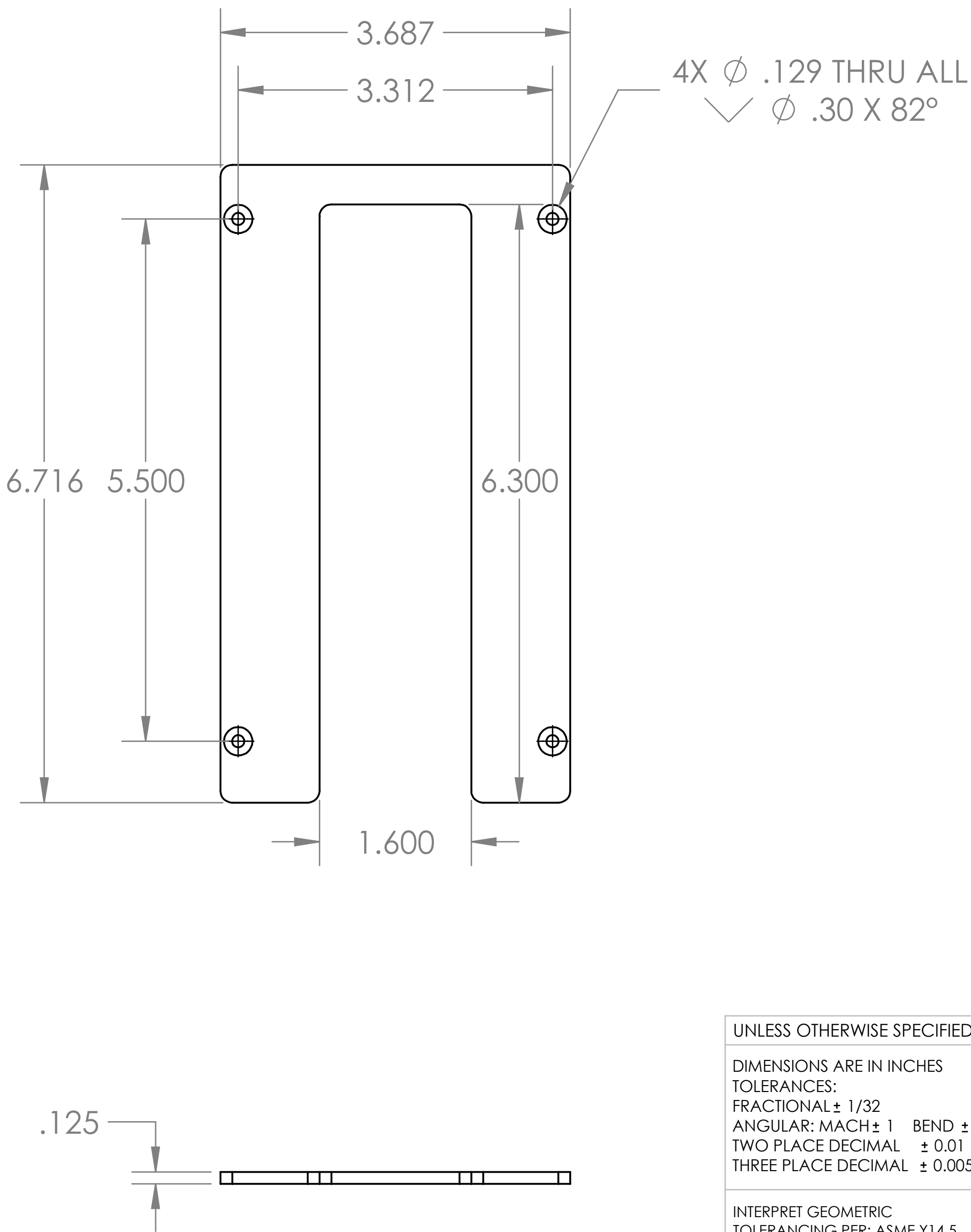
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023	LONG SIDE PANEL
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A / DWG. NO. 23-2-2-103 / REV
MATERIAL AL 6061-T6				SCALE: 1:2 / WEIGHT: / SHEET 1 OF 1

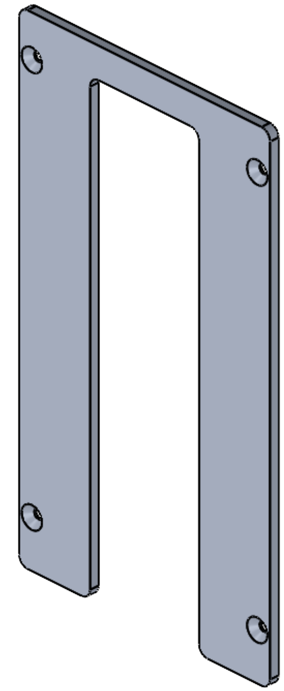


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: CROSS MEMBER
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-2-104 — REV
MATERIAL AL 6061-T6				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: CROSS MEMBER FOR BATTERY
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-2-105 — REV
MATERIAL AL 6061-T6				SCALE: 1:1 — WEIGHT: — SHEET 1 OF 1



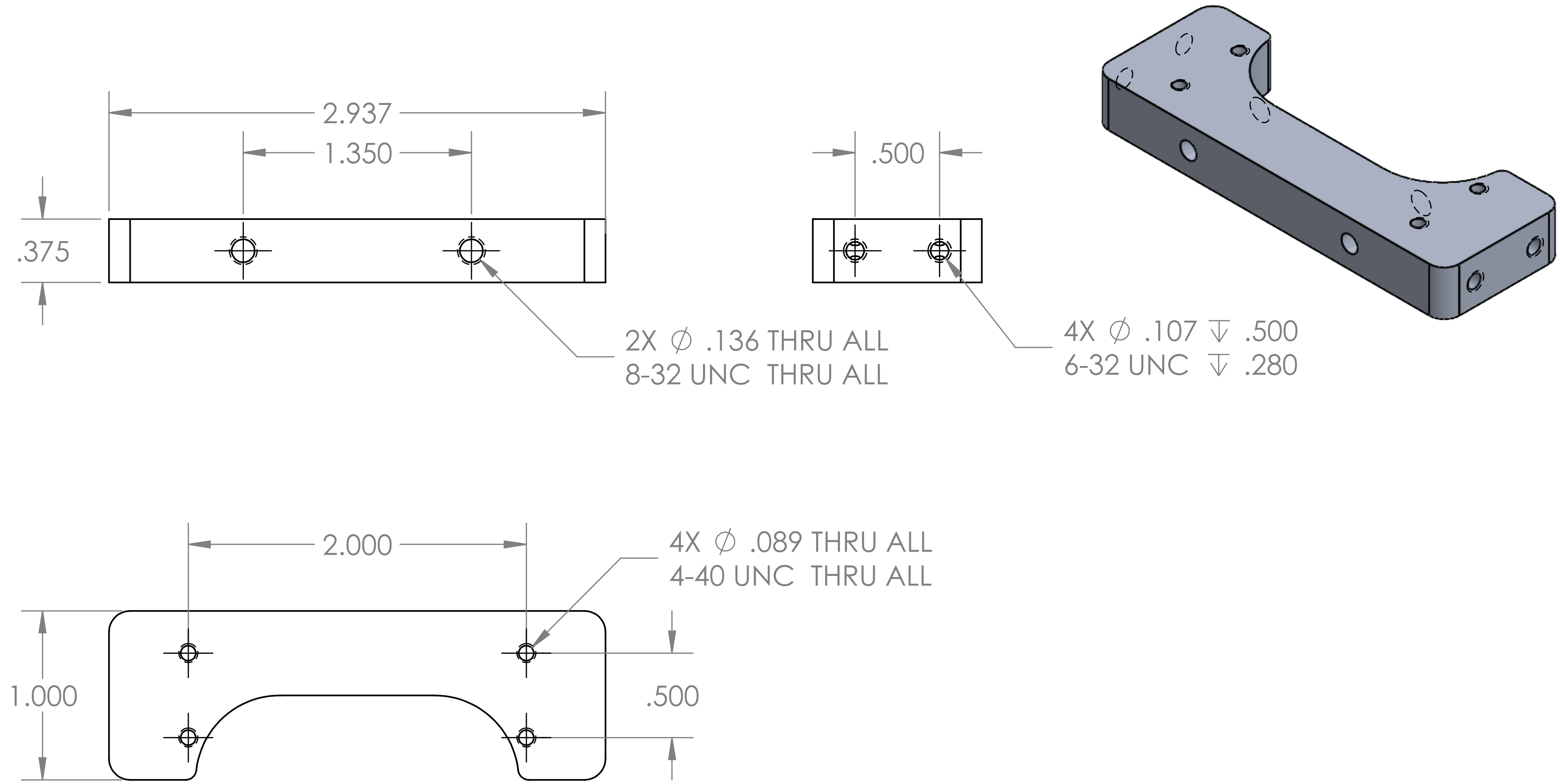


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	JR	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL PC			

TITLE:

LONG SIDE PANEL CUTOUT

SIZE	DWG. NO.	REV
A	23-2-2-107	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
AL 6061-T6

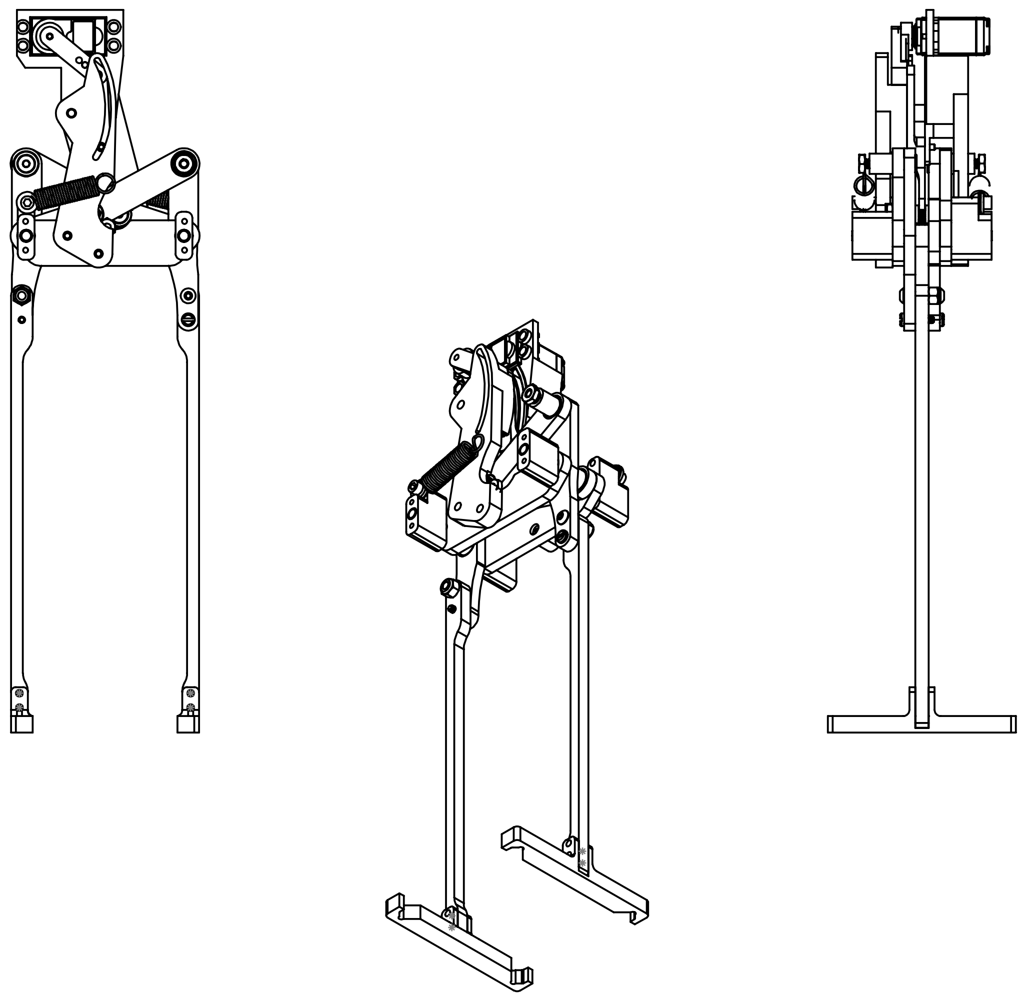
	NAME	DATE
DRAWN	JR	5/11/2023
CHECKED	JR	5/11/2023

HPRC WPI AIAA

TITLE:
NOSECONE ADAPTER CROSS MEMBER

SIZE A | DWG. NO. 23-2-2-108 | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



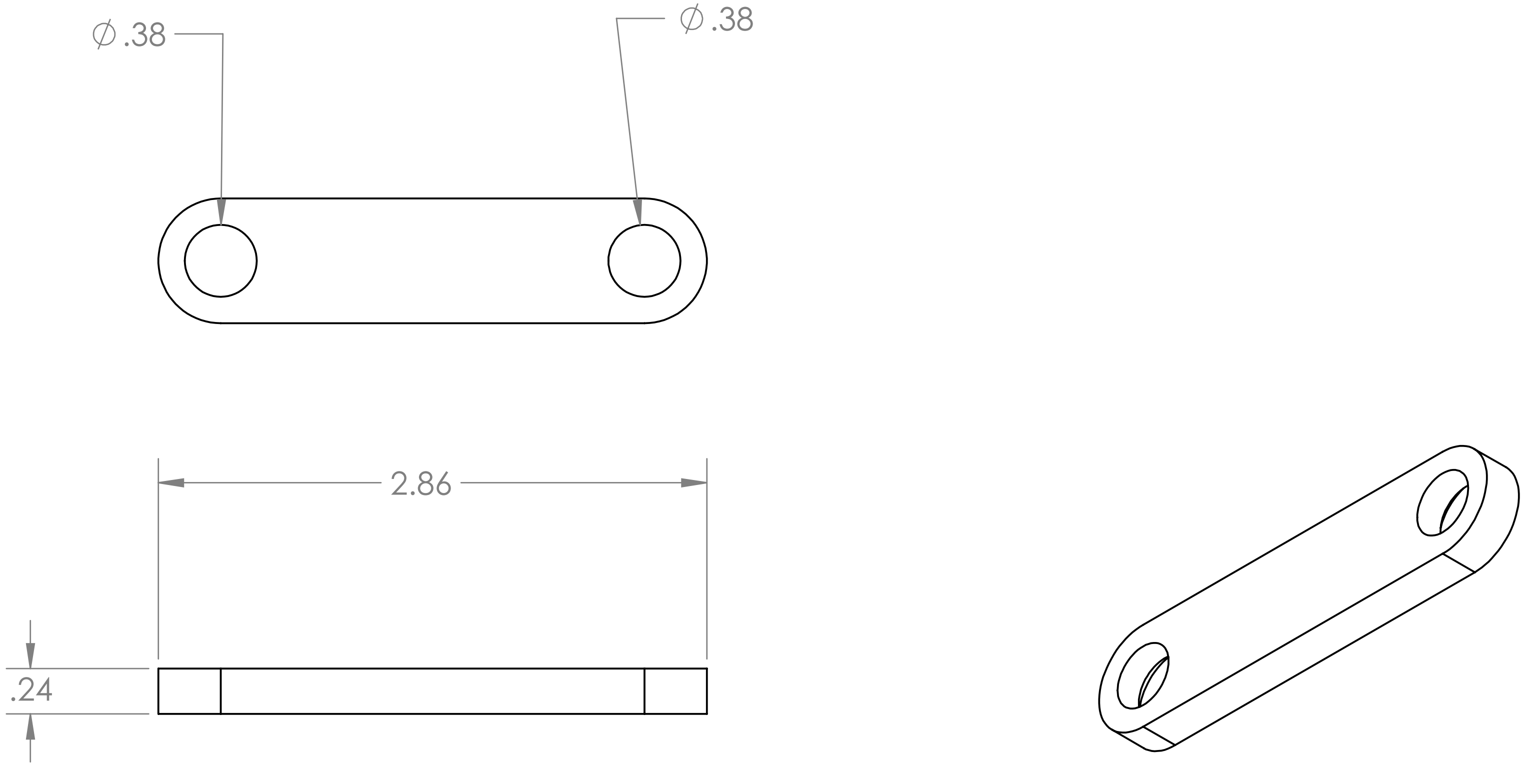
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL			

HPRC WPI AIAA

TITLE: T-Bar

SIZE	DWG. NO.	REV
A	23-2-2-200	

SCALE: 1:8 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
Carbon Fiber

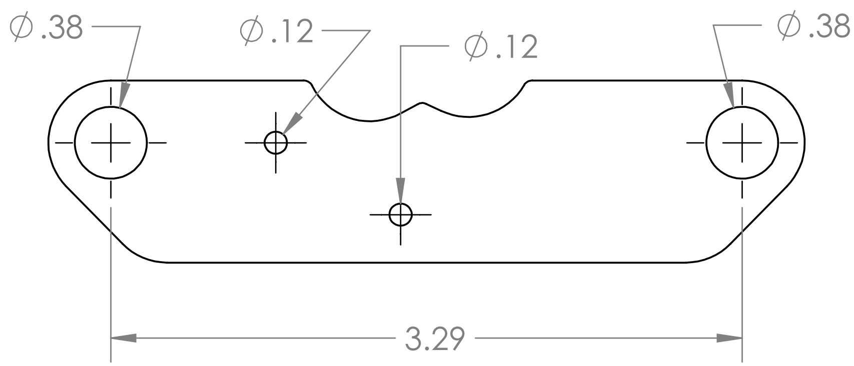
	NAME	DATE
DRAWN	HC	5/10/2022
CHECKED	TMO	5/12/2022

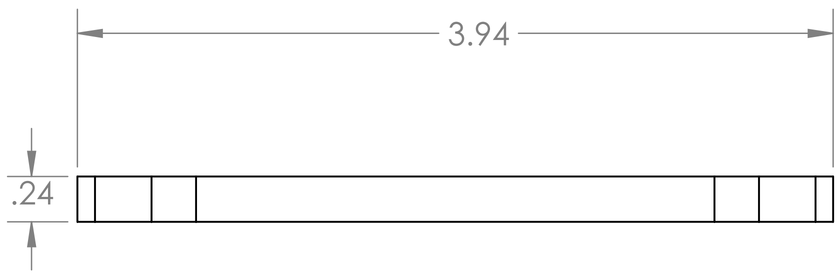
HPRC WPI AIAA

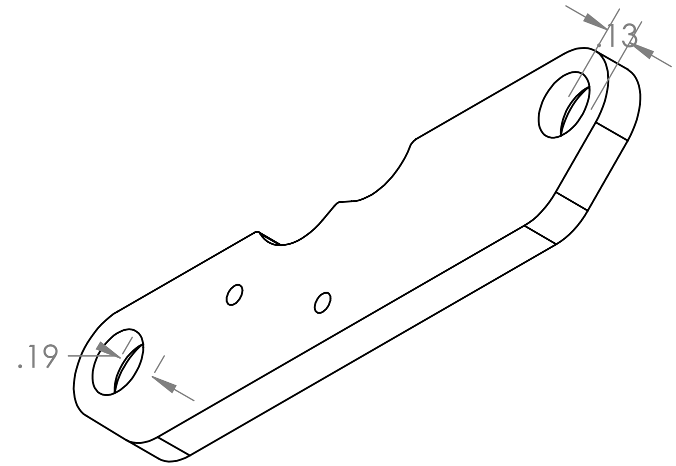
TITLE:
Coupler Link

SIZE	DWG. NO.	REV
A	23-2-2-201	

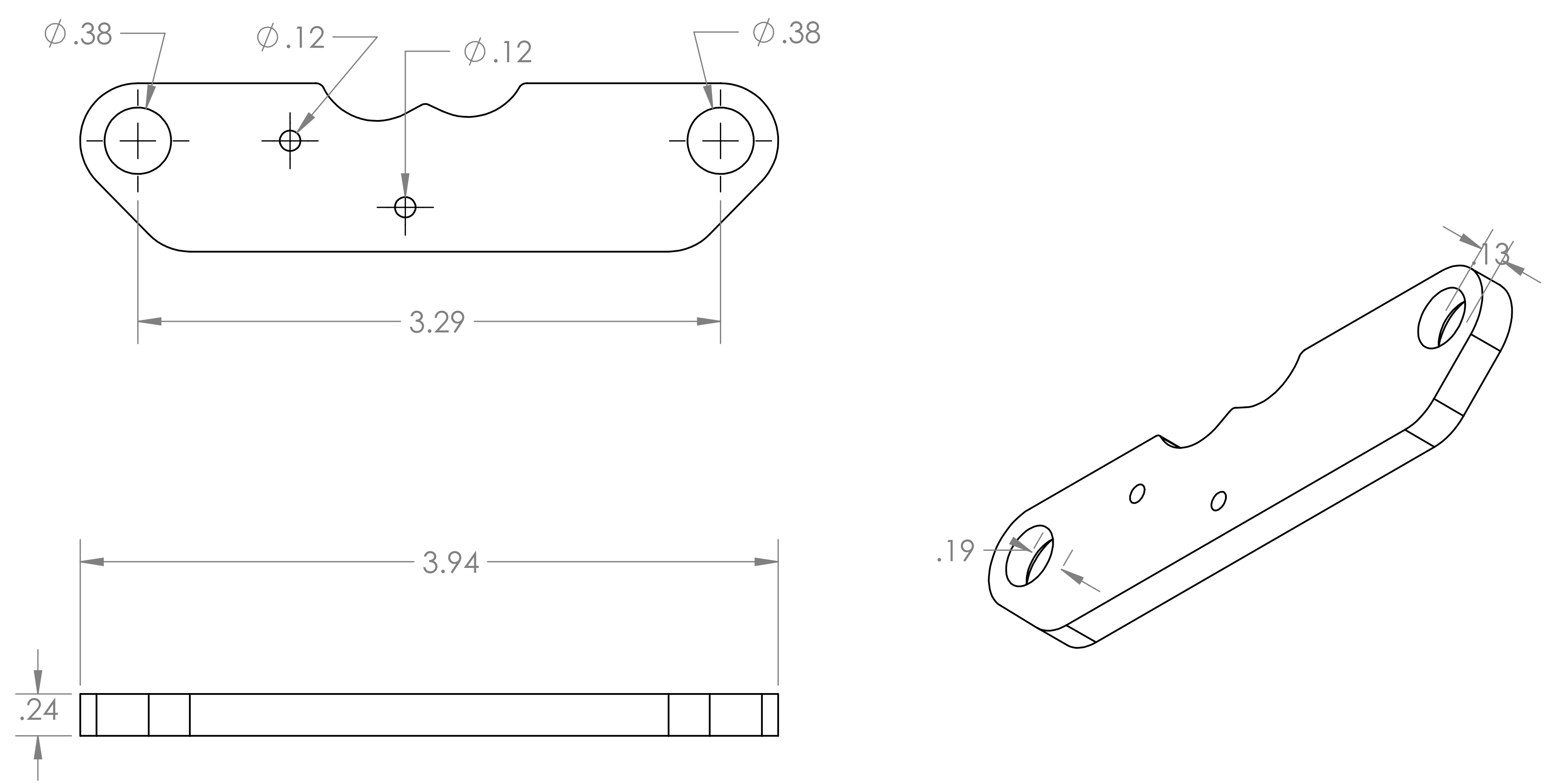
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



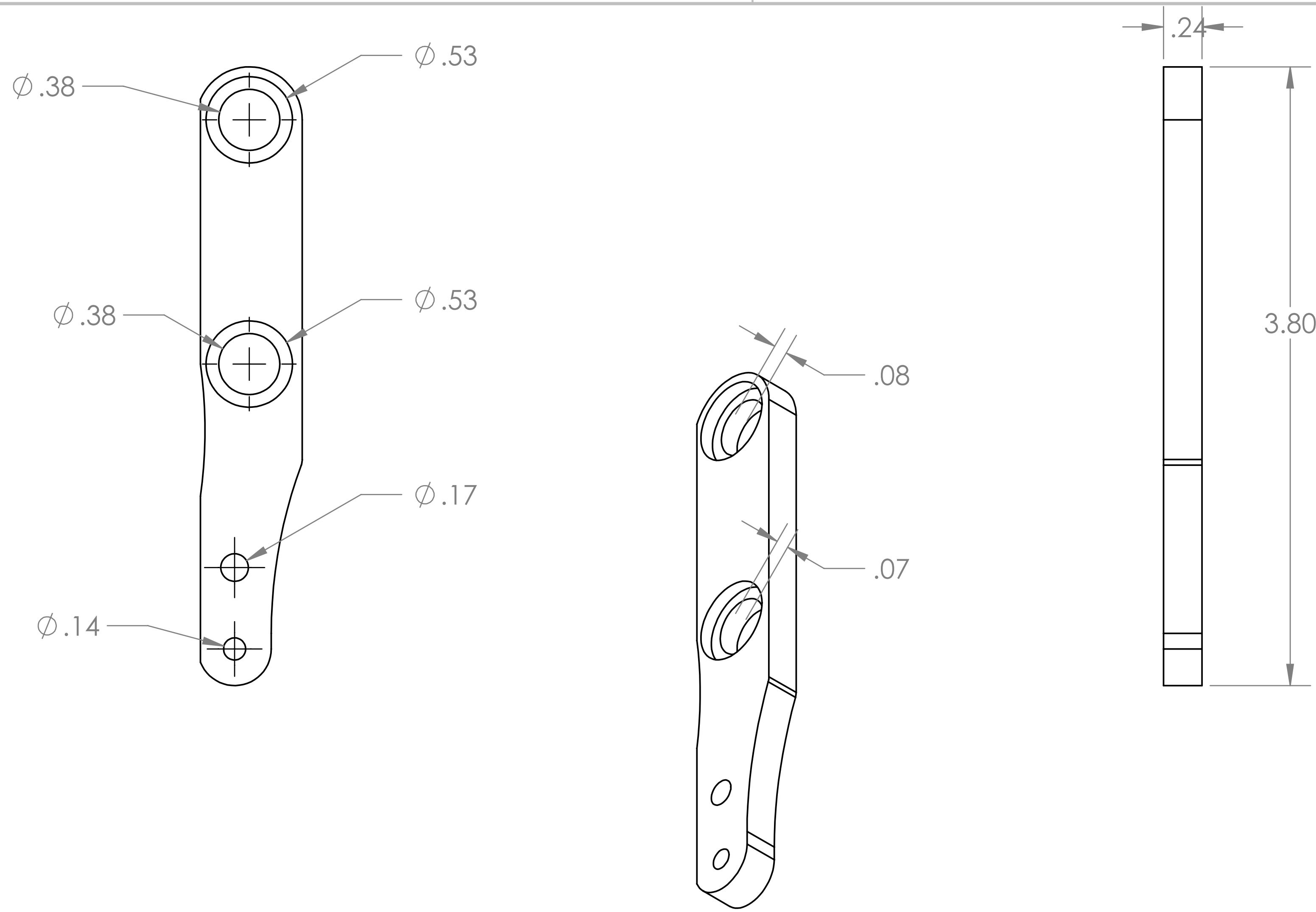




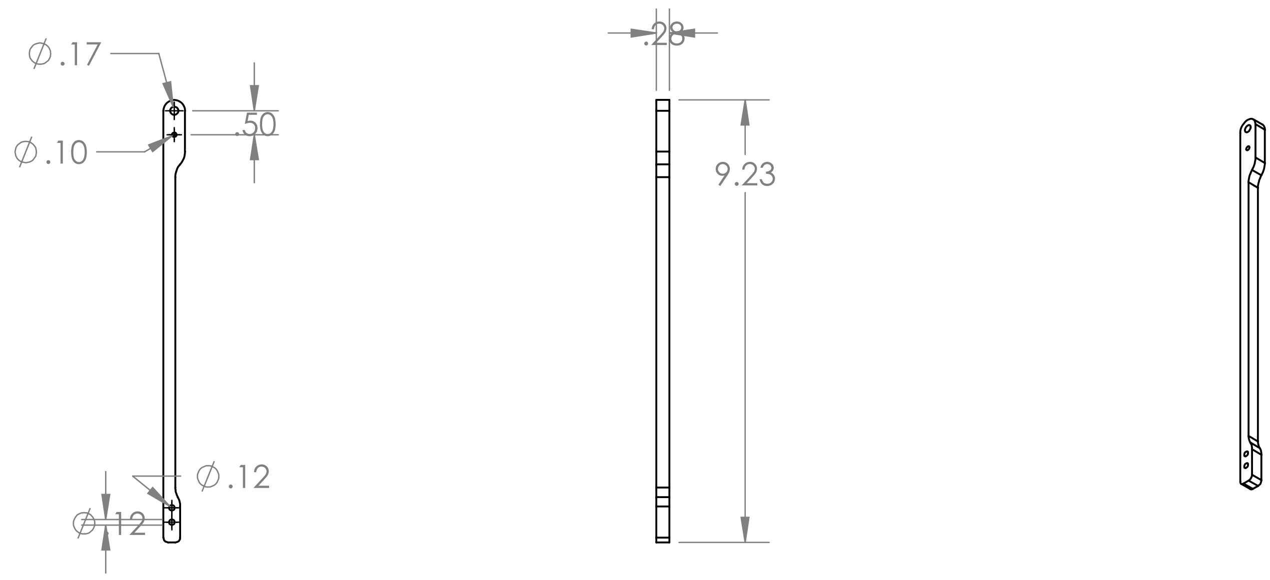
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Ground Link
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022	
	CHECKED	TMO	5/12/2022	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-202 · REV
MATERIAL Carbon Fiber				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: LOWER BODY TUBE		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	**INITIALS**	5/10/2022			
	CHECKED	TMO	5/12/2022			
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A	DWG. NO. 23-2-2-203	REV
MATERIAL **INSERT MATERIAL**				SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: T-Bar Link
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022	
	CHECKED	TMO	5/12/2022	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A / DWG. NO. 23-2-2-206 / REV
MATERIAL Carbon Fiber				SCALE: 1:1 / WEIGHT: / SHEET 1 OF 1

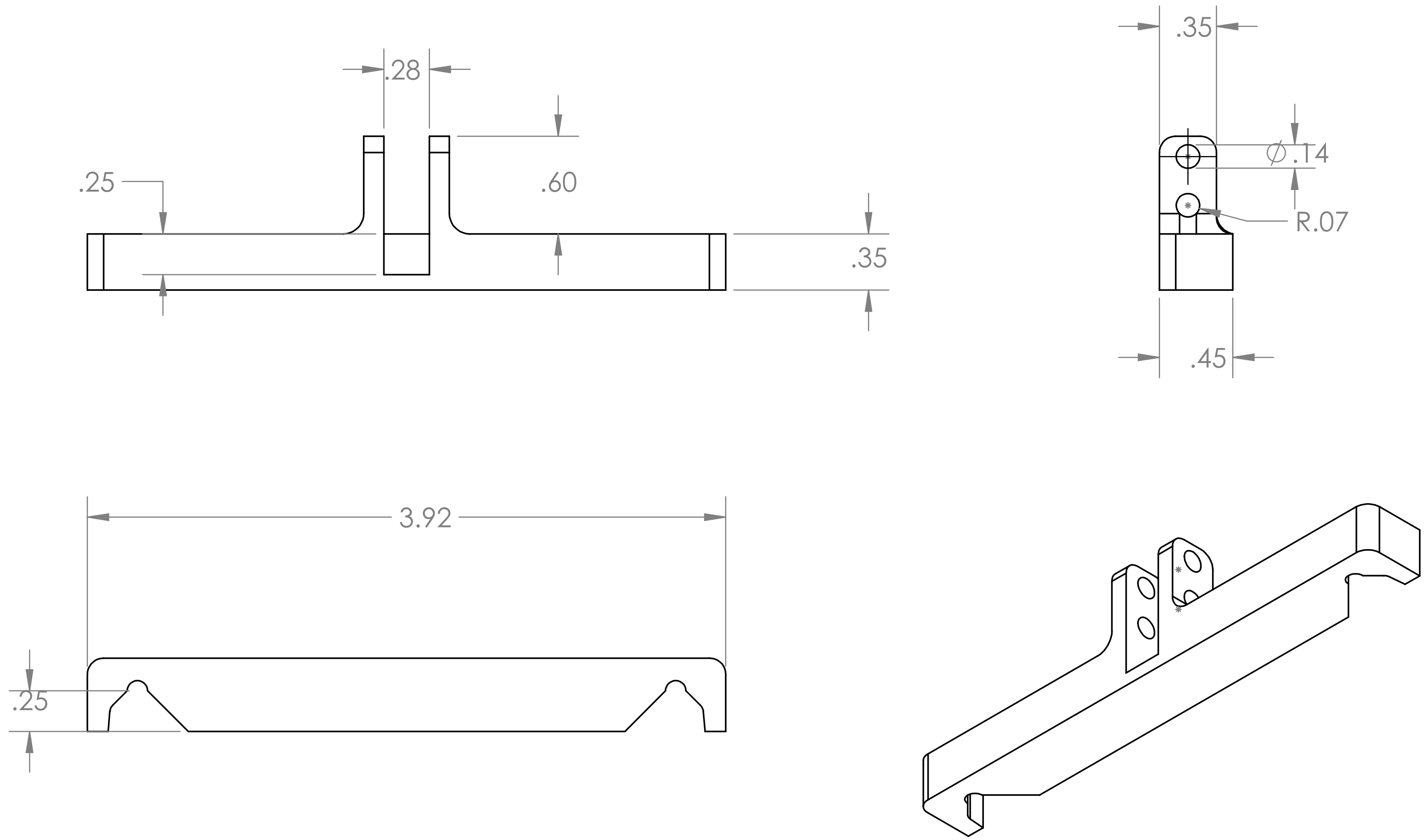


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Carbon Fiber			

HPRC WPI AIAA

TITLE: T-Bar Vertical Extender

SIZE	DWG. NO.	REV
A	23-2-2-207	
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

TITLE:

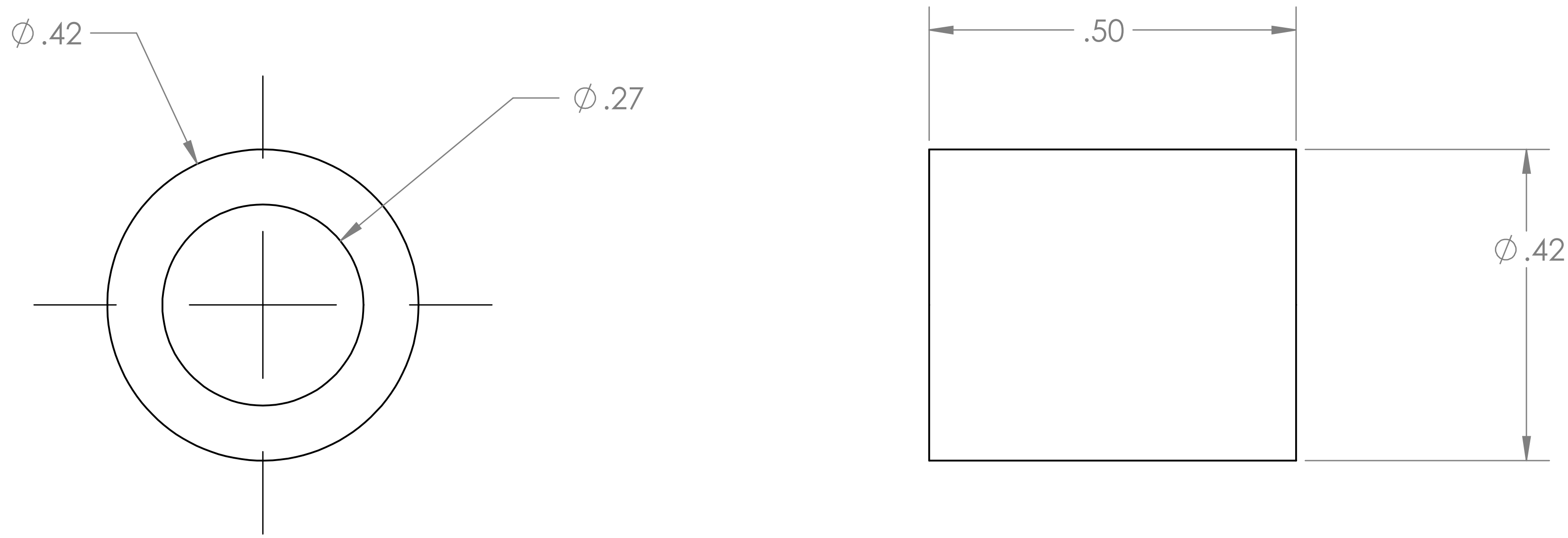
T-Bar Horizontal Extender

SIZE	DWG. NO.	REV
A	23-2-2-208	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

2 | 1

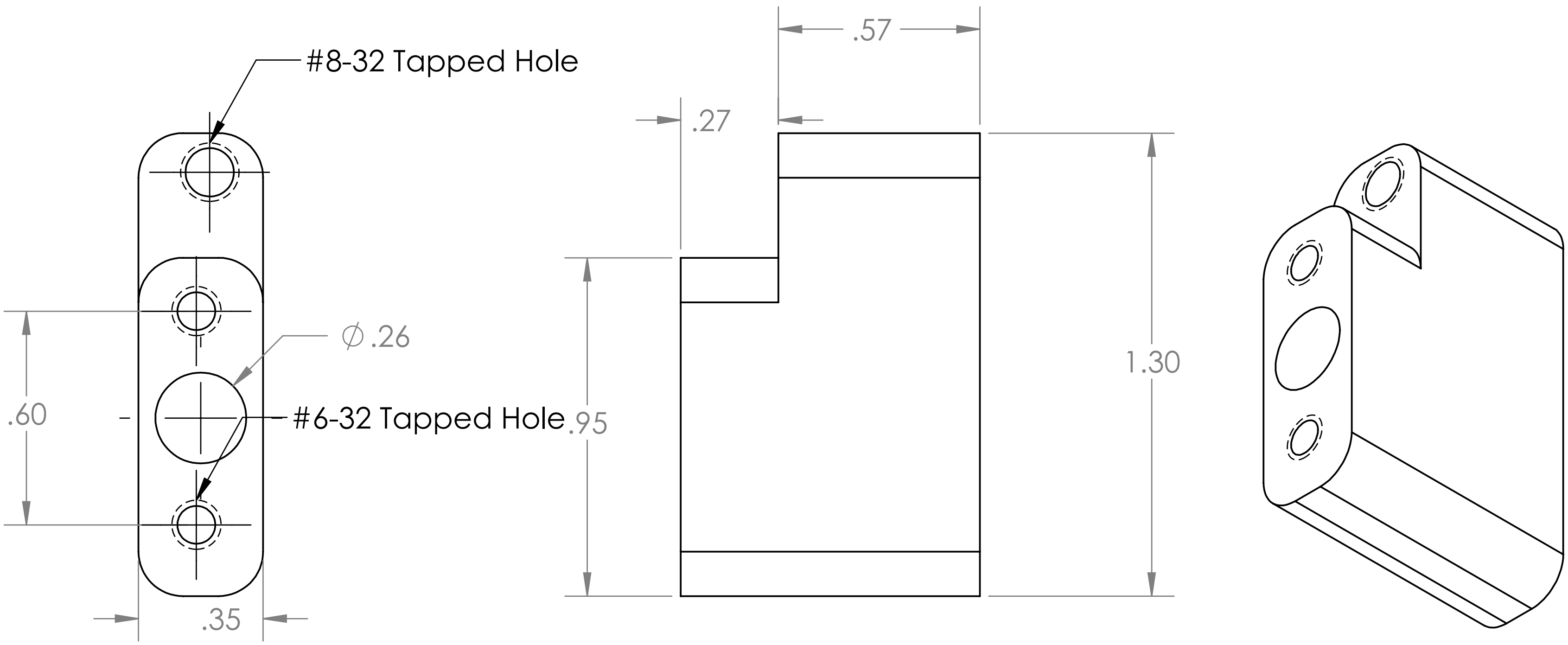
B



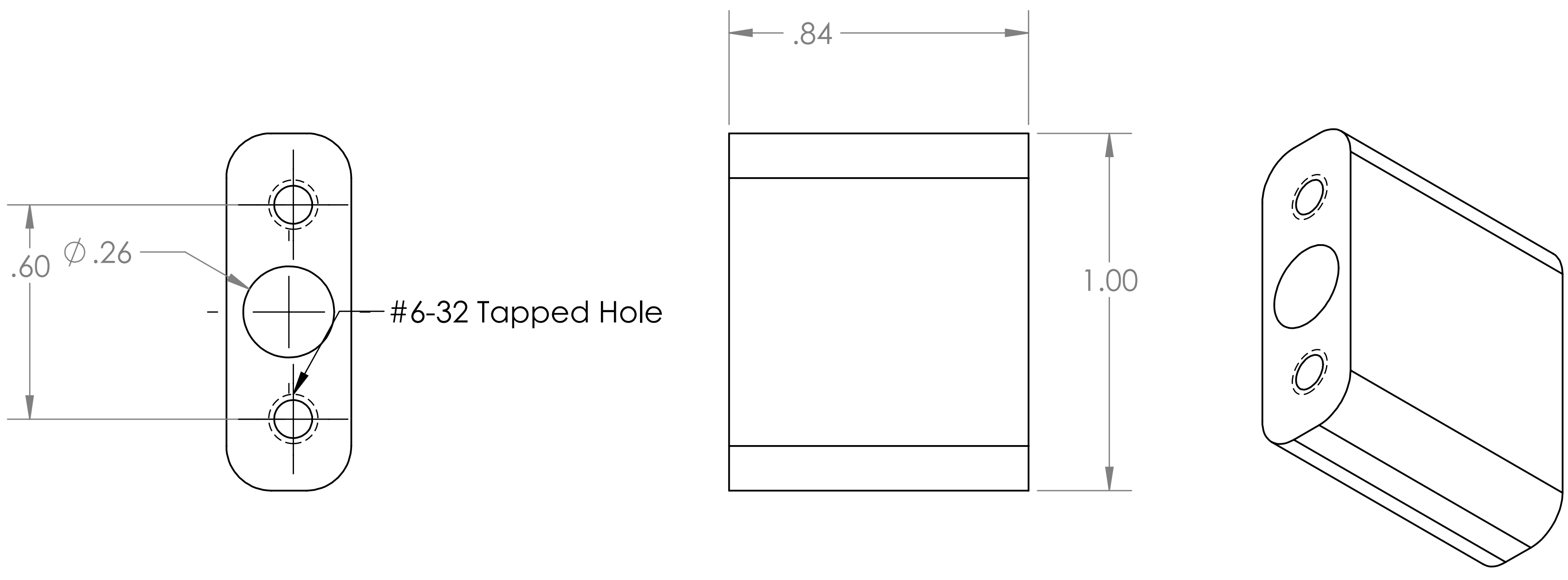
A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022	Spacer
	CHECKED	TMO	5/12/2022	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-209 · REV
MATERIAL Polycarbonate				SCALE: 4:1 · WEIGHT: · SHEET 1 OF 1

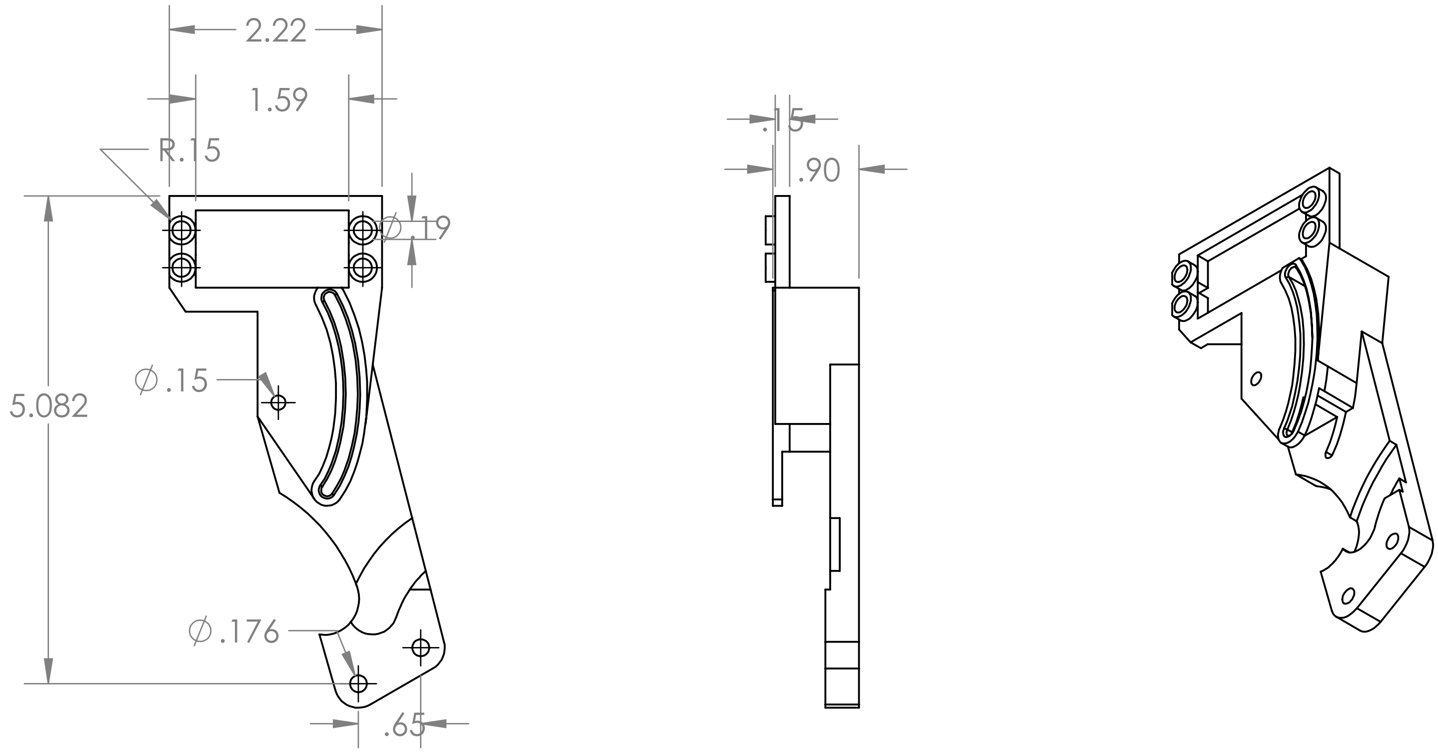
2 | 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: T-Bar Spacer Left	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022		
	CHECKED	TMO	5/12/2022		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A	DWG. NO. 23-2-2-210 — REV
MATERIAL Aluminum 6061				SCALE: 2:1	WEIGHT: — SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: T-Bar Spacer Right	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022		
	CHECKED	TMO	5/12/2022		
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A	DWG. NO. 23-2-2-210 / REV
MATERIAL Aluminum 6061				SCALE: 2:1	WEIGHT: / SHEET 1 OF 1



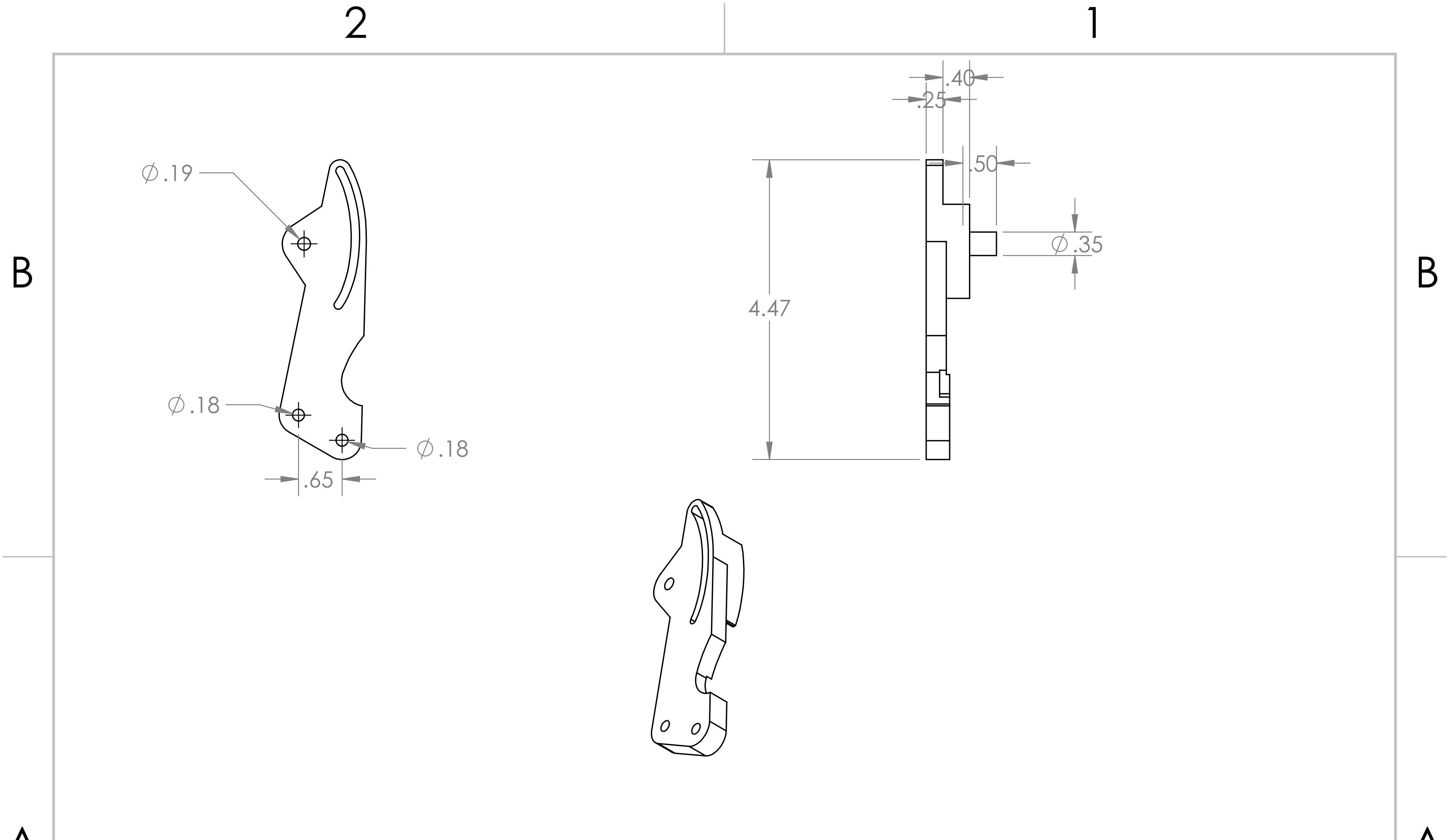
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA		
MATERIAL Polycarbonate			

TITLE:

Servo Base 1

SIZE	DWG. NO.	REV
A	23-2-2-218	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



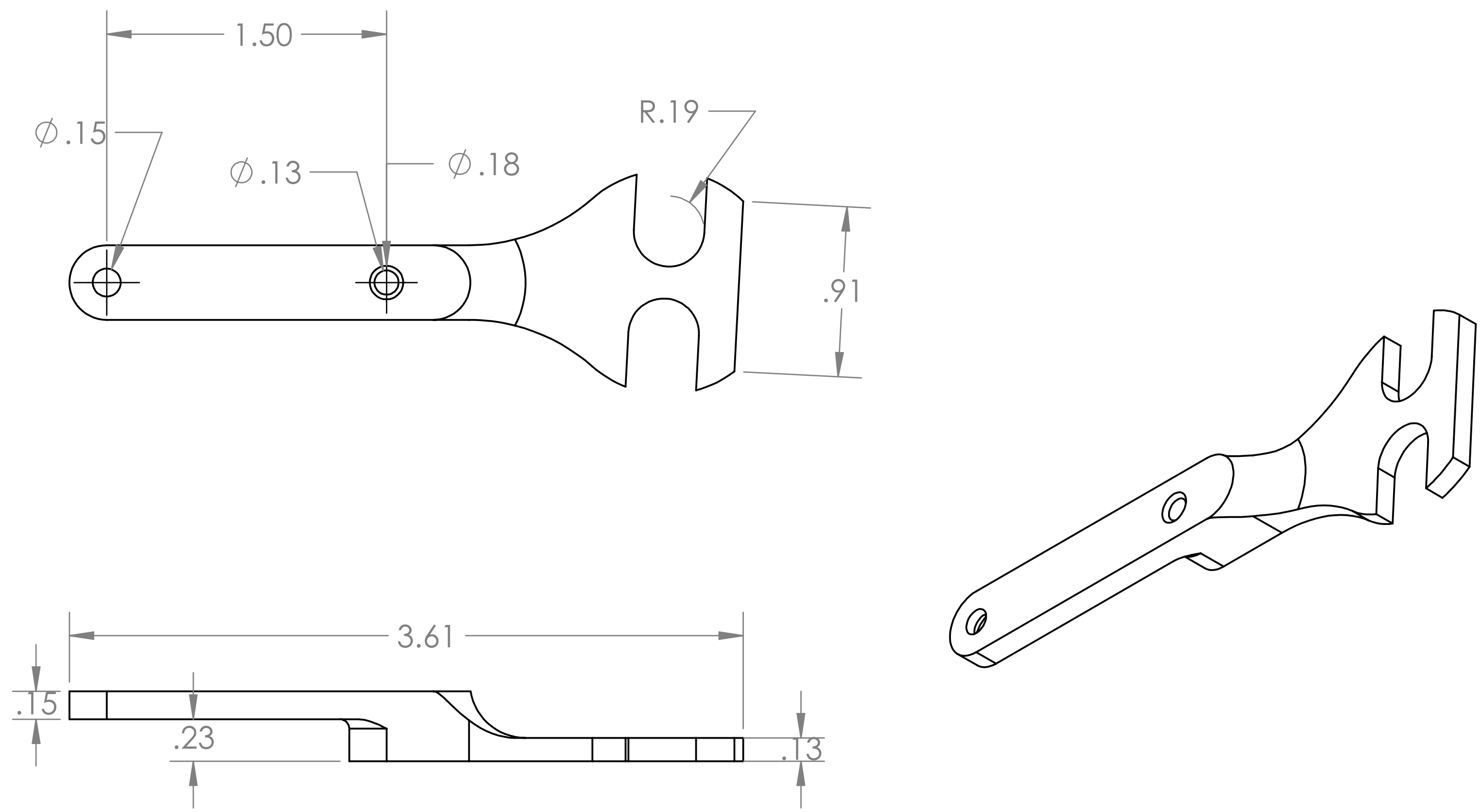
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022
	CHECKED	TMO	5/12/2022
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

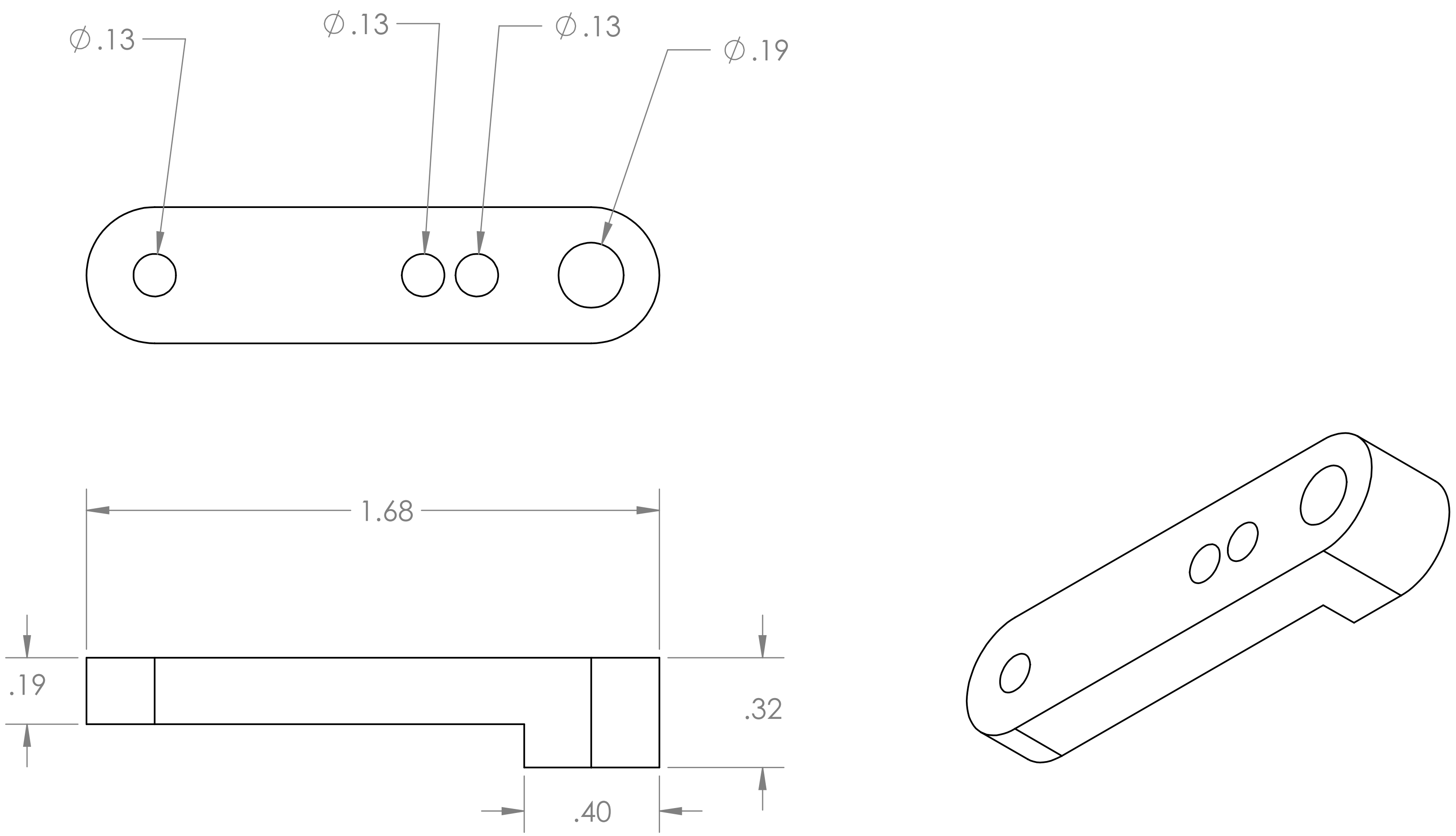
TITLE: Servo Base 2

SIZE	DWG. NO.	REV
A	23-2-2-219	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Inverter 2
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	HC	5/10/2022	
	CHECKED	TMO	5/12/2022	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A DWG. NO. 23-2-2-220 REV
MATERIAL Polycarbonate				SCALE: 1:1 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
INSERT MATERIAL

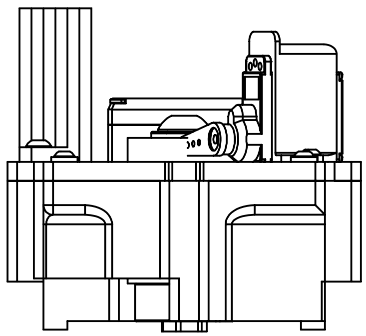
	NAME	DATE
DRAWN	HC	5/10/2022
CHECKED	TMO	5/12/2022

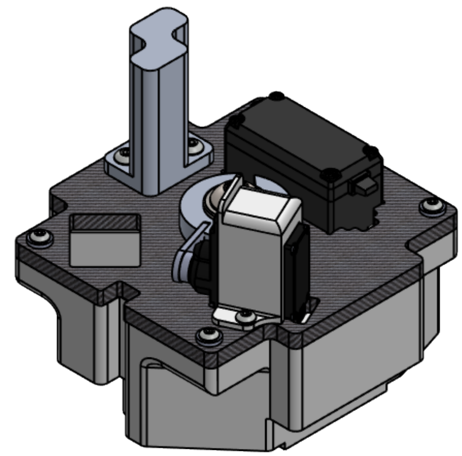
HPRC WPI AIAA

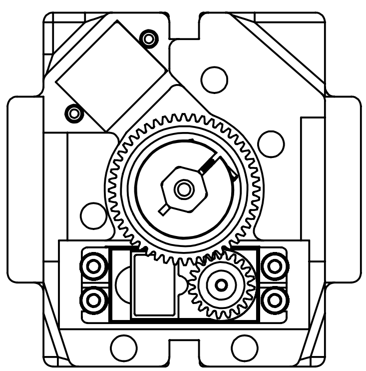
TITLE: Servo Horn

SIZE A | DWG. NO. 23-2-2-221 | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

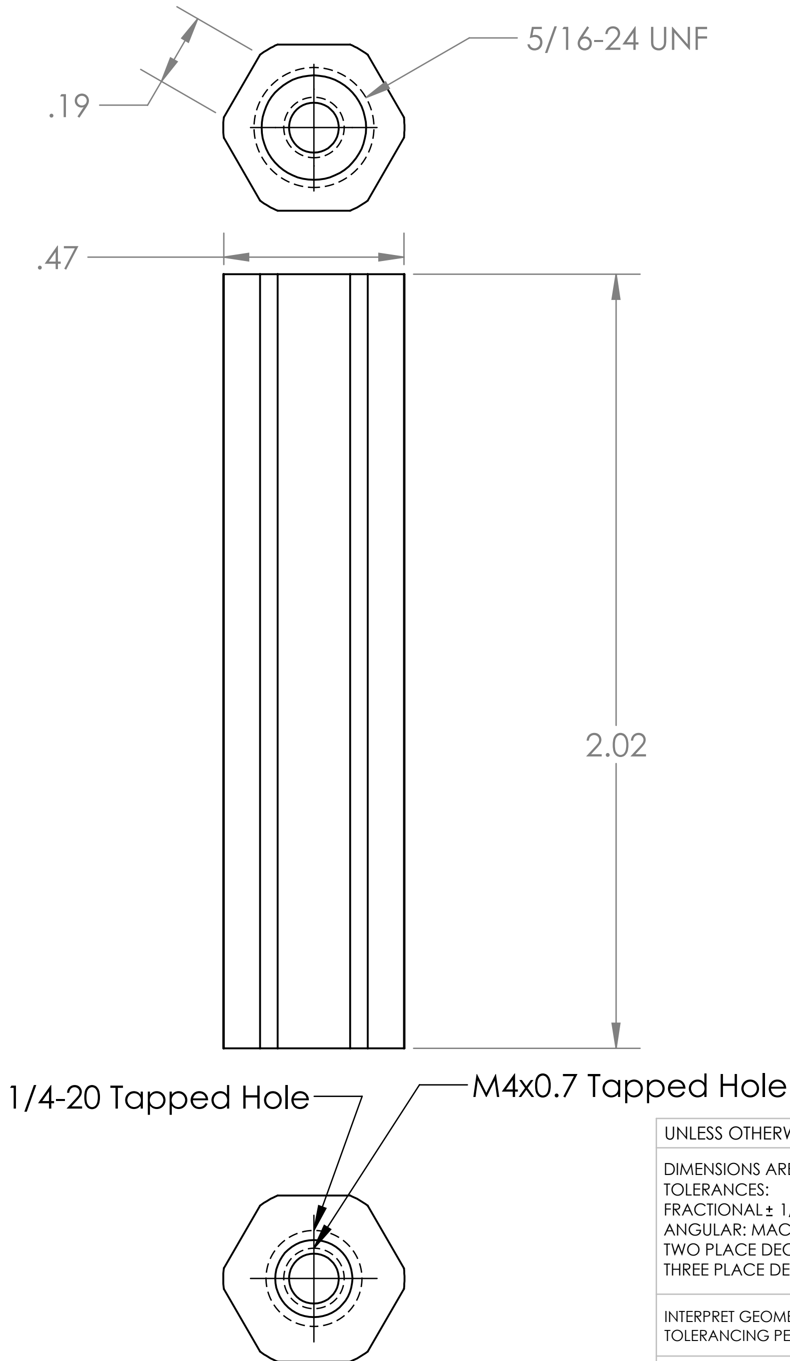


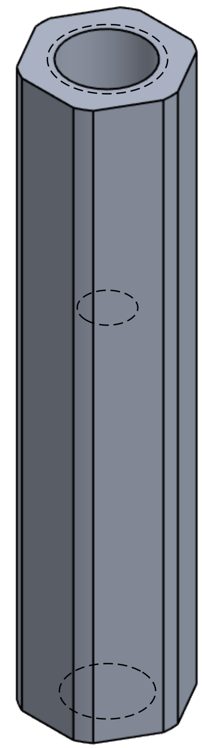




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: LOCKING SCREW ASSEMBLY
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023	
	CHECKED	JR	5/10/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-2-300 — REV
MATERIAL **INSERT MATERIAL**				SCALE: 1:2 — WEIGHT: 0.86 lb — SHEET 1 OF 1

2 | 1



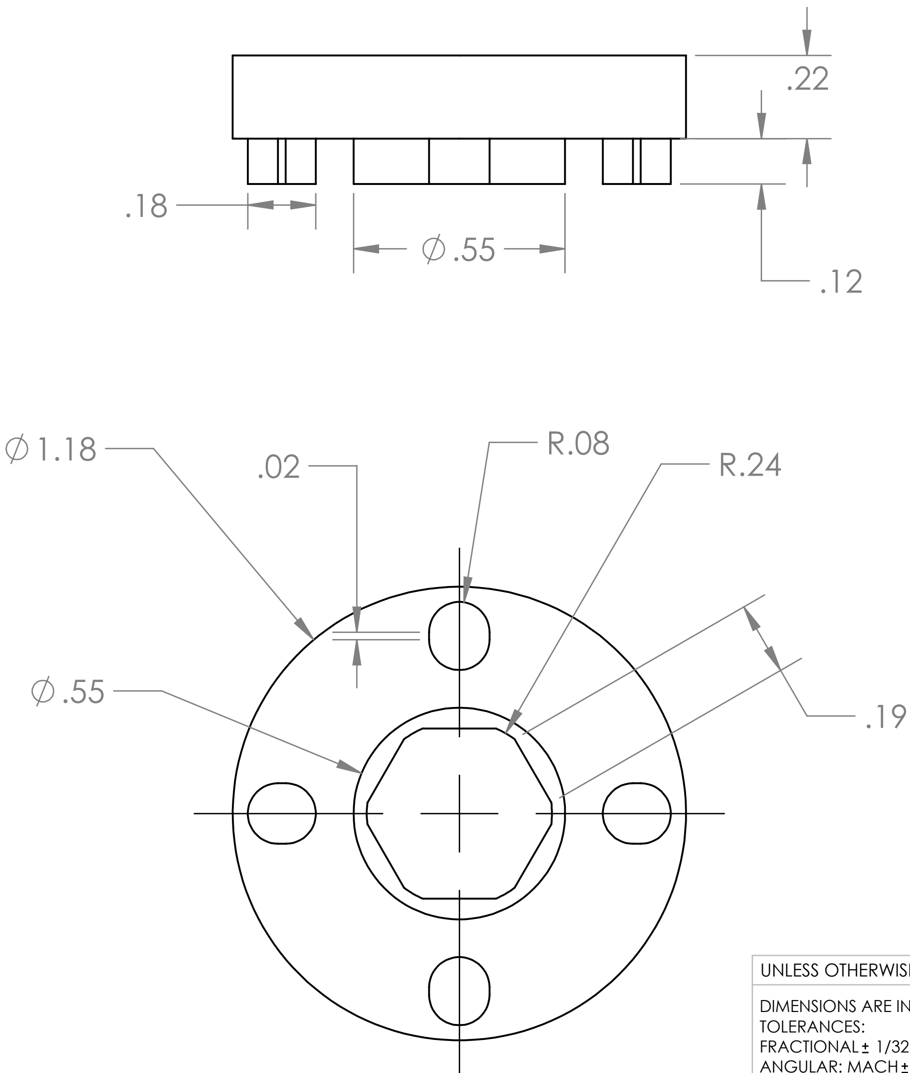


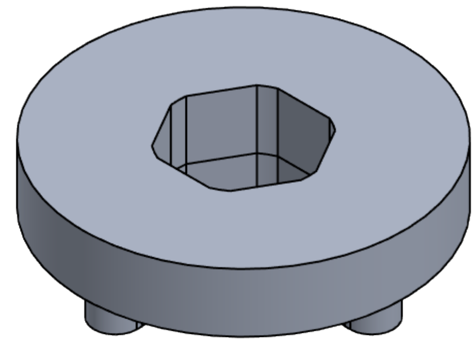
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA		
MATERIAL Aluminum 6061-T6			

TITLE:

CUSTOM REX SHAFT

SIZE	DWG. NO.	REV
A	23-2-2-301	
SCALE: 2:1	WEIGHT: 0.024 lb	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061-T6

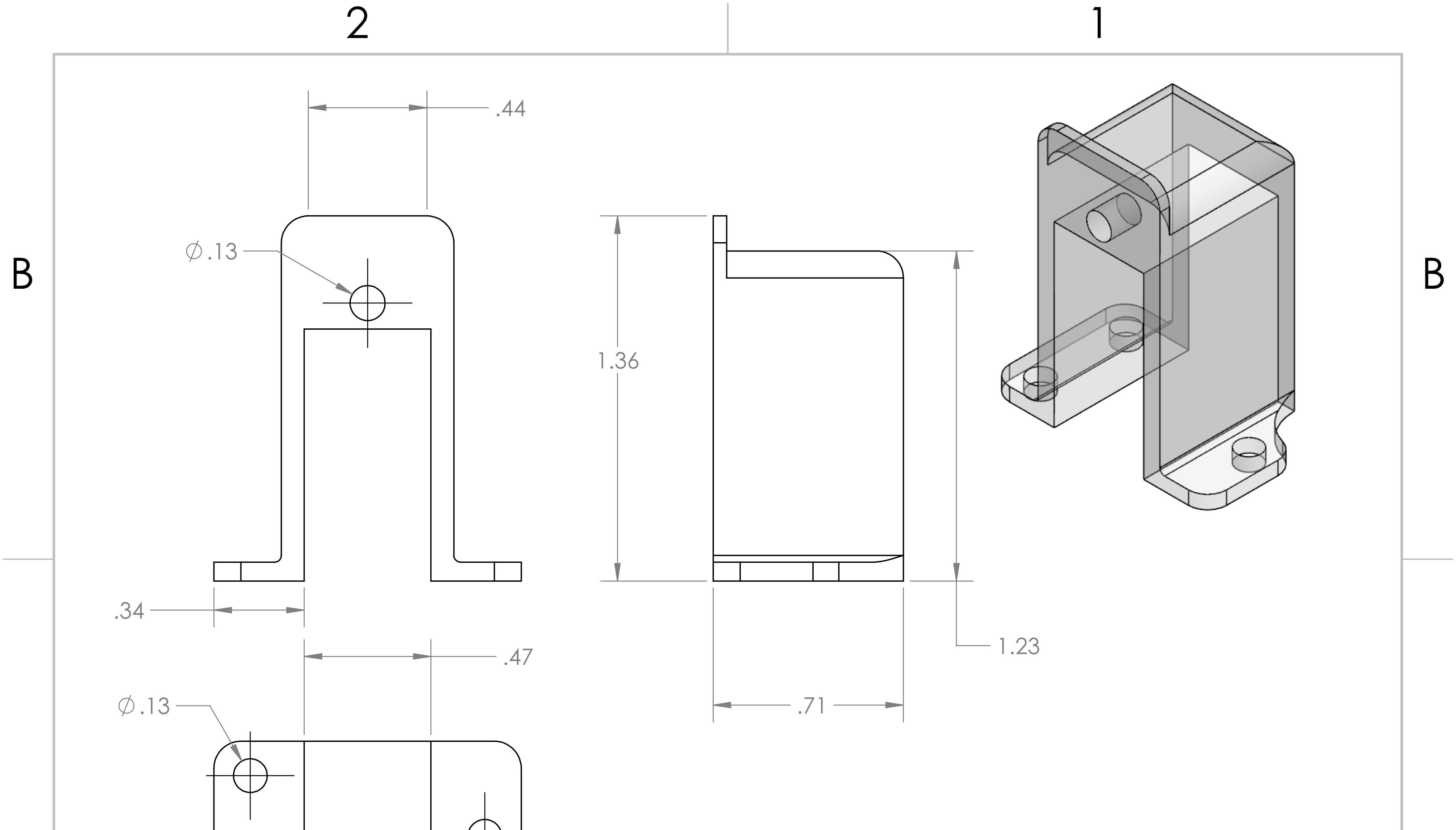
	NAME	DATE
DRAWN	LE	5/10/2023
CHECKED	JR	5/10/2023

HPRC WPI AIAA

TITLE:
CUSTOM GEAR HUB

SIZE A | DWG. NO. 23-2-2-302 | REV

SCALE: 2:1 | WEIGHT: 0.0214 lb | SHEET 1 OF 1



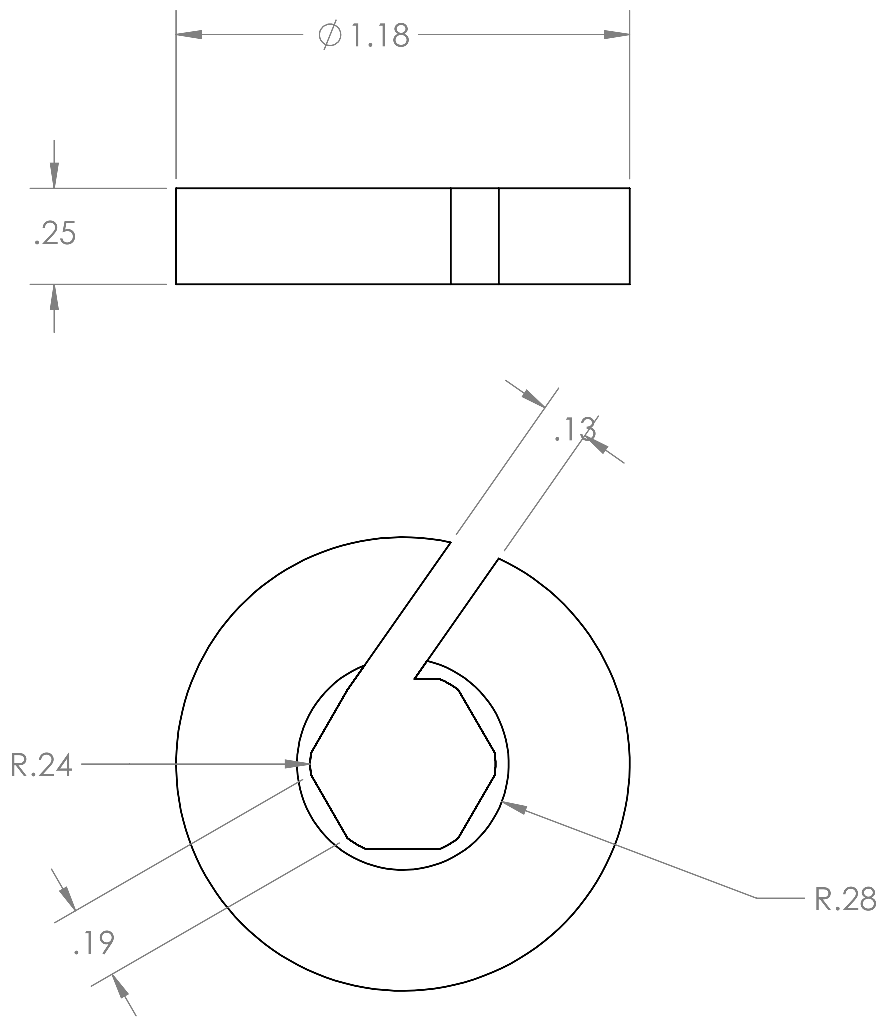
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

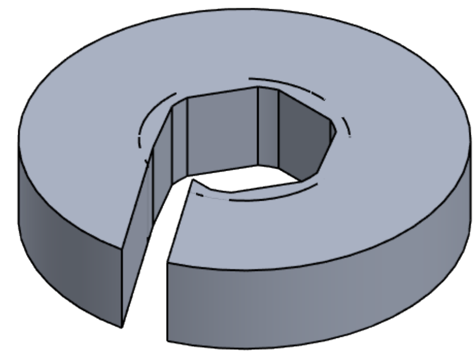
HPRC WPI AIAA

TITLE:

LOCKING SERVO MOUNT

SIZE	DWG. NO.	REV
A	23-2-2-303	
SCALE: 2:1	WEIGHT: 0.00831lb	





UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Aluminum 6061-T6			

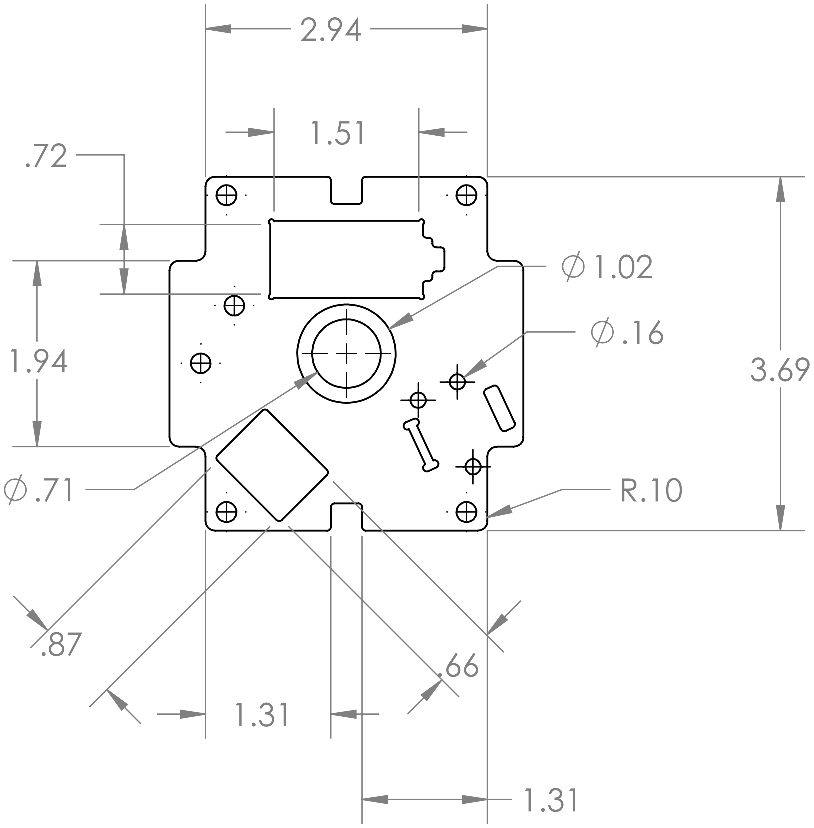
HPRC WPI AIAA

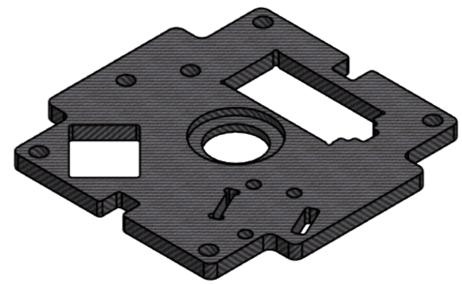
TITLE:

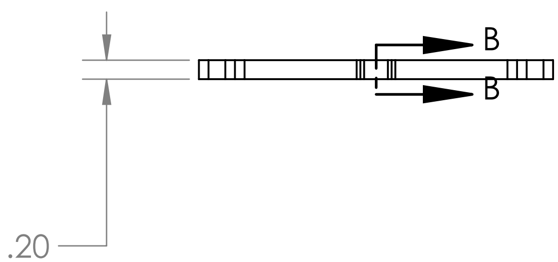
LOCKING SERVO HORN ADAPTER

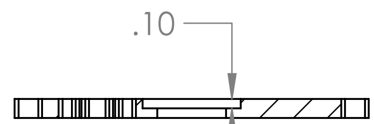
SIZE	DWG. NO.	REV
A	23-2-2-304	

SCALE: 2:1 WEIGHT: 0.00538 lb



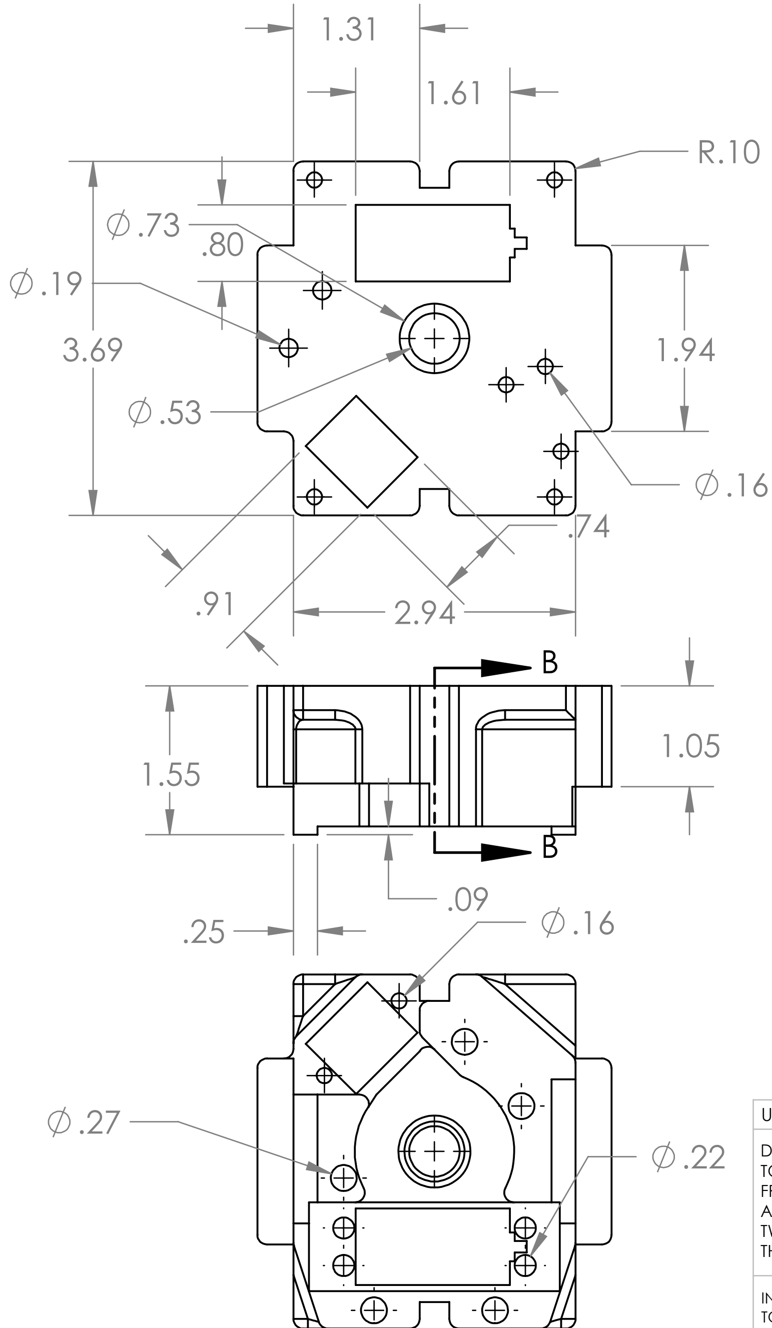


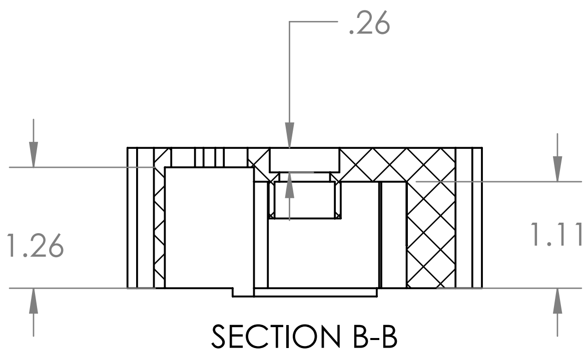




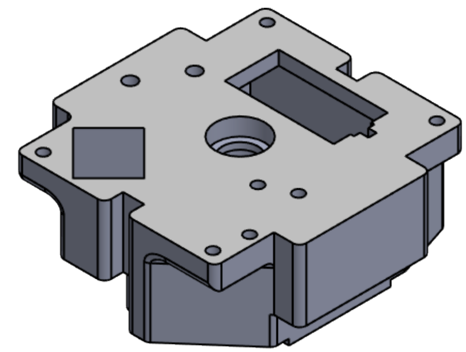
SECTION B-B

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023	LOCKING SCREW TOP PLATE
	CHECKED	JR	5/10/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-305 · REV
MATERIAL Carbon Fiber				SCALE: 1:2 · WEIGHT: 0.0966 lb





SECTION B-B



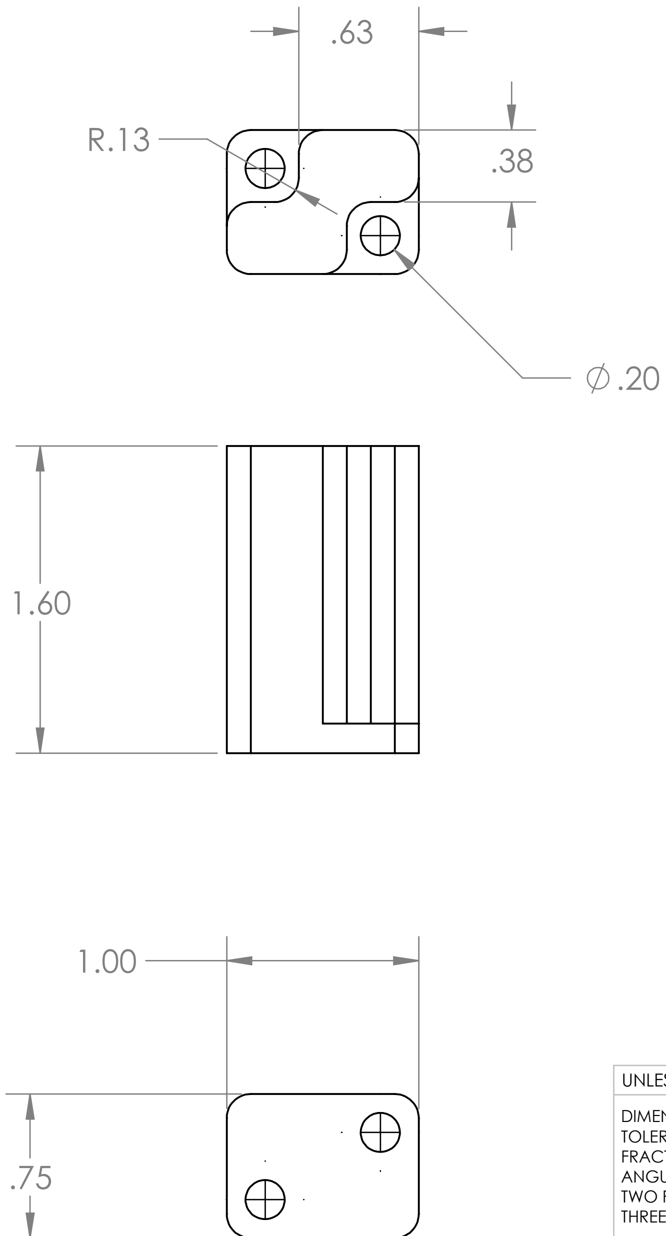
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

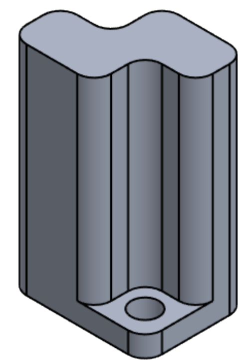
HPRC WPI AIAA

TITLE:

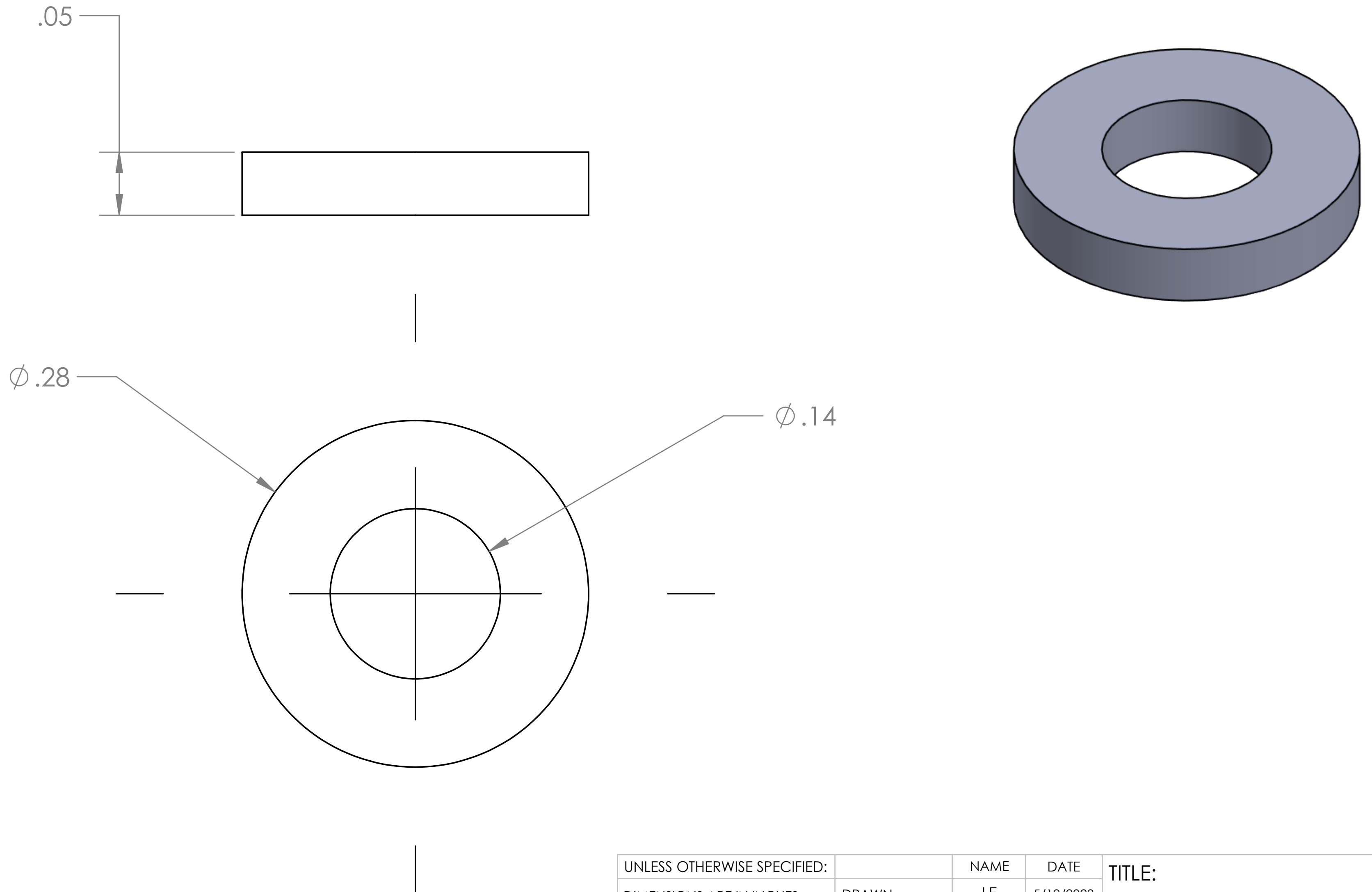
LOCKING SCREW BOTTOM PLATE

SIZE	DWG. NO.	REV
A	23-2-2-306	
SCALE: 1:2	WEIGHT: 0.17 lb	





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023	BALLAST MASS
	CHECKED	JR	5/10/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-307 · REV
MATERIAL Aluminum 6061-T6				SCALE: 1:1 · WEIGHT: 0.0743 lb



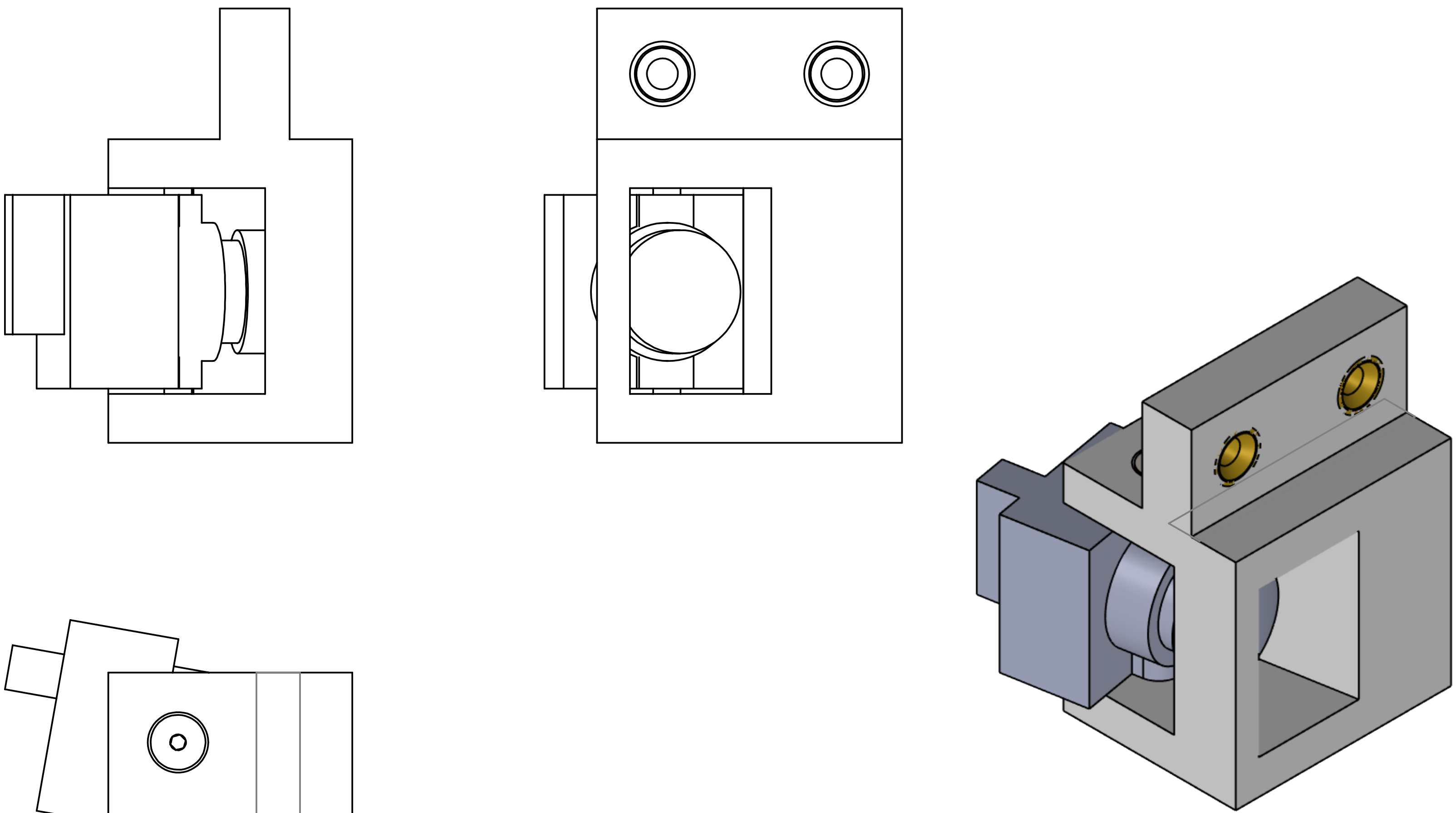
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

TITLE: SPACER

SIZE	DWG. NO.	REV
A	23-2-2-309	

SCALE: 8:1 WEIGHT: 0.000081 lb

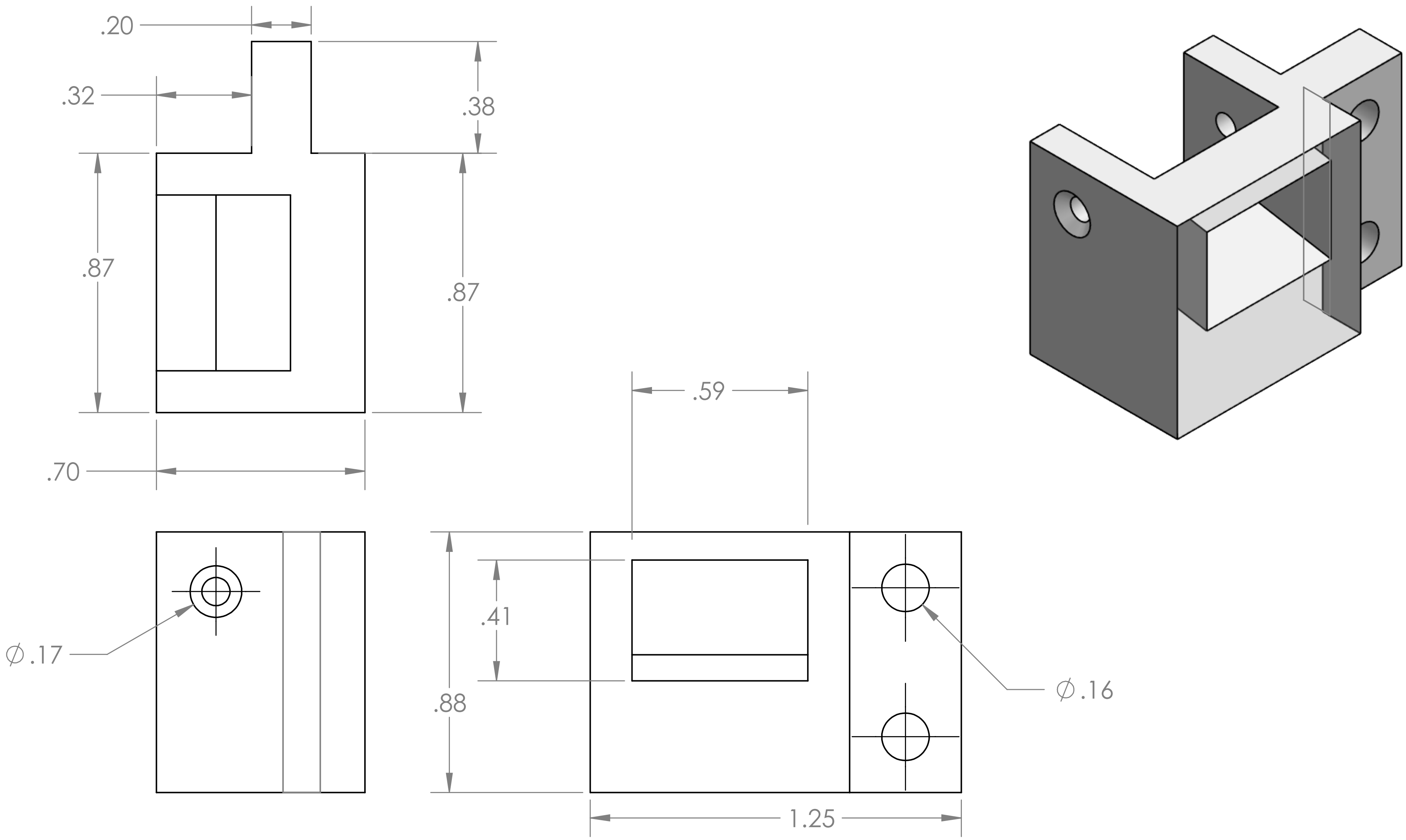


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL **INSERT MATERIAL**			

HPRC
WPI AIAA

TITLE:
CAMERA MOUNT ASSEMBLY

SIZE	DWG. NO.	REV
A	23-2-2-400	
SCALE: 2:1	WEIGHT: 0.0236 lb	



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC WPI AIAA

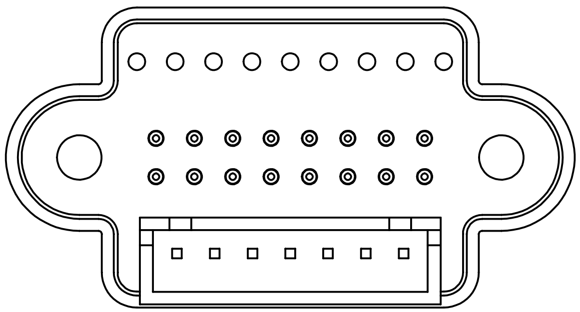
TITLE:

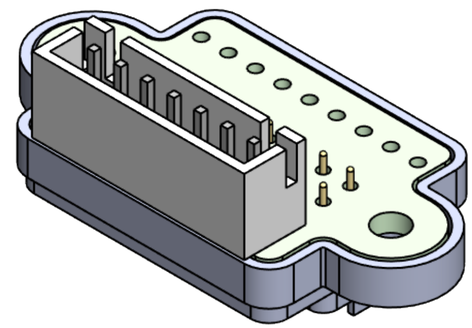
CAMERA RETENTION MOUNT

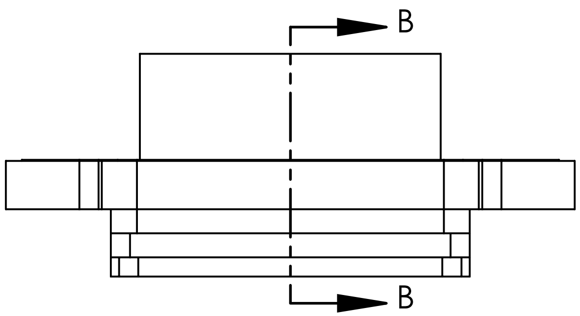
SIZE	DWG. NO.	REV
A	23-2-2-401	
SCALE: 2:1	WEIGHT: 0.0161 lb	

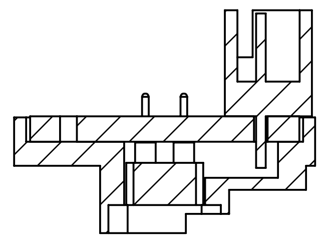
2 | 1

B



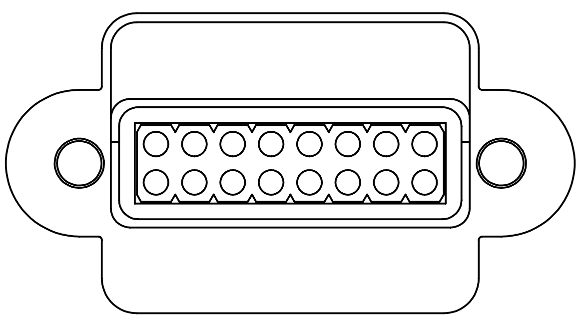






SECTION B-B

A

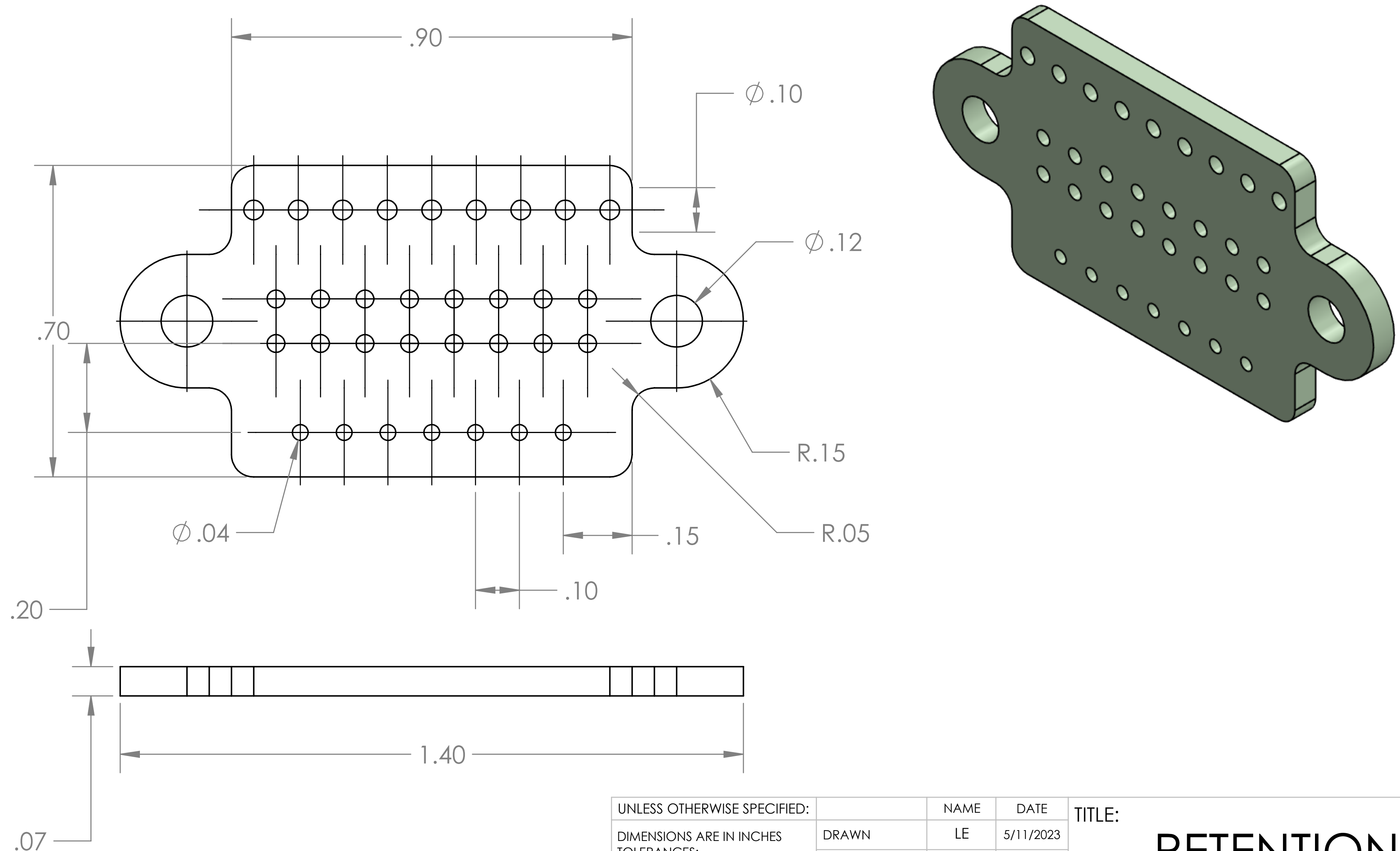


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: RETENTION UMBILICAL ASSEMBLY
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-500 · REV
MATERIAL **INSERT MATERIAL**				SCALE: 2:1 · WEIGHT: 0.00831 lb

2 | 1

2 | 1

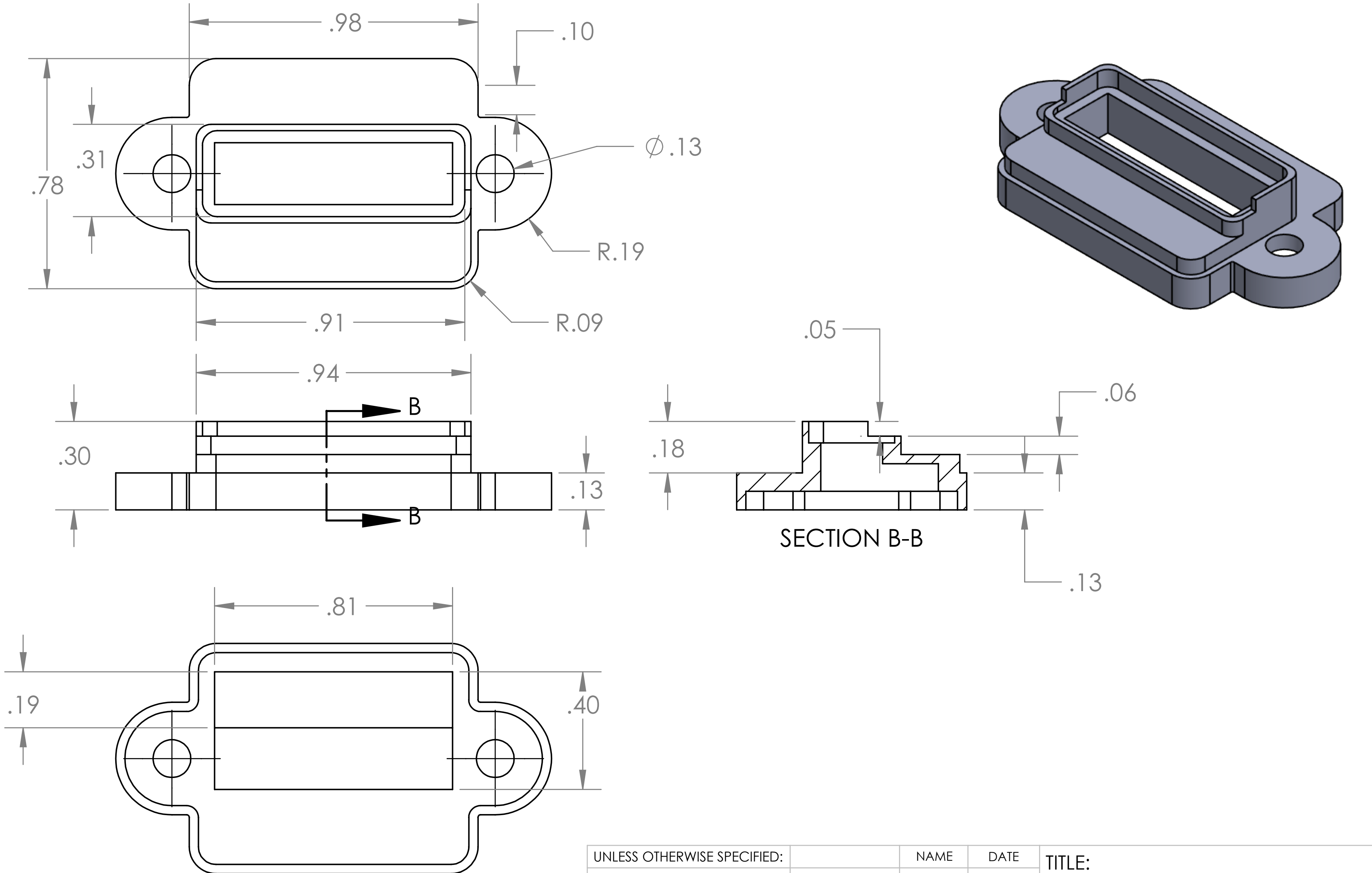
B | B



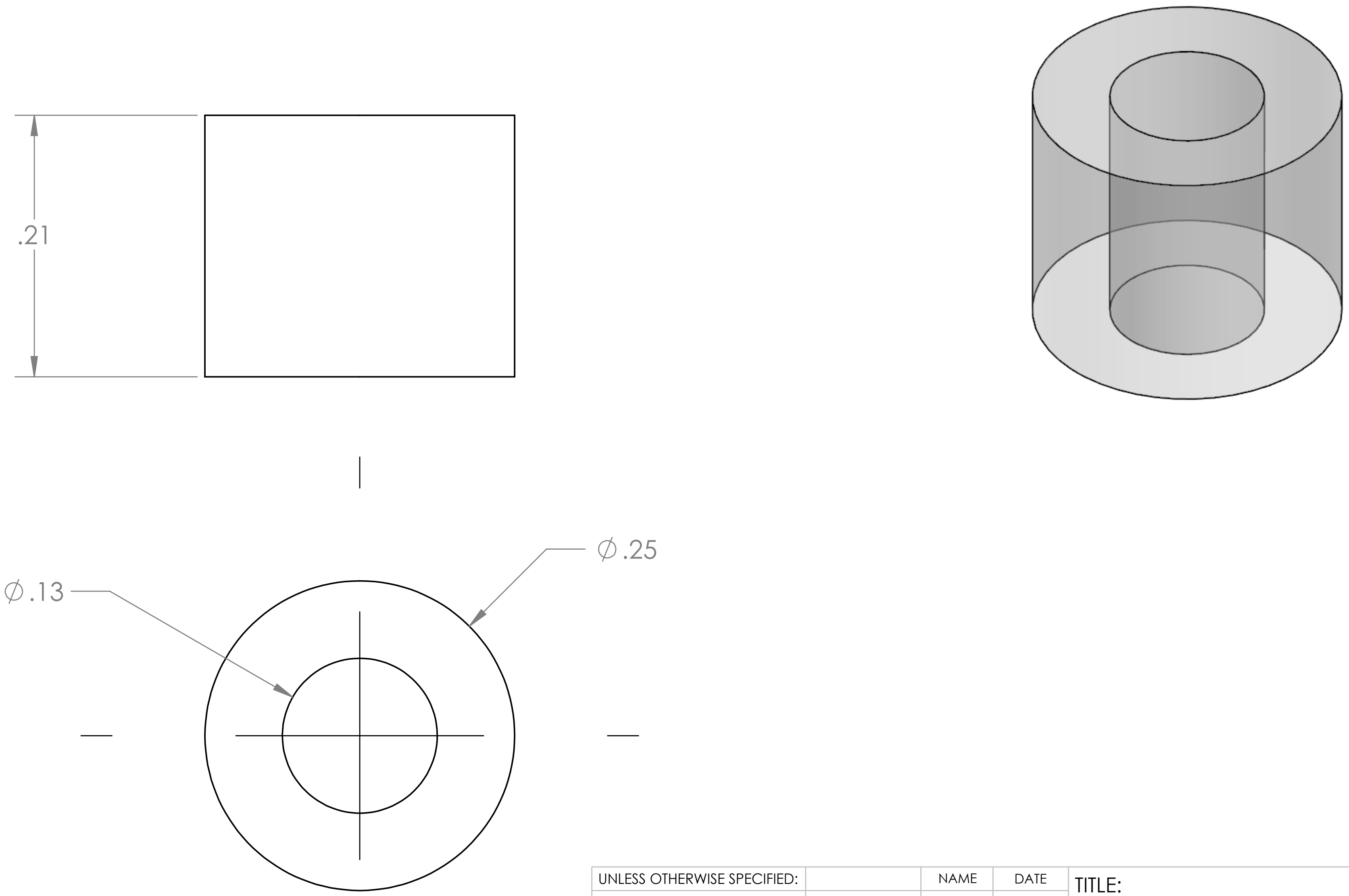
A | A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	RETENTION UNBILICAL PCB
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-501 · REV
MATERIAL PCB				SCALE: 3:1 · WEIGHT: 0.00169 lb

2 | 1

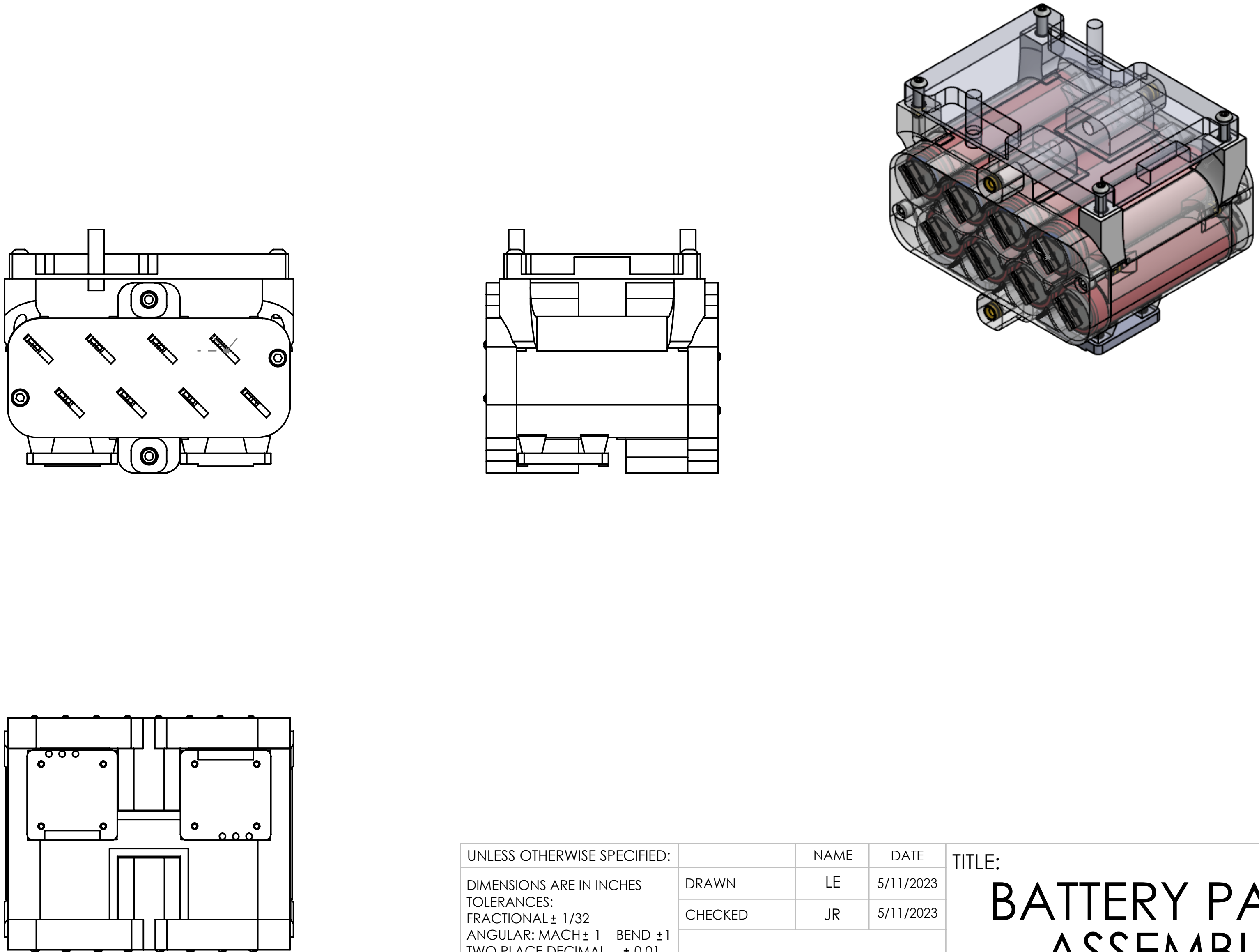


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: RETENTION UMBILICAL HOUSING
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-2-502 · REV
MATERIAL Polycarbonate				SCALE: 2:1 · WEIGHT: 0.00243 lb



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	RETENTION UMBILICAL SPACER
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5				SIZE A	DWG. NO. 23-2-2-503	REV
MATERIAL Polycarbonate				SCALE: 8:1	WEIGHT: 0.00033 lb

HPRC WPI AIAA



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL **INSERT MATERIAL**			

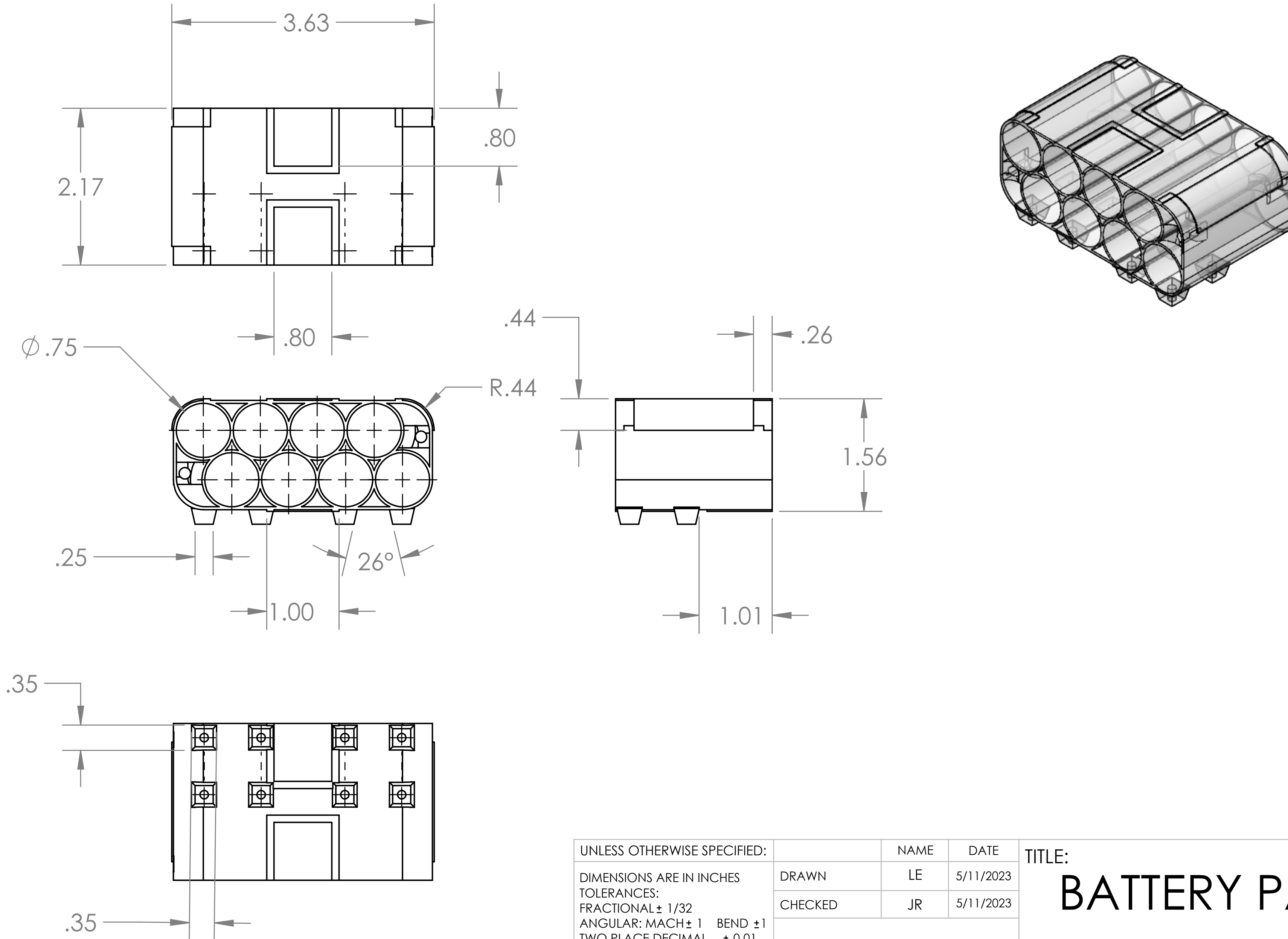
HPRC WPI AIAA

TITLE:

BATTERY PACK ASSEMBLY

SIZE	DWG. NO.	REV
A	23-2-2-600	

SCALE: 1:2 WEIGHT: 1.18 lb SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL: Polycarbonate

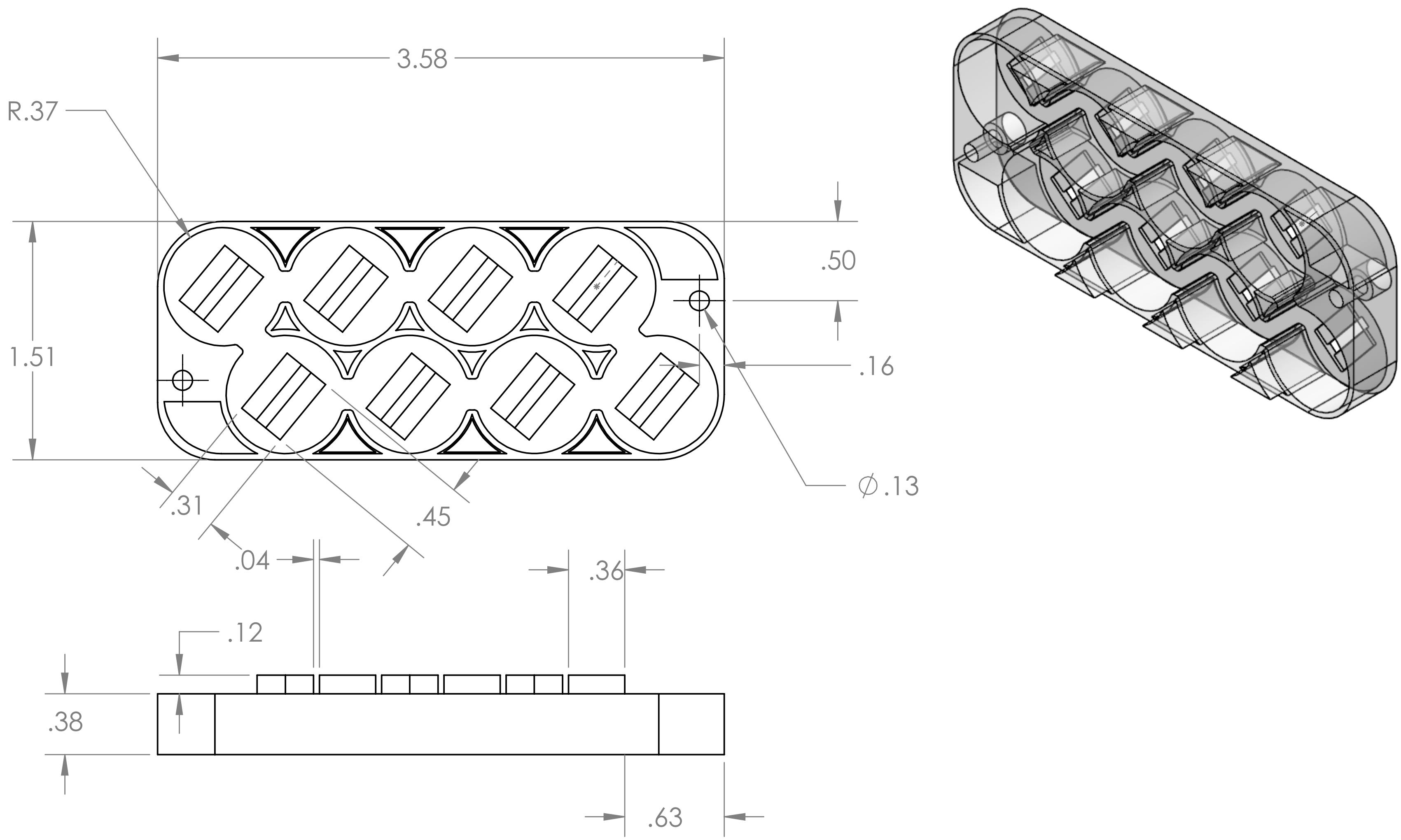
	NAME	DATE
DRAWN	LE	5/11/2023
CHECKED	JR	5/11/2023

HPRC WPI AIAA

TITLE: BATTERY PACK

SIZE	DWG. NO.	REV
A	23-2-2-601	

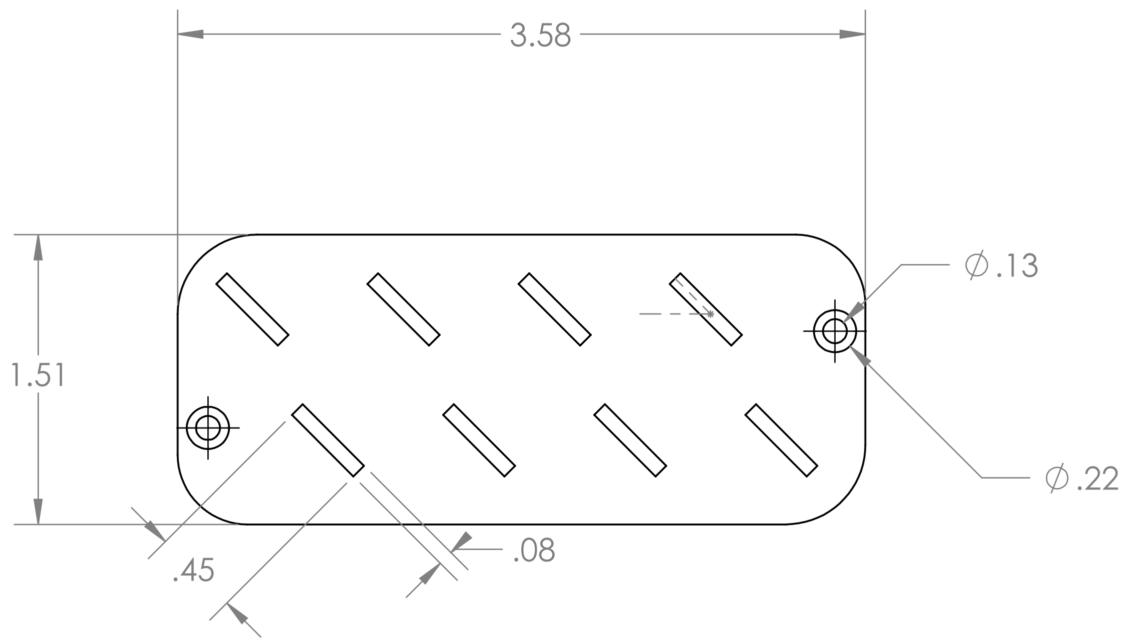
SCALE: 1:2 WEIGHT: 0.1015 lb

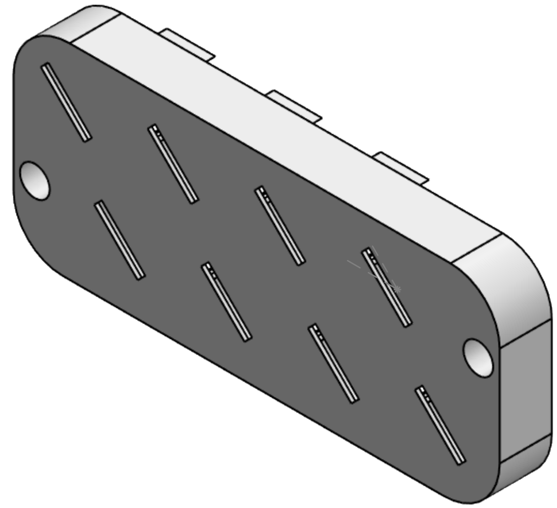


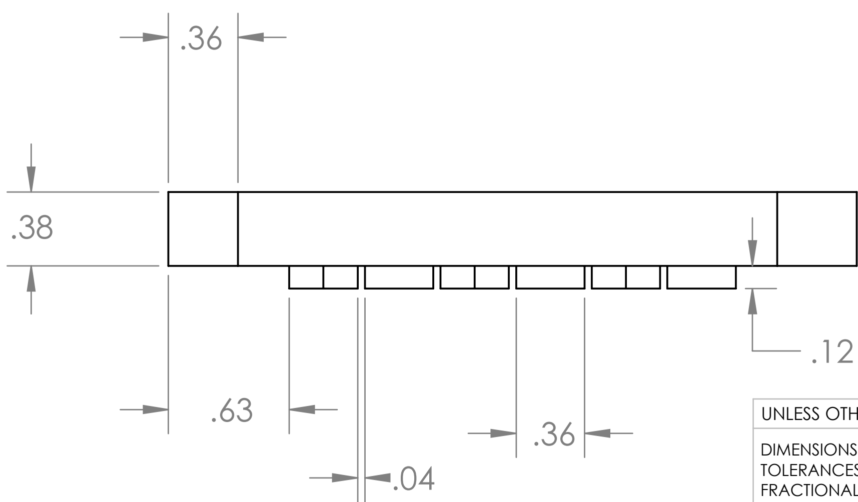
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: BATTERY PACK TOP
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A DWG. NO. 23-2-2-602 REV
MATERIAL Polycarbonate				SCALE: 1:1 WEIGHT: 0.0364 lb

2 1

B



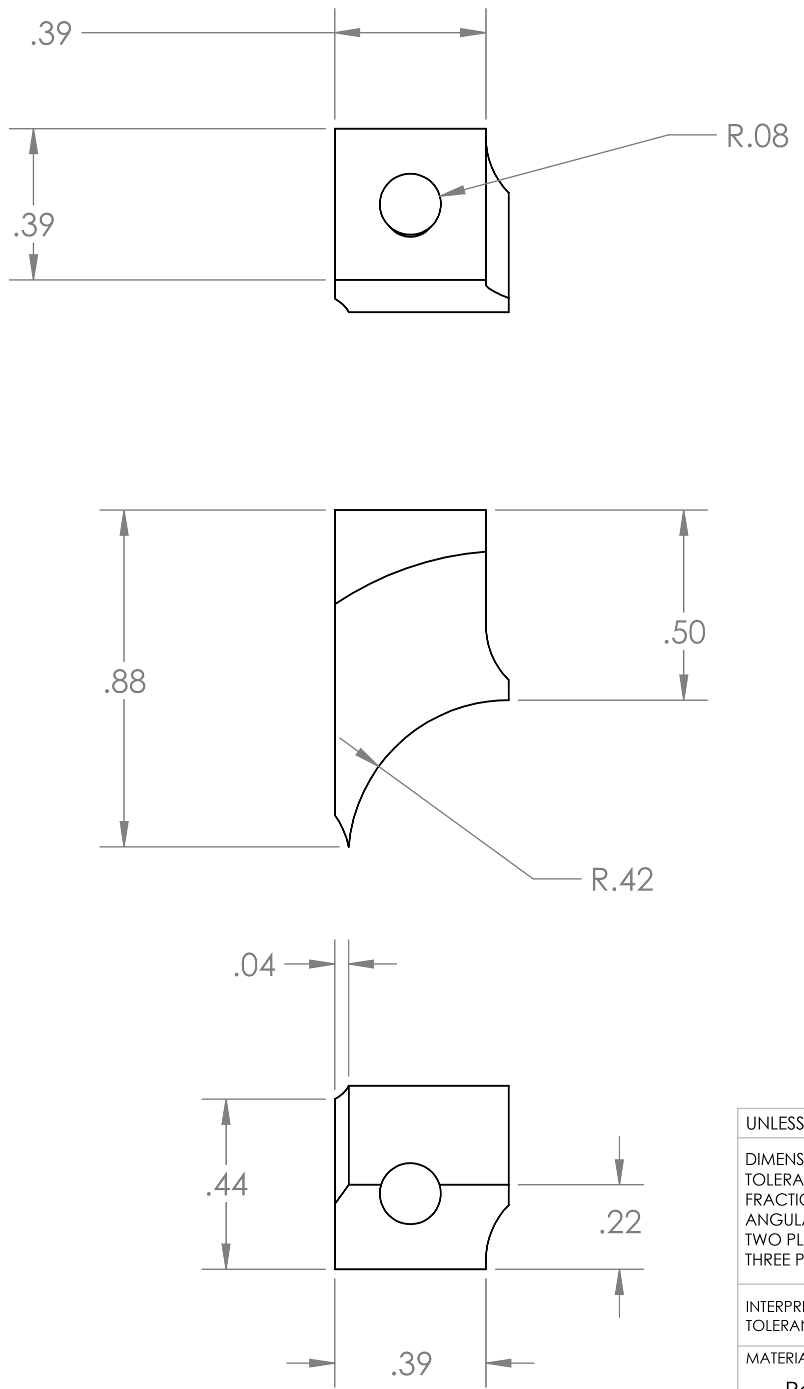


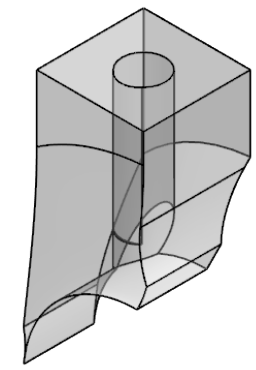


A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: BATTERY PACK BOTTOM
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A	DWG. NO. 23-2-2-603	REV
MATERIAL Polycarbonate				SCALE: 1:1	WEIGHT: 0.041 lb

2 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC
WPI AIAA

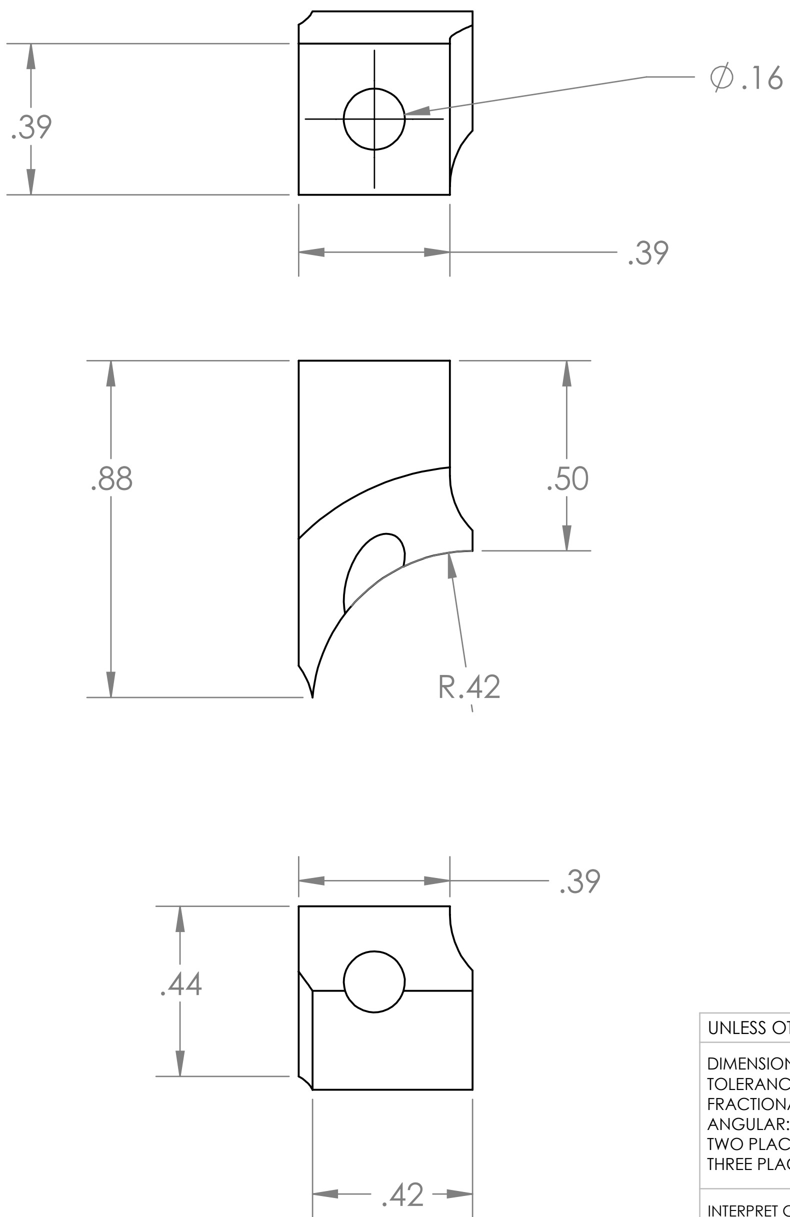
TITLE:

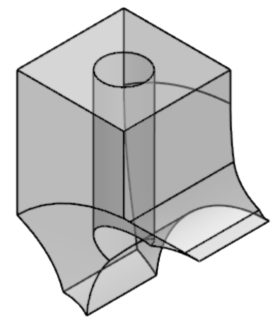
Z NEGATIVE STANDOFF

SIZE	DWG. NO.	REV
A	23-2-2-606	
SCALE: 2:1	WEIGHT: 0.00325 lb	

2 1

B B

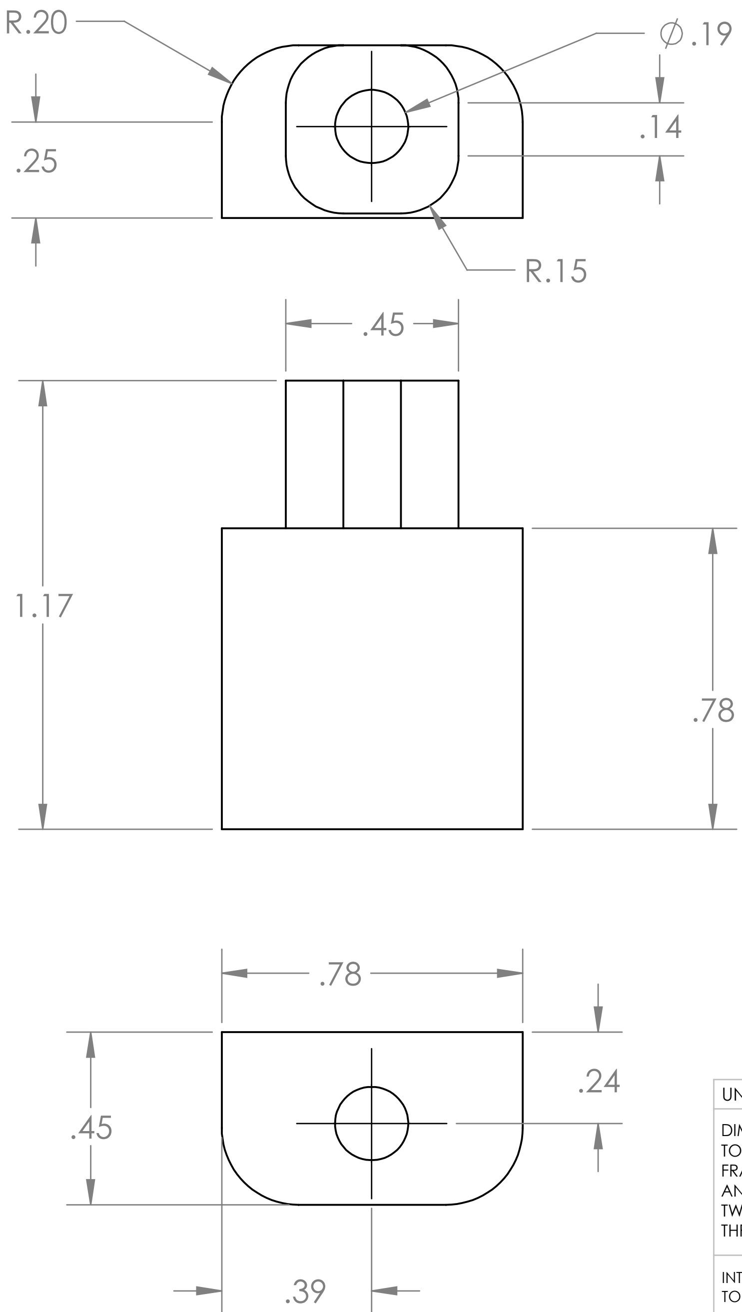


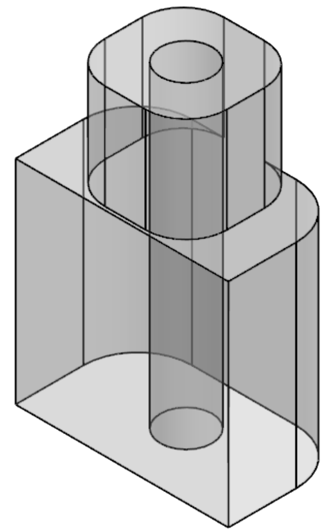


A A

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: Z POSITIVE STANDOFF
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023	
	CHECKED	JR	5/11/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-2-607 — REV
MATERIAL Polycarbonate				SCALE: 2:1 — WEIGHT: 0.00325 lb

2 1





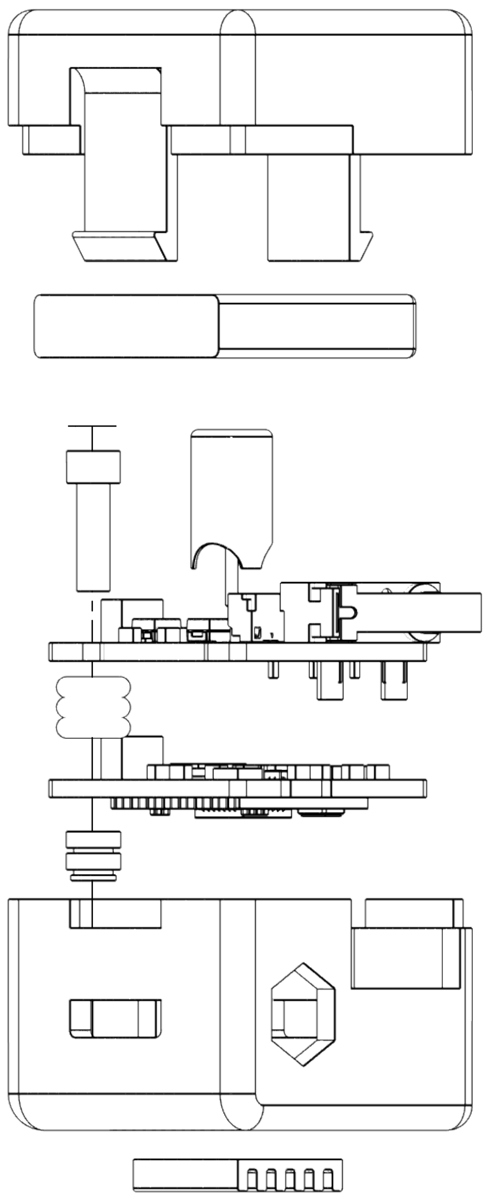
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	LE	5/11/2023
	CHECKED	JR	5/11/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

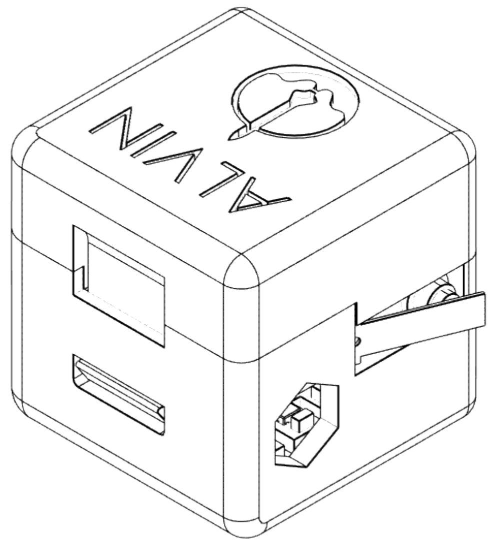
HPRC WPI AIAA

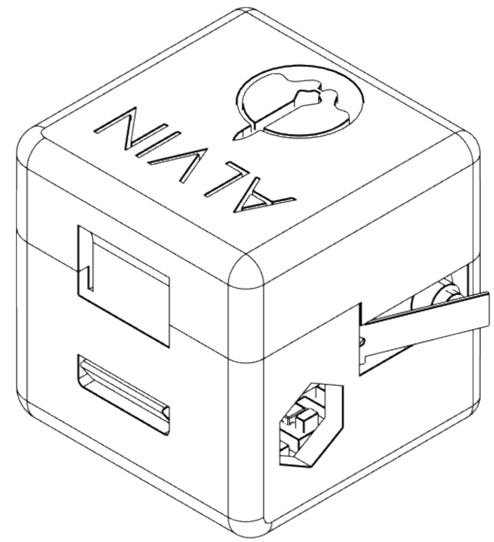
TITLE:

BATTERY PACK MOUNTING EXTENSION

SIZE	DWG. NO.	REV
A	23-2-2-608	
SCALE: 2:1	WEIGHT: 0.0128 lb	







PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF HIGH POWER ROCKETRY CLUB (HPRC).ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF HIGH POWER ROCKETRY CLUB (HPRC) IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

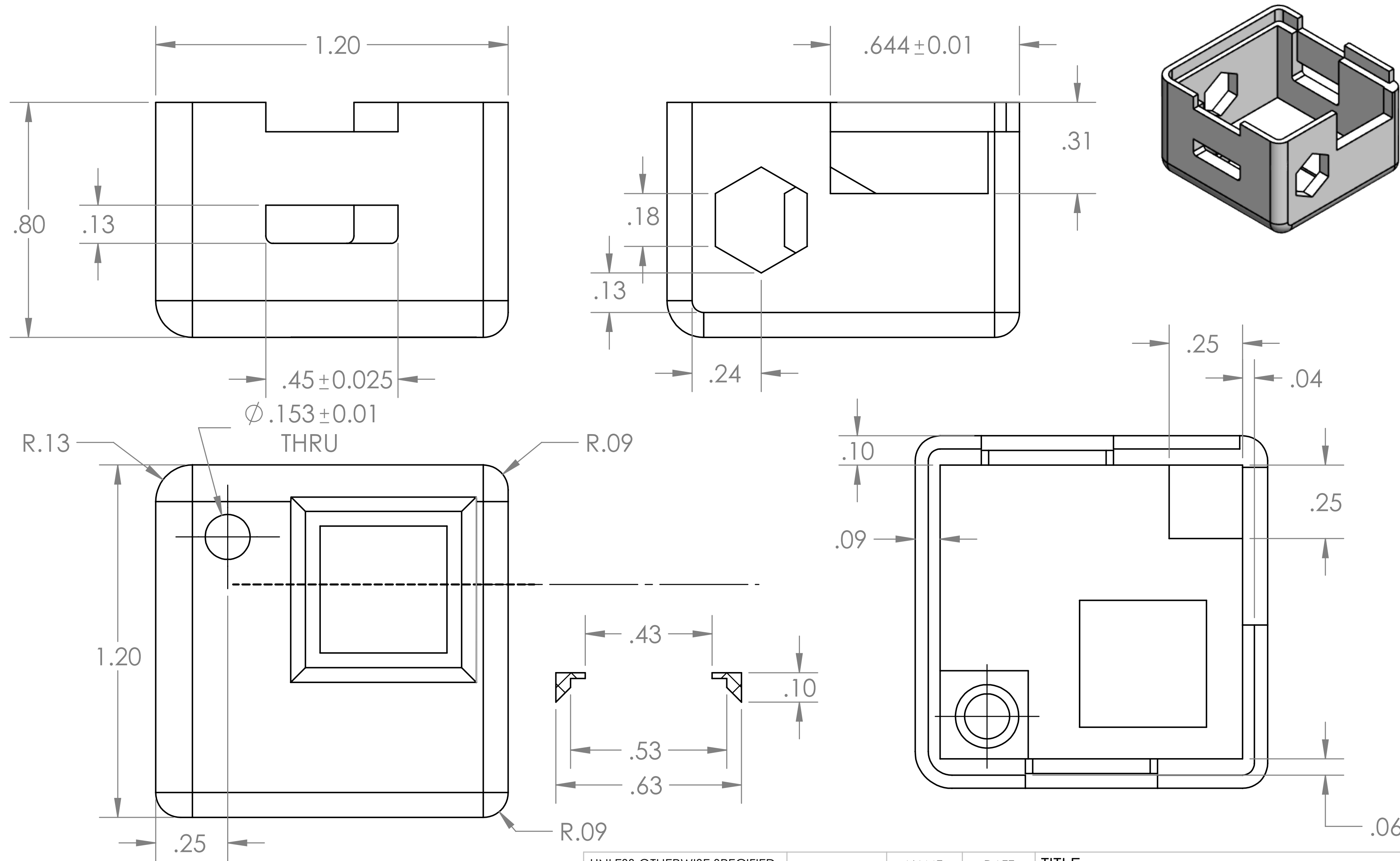
	NAME	DATE
DRAWN	ZC	2/23/2023
CHECKED	JR	2/23/2023

HPRC
WPI AIAA

TITLE:

CUBE ASSEMBLY

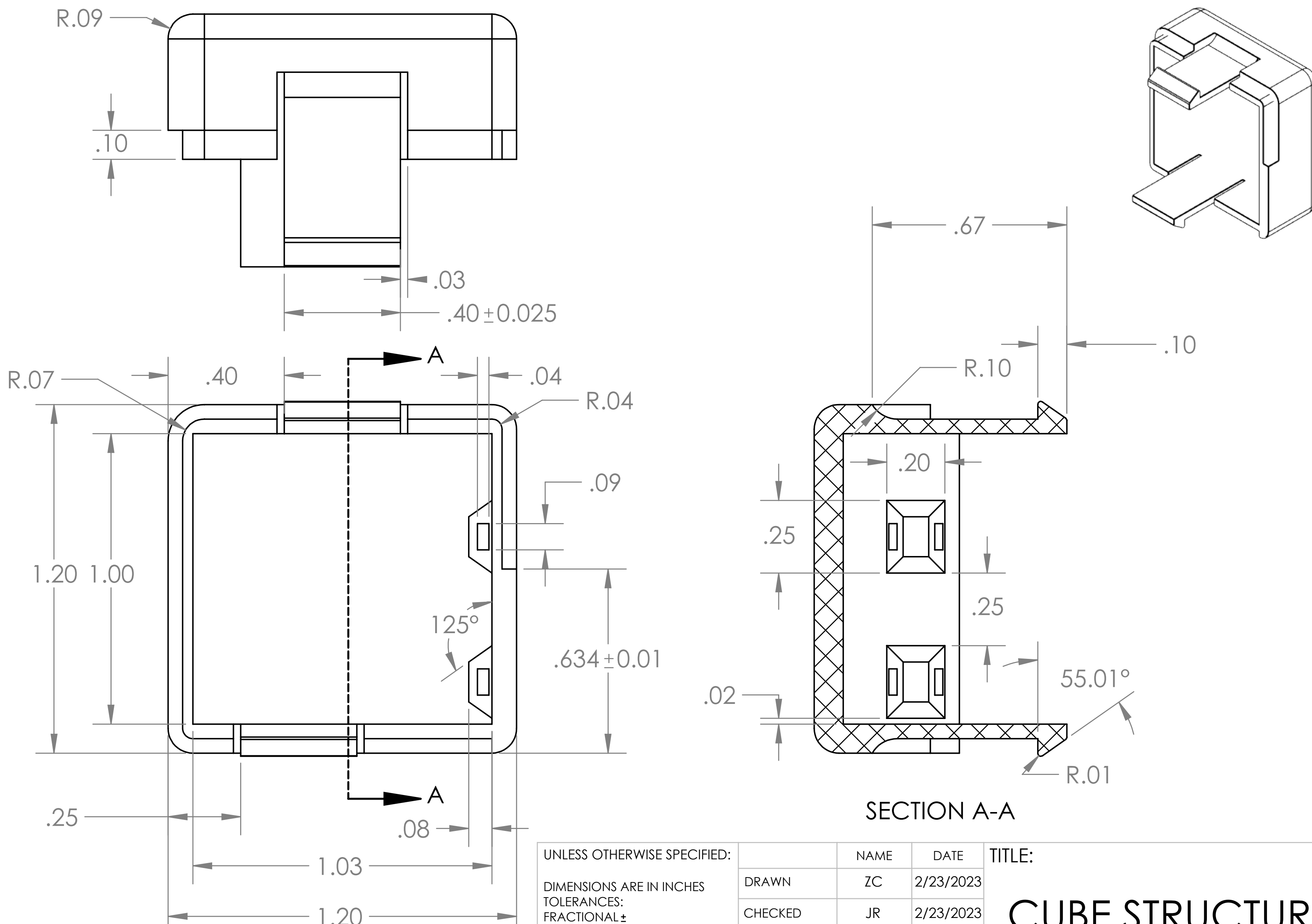
SIZE	DWG. NO.	REV
A	23-2-3-100	
SCALE: 3:2	WEIGHT: 0.0584 lb	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	ZC	2/23/2023	CUBE STRUCTURE A
	CHECKED	JR	2/23/2023	
INTERPRET GEOMETRIC TOLERANCING PER:	HPRC WPI AIAA			SIZE A DWG. NO. 23-2-3-101 REV
MATERIAL Polycarbonate				SCALE: 2:1 WEIGHT: 0.0139 lb SHEET 1 OF 1

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Polycarbonate

	NAME	DATE
DRAWN	ZC	2/23/2023
CHECKED	JR	2/23/2023

HPRC WPI AIAA

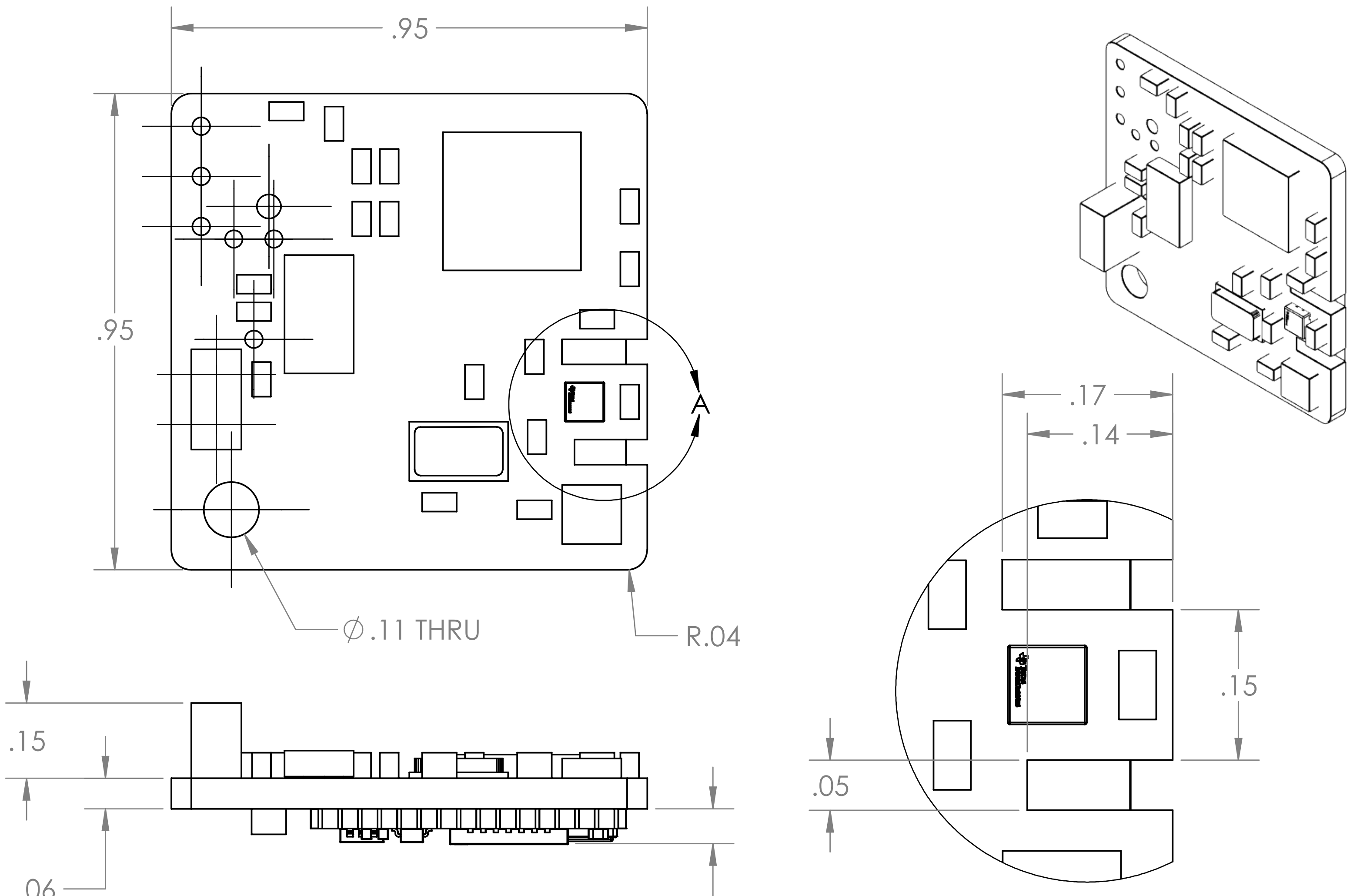
TITLE:

CUBE STRUCTURE B

SIZE A | DWG. NO. 23-2-3-102 | REV

SCALE: 2:1 | WEIGHT: 0.013 lb | SHEET 1 OF 1

2 1



DETAIL A
SCALE 6 : 1

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UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
FIBERGLASS

	NAME	DATE
DRAWN	NL	5/09/2023
CHECKED	JR	5/09/2023

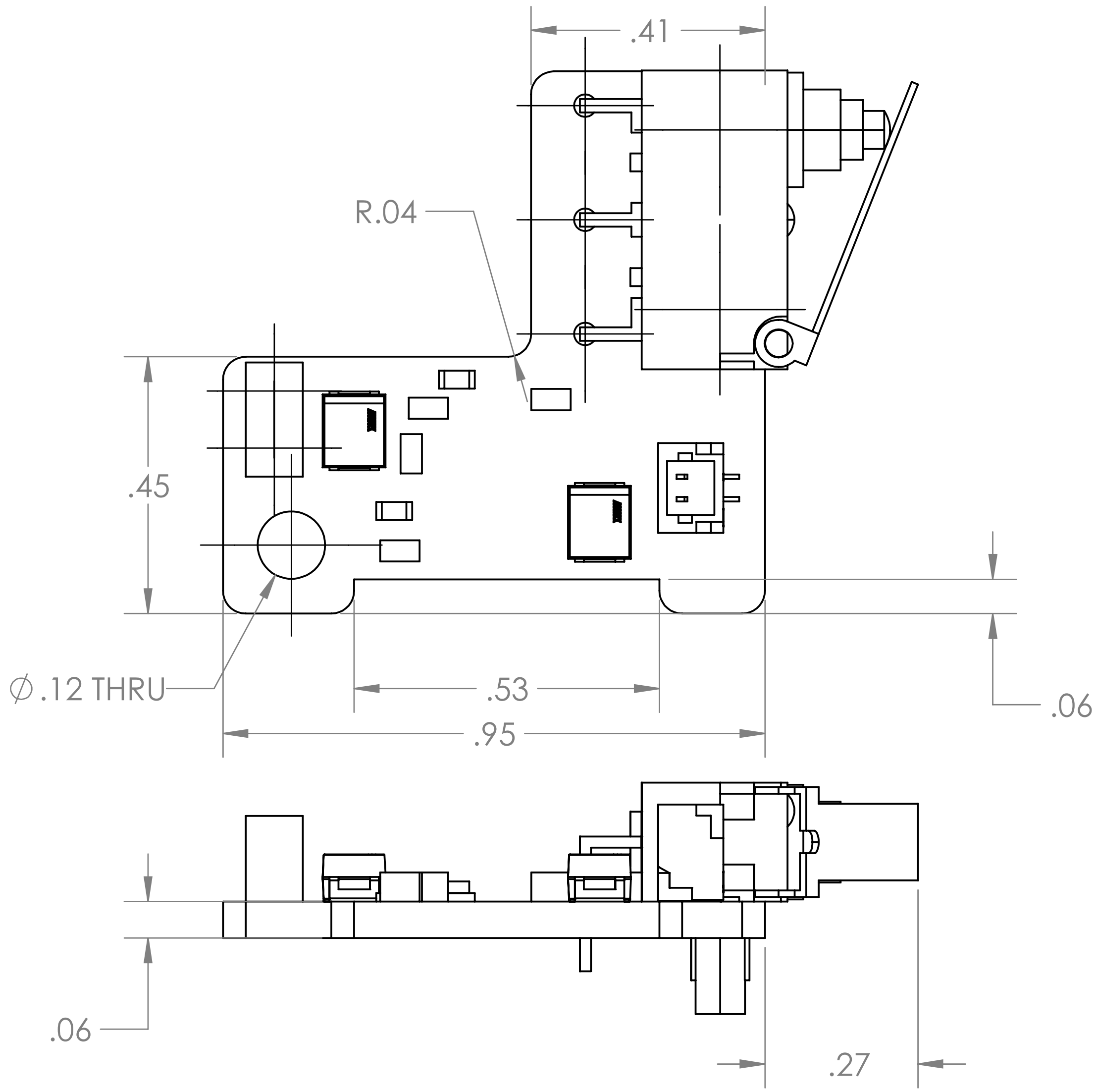
HPRC WPI AIAA

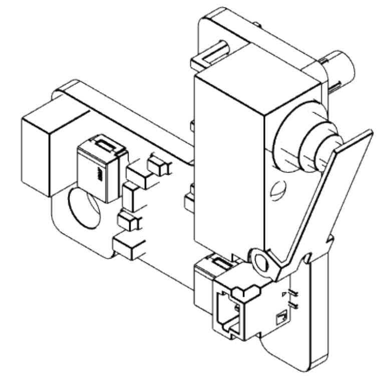
TITLE:

CUBE MAIN BOARD

SIZE	DWG. NO.	REV
A	23-2-3-103	

SCALE: 3:1 WEIGHT: 0.008 lb SHEET 1 OF 1





SCALE 2:1

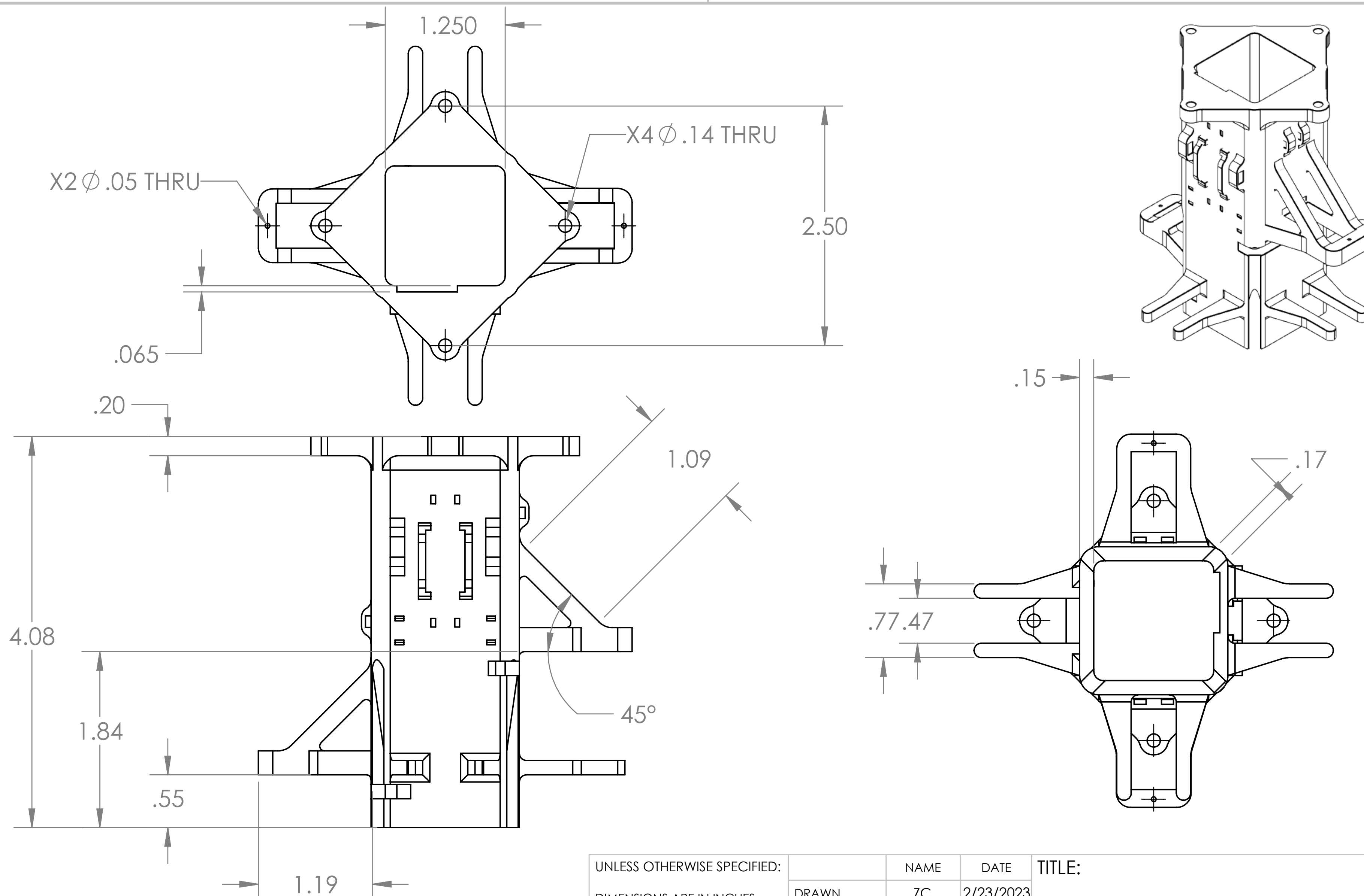
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	NL	5/10/2023
	CHECKED	JR	5/10/2023
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL Fiberglass			

HPRC WPI AIAA

TITLE:

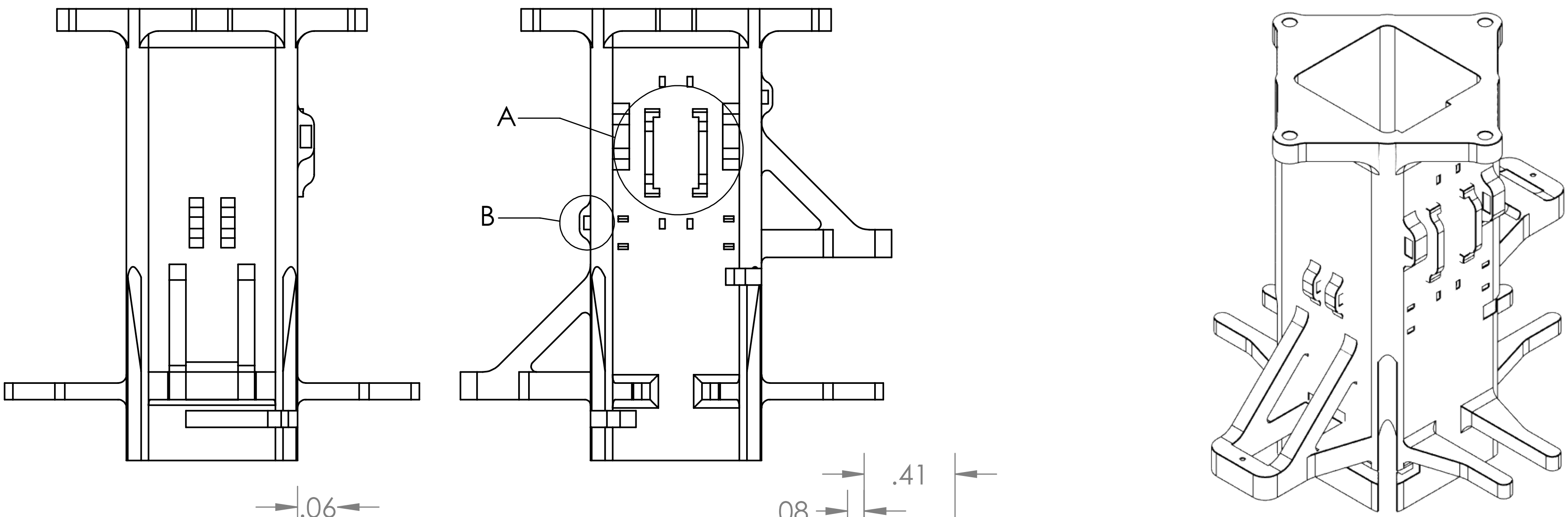
CUBE POWER BOARD

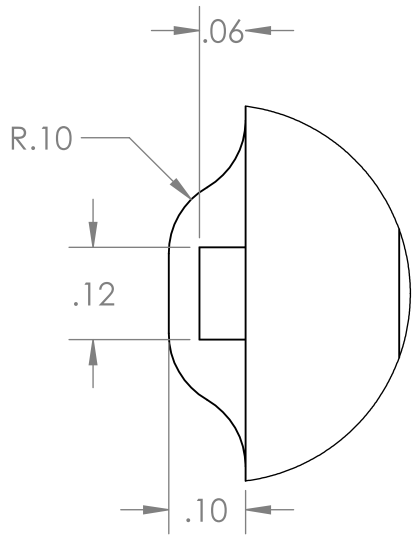
SIZE	DWG. NO.	REV
A	23-2-3-104	
SCALE: 3:1	WEIGHT: 0.0057 lb	SHEET 1 OF 1



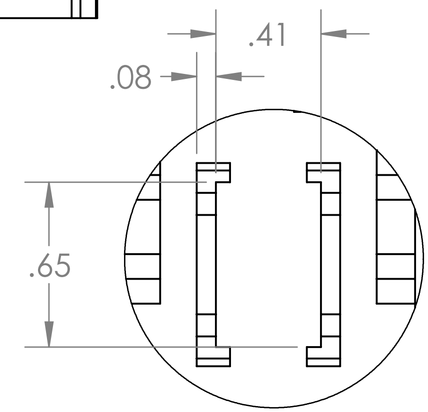
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
	DRAWN	ZC	2/23/2023	MAIN RETENTION TOWER
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	CHECKED	JR	2/23/2023	
INTERPRET GEOMETRIC TOLERANCING PER:				SIZE A — DWG. NO. 23-2-3-201 — REV
MATERIAL Polycarbonate				SCALE: 2:3 — WEIGHT: 0.1287 lb — SHEET 1 OF 2

HPRC WPI AIAA





DETAIL B
SCALE 4 : 1



DETAIL A
SCALE 4 : 3

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Polycarbonate

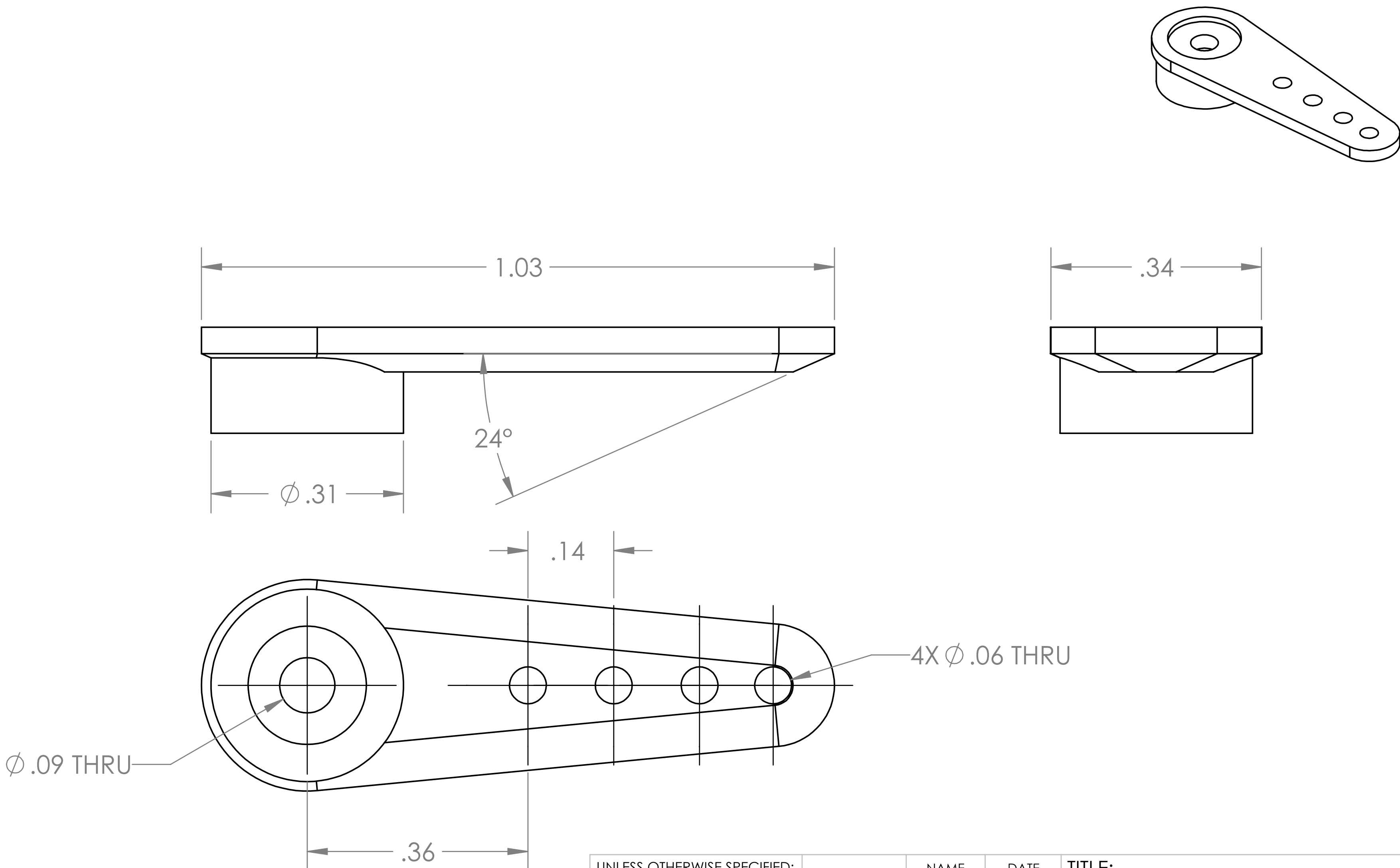
	NAME	DATE
DRAWN	ZC	
CHECKED		

HPRC WPI AIAA

TITLE:
MAIN RETENTION TOWER

SIZE	DWG. NO.	REV
A	23-2-3-201	

SCALE: 2:3 WEIGHT: SHEET 2 OF 2



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF HIGH POWER ROCKETRY CLUB (HPRC).ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF HIGH POWER ROCKETRY CLUB (HPRC) IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ALUMINUM

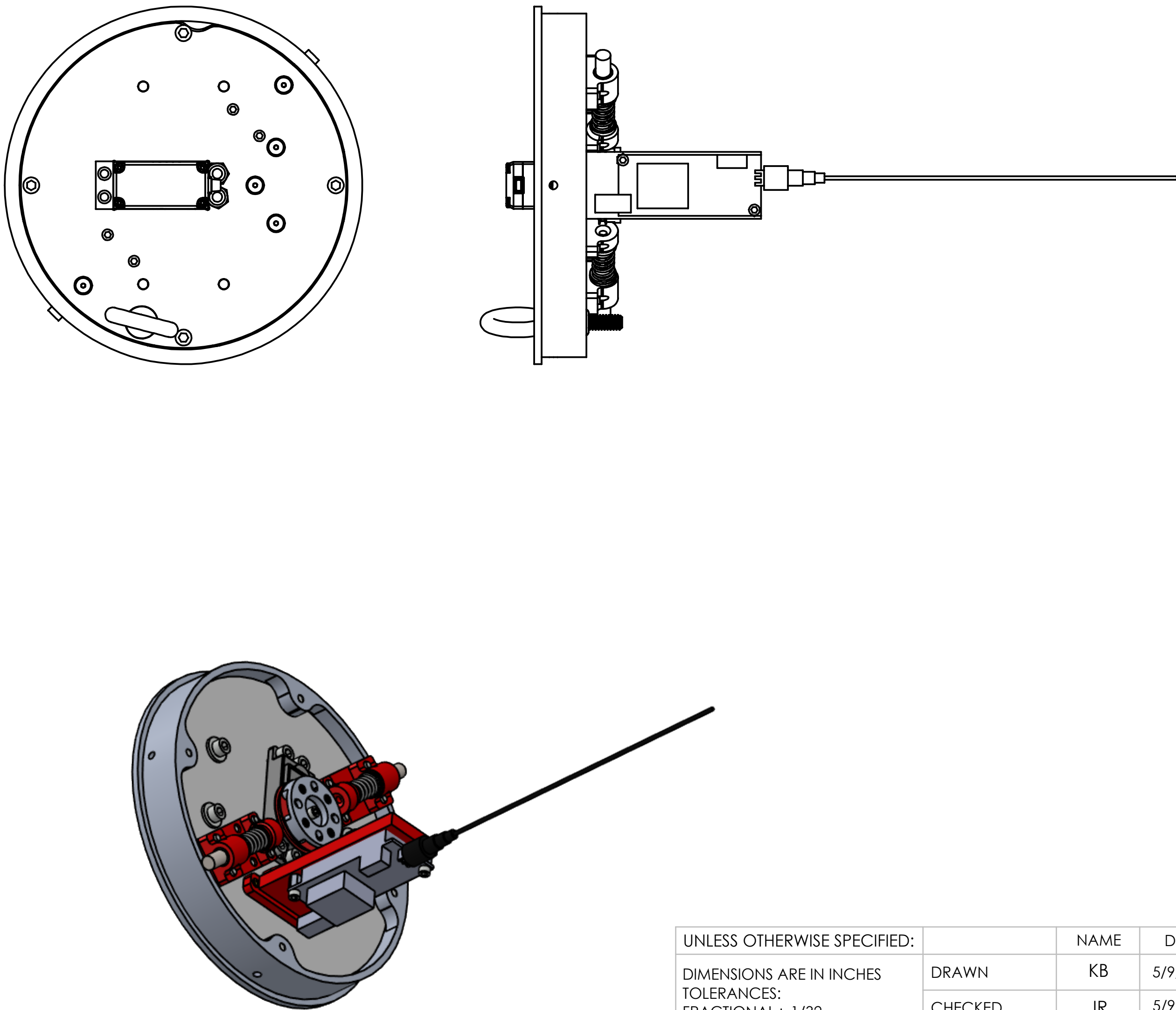
	NAME	DATE
DRAWN	NL	5/10/2023
CHECKED	JR	5/10/2023

HPRC WPI AIAA

TITLE:

SERVO CITY B25T HORN

SIZE	DWG. NO.	REV
A	23-2-3-202	
SCALE: 2:1	WEIGHT: 0.0396 lb	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL			

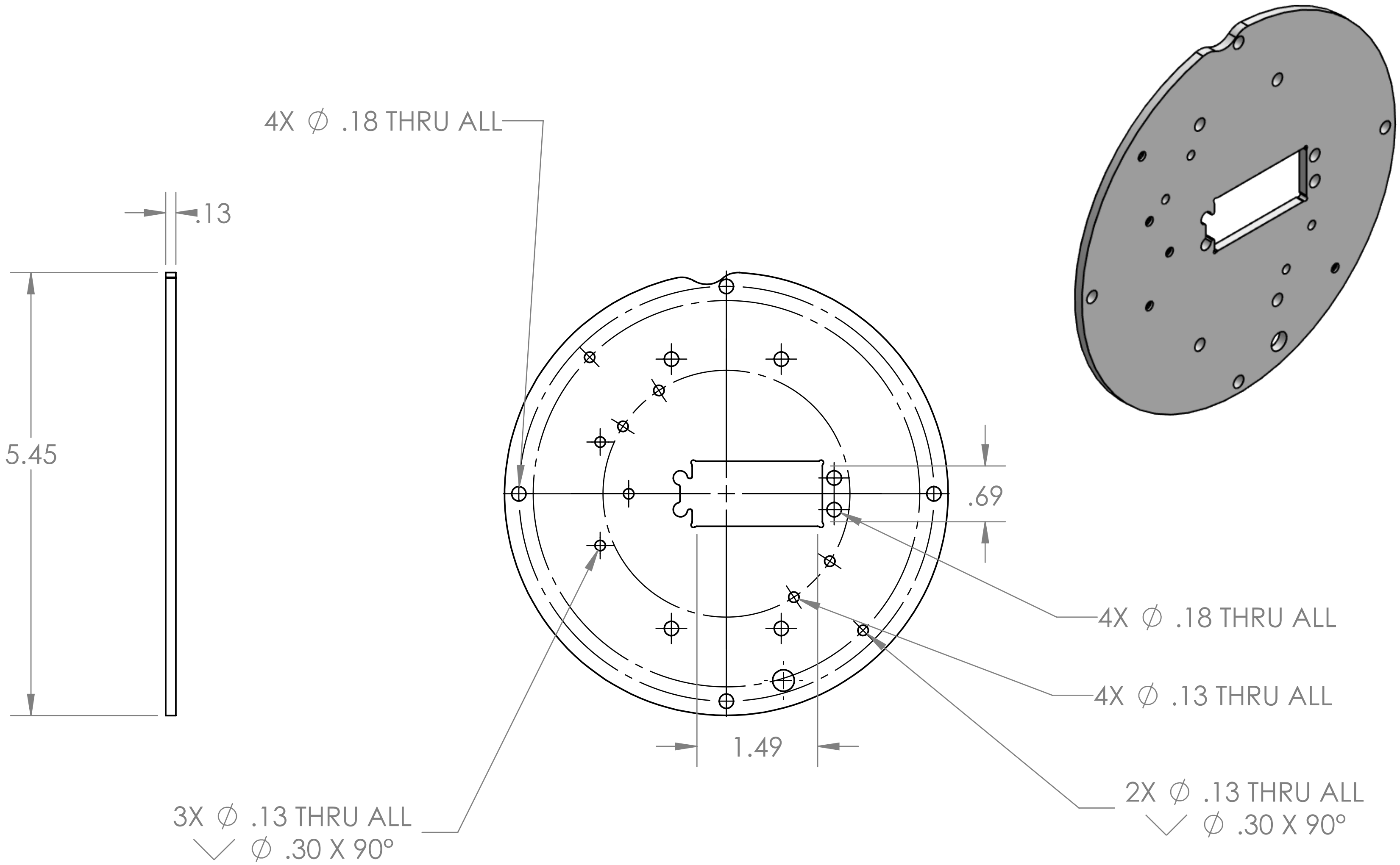
HPRC WPI AIAA

TITLE:

PAYLOAD ADAPTER

SIZE	DWG. NO.	REV
A	23-2-4-000	

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1



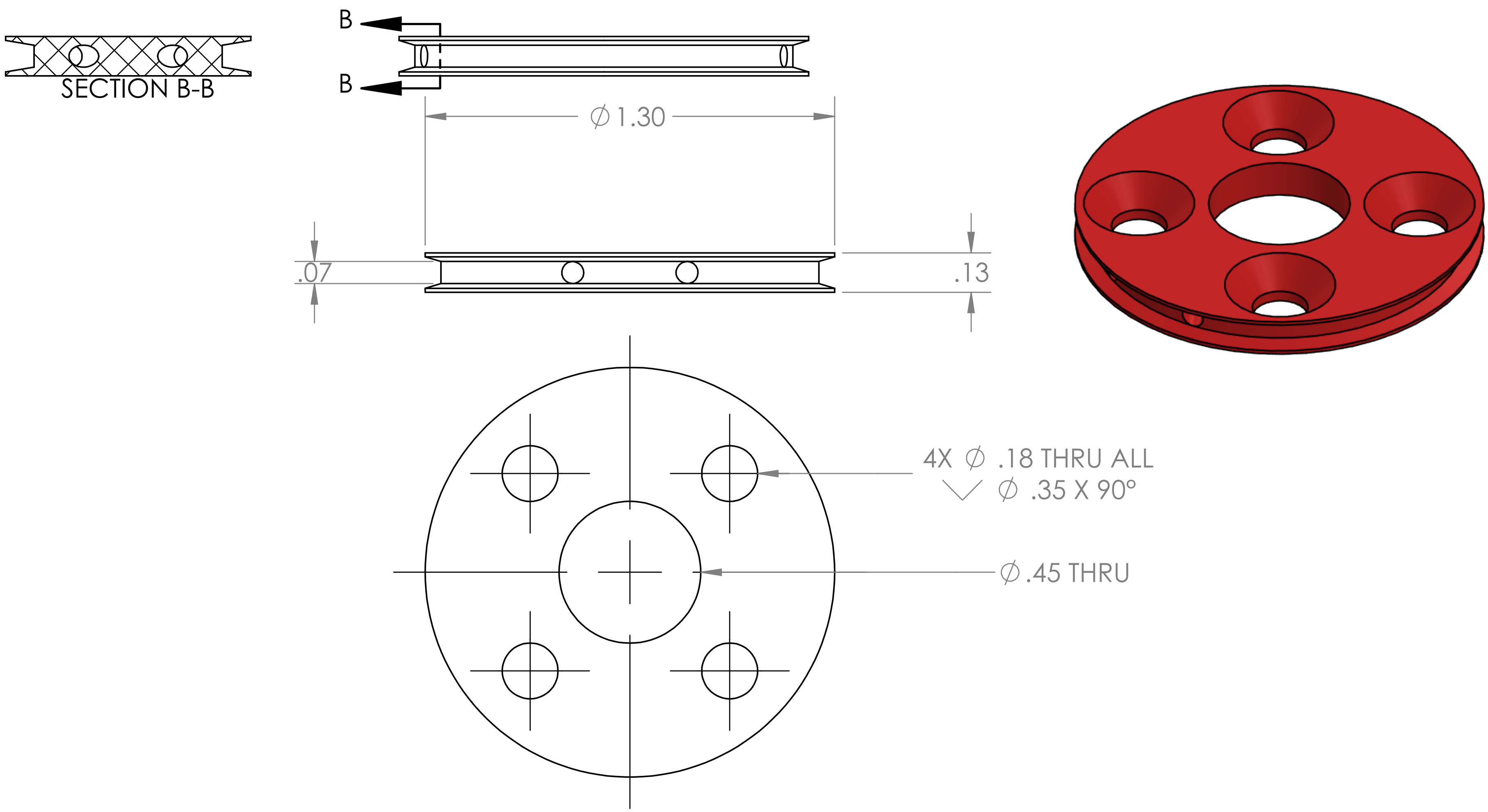
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G-10 Fiberglass			

TITLE:

NOSECONE BULKHEAD

SIZE	DWG. NO.	REV
A	23-2-4-001	

SCALE: 1:2 WEIGHT: 0.18 lb SHEET 1 OF 1



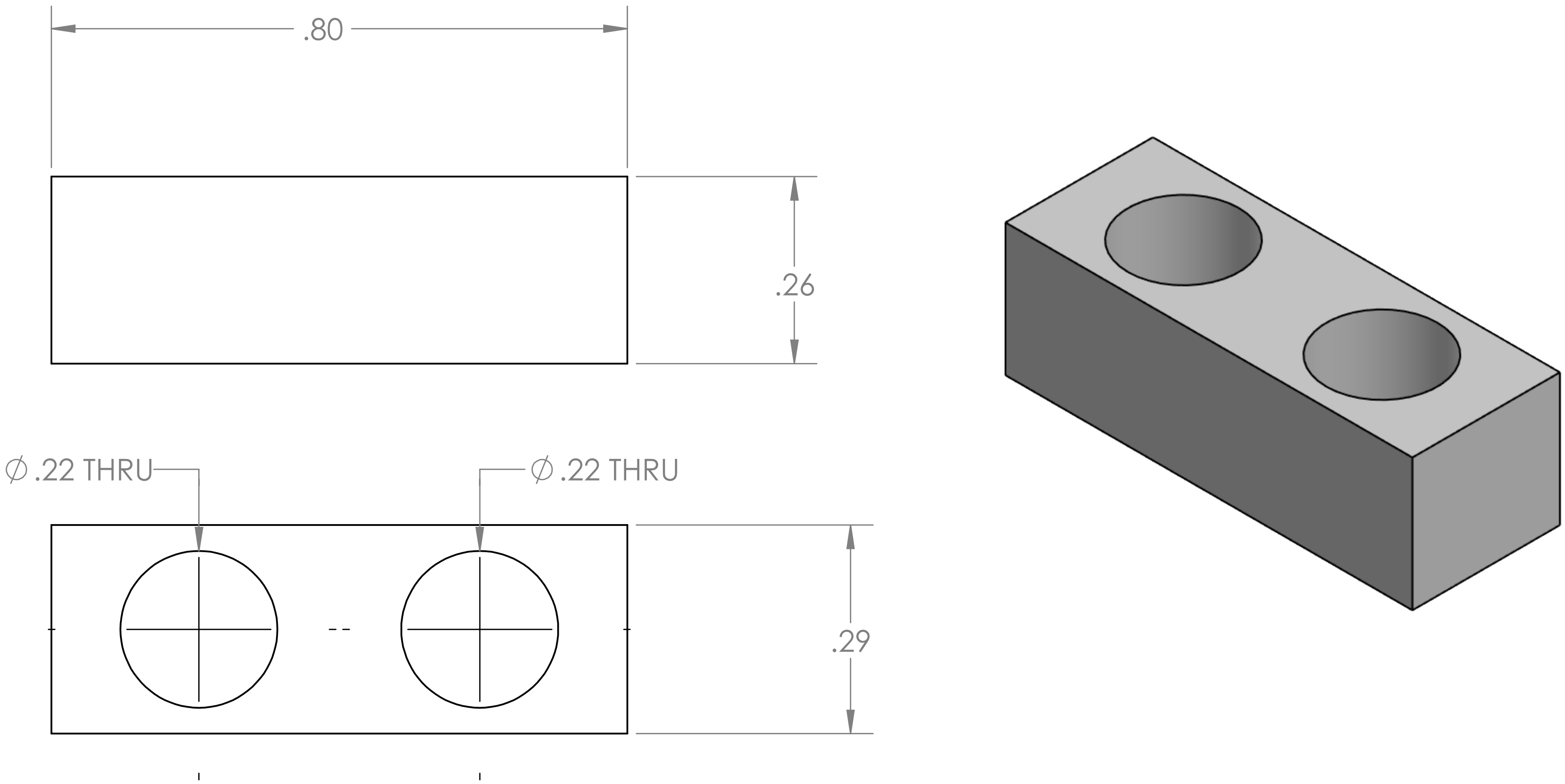
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL Polycarbonate			

HPRC
WPI AIAA

TITLE:
LOWER BODY TUBE

SIZE	DWG. NO.	REV
A	23-2-4-002	

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
polycarbonate

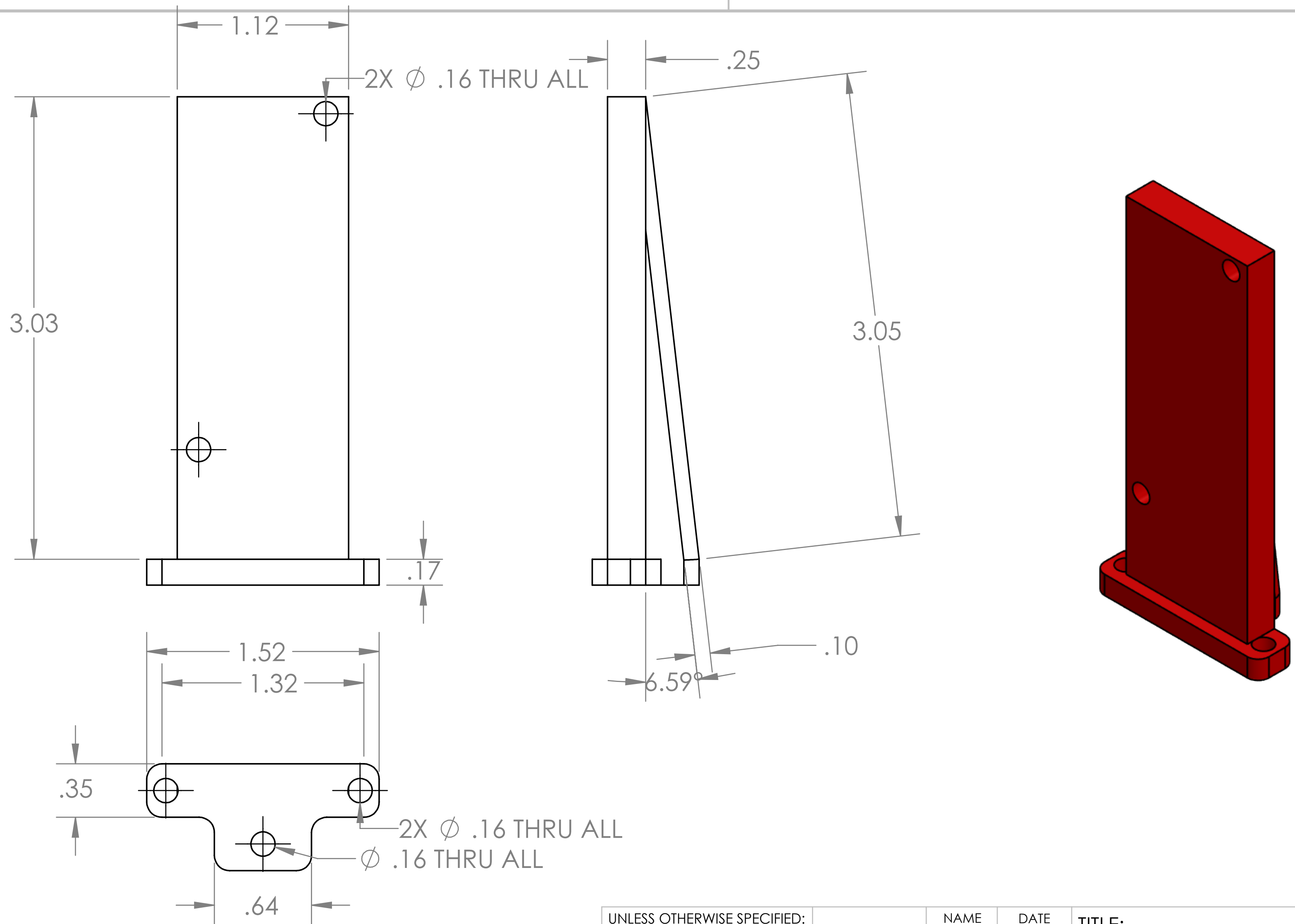
	NAME	DATE
DRAWN	KB	5/9/2023
CHECKED	JR	5/9/2023

HPRC
WPI AIAA

TITLE:
SERVO MOUNT

SIZE A | DWG. NO. 23-2-4-003 | REV

SCALE: 4:1 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL
polycarbonate

	NAME	DATE
DRAWN	KB	5/9/2023
CHECKED	JR	5/9/2023

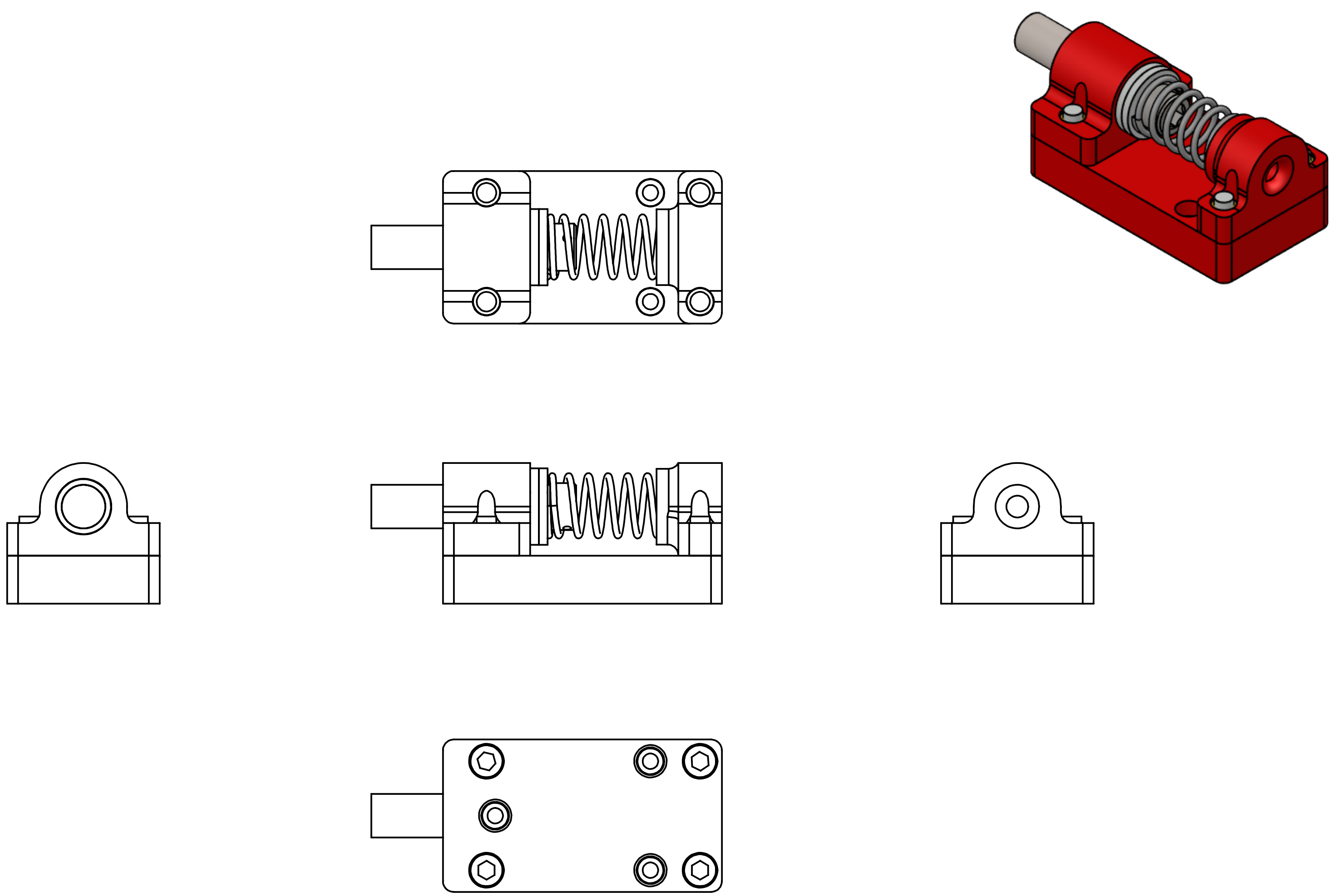
HPRC WPI AIAA

TITLE:

BIG RED B MOUNT

SIZE A | DWG. NO. 23-2-4-006 | REV

SCALE: 1:1 | WEIGHT: 0.03 LB | SHEET 1 OF 1



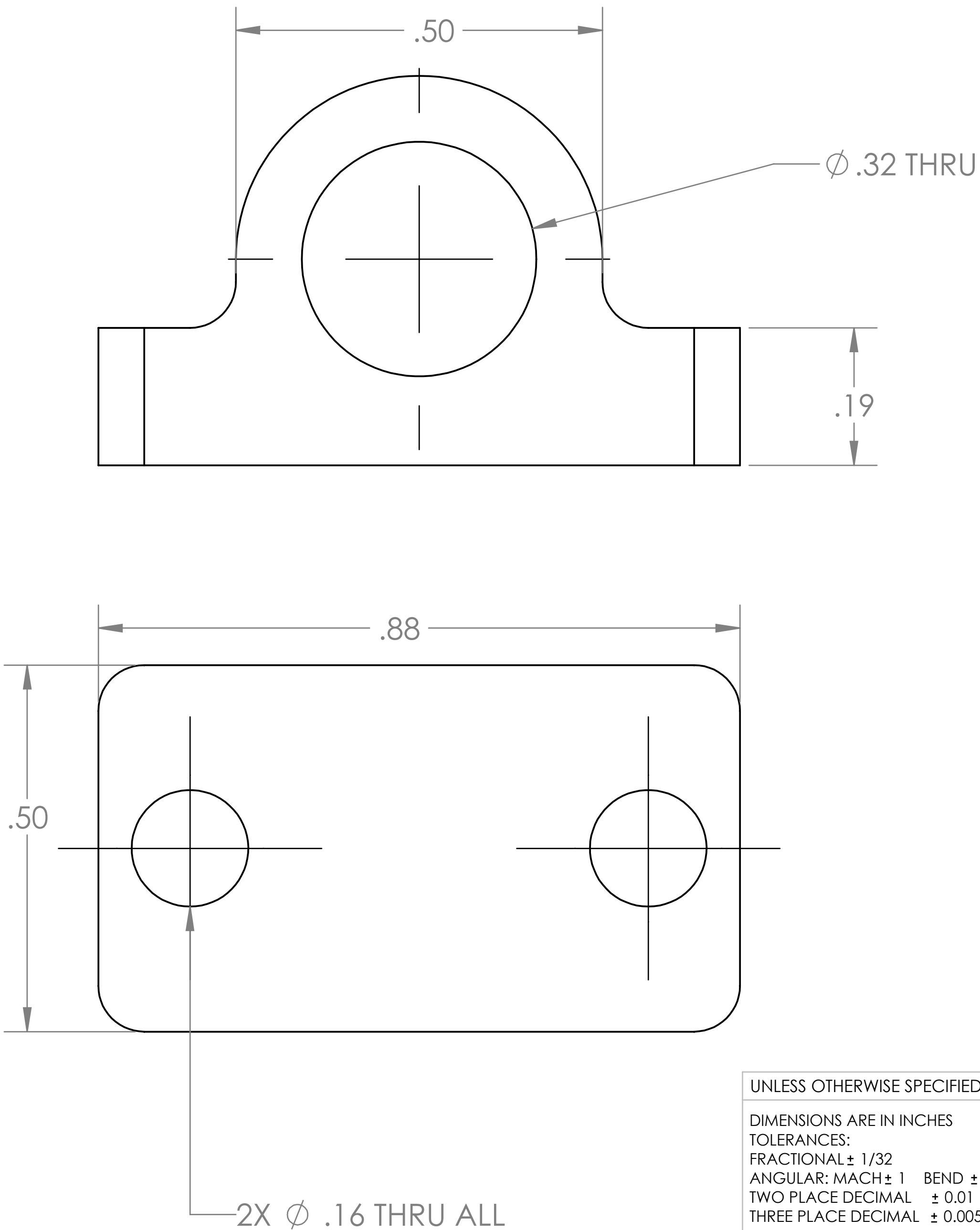
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL			

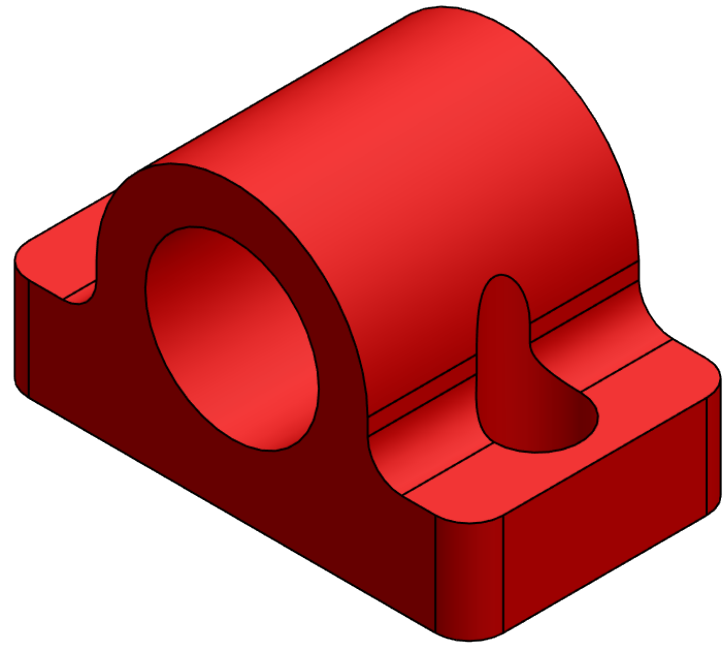
TITLE:

SPRING PIN ASSEMBLY

SIZE	DWG. NO.	REV
A	23-2-4-100	

SCALE: 1:1 WEIGHT: 0.047LB SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
polycarbonate

	NAME	DATE
DRAWN	KB	5/9/2023
CHECKED	JR	5/9/2023

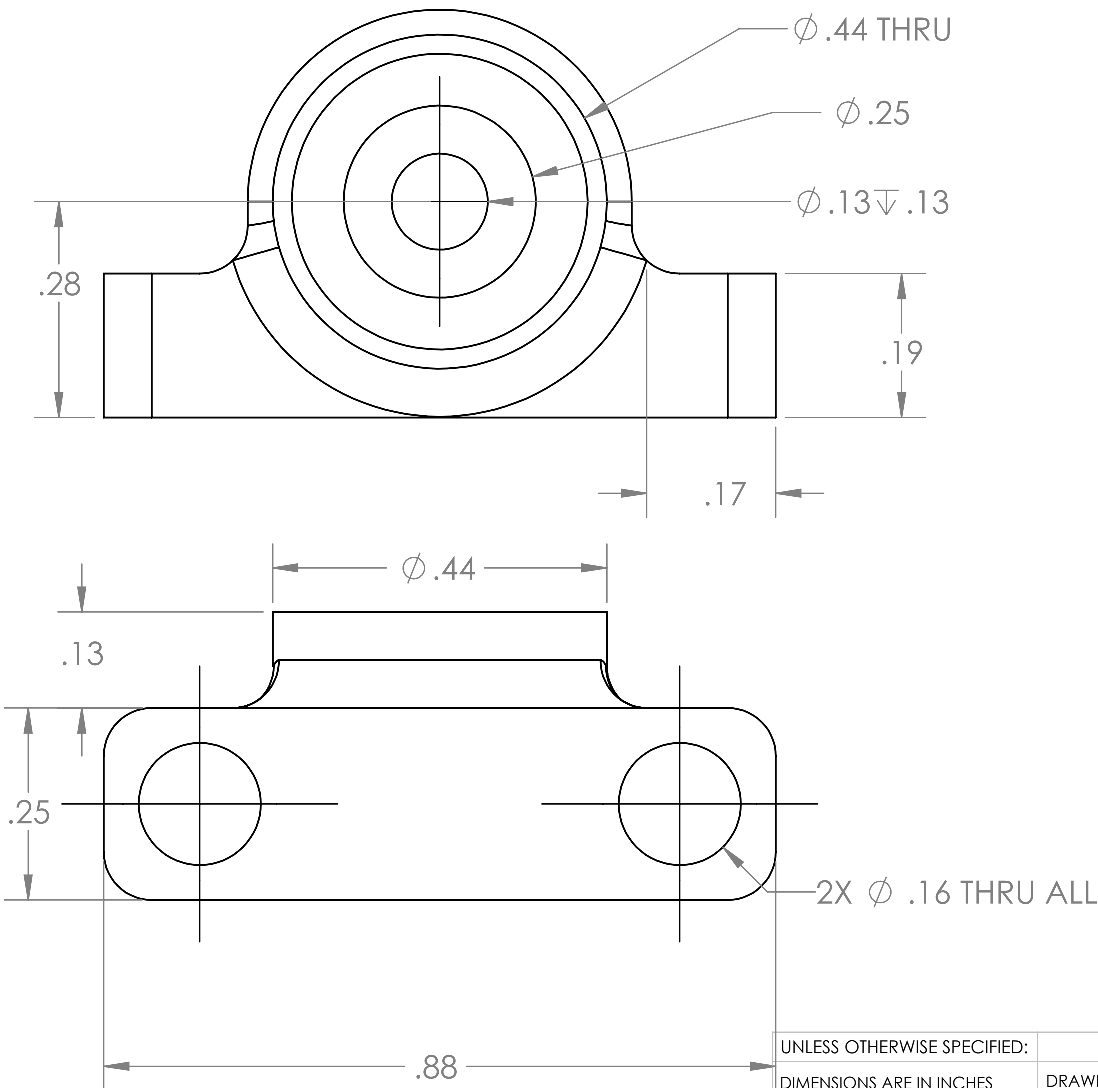
HPRC
WPI AIAA

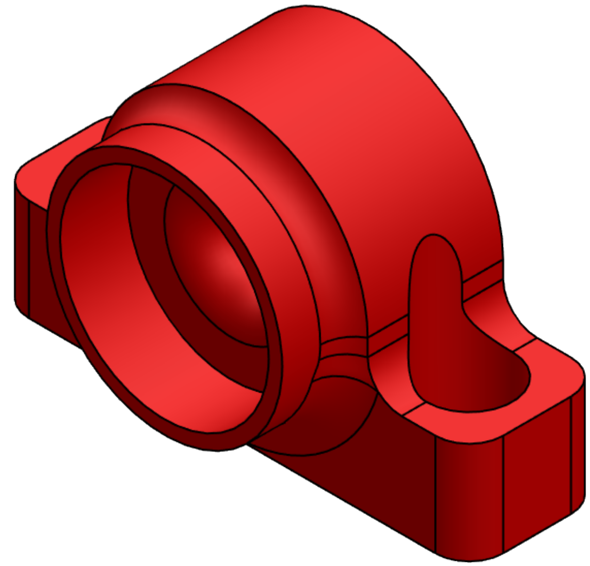
TITLE:

BEARING HOLDER

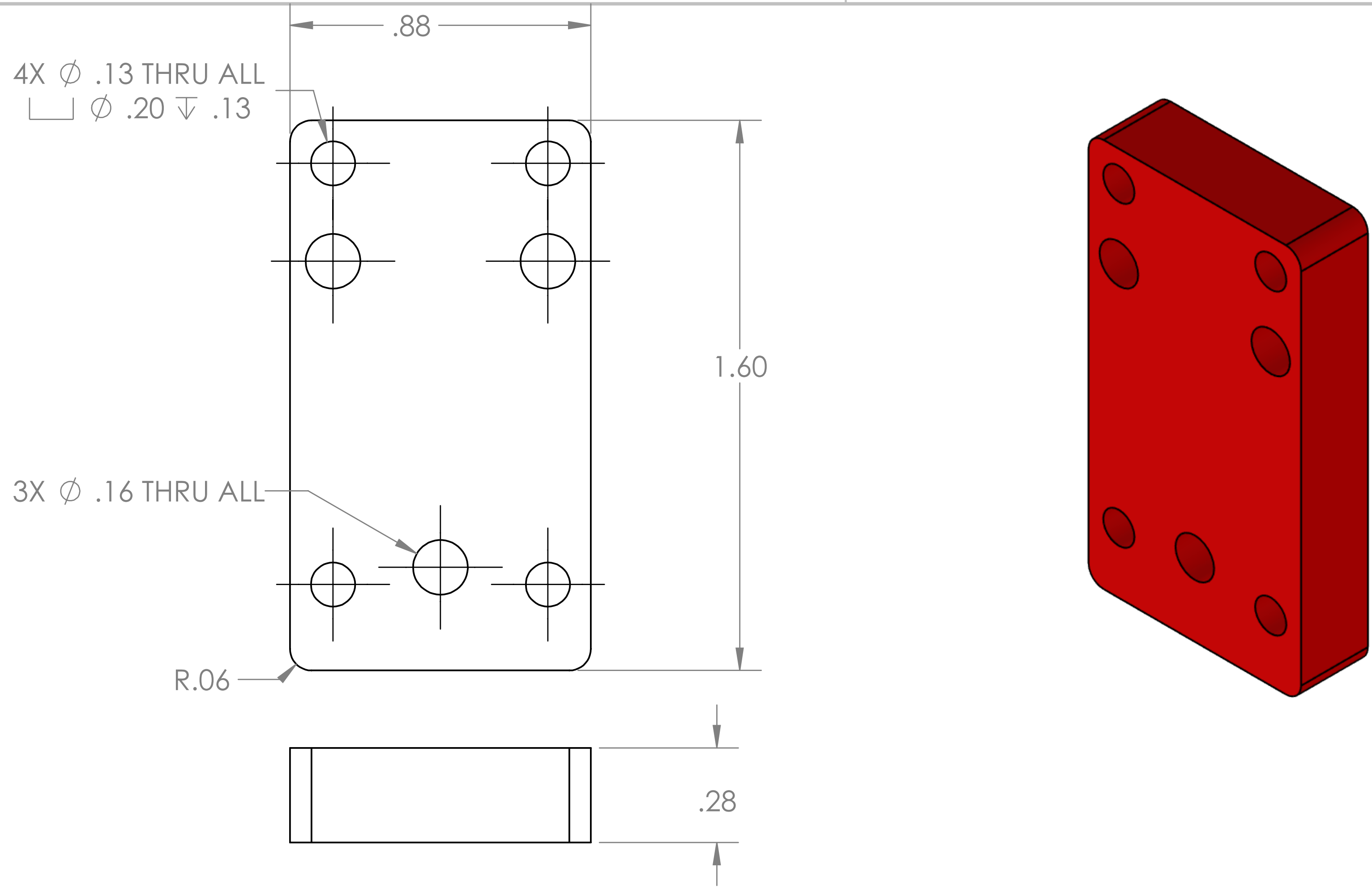
SIZE **A** DWG. NO. 23-2-4-101 REV

SCALE: 4:1 WEIGHT: SHEET 1 OF 1

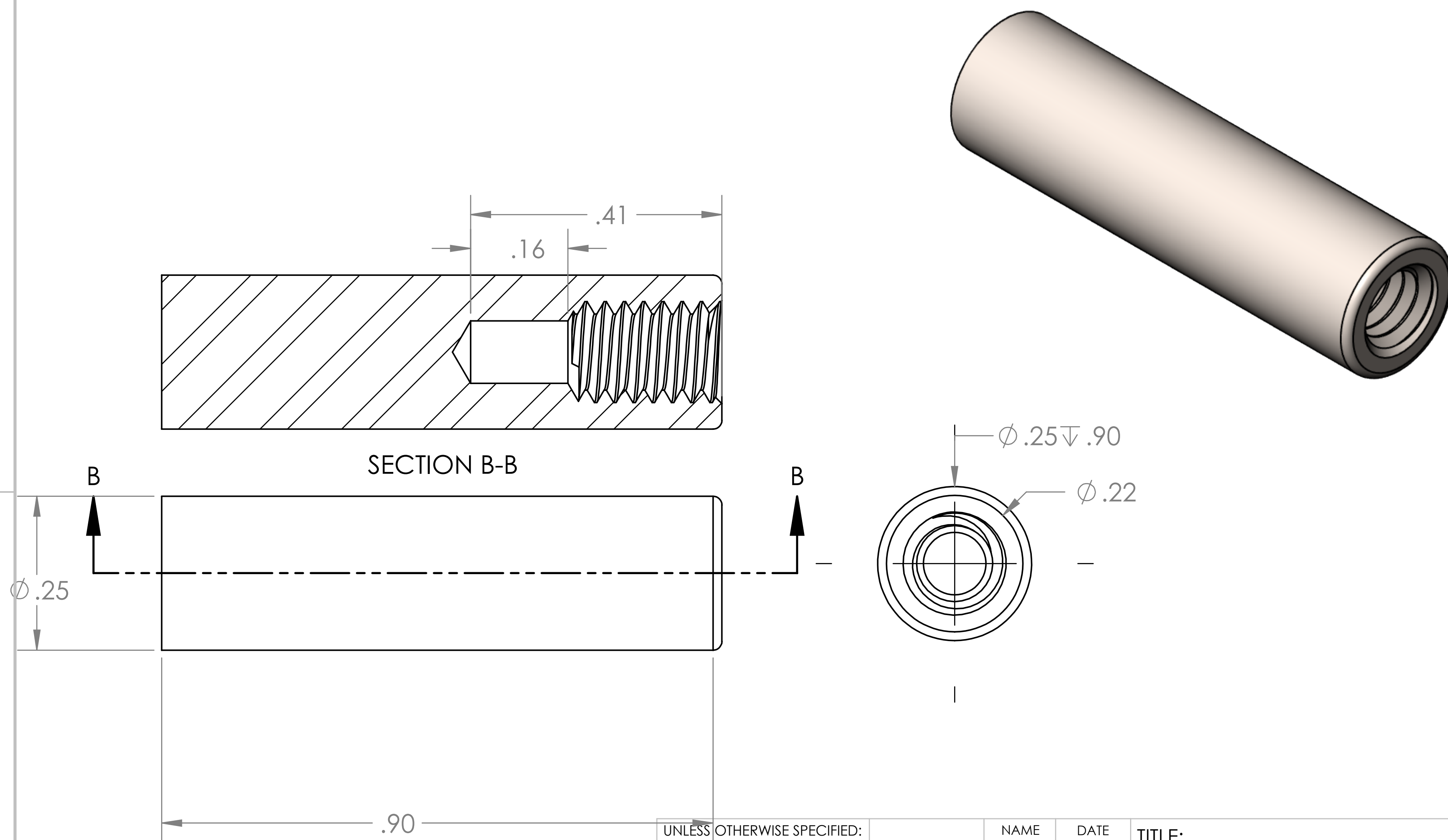




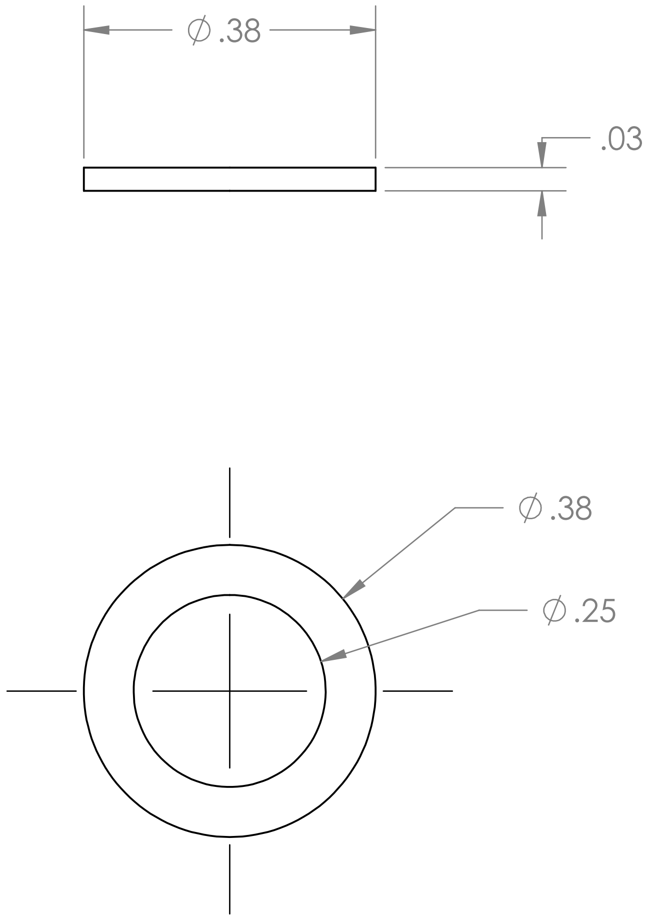
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023	SPRING BACKING
	CHECKED	JR	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-4-102 — REV
MATERIAL polycarbonate				SCALE: 4:1 — WEIGHT: — SHEET 1 OF 1

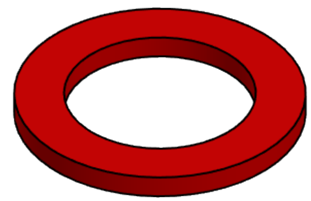


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: MOUNT BASE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023	
	CHECKED	JR	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-4-103 · REV
MATERIAL polycarbonate				SCALE: 2:1 · WEIGHT: .01 LB · SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023	PIN
	CHECKED	JR	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A · DWG. NO. 23-2-4-104 · REV
MATERIAL ALLOY STEEL				SCALE: 4:1 · WEIGHT: .01 LB · SHEET 1 OF 1



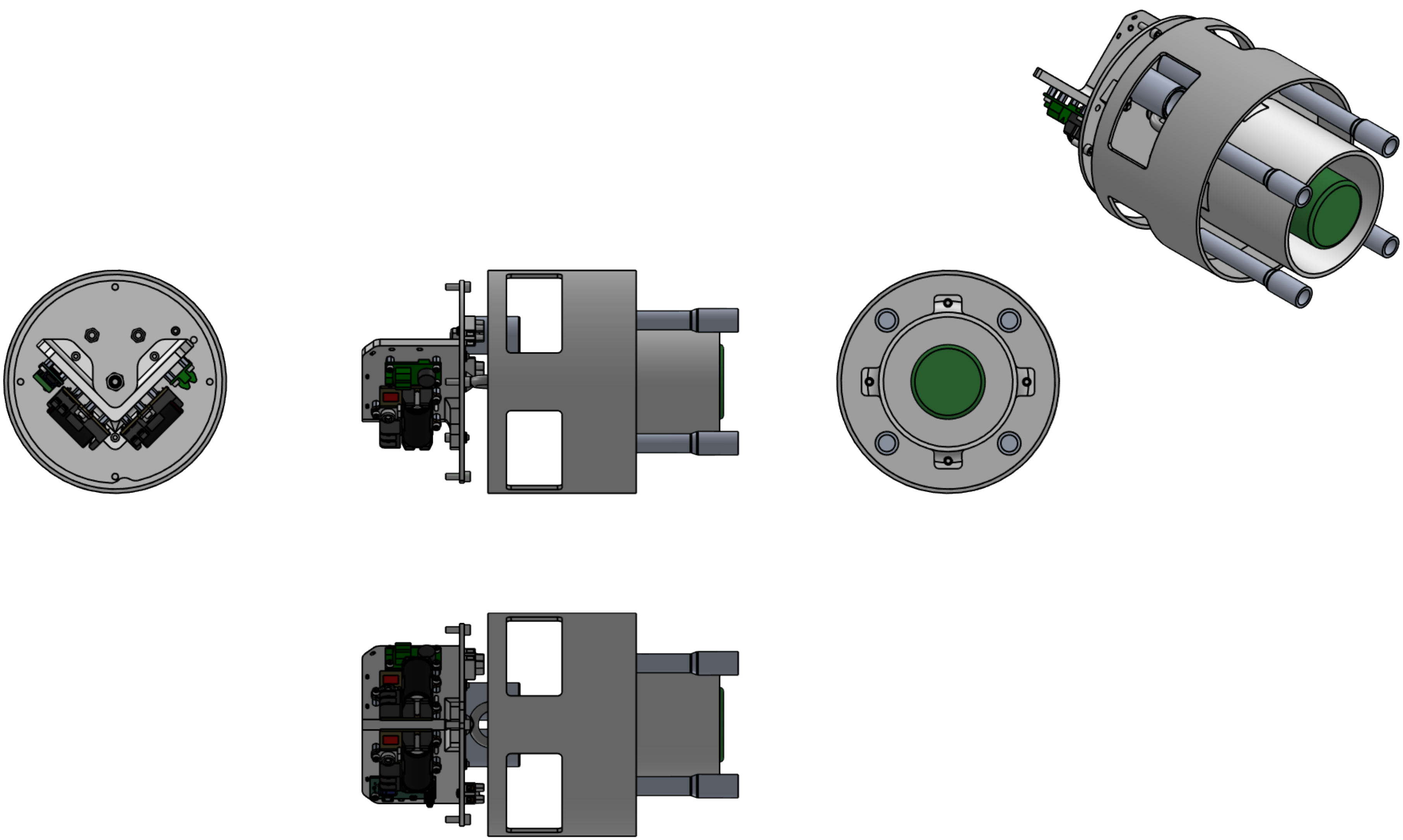


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL polycarbonate			

TITLE:

SPRING SPACER

SIZE	DWG. NO.	REV
A	23-2-4-105	
SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL			

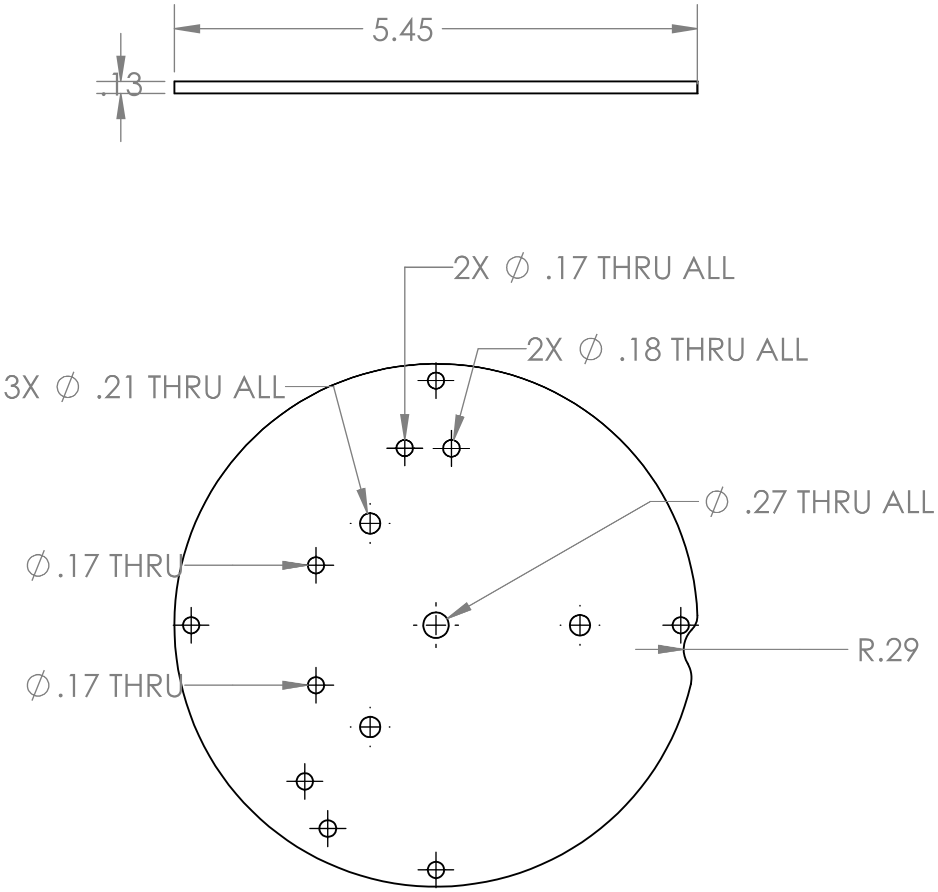
HPRC WPI AIAA

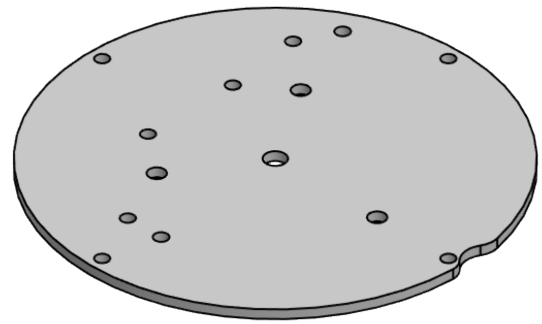
TITLE:

PAYLOAD RECOVERY BAY

SIZE	DWG. NO.	REV
A	23-2-5-000	

SCALE: 1:4 | WEIGHT: ~2.45LB | SHEET 1 OF 1





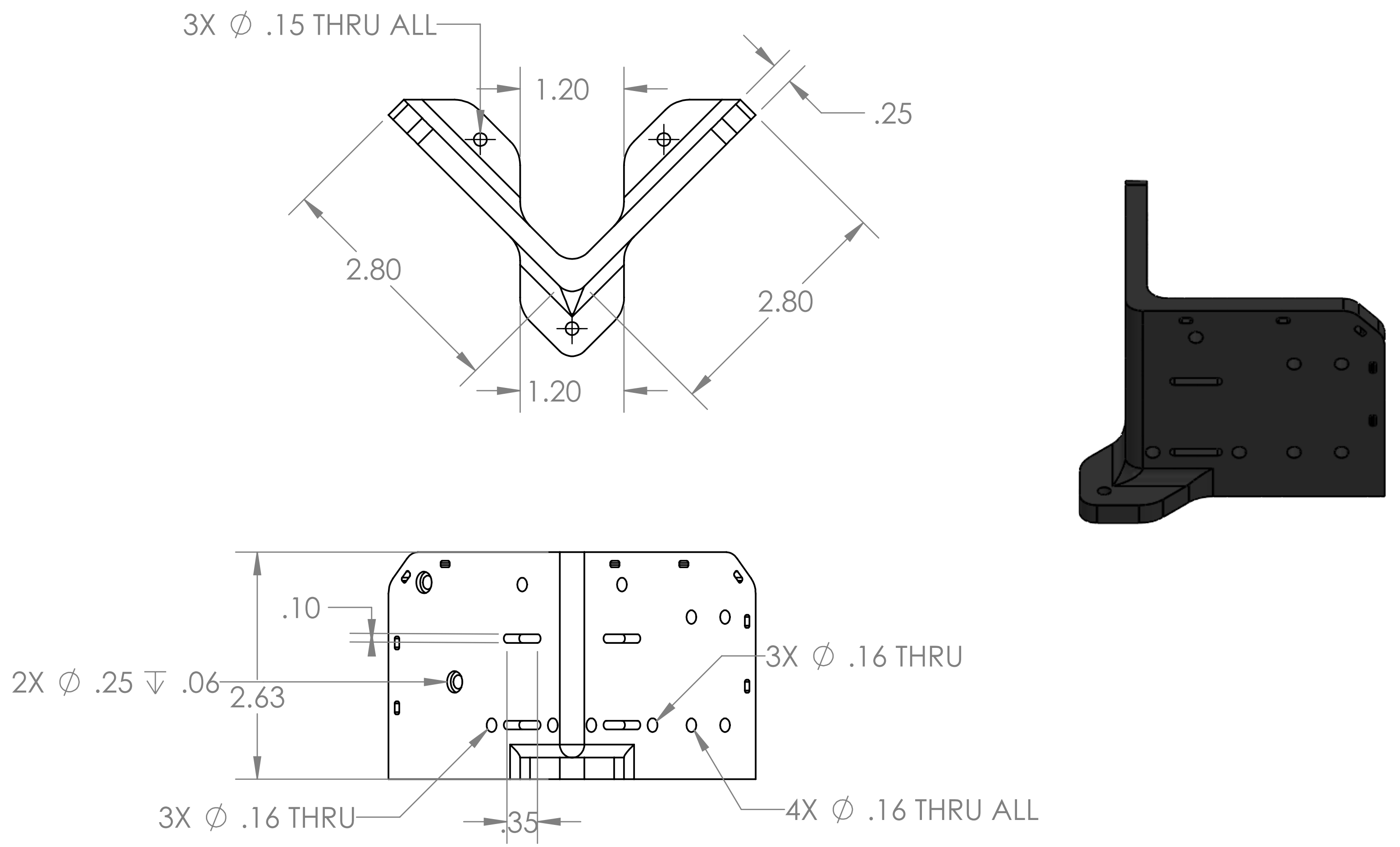
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5			
MATERIAL G10 Fiberglass			

HPRC WPI AIAA

TITLE:

BULKHEAD

SIZE	DWG. NO.	REV
A	23-2-5-101	
SCALE: 1:2	WEIGHT: 0.186 LB	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: ALTIMETER PLATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023	
	CHECKED	JR	5/9/2023	
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA			SIZE A — DWG. NO. 23-2-5-102 — REV
MATERIAL polycarbonate				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

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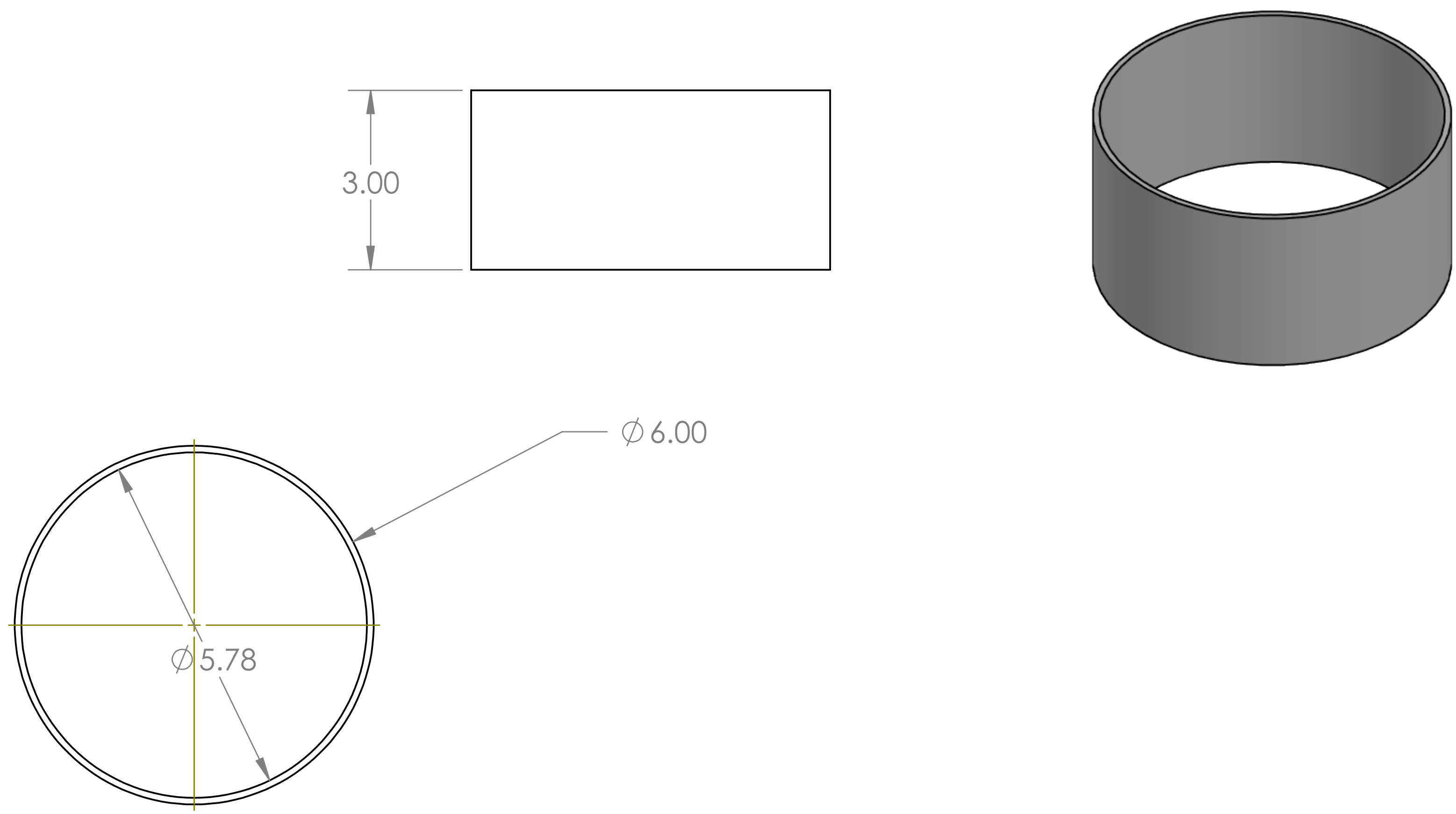
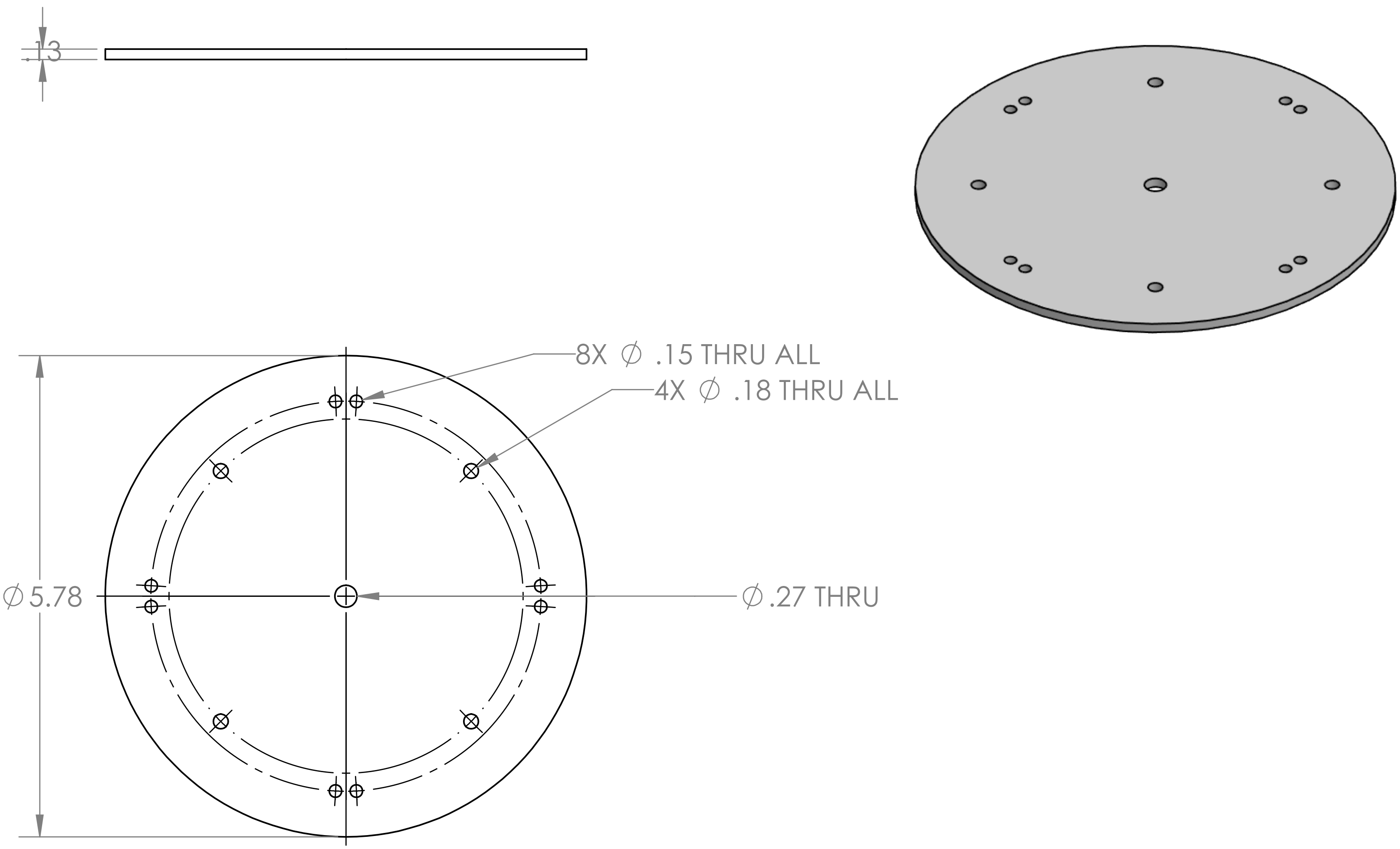


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/9/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA		
MATERIAL G10 Fiberglass			

TITLE:
PISTON COUPLER TUBE

SIZE	DWG. NO.	REV
A	23-2-5-201	
SCALE: 1:3	WEIGHT: 0.474 lb	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
G10 Fiberglass

	NAME	DATE
DRAWN	KB	5/9/2023
CHECKED	JR	5/9/2023

HPRC
WPI AIAA

TITLE:

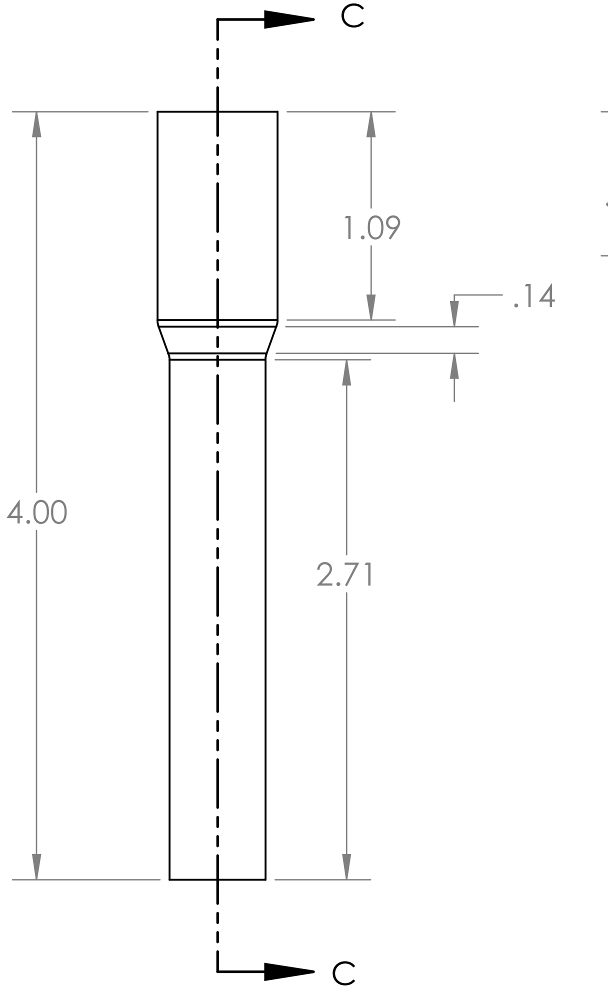
PISTON BULKHEAD

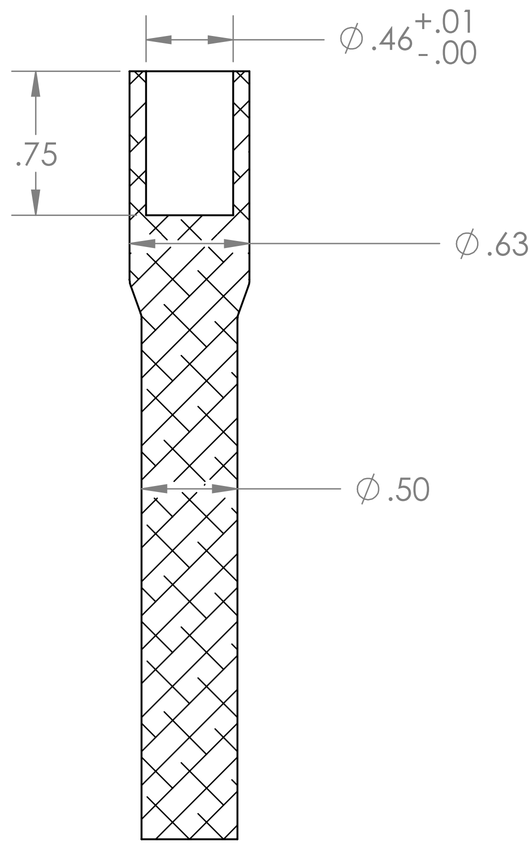
SIZE A | DWG. NO. 23-2-5-202 | REV

SCALE: 1:2 | WEIGHT: 0.21 lb | SHEET 1 OF 1

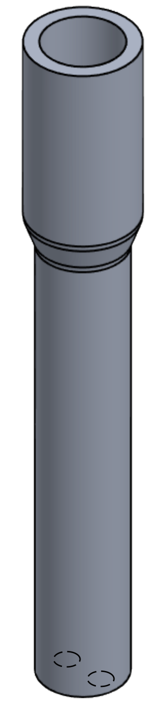
2 | 1

B | B

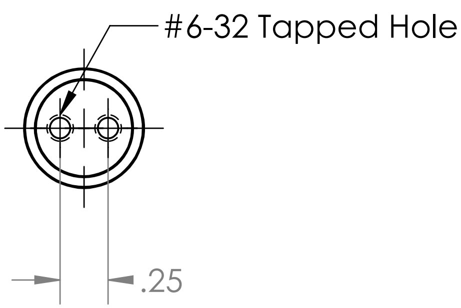




SECTION C-C



A | A



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
ANGULAR: MACH ± 1 BEND ± 1
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL
Aluminum 6061-T6

	NAME	DATE
DRAWN	LE	5/9/2023
CHECKED	JR	5/9/2023

HPRC WPI AIAA

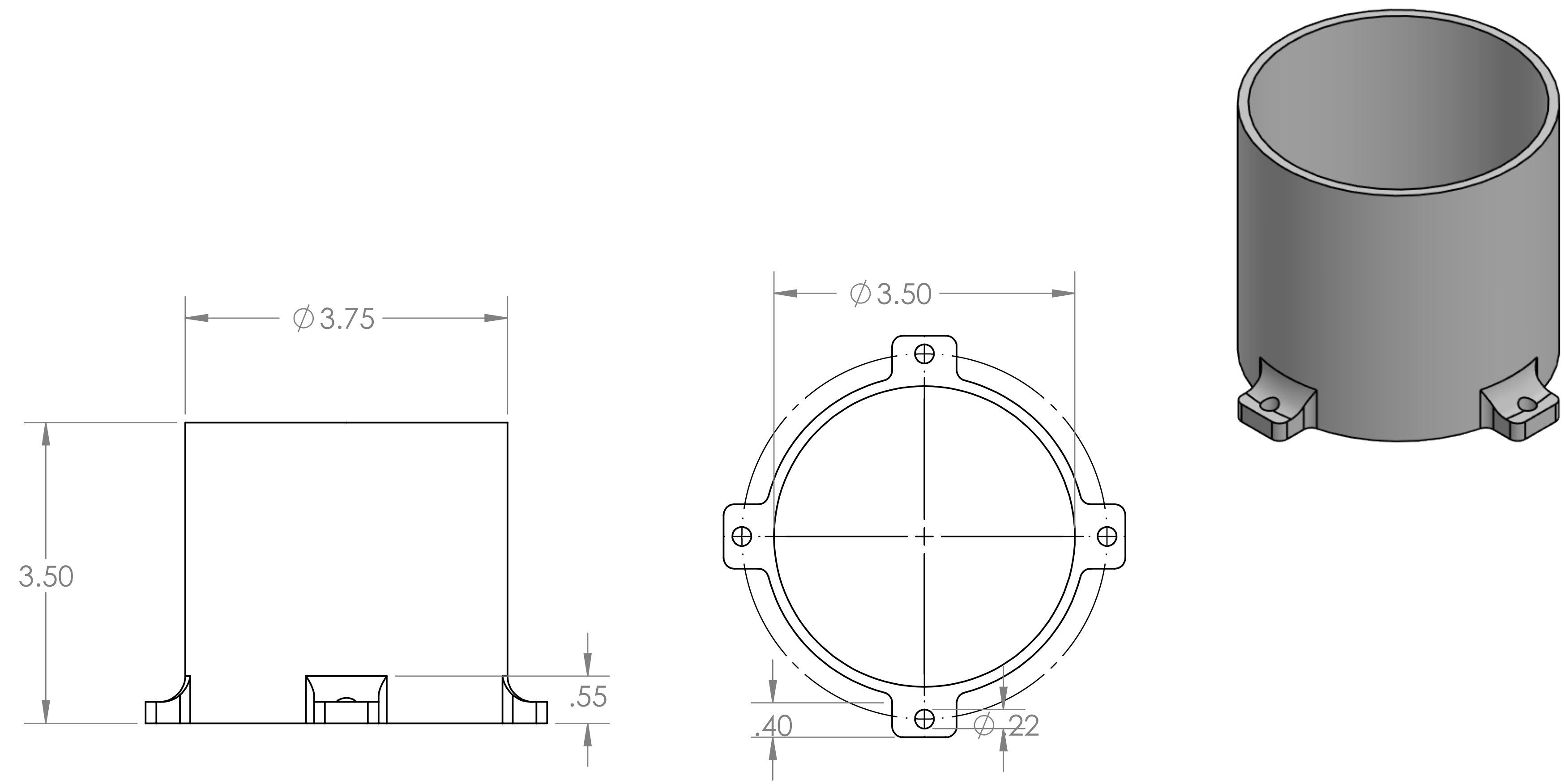
TITLE:

PISTON STANDOFF

SIZE	DWG. NO.	REV
A	23-2-5-203	

SCALE: 1:1 | Weight: 0.0757 lb | SHEET 1 OF 1

2 | 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/32 ANGULAR: MACH ± 1 BEND ± 1 TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005	DRAWN	KB	5/8/2023
	CHECKED	JR	5/9/2023
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5	HPRC WPI AIAA		
MATERIAL Polycarbonate			

TITLE:

PARACHUTE HOLDER

SIZE	DWG. NO.	REV
A	23-2-5-204	
SCALE: 1:2	WEIGHT: 0.309 lb	SHEET 1 OF 1

Acknowledgments

The team’s authors and members would like to thank the team’s sponsors, our rocketry advisor Curtis Heisey, and the various WPI administrators that have given their time and resources to the team.

References

[1] “Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure.” C393/C393M, www.astm.org/c0393_c0393m-20.html. Accessed 12 May 2023.

[2] “Standard Practice for Determining Sandwich Beam Flexural and Shear Stiffness.” D7250/D7250M, www.astm.org/d7250_d7250m-20.html. Accessed 12 May 2023.

[3] Pilkey, Walter D., and Deborah F. Pilkey. Peterson’s Stress Concentration Factors, 3rd Edition. John Wiley & Sons, 2008.

[4] Knacke, T. W., Parachute recovery systems: Design manual, Para Publishing, 1992.