Husker Rocketry Spaceport America Cup Competition Report

Team 132 Project Technical Report for the 2023 Spaceport America Cup

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Abstract

As a design team within the UNL Aerospace Club, Husker Rocketry designs, constructs, and flies high-power rockets for a competition of its choosing annually. This year, the UNL Husker Rocketry team has chosen to participate in the Spaceport America Cup competition, specifically the 10k COTS category. The rocket, named EVE, is 9.08 ft. long and has a 6.17 in. diameter. It will be powered by a commercially produced motor to reach a target altitude of 10,000 ft. Design and modeling of the rocket used the flight simulator software OpenRocket. This software helped to find the optimal dimensions and motor for the rocket that would achieve a goal of a 10,000 ft altitude while avoiding speeds too close to mach 1, during which air flow dynamics become highly irregular and more difficult to ensure safe rocket flight. Flight simulations indicate apogee at 10,180 ft and a maximum velocity of about 621 miles per hour. The parts for the rocket are commercialized off-the-shelf items from various rocketry retailers. Our payload this year revolves around the stresses experienced by plants through a launch to 10,000 ft. and the continued viability of the plants. To achieve this testing, plants will initially be grown in rockwool cubes using hydroponics until the plants reach the 2-3 week mark. Half of the plants will be placed in the rocket and launched to 10,000 ft. while the others will continue to grow in a local greenhouse. Data from the barometer, thermometer, and the strain gauge during the launch will be collected. Plant growth and health will be compared between the launched plants to those remaining on the ground. Differences in growth will be recorded, and data between the two environments will be analyzed for factors that may have contributed to different growth patterns.

Nomenclature

S = Swing area (in^2)
AR = Aspect ratio
λ = Taper ratio
Cr = Root chord (in)
Ct = Root tip (in)
b = Semi-span (in)
T = temperature (F)
h = altitude at max speed (ft)
P = pressure (psi)
t = thickness (in)
a = speed of sound (ft/s)
Vf = fin flutter velocity (ft/s)
G = Shear modulus (psi)

I Introduction

Husker Rocketry is a student-led design team that takes high powered rockets from design to launch. We are a subset of the University of Nebraska-Lincoln's (UNL) Aerospace Club and teach members how to build certification rockets, as well as building a competition rocket each year with a unique payload. We work with the Aerospace Club advisors and our Rocketry mentor to manage the club and teach members how to properly build rockets. We are open to all majors and ages of undergraduates.

The team has multiple leads that manage the overarching club, including the logistics, budget, overseeing the rocket design and construction, and planning travel to launch sites. The leads also help to teach new members how to build rockets by helping each general member construct their own level 1 certification high powered rocket and teach them how to help out with the different construction stages of our competition rocket. This year, we helped 6 members achieve their level 1 rocketry certification and some of the leads are looking towards getting their level 2 certifications this summer. This summer is the first time since before covid that our team has traveled to competition, but starting this year we are hoping to make competing in annual competitions a central part of our team again.

Our team management strategies include training each general member to construct their own rocket to build knowledge in model rocketry, communicating between all the leads and general members for important deadlines and events, and providing proper feedback for improvements that can be made on their rockets. Due to UNL not having an aerospace engineering major, a majority of aerodynamic knowledge is gained via the UNL Aerospace Club. This allows members to learn about aerodynamics and aeronautic systems. Through this, a multitude of skills are gained through the club. Including computer aided design (CAD) and flight simulation skills. For the Rocketry team, tasks are regularly delegated across the entire team such that no single person has to worry about completing an important subsection of the rocket by themselves.

This year, there are two main leads: electrical and payload, and design and construction. The payload and avionics section of the competition rocket include many electrical components that require careful wiring and programming. Through this, team members who do not have much experience with electrical systems get the opportunity to get hands-on experience. The same situation is applied to the design and construction team, as members who may not have much experience with CAD or simulations get the opportunity to design complex rocket models, as well as be a part of different construction processes that deal with epoxy, fiberglass, and carbon fiber composites. The team utilizes UNL's aerospace lab equipment to design new iterations of payloads, electronics, and frames to achieve a proper, flying, rocket.

II System Architecture Review

A fiberglass parabolic nose cone is attached to the main body tube made of fiberglass as well, which holds the payload section as well as the avionics bay. The payload for the rocket will contain nine corn plant samples. These samples will yield data for the temperature and pressure that the plants receive for the duration of the flight. This is where the rocket earned its name, EVE, standing for "Enclosed Vegetation Environment." The main tube also holds the drogue and main parachute. Attached to the main tube is the booster rube, containing the rocket motor inside an inner tube which is held by three inner centering rings. Attached to the booster tube is a set of four fiberglass trapezoidal fins set 90° from each other. The avionics bay is split into two separate sections, wired for dual redundancy, that include trackers and altimeters. Eve is 111 inches (9.08ft) in length. EVE will fly on a M-1850W White Lightning motor.

2.1 Solidworks Models

Before we began construction on EVE, we first created CAD models in order to better visualize the final design for the rocket. This included designing the outer airframe in Solidworks, as well as the inner components, such as the inner tube, centering rings, bulkheads, avionics bay, and payload area. This helped us to finalize the dimensions for each aspect of the rocket, as well as design the final CAD models for the avionics bay and payload before 3D printing them. Figure 1 shows this Solidworks model and Figure 2 is a cutaway view showing the interior of the rocket. Further breakdowns of the Solidworks models can be seen in Appendix 6.6, which contains the engineering drawings for each of the main rocket components.

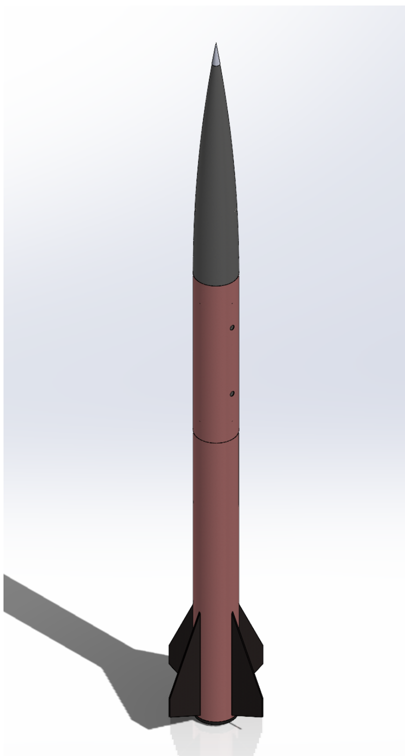


Fig. 1 Solidworks model of EVE - outside view

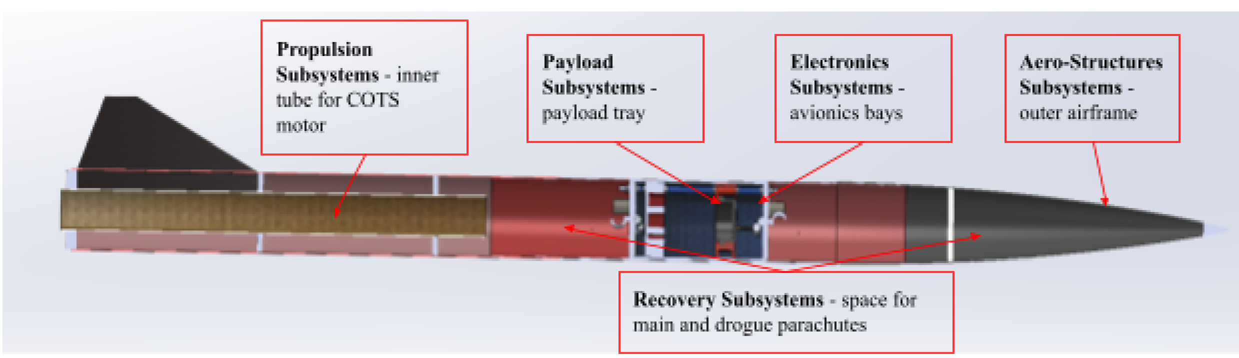


Fig. 2 Solidworks model of EVE - inside view

2.2 OpenRocket Analysis

We also modeled EVE in OpenRocket before construction to make sure the stability and apogee met our expectations and the competition guidelines. This allowed us to make different variations of the rocket without wasting materials and figure out the exact materials we needed to purchase to construct the airframe.

The final design we settled on for the rocket had a predicted stability of 1.77 calibers. The total length of the rocket was 111 inches, with a center of gravity at 74.821 inches from the nose cone, and a center of pressure at 85.764 inches from the nose cone. The estimated apogee for this rocket was 10,180 feet, with a max velocity of 912 ft/s (which is Mach 0.84) and a maximum acceleration of 344 ft/s^2. The OpenRocket model with center of gravity and center of pressure marked can be seen in Figure 3.

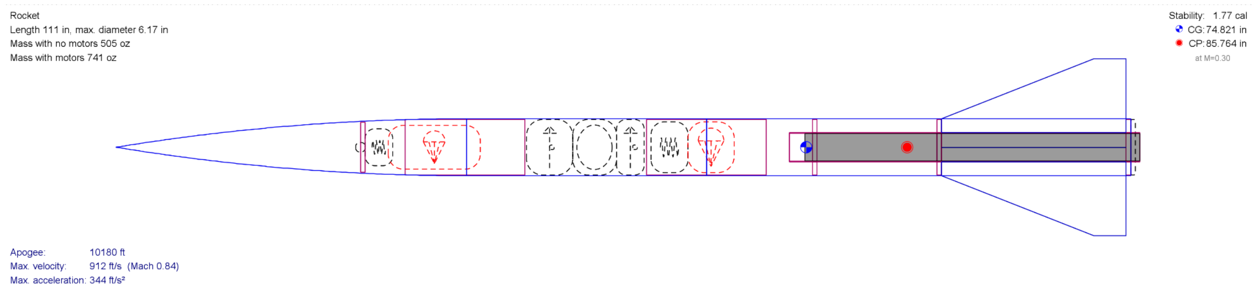


Fig. 3 OpenRocket design for EVE

2.2.1 Stability Analysis

A plot of the stability throughout the flight is shown in Figure 4, with an assumed wind speed of 6 mph.

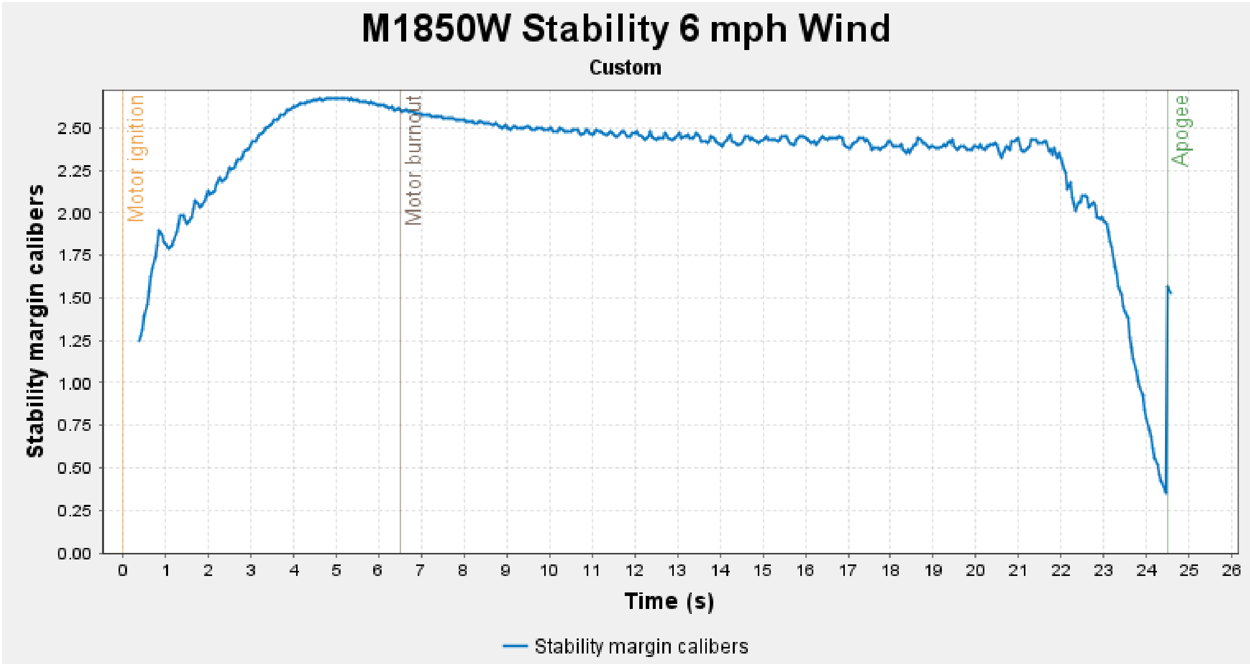


Fig. 4 Flight stability simulation for M1850W

2.2.2 Simulation Analysis

To make predictions on what the rocket flight will resemble, multiple simulations were conducted through the rocket simulation software OpenRocket. This simulation allowed for the predicted altitude, velocity, and acceleration to be plotted. A plot for one of the simulations is shown in Figure 5 below.

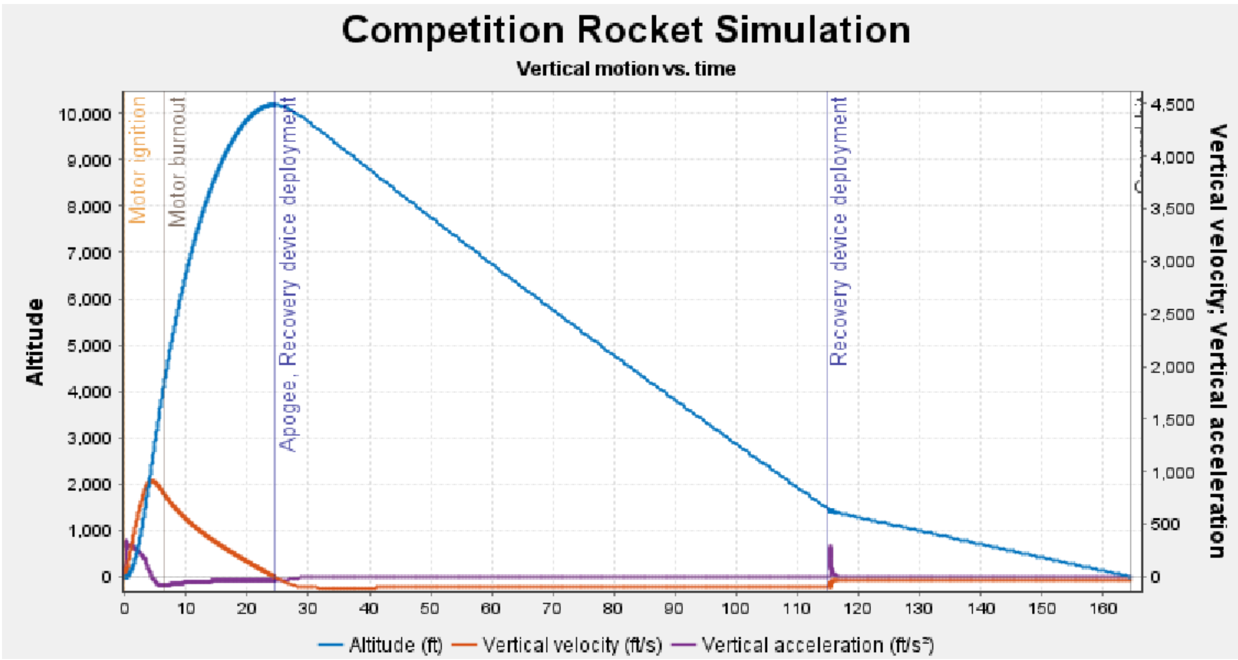


Fig. 5 OpenRocket simulation graph of the EVE's Altitude, Vertical Velocity, and Vertical Acceleration

Key numerical values were also created from the simulation. Below in Figure 6 shows key values for EVE's flight profile.

Velocity off rod	Apogee	Velocity at deployment	Optimum delay	Max. Velocity	Max. Acceleration	Time to apogee	Flight Time	Ground hit velocity
101 ft/s	10184 ft	92.3 ft/s	18 s	912 ft/s	344 ft/s^2	24.4 s	165 s	28.5 ft/s

Fig. 6 Data from OpenRocket simulation trials

2.3 Propulsion Subsystems

The propulsion system of the rocket went through many changes during the design process. Originally, the propulsion system was going to be an L-motor that would take our rocket to a target apogee of 7,000 ft. This original rocket was set to have a 4 in diameter that would be 6 ft tall. When we received feedback after the first progress report that our apogee was too low for the competition, design and concept ideas needed to be changed. In order to figure out what kind of motor would suit best for the project, we consulted our mentor on what motor would work best. Our mentor told us that an M-1850W from AeroTech would get us to the desired apogee of 10,000 ft for the competition. As such, we constructed the entire airframe around this motor. This major change in design did result in a larger diameter and height for the rocket. For the finalized design, our motor goes inside a 75/7680 motor case. This motor case holds 6 individual motor grains when assembling the motor. Between each motor grain is an o-ring to prevent pressure and gas escaping from small gaps between the motor grain and the liner in the motor case. After the grains are carefully inserted into the motor case, the forward seal disk, forward closure, and rear closure are inserted into the motor case, enclosing the grains in the motor case. After the motor has been assembled, it is then inserted into the inner tube of the booster tube. This is then closed off by twisting on the motor retainer. This hold the motor in place such that it is secured with no wiggle room. This completes the process of loading the loaded motor into the rocket securely.

To wire up the rocket for launch, the rocket is taken to the launch pad after the airframe is entirely assembled. The rocket then has its two 1515 rail buttons slide into the launch rail. After the launch rail is raised vertically, a wire is then inserted into the bottom of the motor until it reaches the top of the motor. After checking and confirming that the wires are connected and making a complete circuit with the launch crew, the rocket is set to launch.

2.4 Aero-Structures Subsystems

The entire airframe was designed around two main parts for the rocket, the motor and the payload. The payload is enclosed inside the rocket and is in between the upper avionics and lower avionics bay. This resulted in the rocket design needing to only be in three major pieces, the nose cone, main tube, and booster tube. Due to time constraints, these three pieces for the airframe were purchased from various rocketry retailers. All of these airframe components are made out of fiberglass. The booster tube was designed entirely around the length and diameter of the motor. After the length and diameter were decided, fins were designed such that they are inserted into 4-20 in by 0.2 in holes. Filets were then applied to the fins by using 40-minute epoxy mixed with phenolic microballoons to strengthen the chemical bonds. Another filet was added to the bottom centering ring to the booster tube and motor retainer. This ensures that no part in the booster tube can become loose during flight. The system weights, measurements, and performance data can be found in 6.1.

2.4.1 Design and Dimensions

The fiberglass nose cone has a length of 36.0 in, a base diameter of 6.17 in, and a wall thickness of 0.079 in. A 13.0 in blue tube coupler is epoxied into the nose cone and has a shoulder length of 6.25 in, with a diameter of 5.75 in, and a wall thickness of 0.72 in. The nose cone contains a 5.45in diameter birch plywood bulkhead that is 0.5 in thick that has a 1-inch diameter galvanized steel i-bolt drilled in its center. The i-bolt has a quicklink attached that holds one end of the tubular nylon shock cord.

The fiberglass main body tube has a length of 26.0 in, an outer diameter of 6.17 in, an inner diameter of 6.0 in, and a wall thickness of 0.09 in. The main body tube has a blue tube coupler that has an outer diameter of 5.99 in, an inner diameter of 5.66 in, and is 13.0 in in length.

The fiberglass booster tube has a length of 46 in, an outer diameter of 6.17 in, an inner diameter of 6.0 in, and a wall thickness of 0.09in. The booster tube has 4-20 in by 0.20 in holes that are 0.5 in from its bottom. These holes are where the fins go into. The tabs on the fins have a length of 20 in, and have a height of 1.495 in. The root chord of the fin is 20 in, the tip chord is 3.5 in, the height is 6.5 in, the sweep length is 16.5 in, the sweep angle is 68.5°, and the thickness is 0.2 in. The material for the fins is G-10 fiberglass. A filet made from epoxy and phenolic microballoons with a radius of a 0.5 in is applied on the fins for structural support. For the motor mount, the material of the inner tube is kraft phenolic and is 38 in long, has an outer diameter of 3.18 in, has an inner diameter of 3 in, and has a wall thickness of 0.09 in. Attached to the inner tube are three birch plywood centering rings. These centering rings have an outer diameter of 6.0 in, have an inner diameter of 3.18 in, and have a thickness of 0.5 in. The displacement from the bottom of the booster tube for these centering rings are 0 in, 20.5 in, and 34 in. The bottom two centering rings are placed such that the fin tabs are directly between them with little to no space between. The top centering ring is placed such that the rocket motor, when inserted, slides past the centering ring by about an inch. This top centering ring contains a 1-inch i-bolt where a quicklink is attached to hold one end of the tubular nylon shock cord. The rail buttons are securely attached to the rocket by having them screwed into the bottom and middle centering rings that are epoxied at the midpoint and end of the screw. This ensures that the rail buttons can rotate and easily glide off the launch rail. Figure 7 below shows components of EVE pre and post assembly into the final rocket.

Fig. 7 Disassembled view of EVE with all components (left), EVE fully assembled (right)

2.4.2 Construction

The fiberglass body tube, nosecone, and fins were purchased from various rocket suppliers, as were the blue tube couplers and the motor mount. We also purchased three ½ inch centering rings. We made by hand three ½ inch bulkheads out of birch plywood and used PLA filament to 3D print the payload plant tray and avionics bay using Bambu Labs and Prusa printers.

We had to cut the body tube into two pieces to allow for dual separation. One piece was used for the main body tube, and the other piece was turned into the booster tube. Fins were attached to the rocket using epoxy mixed with 40 minute epoxy. We also used 40 minute epoxy mixed with small bits of carbon fiber to secure the blue tube couplers to the inside of each section of the body tube, to secure the centering rings to the motor mount tube, and to secure the centering rings to the inside of the main body tube. Because we were working with epoxy and fiberglass during this process, we made sure to take the proper steps to mitigate the risk of hazardous materials, the breakdown of which can be seen in the matrix in appendix 6.3. We then drilled small holes in the body tube in the area around the inner tube and syringed in epoxy to further secure it. We made 1 inch epoxy filets to further secure the fins to the body tube and created a filet around the bottom of the motor mount. The epoxy was mixed with phenolic microballoons in order to further strengthen it and create a stronger bond to the fiberglass. We also drilled two holes in the main body tube to screw in 1515 rail buttons to allow us to mount the rocket on the launch frame.

Once the main airframe was assembled, holes were drilled through the body tube, blue tube, and avionics bay bulkheads and inserted screws to ensure that the avionics and payload were secure during launch. We also drilled 4 holes to insert nylon shear pins around each of the separation lines. The pins have a shear force of around 45 pounds, which ensures that the rocket stays together during flight, but separates when the ejection charges fire. Holes were also made into the avionics bay areas to ensure the altimeters can accurately read pressure values during flight.

2.5 Electronics Subsystems

The primary electronics in the avionics bay are the altimeters and trackers, which allow us to record data on the rocket's flight and locate the rocket after launch. The altimeters are also wired to the ejection charges and send signals for separation. We have a total of 2 trackers and 4 altimeters throughout our 2 avionics bays, which are wired for dual redundancy. There are two circuits. The circuit contains a battery that supplies power when the key switches are turned on. Further down, the circuit connects to the two Raven Blue Altimeters in the upper avionics bay and a GPS tracker. At the altimeters a wire connects the wire that sends a charge to the ignition charge to separate the nose cone and main body tube. At the bottom avionics bay a similar circuit is in place, however, there are no trackers in the circuit and the ignition charge is set to explode when the rocket is at apogee. A diagram of the two electrical circuits can be found in figure 8. The recovery system testing for the electronics can be found in appendix 6.2.

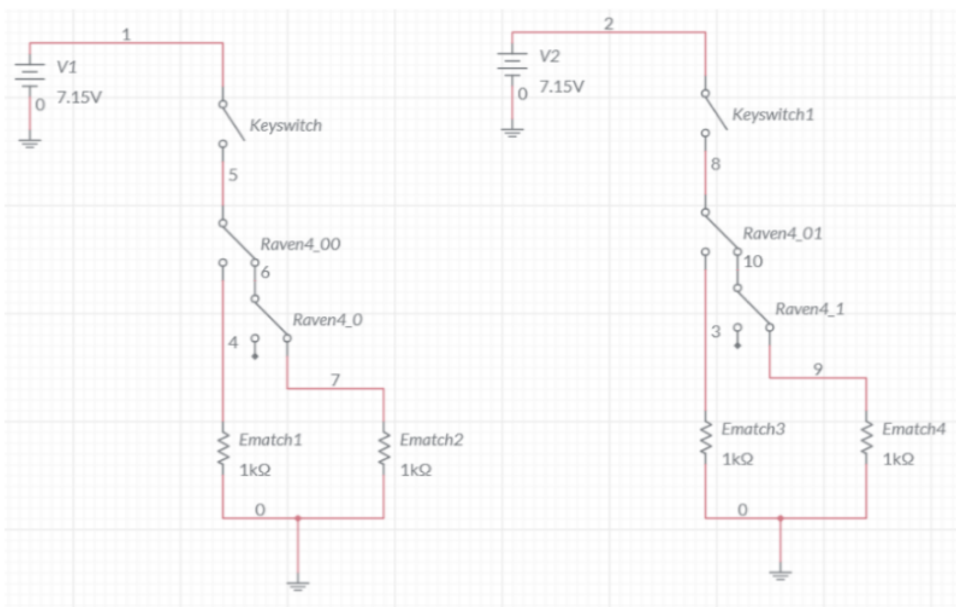


Fig. 8 Electrical diagram of the altimeters

2.5.1 Ground Station and Tracking

To track where EVE travels if it were to fly out of the sight of the club members, two sets of GPS trackers and a ground station were used to locate where EVE lands. The trackers and ground control were bought from the company Featherweight Altimeters. The trackers and ground station are capable of communication between each other from 164,000 feet away. The trackers are capable of lasting for over 16 hours on a single, small LiPo cell. The trackers use 915 Mhz signal to pair with the iphone using bluetooth and communicate latitudinal and longitudinal positions onto the iphone. The trackers also actively transmit the altitude that the rocket is at during its flight. Figure 9 shows the tracker and Figure 10 shows the ground station.

Fig. 9 Featherweight Altimeters tracker

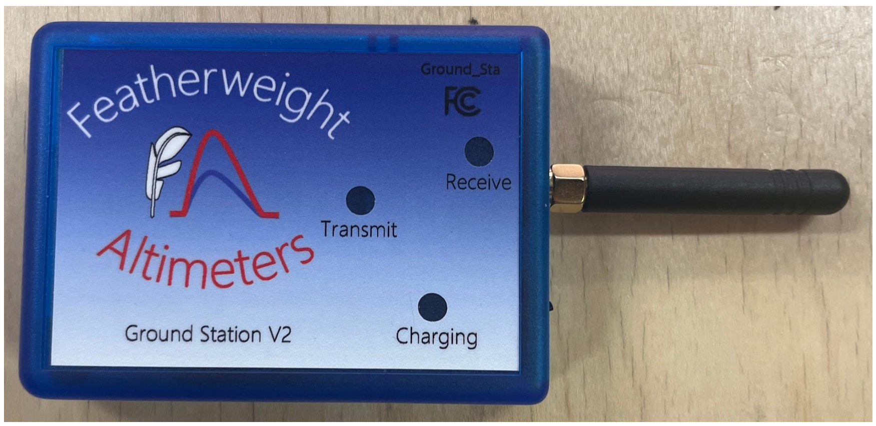


Fig. 10 Featherweight Altimeters ground station

2.5.2 Altimeters

The rocket tracks how high it is by using four altimeters to track its altitude and store data from the flight. We bought our altimeters from the company Featherweight Altimeters. The original altimeters we were using for the test launch were Raven 4s, but we purchased 4 Blue Ravens, which are the most recent model, which we will be using in the competition launch of our rocket. A side-by-side of the two altimeter types can be seen in Figure 11. Blue Ravens have all the same abilities as the Raven 4s, with the addition of having bluetooth capabilities, allowing us to monitor the rocket's altitude through a phone app. The altimeters record the rocket's altitude throughout the duration of the flight and allow us to generate graphs. The altimeters are also used to dictate when the ejection charges ignite and deploy the drogue and main parachutes. We programmed the drogue chute to deploy when the altimeter is at apogee and the main chute deploys when the altimeter reads 1,500ft.

Fig. 11 Raven 4 Altimeter (left) and Blue Raven Altimeter (right)

2.5.3 Avionics Bay

The Avionics bay was designed in three main sections, two avionics bays and one payload section. The bottom avionics bay houses a system to separate the main tube and booster tube to deploy the drogue chute. This avionics bay was designed to be dual redundant, with two sets of the ejection charges in case of a failure. Each redundant system includes an altimeter, a tracker, a battery, a key switch, and a mass of black powder. The drogue system was designed to fire at apogee. The back-up drogue system was also designed to fire at apogee but with a half second delay and a slightly larger black powder charge. The entire assembled avionics bay and payload section can be seen in Figures 12 and 13. The cage for the top payload was designed to securely hold all of the electronic systems while being lightweight, and 3-D printed with PLA.

The middle section is the least complex, as it is the section that holds the payload of plants. The plant holder is simply a cylinder with 1.5 inches squares cut into it. There were also 3-D printed gaskets to slow down the moisture in this middle section to either avionics bay.

The bottom avionics bay holds only the altimeters and supporting hardware, and as such was smaller than the top avionics bay. The alimiters were programmed to trigger at 1500 feet and while the pressure is increasing with one on a half second delay with a slightly larger black powder charge. This charge deploys the main parachute.

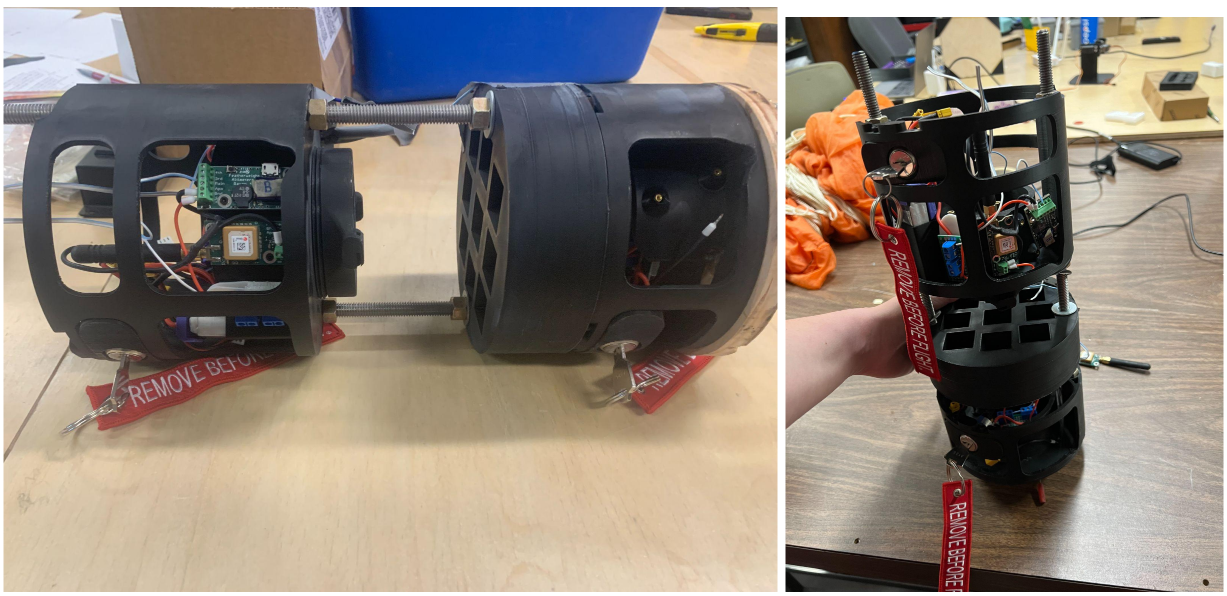


Fig. 12 Vertical and horizontal view of avionics bays and payload without plants

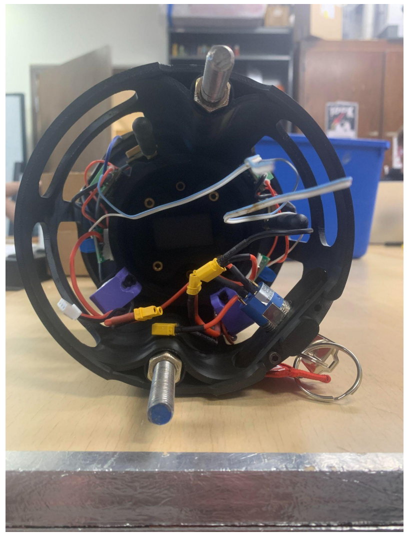


Fig. 13 Top down view of avionics bay

2.6 Payload Subsystems

The main focus of the payload is to experiment how the stress of a plant going 10,000 feet in the air grows afterwards compared to the samples growing in a local greenhouse. We will grow around 30 corn plants total, with 10 staying in the greenhouse as control variables, 11 traveling with us to the competition but not going in the rocket, and 9 plants going in the payload of the rocket. This will allow us to directly compare the final outcomes of all of the plants once they are all replanted in the greenhouse. The corn samples in the payload will be put in rockwool cubes that are exactly 1 inch in volume, as seen in Figure 14, allowing them to fit perfectly in the holes in the payload tray and keep the plants moist while in the rocket. The rockwool cubes that hold the corn were chosen due to its rigid structure and availability at the time. Both corn samples that are being launched and those that are not will be roughly 2-3 weeks old at the time of launch, meaning they will be approximately 2 inches or less in length.

We will have a camera and lights in the payload section, allowing us to see any changes to the plants that happen during the flight. We will also measure the temperature, pressure, and humidity in the payload in order to get as much data as possible on a range of factors, which we can use in our analysis of the corn plants' growth.

Fig. 14 Payload area of the avionics bay where small corn sample is kept (left) and picture of rockwool (right)

2.7 Recovery Subsystems

We used a dual separation parachute system to ensure that our rocket is able to land safely. Thus, we have our main parachute in the nose cone, which is the first separation, and our drogue parachute in the body of the rocket at the second point of separation. We have 40ft of shock cord connecting the main parachute to the nose cone and 30ft of shock cord connecting the drogue chute to the body tube. The main parachute is 32 inches in diameter and the drogue chute is around 3 feet in diameter. The main chute and drogue chutes deploy at apogee and 1,500ft, respectively, which is programmed into the altimeters.

The other main part of our recovery system is the trackers, which allow us to locate the rocket once it lands. This way if the rocket lands somewhere out of eyesight due to wind or other factors, we are still able to find and successfully recover the rocket.

III Mission Concept of Operations Overview

3.1 Mission Summary

The flight goal for EVE is broken down into six main stages, which are explained in further detail in section 3.2 and visualized in Figure 15. These stages detail the entire flight of the rocket. For each stage, the corn inside the rocket is constantly undergoing pressure and temperature analysis. Since it is inside the rocket for the entire flight, its purpose does not change for any of the phases. The mission phases focus more on the stages of the rocket flight.

3.2 Mission Phases and Nominal Operations

Phase 1 - Standby: This phase begins when the rocket is on the rails and ready for launch. This phase includes all of the pre-flight preparation, such as putting the motor in the rocket, putting the rocket on the launch rail, arming the avionics bay, hooking up the wires inside the motor. This phase ends when the launch crew confirms that there is a complete circuit in the wire to the launch controller and the fire signal is sent to the igniter.

Phase 2 - Liftoff: This phase begins when the fire signal is received by the igniter, the rocket generates enough thrust and leaves the launch rail. This phase ends when the rocket clears the launch rail.

Phase 3 - Flight: This phase begins immediately after the rocket leaves the launch rail. The rocket’s velocity approaches its maximum velocity until motor burnout occurs. This phase ends when the rocket reaches apogee and enters freefall.

Phase 4 - Drogue Chute: This phase begins immediately after the rocket achieves apogee. At apogee, the altimeter sends a signal from to a firework initiator. The firework initiator, that is inserted into the black powder in the ejection charge, ignites and generates enough pressure such that the booster tube and the main body tube separate from each other. After separation, the drogue chute that is attached to the middle shock chord deploys and slows the rocket's descent.

Phase 5 - Main Chute: This phase begins after the drogue chute has deployed. The rocket continues its descent until the main parachute deploys. In our rocket, the main chute is programmed to deploy when the rocket has fallen to an altitude of 1,500ft during the descent. This phase ends once the main chute is fully deployed.

Phase 6 - Landing: This phase begins after the main chute has deployed. The rocket's descent is further slowed and it continues falling until it hits the ground. The landing phase ends when all pieces of the rocket, including the parachutes, have landed and are no longer in freefall.

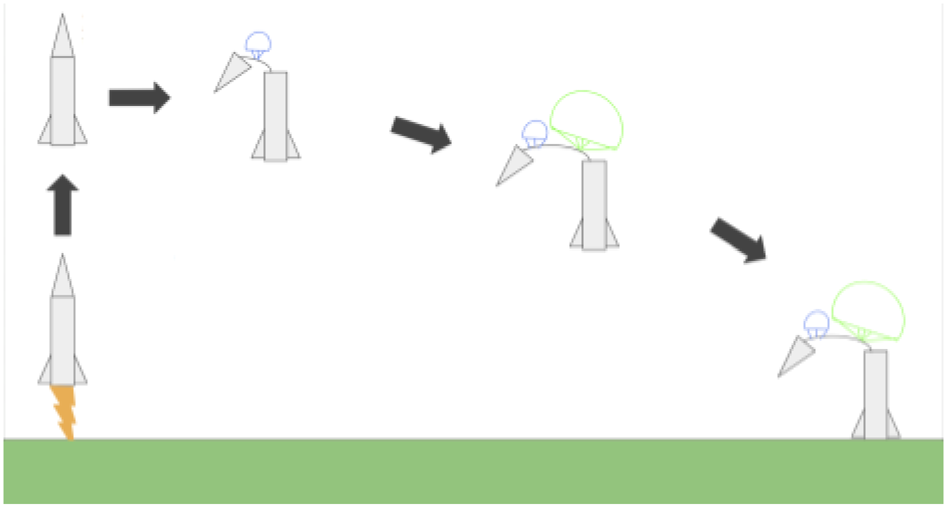


Fig. 15 Diagram representing the five main mission phases occurring after Standby phase has ended

IV Tests

4.1 Ejection Charge Test

In order to ensure our rocket separated properly, we performed an ejection charge test. For this test, we fully assembled the rocket with shear pins, attached the parachutes, and wired up the ejection charges. We tested firing the ejection charges for the main and drogue parachutes independently to make sure that the rocket successfully separated and the parachute extended. We used 6 grams of black powder to ignite the ejection charge. Both ejection trials were successful. Before and after images from the ejection charge test, shown in Figures 16 and 17, show the successful separation of the nose cone and body tube for the main parachute.

Fig. 16 Rocket setup before separation test

Fig. 17 ***Successful separation test of EVE***

4.2 Test Launch

In order to test the simulations and ensure that EVE will fly like predicted, as well as verify adherence to the Design Test and Evaluation Guide [1], a test flight was performed. EVE's test flight was conducted at a Tripoli launch event in Concord, NE. EVE was assembled at the event and examined by the experts there for any safety hazards. The test launch was a success, with a straight launch and EVE reaching an apogee similar to our predictions. The recovery system and electronics also worked properly, allowing us to collect data from the flight, and the rocket survived the impact with the ground. Throughout the test launch, we made sure to follow the proper procedures for each step of the process: assembly, pre-flight, launch, and recovery. Checklists for each of these steps can be found in appendix 6.5. We also made sure to mitigate any potential risks that could occur from the launch, a breakdown of the risk analysis can be found in the matrix in appendix 6.4.

4.2.1 Setup

EVE was separated during travel to the site so that it could fit in our vehicle. The rocket was in 5 main pieces: Lower body tube, main body tube, nose cone, avionics bay, and motor. A picture of it disassembled can be seen in Figure 18. Once arriving at the launch site the rocket was completely assembled. We set up a table and brought all of the required tools to assemble the rocket on site. An example of the assembled rocket can be seen in Figure 19.

Fig. 18 Eve Disassembled Before Test Flight

Fig. 19 EVE Fully Assembled Before Test Flight

After EVE was assembled, and was inspected by level 3 certified tripoli members at the launch site, EVE was set to be launched. An image of EVE being set up on the launch rail can be seen in Figure 20.

Fig. 20 EVE Set on Launch Rail and Ready for Launch

4.2.2 Rocket Performance

Overall the rocket performed as we expected it to. The launch was straight, the apogee was nearly 10,000 feet, both parachutes deployed at the proper times, and the rocket survived the impact with the ground. An image of the rocket in flight can be seen in Figure 21. The apogee was a bit under the simulated value, reaching only 9,760 feet, and the rocket stayed under mach 1. This was most likely due to drag that was created by unsanded epoxy around the fins, and also due to normal factors like atmospheric conditions and unpredictable airflows. The rocket also flew past the cloud ceiling, which could have added additional airflow and weather factors that contributed to a slightly lower apogee.

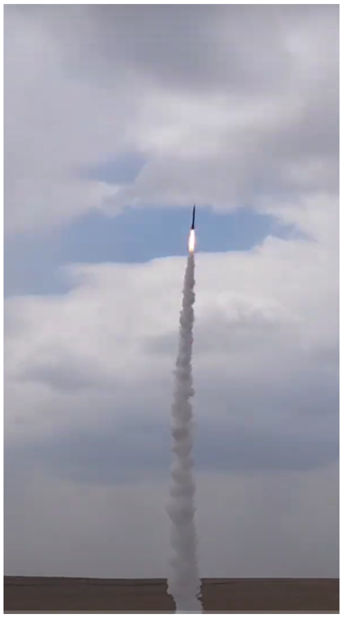


Fig. 21 Eve During Liftoff

4.2.3 Recovery Performance

The recovery devices on the rocket worked exactly as designed, as we designed the rocket with multiple redundant systems and excess black powder so that the rocket would separate. The result was the rocket being successfully recovered with no damage. After analyzing the data, the parachutes worked as predicted and deployed at the proper altitudes. This test also proved that our altimeters worked properly and sent off the charges at the right times to deploy the parachutes. Figure 22 shows EVE's descent from the flight after the main parachute deployed at an altitude of 1,500 ft, as well as the site where EVE landed. It is shown that EVE is in one piece, held together with a shock cord.

Fig. 22 EVE's descent from the flight (left) and landing site (right)

4.3 Test Launch Data Compared to Simulation Data

All of the values we obtained from the test launch - altitude, velocity, and acceleration - ended up being less than the predicted values we got by running the simulation in OpenRocket. This was expected, since the simulation couldn't take into account the specific wind speed and other atmospheric conditions that the rocket experienced during the actual launch. However, all of the values were reasonably close enough to the predicted values that we can say the rocket performed as expected. Below are the graphs of the data gathered for altitude (Figure 23), velocity (Figure 24), and acceleration (Figure 25) during the test launch flight.

4.3.1 Altitude

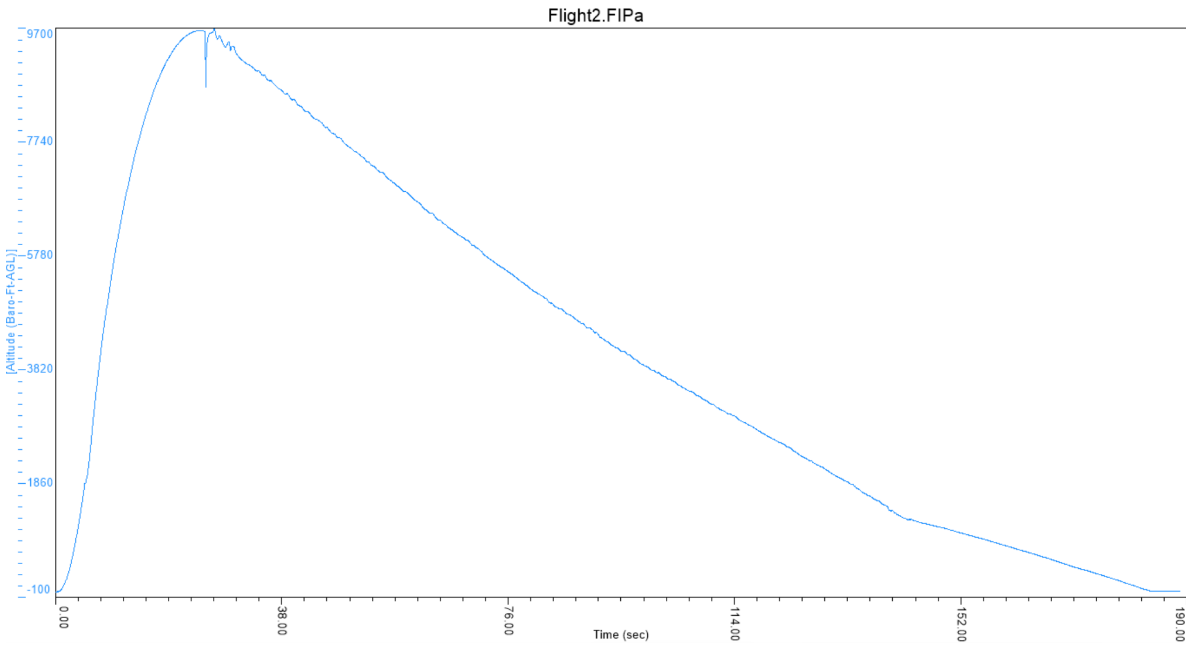


Fig. 23 Graph of altimeter data for altitude during test flight

The altitude reached by the launch was within 5.2% of the projected altitude, which can be attributed to the random fluctuations in the atmospheric conditions. The projected altitude was 10,180 feet while the rocket reached 9,760 feet.

4.3.2 Velocity

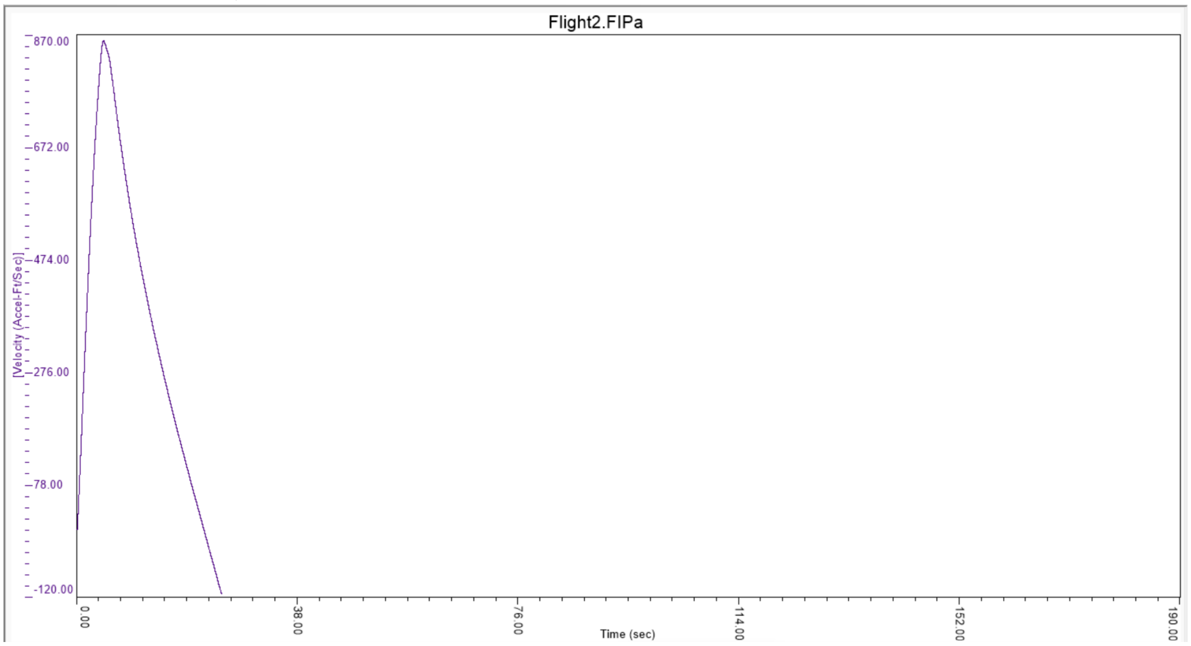


Fig. 24 Graph of the altimeter data for velocity during test flight

The max velocity of 880 ft/s is close to the predicted value of 912 ft/s, but most importantly, is well below the mach 1 threshold (1,125 ft/s) that would cause unpredictability.

4.3.3 Acceleration

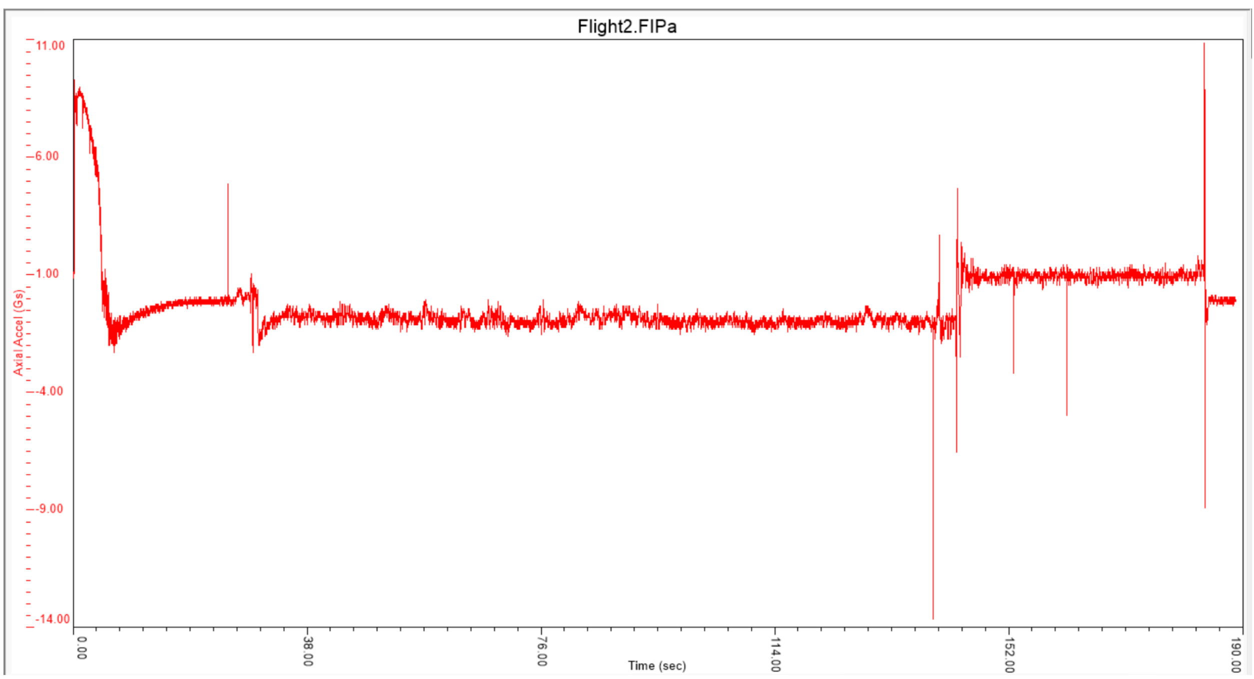


Fig. 25 Graph of the altimeter data for acceleration during test flight

The acceleration reached a sustained 316.59 ft/s^2 which was lower than the predicted value of 344 ft/s^2. The spikes in the second half of the graph are due to the black powder charges firing and compressing the air around the altimeters.

V Conclusion and Lessons Learned

5.1 Key Findings

Overall the test flight and landing of EVE was a success and behaved as planned. However, it was not perfect and certain designs can be changed to make it perform better. Our mentor has advised that our redundant electronic systems (four altimeters) could be simplified. The nose cone and the upper body tube were tied at equal distances from the parachute. This created the potential for the nose cone and main body tube (where the avionics bay and payload are located) to swing and collide into each other causing unnecessary damage. A picture of this occurring can be seen in figure 21; a shock cord was lengthened to address this issue . In terms of performance the rocket performed slightly worse than expected with regard to reaching the design altitude and velocity during flight. This is due to roughness on the body tube from the epoxy filets for the fins not curing perfectly round and epoxy residue that dripped and cured in other locations besides next to the fins, ultimately causing unwanted drag forces on the rocket.

5.2 Future Improvements

To increase the performance of EVE, designing a lighter avionics section could further improve the performance. The avionics bay is over-redundant so to improve this, the upper and lower avionics bay were wired through the payload onto the same circuit. Further improvements can be done by having a smoother body tube. This can be accomplished by implementing tape on the sides of the body tube next to the fins to catch any epoxy that drips onto it. Along with reducing stray epoxy, a phenolic thickening agent was used allowing the filets on the fins to keep their shape while curing. Another known issue was the collision of the nose cone with the main tube after apogee when the drogue parachute was deployed. To prevent this, the nose cone and main body tube needs to be tied to the shock cord at different distances. This increases the safety of the recovery systems before landing.

5.3 Changes Since Preliminary Design

Originally our rocket was designed a lot smaller than the current model. Due to the competition regulations [2] a larger rocket was needed. This required us to resize everything in our model. The payload section however has received the most changes from the original design. Previous iterations of the payload and avionics cage can be seen in Figure 26. The amount of samples, what kind of data is being recorded from the flight, and types of samples such as corn, tomatoes, and potatoes have all been changed since the first design.

Fig. 26 Previous 3D printed design prototypes for avionics bay and payload tray

VI Appendices

6.1 System Weights, Measures, and Performance Data

6.1.1 Basic Rocket Information

Number of Stages	1
Vehicle Length	111 in
Airframe Diameter	6.17 in
Number of Fins	4
Fin Semi-Span	6.5 in
Tip Chord	3.5 in
Root Chord	20 in
Fin Thickness	0.2 in
Vehicle Weight	46.321 lbs
Propellant Weight	8.710 lbs
Empty Motor Case/Structure Weight	6.04 lbs
Payload Weight	10 lbs
Liftoff Weight	46 lbs
Center of Pressure	74.821 in
Center of Gravity	85.764 in

6.1.2 Propulsion Information

Motor Type	COTS
COTS Manufacturer	AeroTech
Motor Letter Classification	M
Motor Designation	M1850W
Average Thrust	304.391 lbf
Total Impulse	1655.943 lbf*s

Motor Burn Time	5.41 s

6.1.3 Predicted Flight Data

We took multiple steps to ensure that the rocket was structurally stable and safe to launch. One of these steps was conducting a fin flutter analysis. This ensures the team that the rocket's speed will not exceed the fin flutter speed, otherwise an extreme moment will occur and could possibly snap the fin. The fin flutter analysis is shown below using the fin flutter equations:

$$S = 0.5(Cr + Ct)b$$

$$AR = \frac{b^2}{S}$$

$$\lambda = \frac{Ct}{Cr}$$

$$T = 59 - 0.00356h$$

$$P = 2116 * \frac{T+459.7}{518.6}^{5.256}$$

$$a = \sqrt{1.4 * 1716.59 * (T + 460)}$$

$$Vf = a\sqrt{\frac{G}{\frac{(1.337AR^3)*P*(\lambda+1)}{2(AR)(\frac{t}{Cr})^3}}}$$

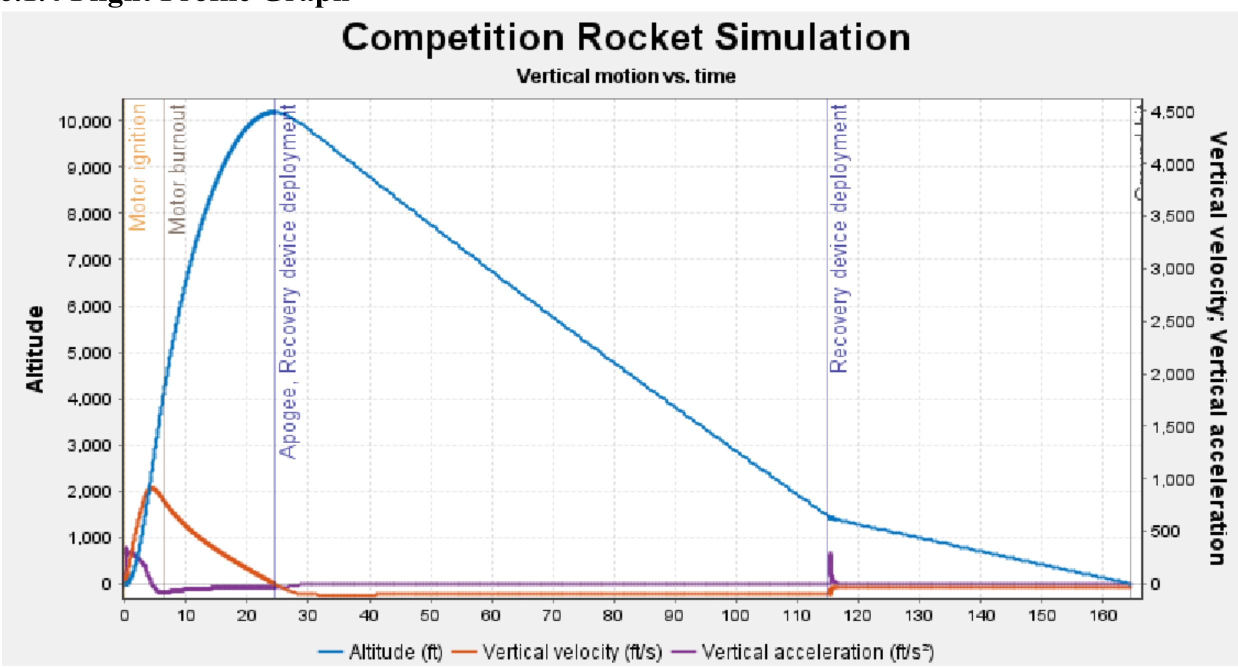
Knowing that the maximum velocity of EVE is 912 ft/s, the fin flutter velocity must not exceed this. By using the formulas shown above, and stating the known variables, the fin flutter velocity can be found. Each variable value and resulting calculation value is shown below.

G = 1,450,000 psi
t = 0.2 in
Cr = 20 in
Ct = 3.5 in
b = 6.5 in
S = 76.4 in^2
AR = 0.553
λ = 0.175
h = 2568.33 ft
P = 13.40 psi
T = 49.9 F
a = 1107 ft/s
Vf = 1596 ft/s

Due to EVE's maximum simulated velocity being only 912 ft/s, and the fin flutter velocity is 1596 ft/s, flying EVE will not result in any fin fluttering to occur.

Launch Rail Length	17 ft
Liftoff Thrust-Weight Ratio	6.571
Rail Departure Velocity	101 ft/s
Minimum Static Margin	1.77 calibers
Maximum Acceleration	344 ft/s^2
Fin Flutter Velocity	1596 ft/s
Target Apogee	10,000 ft
Predicted Apogee	10180 ft

6.1.4 Flight Profile Graph



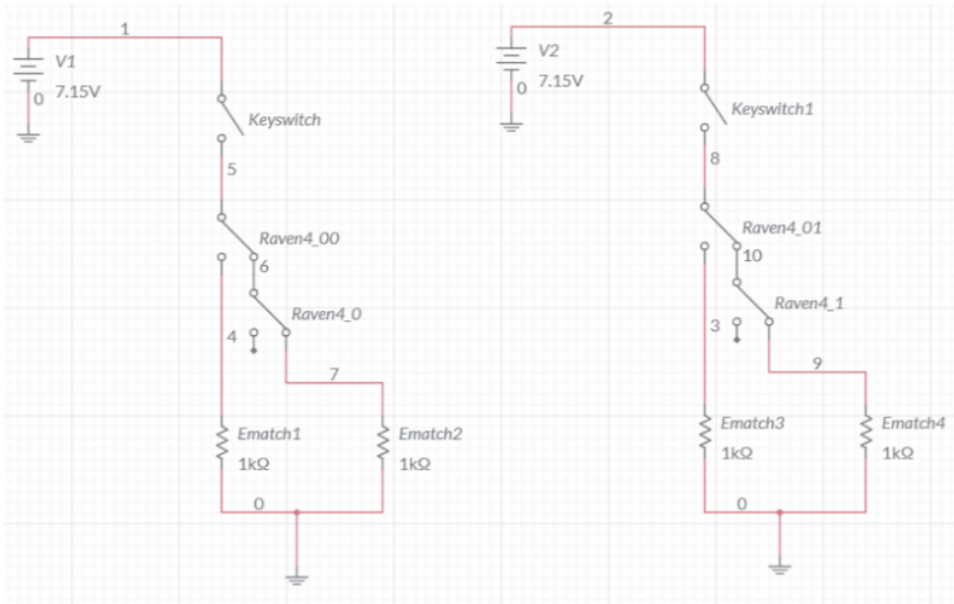
6.1.5 Recovery Information

COTS Altimeters	Raven4 Altimeters by Featherweight
Redundant Altimeters	Raven Blue Altimeters by Featherweight
Drogue Primary Deployment Charge	5.0 grams black powder
Drogue Backup Deployment Charge	5.5 grams black powder
Drogue Deployment Altitude	10,180 ft (apogee)

Drogue Descent Rate	92.3 ft/s
Drogue Shock Chord	Tubular nylon, 30 ft, 0.172 oz/ft
Main Primary Deployment Charge	5.0 grams black powder
Main Backup Deployment Charge	5.5 grams black powder
Main Deployment Altitude	1,500 ft
Main Descent Rate	28.5 ft/s
Main Shock Chord	Nylon flat webbing, 40 ft, 0,0427 oz/ft
Mechanical Links	quick-links

6.2 Project Test Reports

6.2.1 Recovery System Testing



Each of the rocket's recovery electronics has another identical part to complete its task. There are two GPS trackers each being powered to make sure that we can locate the rocket after launch. The rocket also has four sets of altimeters. Two altimeters are secured so the detaching will occur towards the top. Another set of altimeters are secured next to where the bottom will detach. Each system has a pair of electronics in case one of them does not work. The arming sequence will be in the following order: turn on the key for drogue chute recovery, and turn on the key for main chute recovery. In total, two key switches are included in the rocket. Each key will arm its respective recovery. These switches are also attached to the electronics inside of the payload. This includes the sensors for the plants and the camera. The electronics in the payload will not be able to activate until both keys are switched. We are using black powder charges as that is what the team has the most familiarity with. Based on previous work and research, the quantities of black powder were found by doing ejection charge testing on them. The recovery will deploy from the rocket via firework initiators that have its chemical compound inserted into black powder and have its leads inserted into the altimeters.

6.2.2 SRAD Propulsion System Testing

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6.2.3 SRAD Pressure Vessel Testing

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6.2.4 SRAD GPS Testing

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6.2.5 Payload Recovery System Testing

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6.3 Hazard Analysis

There are a lot of hazards that have to be accounted for when constructing a rocket. Some of these hazards stem from the construction phase of the rocket, such as how cutting and sanding fiberglass and working with epoxy and phenolic microballoons can create dust and fumes that are dangerous to breathe in. This requires us to wear masks and safety glasses when working with those materials and take extra steps to ensure our workspace is properly ventilated. Fiberglass is also sharp and can cut or splinter skin easily, and epoxy can burn your skin, meaning we had to wear proper clothing when working with those materials, such as long pants and gloves.

Other hazards can arise from the actual testing of the rocket, as outlined in the Range Standard Operating Procedures [3], so we made sure to mitigate those risks as well. One way we did this was by performing structural checks of the rocket to ensure it would survive the launch and wouldn't fall apart. We were also careful when handling the motor and black powder when preparing the rocket for the test launch. Finally, we were safe when actually testing the rocket, at both the ejection charge test and the test launch, by waiting until the rocket was ready and on the stand before arming the rocket and connecting the wires. We also made sure to stand a safe distance away from the rocket before igniting it.

Hazard Assessment Matrix				
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury After Mitigation**
Breathing in epoxy fumes	Not wearing a proper mask; improper ventilation in workroom	Medium: workroom is enclosed and doesn't have windows; exposed to fumes for extended period of time	Propping open doors to workroom and turning on ventilation system; wearing a respirator mask while working	Low
Breathing in phenolic microballoons when mixing it with epoxy	Not wearing a proper mask; improper ventilation in workroom; using too much microballoons at once	Medium: workroom is enclosed and doesn't have windows; exposed to dust for extended period of time	Propping open doors to workroom and turning on ventilation system; wearing a respirator mask while working; only mixing in small amounts of phenolic microballoons at a time	Low
Burning skin with epoxy	Not wearing proper PPE; spilling epoxy	High: epoxy can get on your hands easily when mixing large amounts of it	Wear proper PPE (gloves, long pants, etc.); mix epoxy slowly and be careful when pouring; change gloves immediately if you get epoxy on them	Medium
Cutting fiberglass body tubes causes cuts or injuries	Not wearing proper PPE; misusing tools	High: rough fiberglass causes splinters easily; cut fiberglass is very sharp	Be careful when handling fiberglass, especially when cutting it; sand down edges so they aren't sharp; wear	Medium

			gloves and safety glasses when working with fiberglass	
Breathing in fiberglass particles when sanding	Not wearing a mask; improper ventilation	Medium: workroom is enclosed and doesn't have windows; exposed to dust for extended period of time	Propping open doors to workroom and turning on ventilation system; wearing a respirator mask while working; only sanding one part/section at a time	Low
Spilled black powder ignites causing injury	Not being careful when pouring black powder for charges; sparks near area with black powder	Low: black powder holders in rocket are relatively small, making it easy to spill some when pouring	Use a mini funnel when pouring black powder; make sure the launch, power tools, and anything else that could create sparks is far away from the pouring area	Very Low
Motor explodes in cabinet	Sparks happen near the stored motor	Low: motors are highly combustible, so a spark from power tools in the workroom could ignite them	Keeping the motors in a fire cabinet; keeping power tools and anything that makes sparks away from the motors when the cabinet is open	Very Low

6.4 Risk Assessment

We took many steps to mitigate the hazards mentioned above. This includes wearing proper PPE and following lab safety protocols when constructing the rocket, as well as following proper launch procedures when testing the rocket.

We also performed multiple checks to make sure the rocket was safe to fly, in order to mitigate any potential structural risks. These steps can be seen in the checklists in appendix 6.5. One way we did this was by checking the rocket at each phase of the building process and fixing or strengthening any part that didn't seem stable enough. Another step we took was getting multiple different experts to look our rocket over and give us feedback on proper building procedures and what we should change to make the rocket better. One of these people was our mentor, who has a lot of experience building model rockets, and looked over our rocket at multiple stages throughout the design process - from our initial OpenRocket simulations to giving us feedback on the final build. He gave us a lot of advice on what dimensions we should go with for our final rocket, good construction techniques to use when building it, and suggestions on changes we should make to the final rocket in order to improve its safety and aerodynamics. He also gave us advice on the recovery aspect, such as what size of parachutes to buy. We also had multiple experts from Tripoli look over our rocket and the avionics bay before the test launch, to make sure that everything looked safe and to ensure that nothing went wrong during the launch. They also helped us properly install the motor and taught us how to pack the parachutes.

Due to the steps we took to mitigate risks, we would rate the overall risk of flying our rocket pretty low. This is because we consulted multiple experts to make sure our construction and pre-flight procedures were safe, as well as performed two different successful tests of the rocket to double check that we did everything properly.

Risk Assessment Matrix					
Mission Phase	**Hazard**	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury After Mitigation**
1 - Standby	The firework initiators discharge early, resulting in the rocket firing prematurely or exploding	Spark or static shock hits the firework initiators	Low - not very likely that a spark happens, but would be catastrophic	Avionics are deep within rocket and enclosed with fiberglass and non-conductive metals	Very Low
	The rocket falls off the launch rails	Rail buttons aren't completely in the slot of the launch rail when the rocket is oriented vertically	Low - not likely, but possible that only one of the launch buttons is in the rail slot	Double check to make sure the rocket is secure when sliding it on the rail; make sure rocket is stable before igniting	Very Low
2 - Liftoff	The rocket fails to ignite	Bad initiators	Low - not likely due to quality and durability of initiator, but still	Test initiators beforehand and make sure that they are in good working	Very Low

			possible	condition	
	Rocket does not ignite when command is given, but does ignite when team approaches to troubleshoot	Bad initiators	Low - not likely due to quality and durability of initiator, but still possible	Test initiators beforehand and make sure that they are in good working condition; do not approach rocket immediately after launch fails, wait around 10 minutes to make sure it's safe; use bluetooth altimeters to ignite rocket from a safe distance	Very Low
3 - Flight	Rocket deviates from flight path, goes tangent to ground, comes in contact with personnel or property at high speed	High wind speeds; rocket stability is too high or too low	Low - our rocket stability is ideal, but winds could still cause issues to happen in the verticality of the flight	Ensure that rocket is stable before flight; check to make sure rocket center of gravity and pressure are the same as in the simulations; don't launch in high speed winds	Very Low
4 - Drogue Chute	The drogue chute doesn't deploy; booster tube is still connected to body tube; rocket's descent is not slowed	Drogue chute is tangled or improperly packed; altimeter fails to send deployment signal; too much friction between coupler and booster tube	Low - steps will be taken to ensure parachute is packed properly and not tangled, but something could still go wrong	Personnel and team members will double check to ensure parachute is packed properly and altimeters are wired correctly	Very Low
5 - Main Chute	The main chute doesn't deploy; nose cone is still connected to body tube; rocket's descent is not slowed	Main chute is tangled or improperly packed; altimeter fails to send deployment signal; too much friction between coupler and main tube	Low - steps will be taken to ensure parachute is packed properly and not tangled, but something could still go wrong	Personnel and team members will double check to ensure parachute is packed properly and altimeters are wired correctly	Very Low
6 - Landing	Rocket lands in a crowded area, causing injury or property	Wind or other atmospheric conditions push the rocket off	Medium - winds are unpredictable and not much	Ensure launch rail is located far away from spectators and people are parked at	Low

	damage	course during flight	can be done to prevent rocket from drifting towards crowds	a safe distance from launch site; have people watching the rocket and sending out a warning if it seems it will land near people	
	Redundant ejection charge does not go off during flight and instead ignites on ground, harming personnel	Improper wiring; altimeter not programmed correctly	Low - wiring will be checked to make sure it is correct, but accidents can still happen	Double and triple check the wiring with both team members and launch personnel; use Blue Raven altimeters to remotely ignite any left over ejection charges while at a safe distance to ensure they don’t harm anyone	Very Low

6.5 Assembly, Preflight, Launch, and Recovery Checklists

6.5.1 Assembly Checklist

1. Each part is checked for dimensions to match simulation data before and after each assembly step
2. Each part is prepared for assembly
3. Each part is fit tested
4. Each part is assembled
5. Each part is double check and left to dry
6. After drying/curing, each part is inspected

6.5.2 Preflight Checklist

1. Motor construction
    a. Follow instruction from motor supplier, AeroTech, on assembling the motor.
2. Payload construction
    a. Thread nuts and washers on to all thread and secure bottom bulkhead.
    b. Attach the batteries to the bottom avionics bay. Then attach the bottom avionics bay and turn on the altimeters to perform pre-flight checks. After the verification of the altimeters, turn off the key switch. And attach the firework charge to the alimeters and thread the wires through the designated holes.
    c. Secure the bottom avionics bay with nuts and attach the plant holder with its washers and nuts.
    d. Attach the batteries to the top avionics bay and add the top avionics bay to the payload with nuts and washers. Turn the key switch on to perform pre-flight checks on the top altimeters. Turn off the key switch once complete. Attach the firework initiators and thread them through the designated holes in the top bulkhead.
    e. Secure the top bulkhead with the nuts and washers. And ensure there is no play in the positions of each component on the all thread.
    f. Measure out 6g of black powder to add to the top bulkhead, and pour it in the designated hole. Bury the ends of the firework initiators in the black powder and secure the whole system with masking tape and insure there are no leaks of the black powder chamber.
    g. Repeat the previous step with the bottom black powder charge, taking care to ensure no leaks of black powder.
    h. Attach the blue tube and ensure the key switches line up with their respective holes.
3. Payload recovery
    a. Check GPS trackers to make sure they connect properly to the ground station.
    b. Interface with the ground station via an iPhone device. This will ensure that the trackers in the rocket can have their location read.
    c. Shock chords are attached to designated quick links in the i-bolts. The 30 ft shock chord is attached to the bottom of the avionics bay and to the top centering ring of the booster tube. The 40 ft shock cord is attached to the top of the avionics bay and to the bulkhead inside of the nose cone.
    d. Parachutes are attached to the center of the shock chords. The drogue parachute is attached to the shock chord between the bottom avionics bay and the top centering ring of the booster tube. The main parachute is attached to the shock chord between the top of the avionics bay and the bulkhead in the nosecone. Fireblankets are also attached during parachute attachment.
    e. Shock chord and parachutes are packed neatly into designated locations. Nosecone and top of main tube contain the main parachute, while the booster tube and bottom of the main tube contain the drogue parachute. Ensure fire blankets are protecting the parachutes when packing them.
4. Final checks

a. Assemble the rocket to all of its components the way it has been designed. Make sure that the parachutes and shock chords are placed in the correct locations.
b. When put together, add shear pins to the designated holes in the body tube and the couplers.
c. Screw in the bulkheads of the avionics bay to secure it to the main body tube.
d. When flight ready, carefully have the rocket slide onto the launch rail. Make sure not to do anything with the switches until the rocket is standing vertically.
e. Turn on the key switches after the rocket is set vertically. The altimeters in the avionics bay should make a “beeping” sound. This means that the altimeters are turned on.
f. Insert the flight electrode into the motor of the rocket motor. To ensure safety, have someone who has permission to help insert the wire into the motor.
g. Check with launch crew that the rocket is ready to launch.

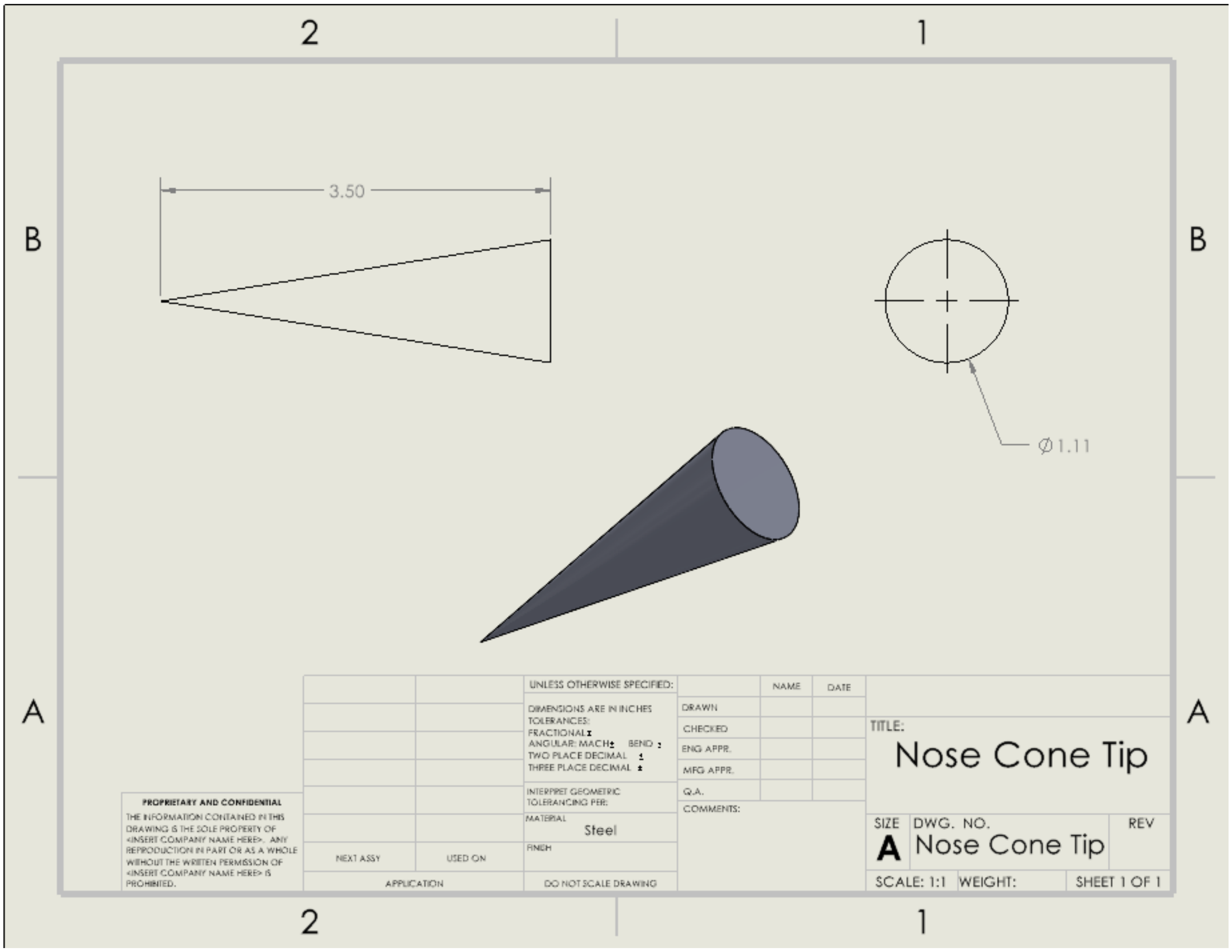
6.5.3 Launch Checklist

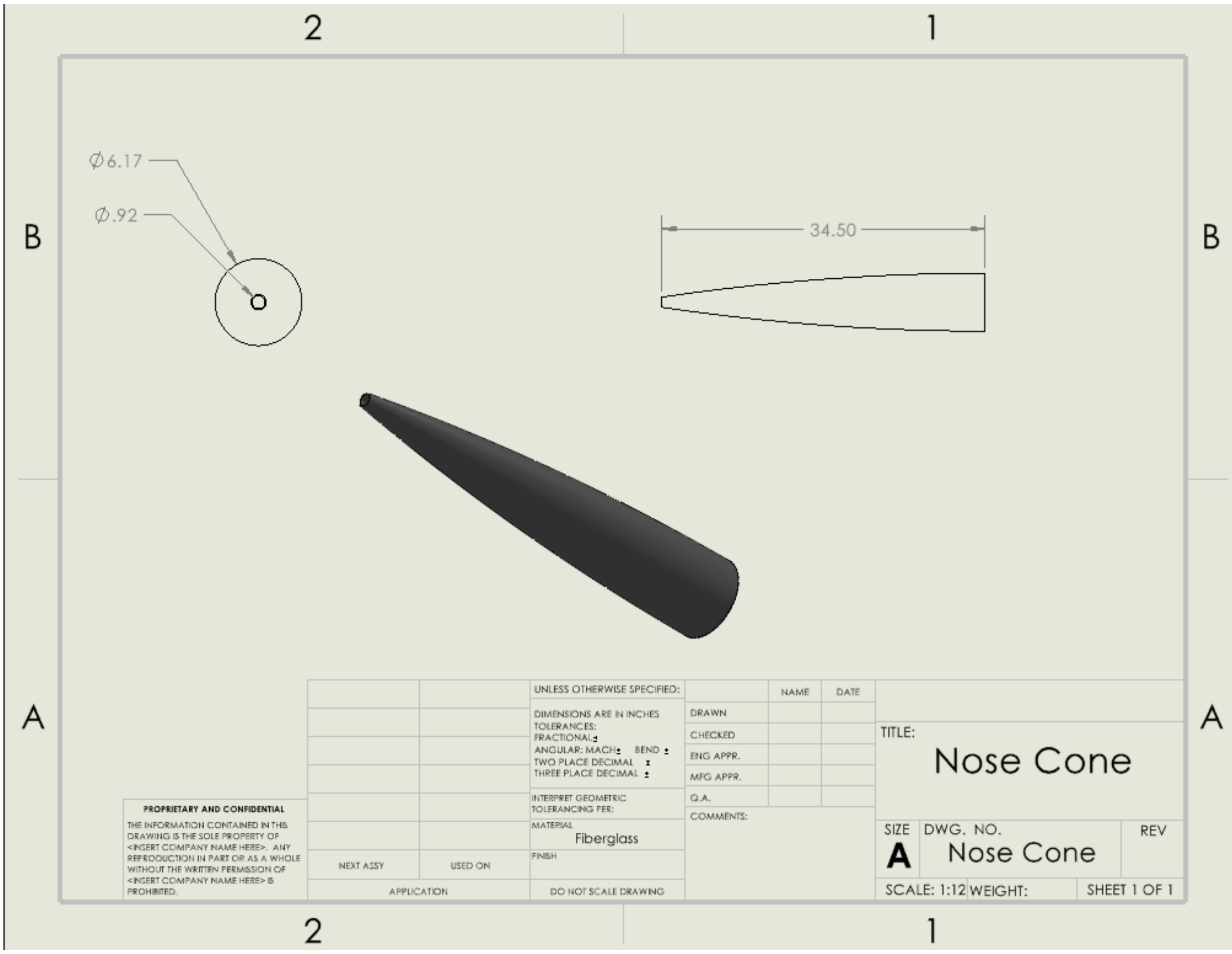
1. Pass preflight checklist
2. Load rocket on launch pole
3. Ignition charge is disconnected and grounded to each other
4. Insert ignition charge
5. Double check ignition charge is good deep in there
6. Double check everything is grounded
7. Remove each key switch individually
8. Ensure raven functionality with beeps
9. Ensure connection to Raven blue’s to double check altimeter function
10. Add launch wires to ignition charge
11. Double check nominal systems
12. Return to base station to safely launch the systems

6.5.4 Recovery Checklists

1. Recovery team items to bring with
   a. Fire extinguisher
   b. Safety glasses
   c. Gloves
   d. Binoculars
   e. Plyers
   f. Box cutter
2. Coming up to rocket, check from a distance everything is nominal
3. Connect to blue ravens to inspect which charges have fired
4. After confirming safe, approach rocket and reinsert RBF keys
5. Inspect charges
   a. If properly discharged continue
   b. If not discharged, use pliers and box cutter in order to remove ejection charge from payload
6. Remove payload from rocket
   a. Inspect for safety and nominal flight
7. Inspect parachutes
8. Store parachutes and payload safely
9. Return to base station with whole rocket

6.6 Engineering Drawings





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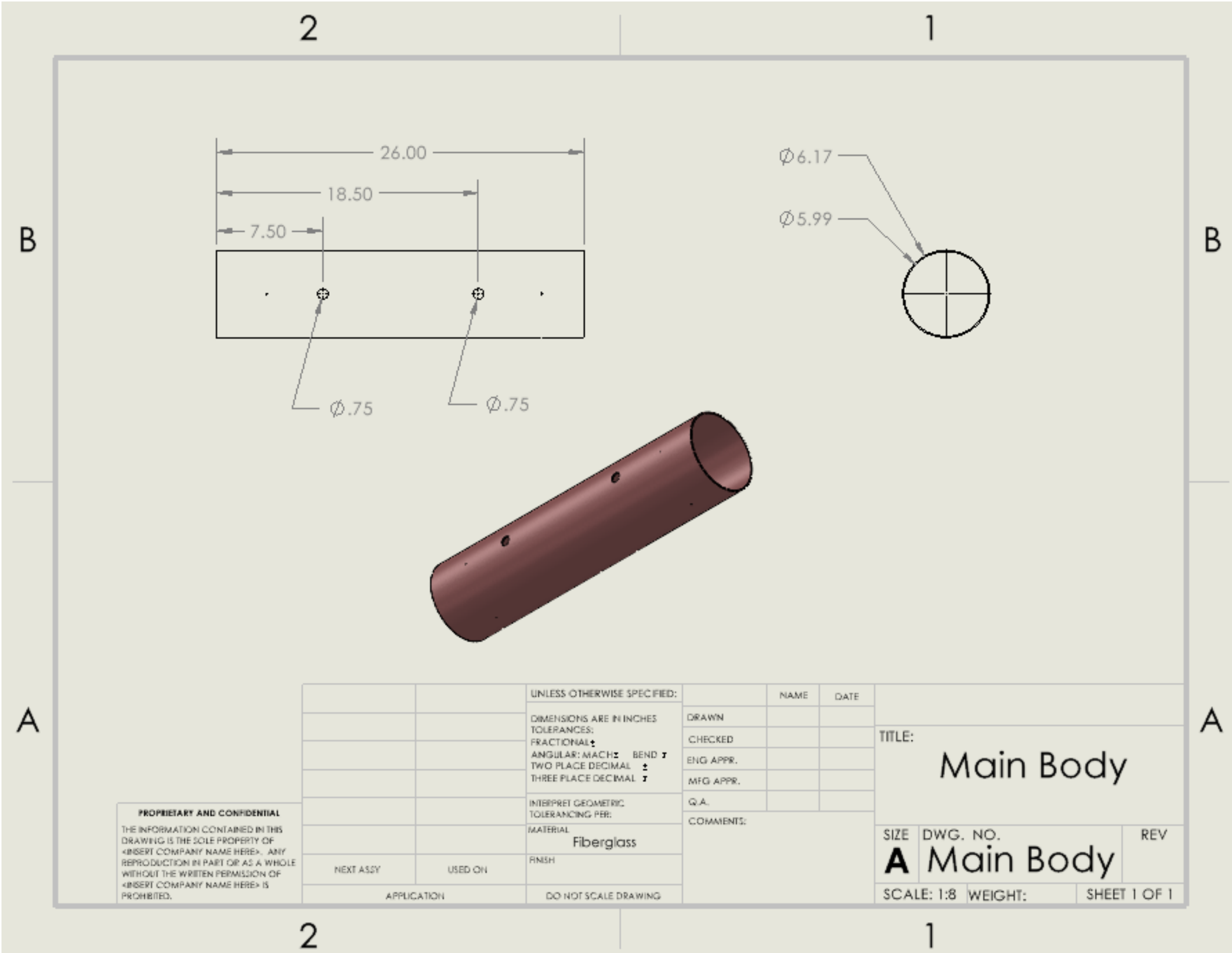
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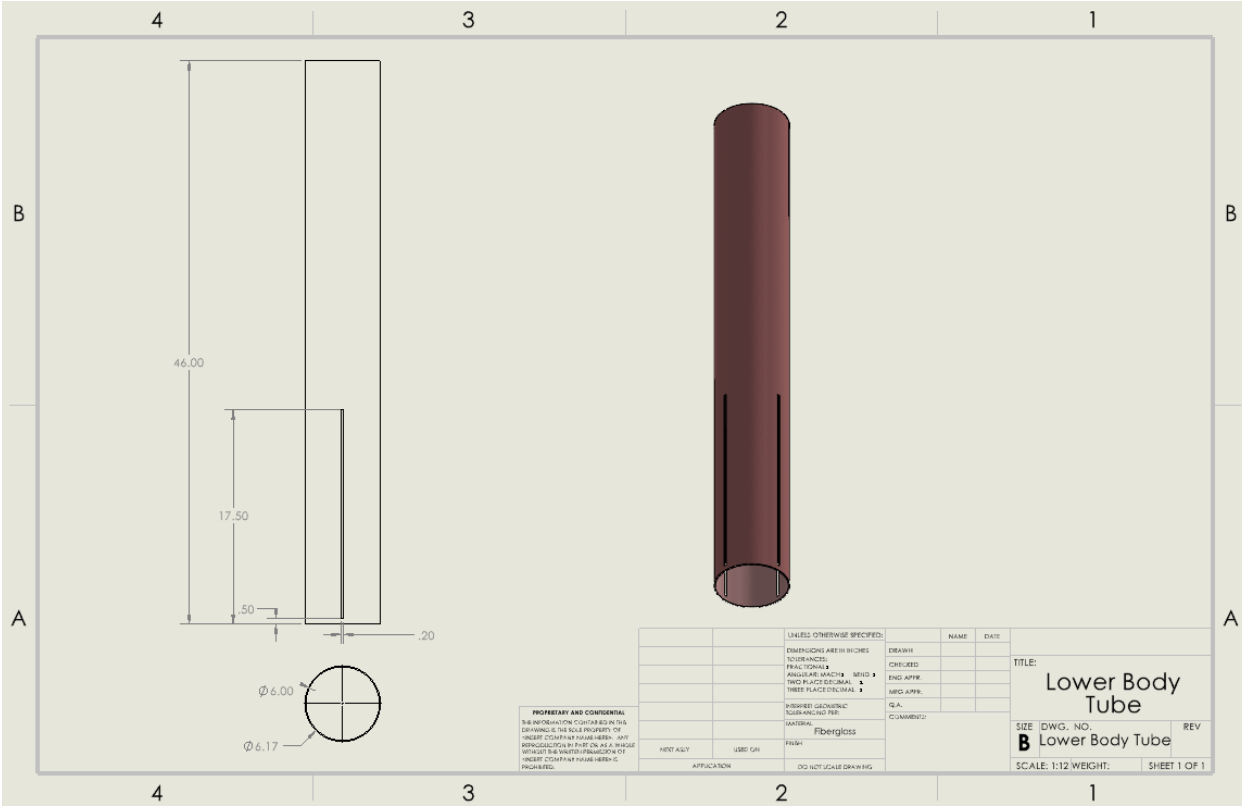
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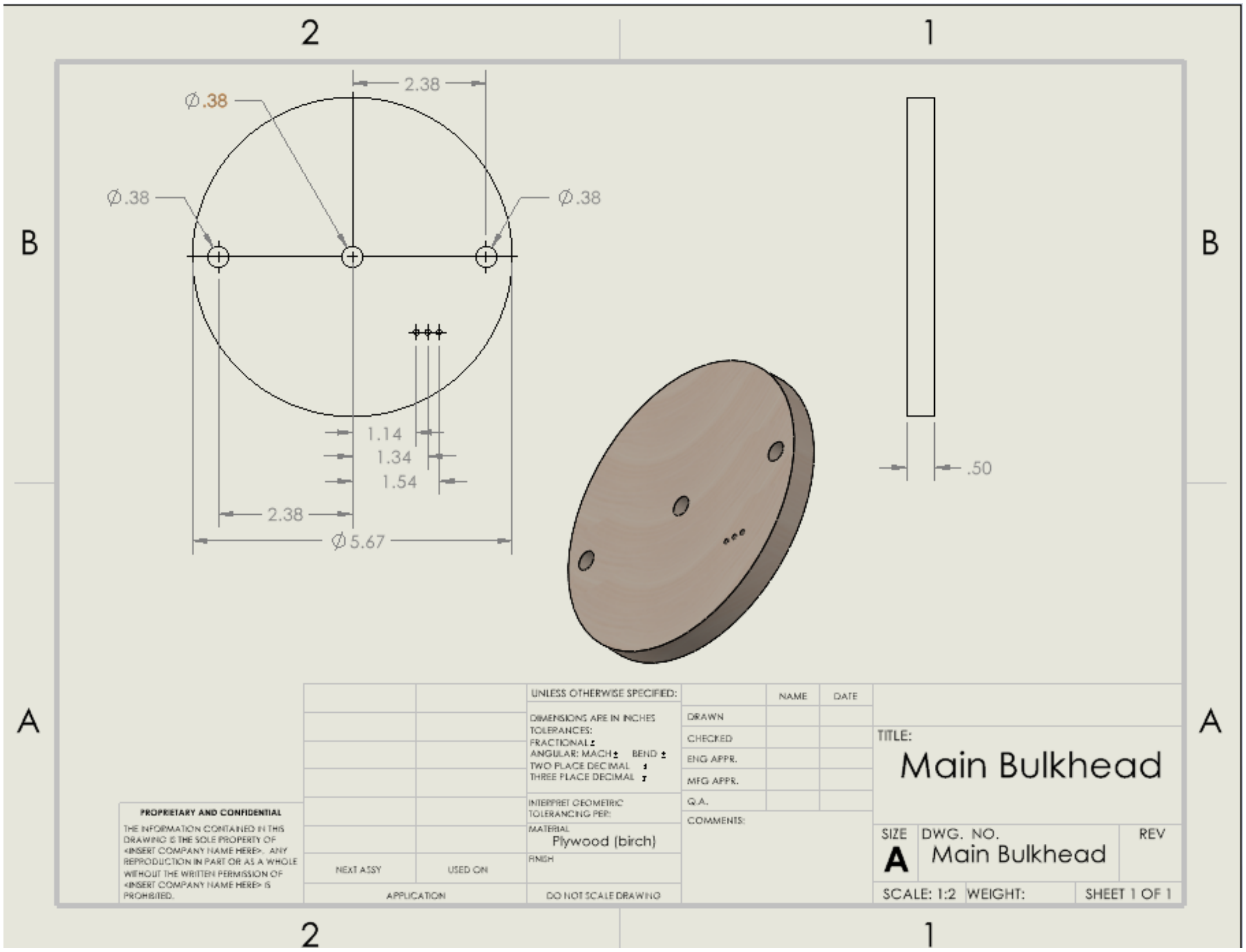
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USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Main Bulkhead
SIZE
A
DWG. NO.
Main Bulkhead
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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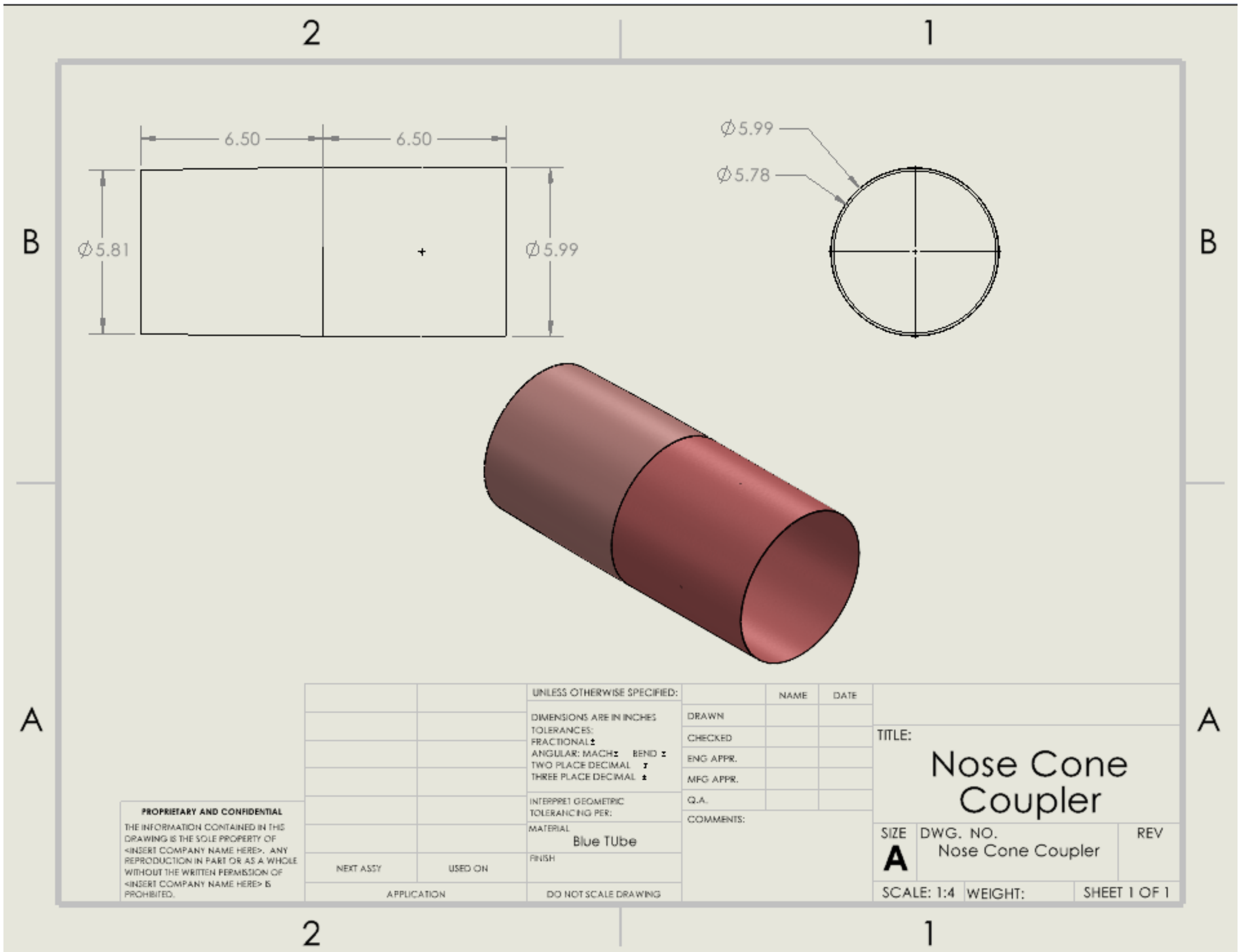

6.50
6.50
Ø5.81
Ø5.99
Ø5.99
Ø5.78
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Blue TUbe
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Nose Cone Coupler
SIZE
A
DWG. NO.
Nose Cone Coupler
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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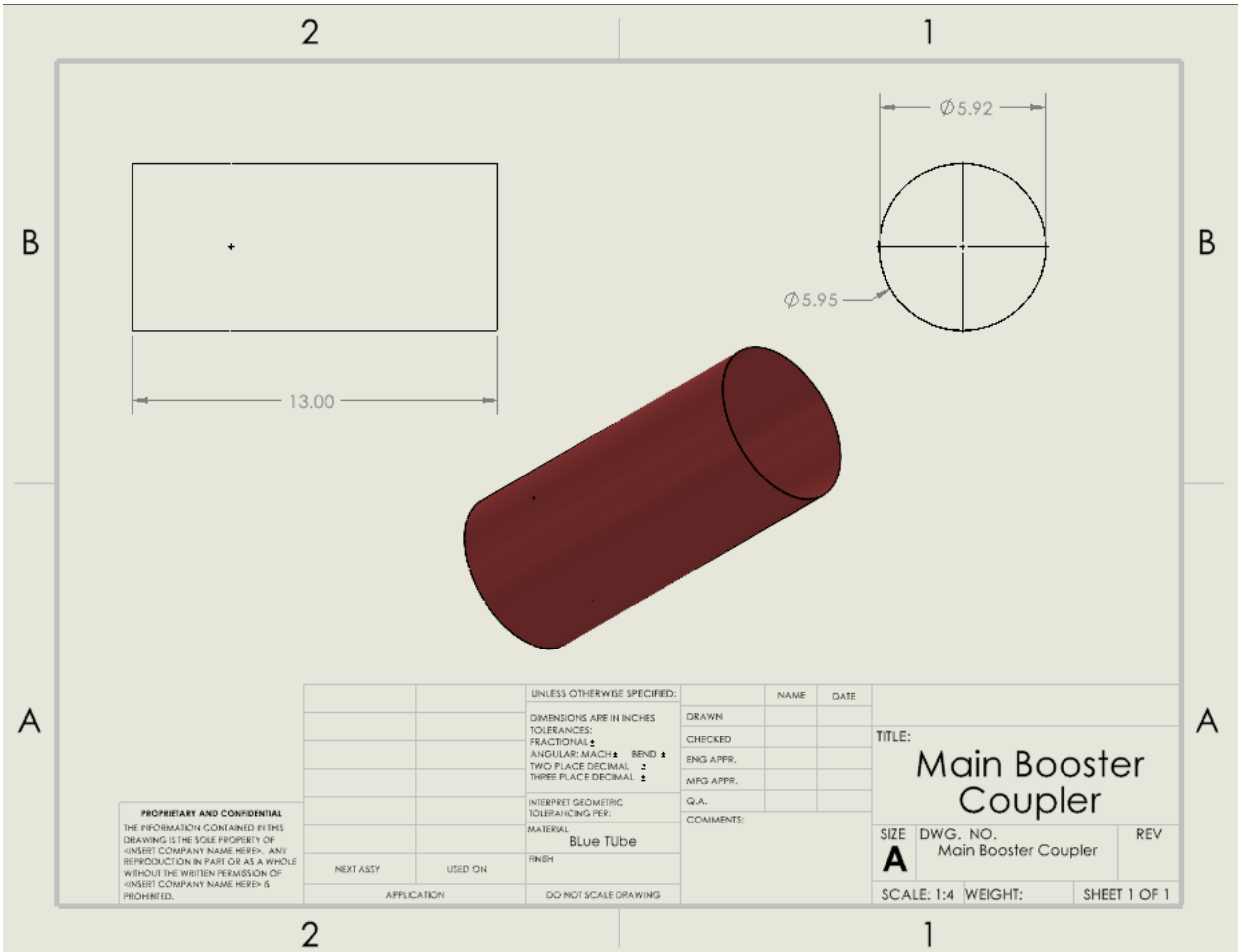
2
1
B
A
Ø5.92
Ø5.95
13.00
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
BLue TUbe
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
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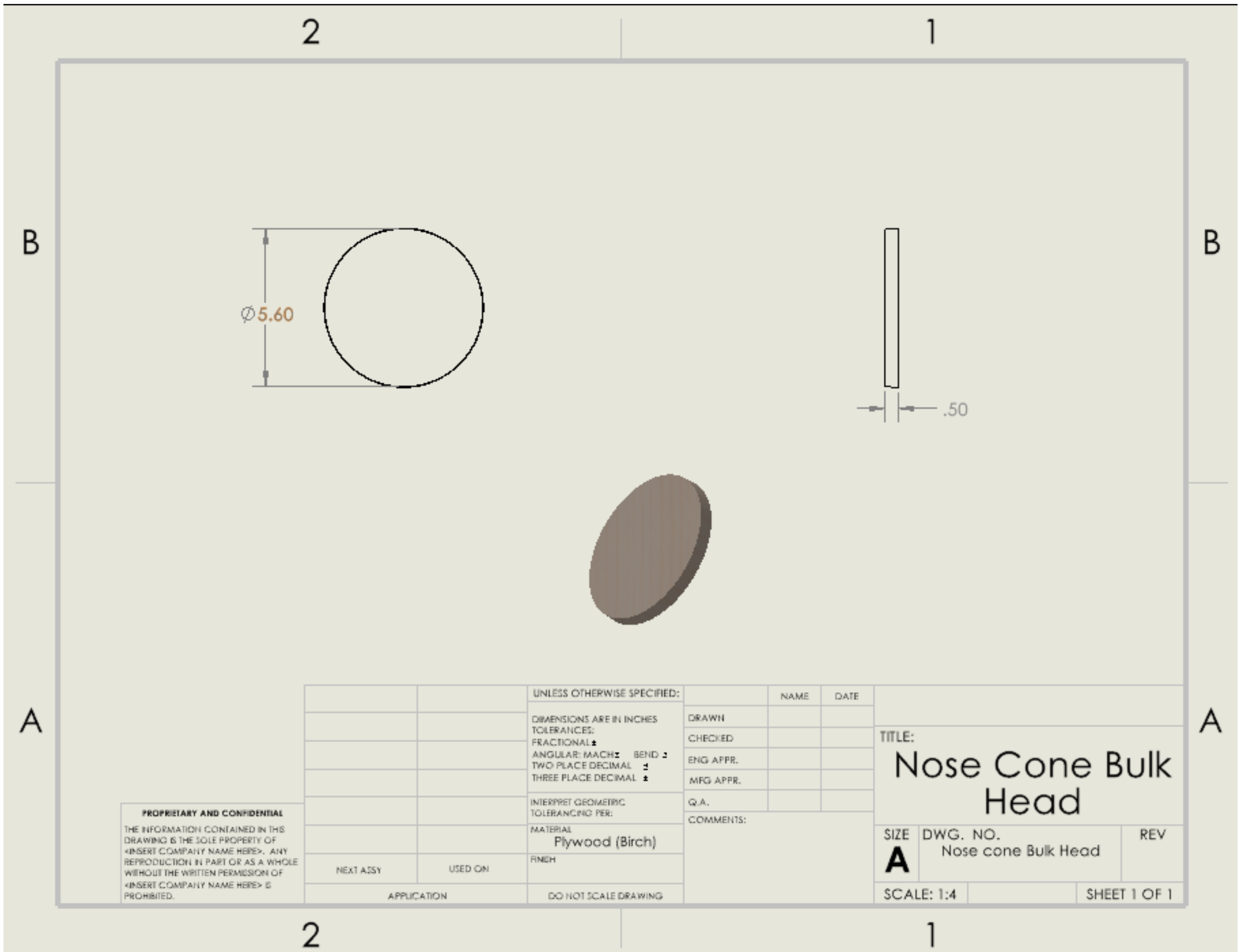
TITLE:
Main Booster Coupler
SIZE
A
DWG. NO.
Main Booster Coupler
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1


Ø5.60
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Plywood (Birch)
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Nose Cone Bulk Head
SIZE
A
DWG. NO.
Nose cone Bulk Head
REV
SCALE: 1:4
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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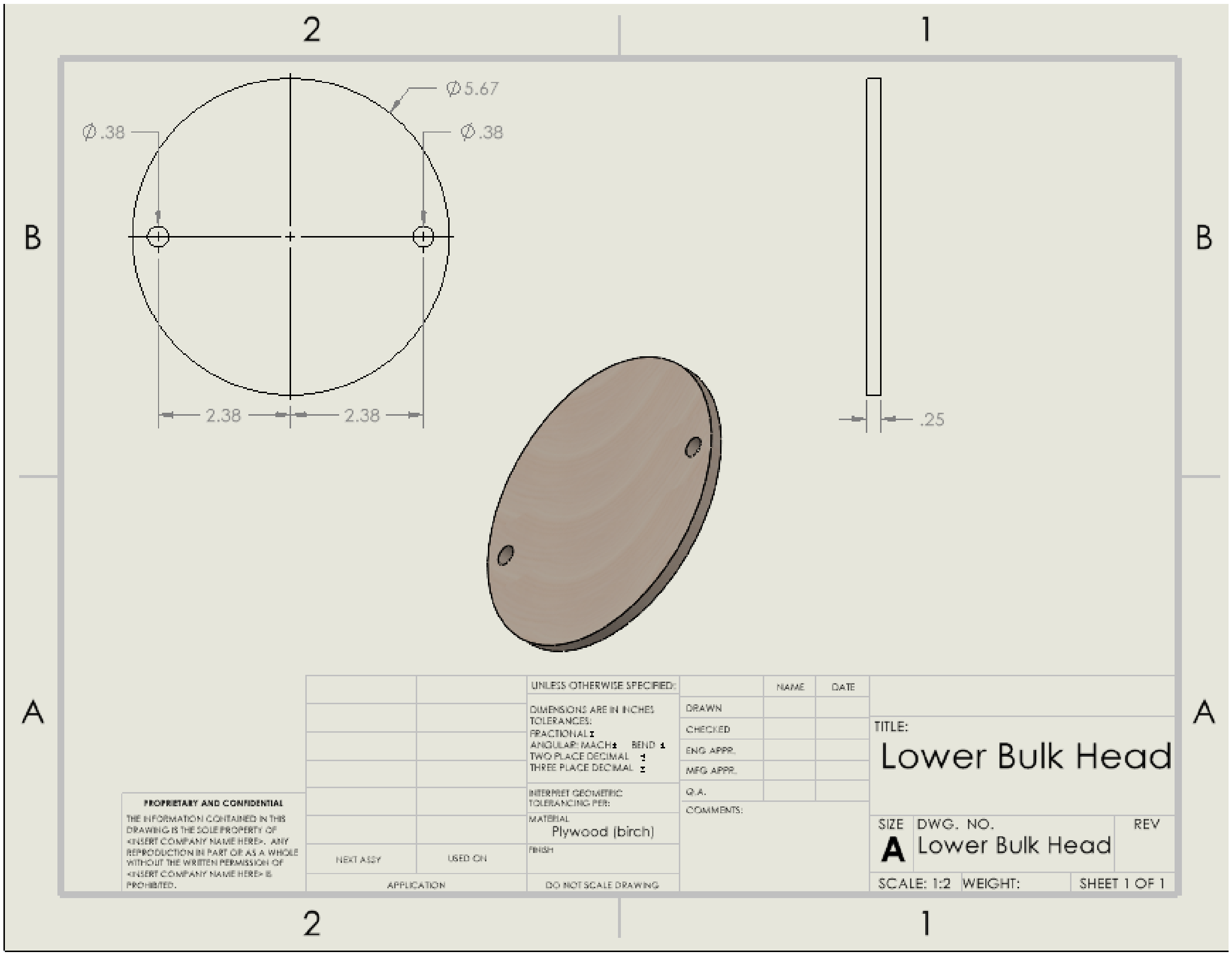
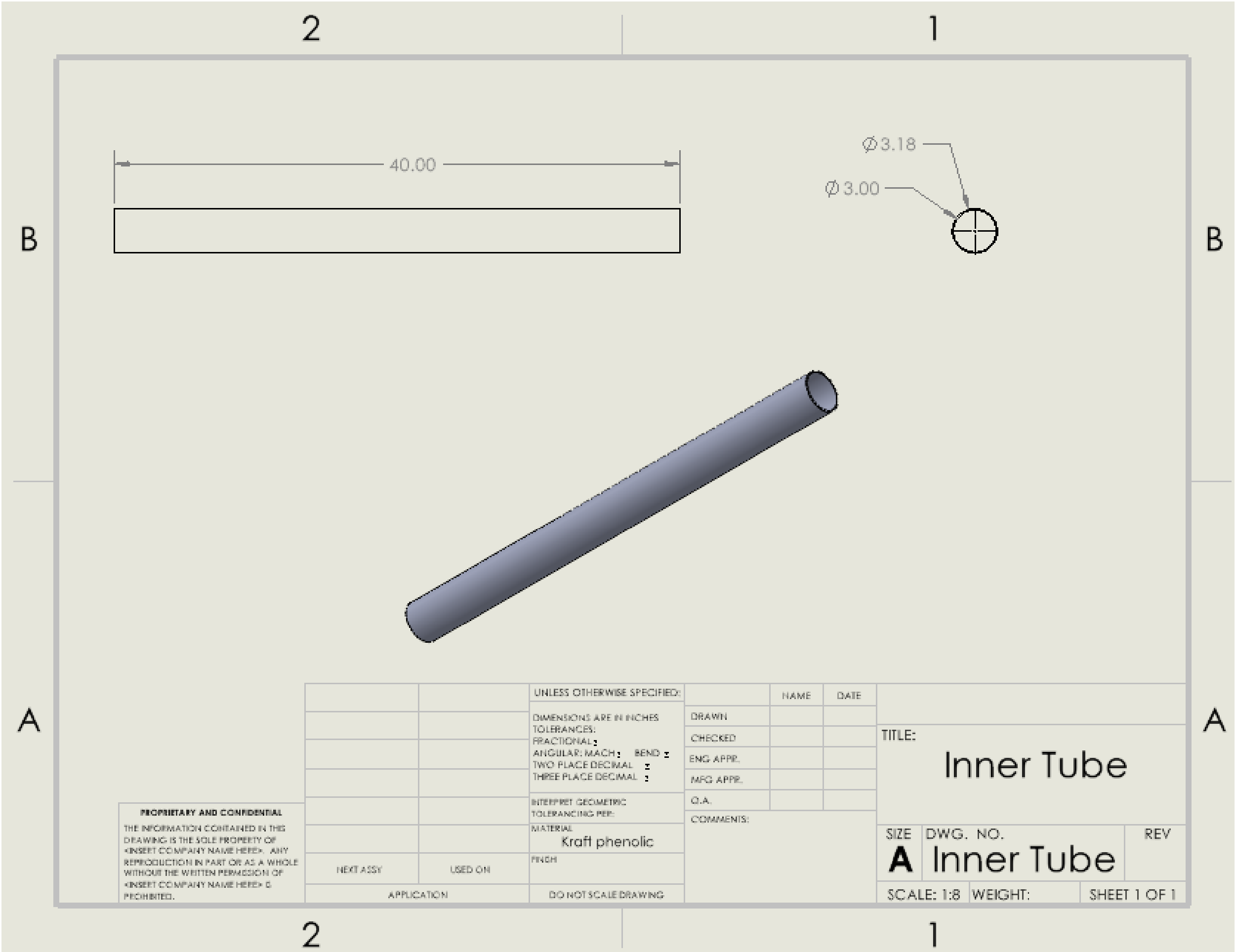

Ø5.67
Ø.38
Ø.38
2.38
2.38
.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Plywood (birch)
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Lower Bulk Head
SIZE
A
DWG. NO.
Lower Bulk Head
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


40.00
Ø3.18
Ø3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Kraft phenolic
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Inner Tube
SIZE
DWG. NO.
REV
A
Inner Tube
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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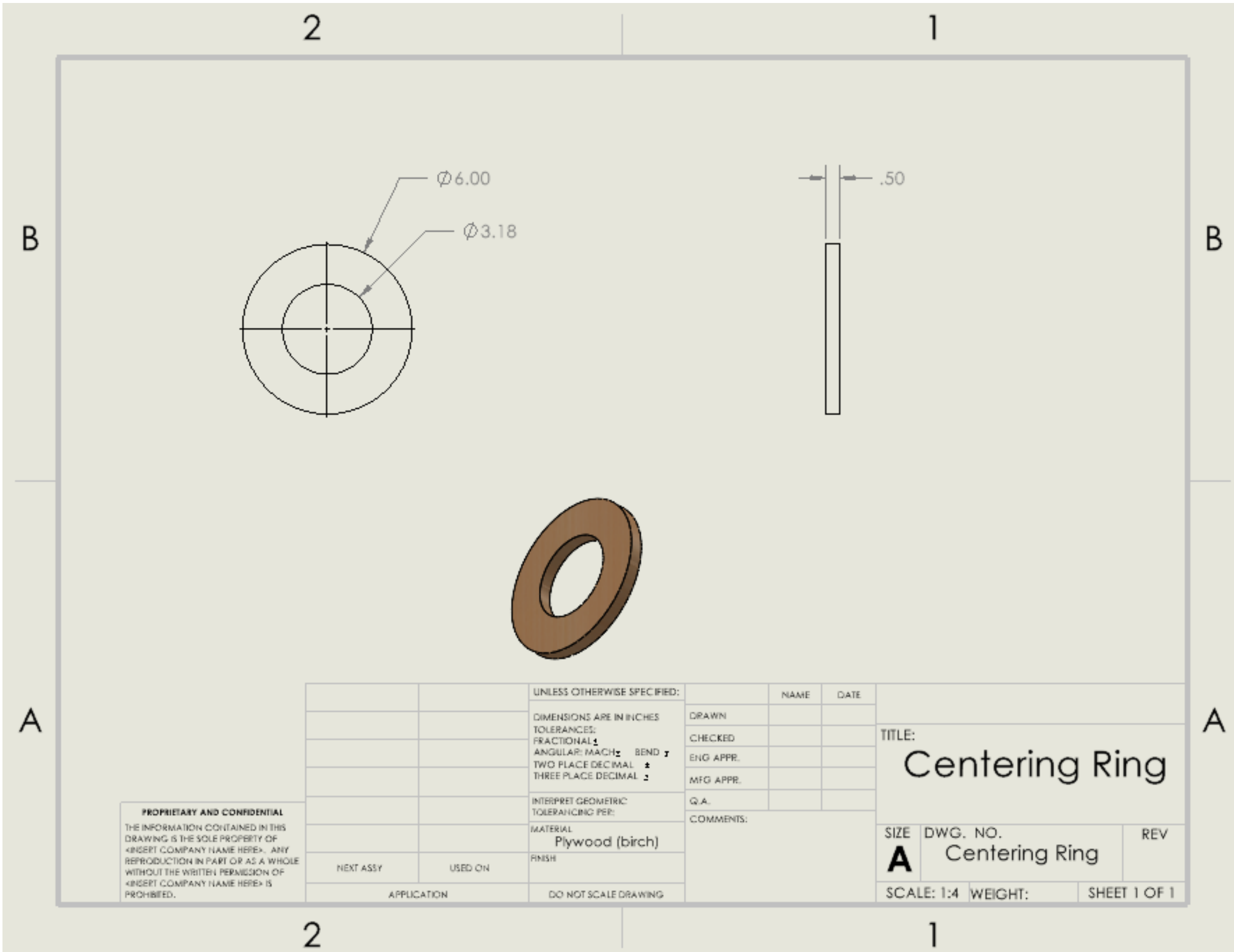
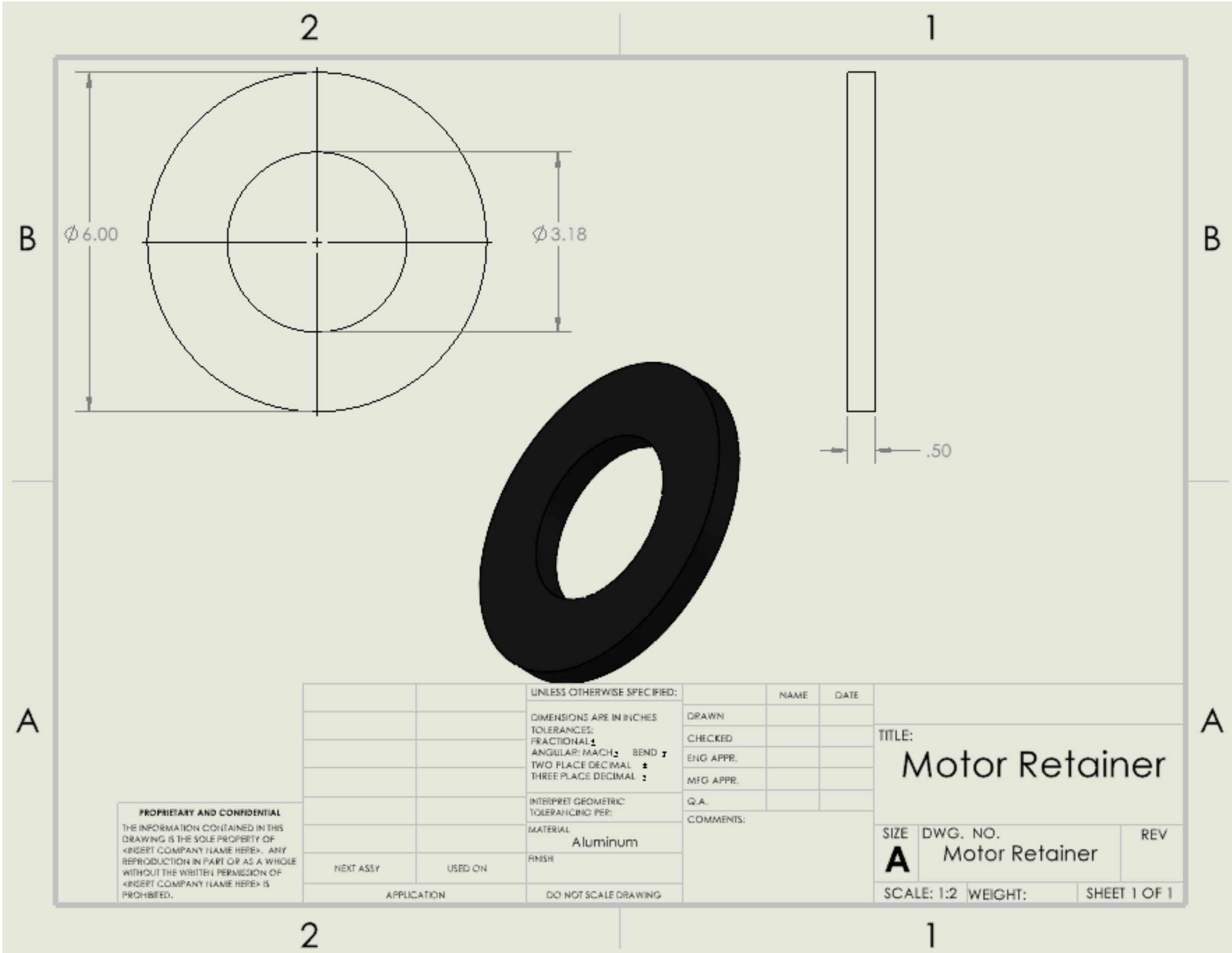
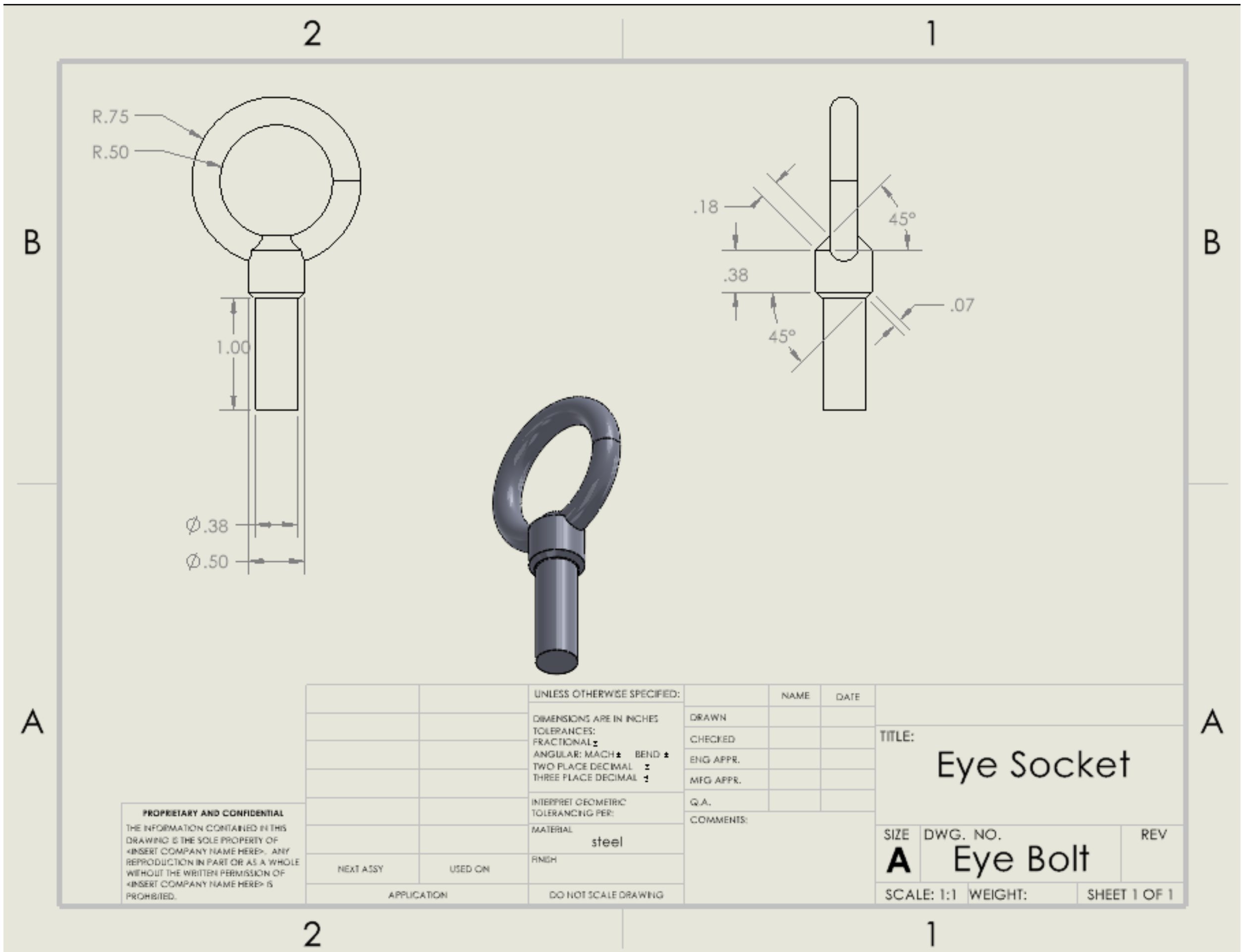

Ø6.00
Ø3.18
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Centering Ring
MATERIAL
Plywood (birch)
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
SIZE
A
DWG. NO.
Centering Ring
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1


Ø6.00
Ø3.18
.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Motor Retainer
SIZE
A
DWG. NO.
Motor Retainer
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


R.75
R.50
1.00
Ø.38
Ø.50
.18
.38
45°
45°
.07
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
steel
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Eye Socket
SIZE
A
DWG. NO.
Eye Bolt
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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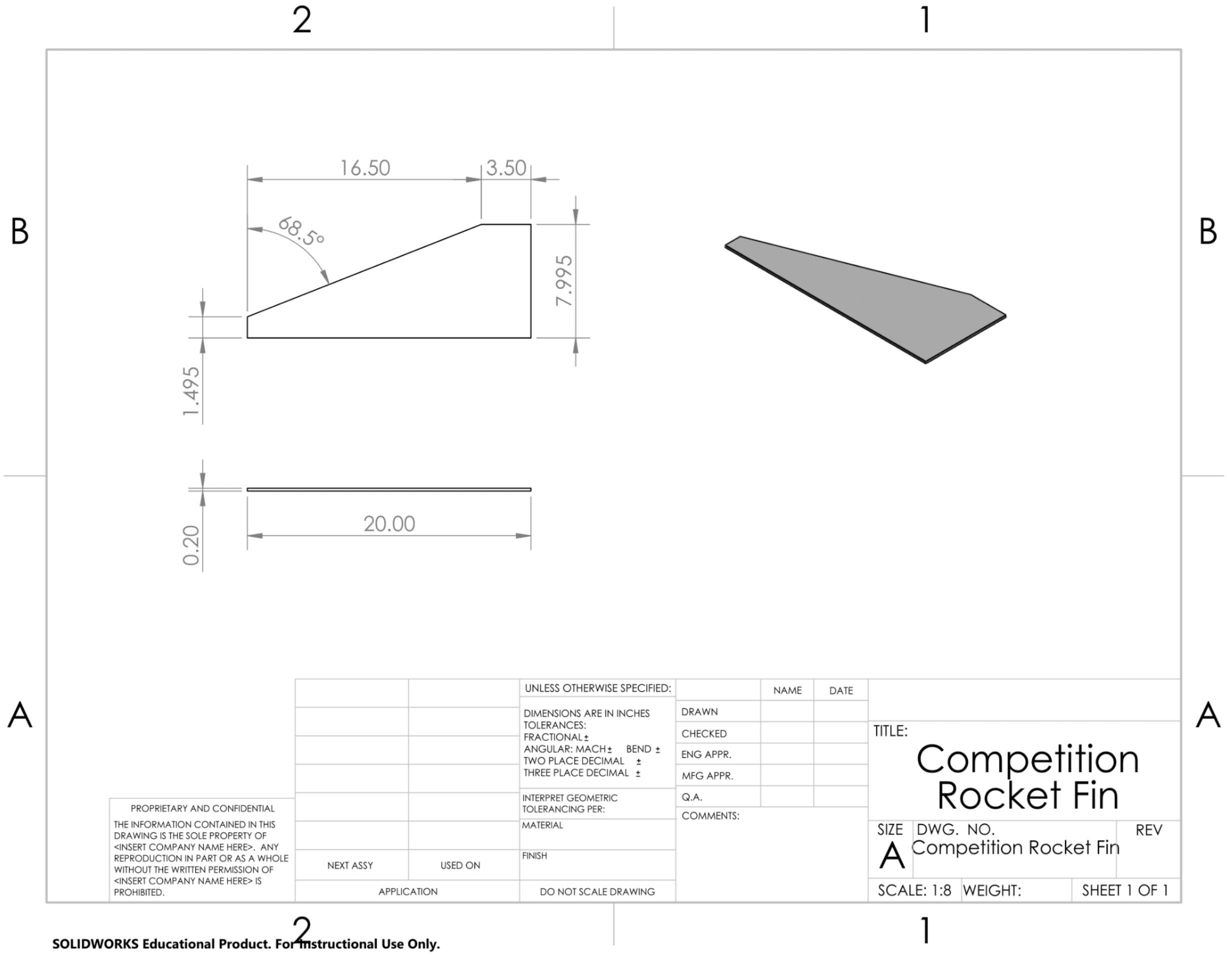
2
1
B
A
16.50
3.50
68.5°
7.995
1.495
0.20
20.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Competition Rocket Fin
SIZE
A
DWG. NO.
Competition Rocket Fin
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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VII References

[1] IREC Design Test and Evaluation Guide, Spaceport America Cup, Effective 04/22/2022, Revision: 2023 V 1.4

[2] IREC Rules and Requirements, Spaceport America Cup, Effective 06/03/2019, Revision: 2023 ver. 1.2

[3] IREC Range Standard Operating Procedures, Spaceport America Cup, Effective 06/03/2019, Revision: Baseline