IO Project Technical Overview

Team 60 Project Technical Report for the 2018 IREC

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For the 2018 Spaceport America Cup (SAC), the Buckeye Space Launch Initiative (BSLI) designed and constructed the IO rocket. IO is a ten-foot tall, six-inch diameter rocket that will be aiming for 10,000 feet above ground level with a student researched and developed solid rocket propulsion system. IO incorporates a large 5U CubeSat bay, which holds both 3U of standard CubeSat payloads as well as the vehicle's avionics and telemetry system, in a 2U format. Payloads have been developed by the Students for the Exploration and Development of Space (SEDS) at Ohio State as well as a team from BSLI. Also onboard is a lander developed by a Mechanical Engineering Capstone group, as a technical demonstrator. Finally, IO features the Active Drag System in its second iteration for BSLI, a drag-based device which controls the vehicles final altitude and hopes to account for variabilities and inaccuracies in simulation of flight and attain a closer apogee to the target or 10,000 feet.

Nomenclature

10k = 10,000 feet
ADS = Active Drag System
AGL = Above Ground Level
AP = Ammonium Perchlorate
BSLI = Buckeye Space Launch Initiative
CFD = Computational Fluid Dynamics
Dragino = Radio Frequency and GPS Module
ESRA = Experimental Sounding Rocket Association
GPS = Global Positioning Satellite
IREC = Intercollegiate Rocket Engineering Competition
km = Kilometer
ksi = Kips per Square Inch
Lora = Long Range
m = Meter
mAh = Milliamp-Hour
MDF = Medium-density Fiberboard
MHz = Megahertz
PCB = Printed Circuit Board
RF = Radio Frequency
RSO = Range Safety Officer
s = Second
SEDS = Students for the Exploration and Development of Space
SRAD = Student Research and Developed
U = CubeSat Unit (10 cm x 10 cm x 11.35 cm)
V = Volt

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. Introduction

THE Buckeye Space Launch Initiative (BSLI) 10k Competition Team is a multidisciplinary student project team from The Ohio State University with the goal of designing, testing, and constructing a high powered rocket to compete in the Experimental Sounding Rocket Association's (ESRA) annual Intercollegiate Rocket Engineering Competition (IREC) 10,000-foot student researched and developed (SRAD) Competition. The 10k Competition Team exists to introduce students to high-powered rocketry and serve as a test bed for new technologies and techniques for the team as a whole. The 10k Competition Team provides a knowledge base and project team setting that prepares students to be successful in both the Buckeye Space Launch Initiative and in their future careers.

The *IO* rocket was designed and built by the BSLI 10k Competition Team to compete in the 2018 ESRA IREC 10k SRAD Competition. *IO* is an eleven-foot tall, six-inch diameter rocket that will be aiming for 10,000 feet above ground level (AGL) with a student researched and developed solid rocket propulsion system. It features a 24-inch ogive nose cone, two 4-foot body tubes, and a 98mm motor tube. The nose cone assembly contains the lander technical demonstrator. The forward body tube holds the recovery system and the 5U CubeSat bay, and the aft body tube holds the Active Drag System (ADS) and the motor. A student-built telemetry system is contained in the avionics CubeSat and is capable of transmitting flight data to the ground station during the mission. Three 1U CubeSat payloads were designed and built to be three different scientific experiments. The recovery system consists of a drogue parachute that will deploy at apogee, and a main parachute that will deploy at 1500 feet above the ground. The motor is an aluminum-HTPB-AP composite solid propellant with 9020 newton-seconds of total impulse.

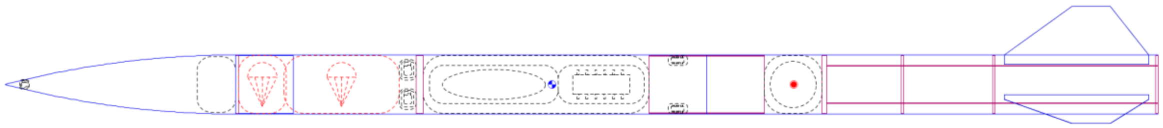


Figure 1. OpenRocket model of IO

The 10k Competition Team structure is given in Fig. 1. The Project Manager handles the administrative tasks for the team and is the primary systems engineer. The Recovery Lead is primarily responsible for safely recovering the rocket after launch, including designing and constructing the parachutes. The Structures Lead works with their team on testing materials and construction of the rocket's airframe, as well as developing better manufacturing techniques. The ADS Lead oversees the design, construction, and testing of the Active Drag System. The Avionics Lead manages the development of avionics and telemetry. The Payload Lead is responsible for both constructing the payload bay and liaising with external teams constructing CubeSat payloads for flight on the rocket. The subsystem leads are also responsible for the team members working on that system under them and reporting progress to the Project Manager.

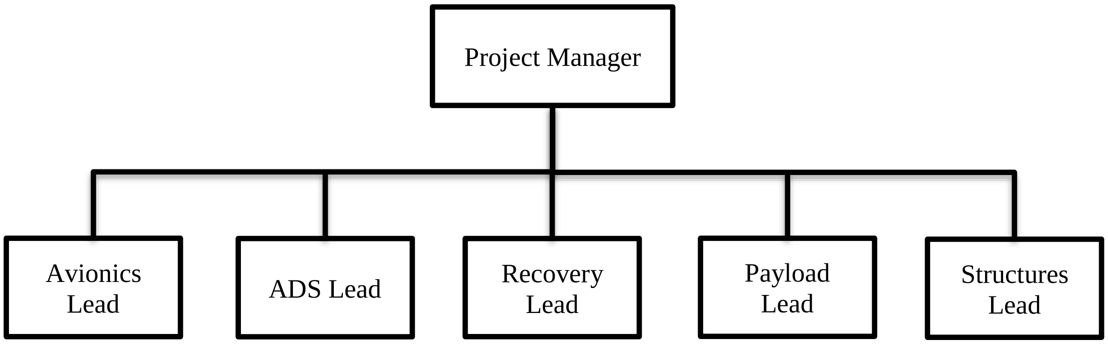


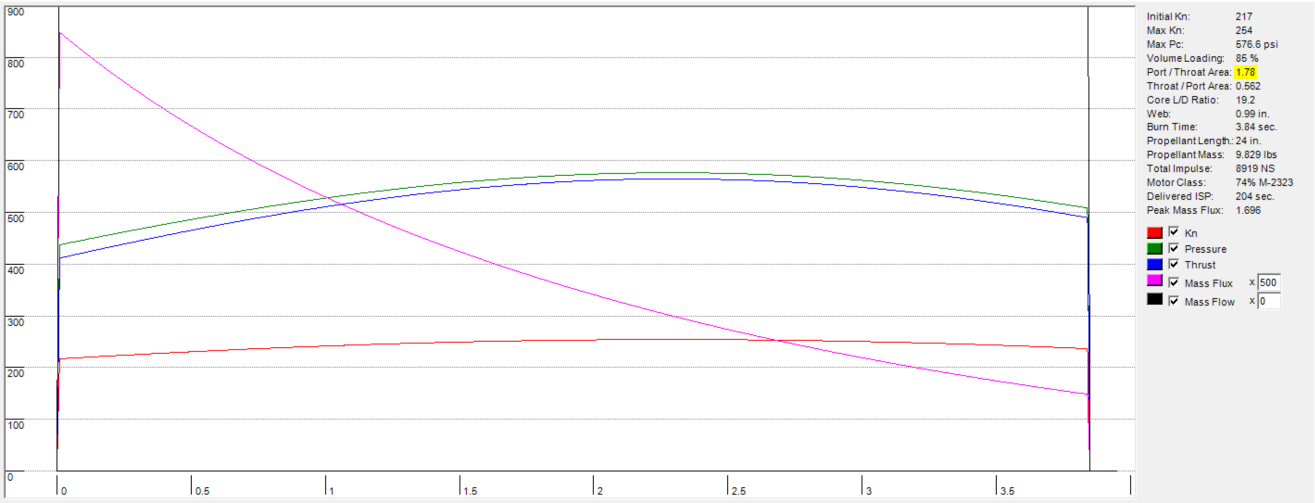
Figure 2. 10k Competition Team Structure

II. System Architecture Overview

IO is a ten-foot tall, 6-inch diameter rocket, with 3 trapezoidal fins and an ogive nosecone. From fore to aft, the main subsystems are the Lander, the Recovery system, the Payload Bay, the Avionics and Telemetry, the Active Drag System, and the motor. The single point of detachment is between the nose cone and the forward body tube, allowing both the drogue and main chutes to be deployed from the Recovery bay. A six inch coupler connects the upper body tube of the rocket to the lower body tube.

A. Propulsion Subsystems

IO has one solid rocket motor. It is a student researched and design N3550 APCP motor, with 9020 Newton-seconds of total impulse. A thrust curve obtained from BurnSim is shown in Figure 3 below.

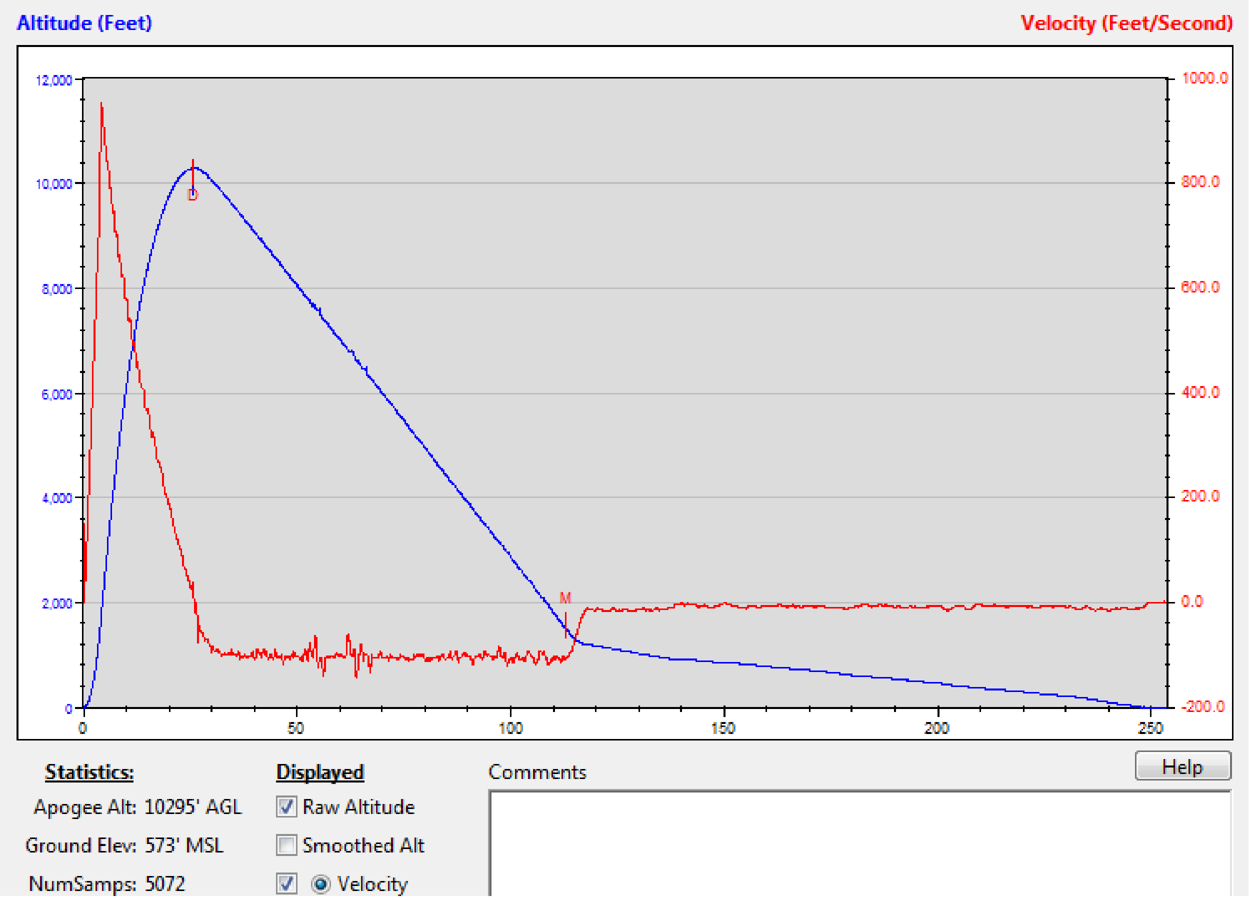


Initial Kn:	217
Max Kn:	254
Max Pc:	576.6 psi
Volume Loading:	85 %
Port / Throat Area:	1.78
Throat / Port Area:	0.562
Core L/D Ratio:	19.2
Web:	0.99 in.
Burn Time:	3.84 sec.
Propellant Length.:	24 in.
Propellant Mass:	9.829 lbs
Total Impulse:	8919 NS
Motor Class:	74% M-2323
Delivered ISP:	204 sec.
Peak Mass Flux:	1.696

Figure 3. Theoretical Motor Thrust Curve

The results obtained from BurnSim were validated with the full-scale test launch of *IO* on April 21, 2018. Data obtained from the flight computers for that test launch is shown in Figure 4 below. The motor is comprised of a mostly magnesium base which while lighter than aluminum propagates the burn at a lower temperature and thus pressure which has prevented unintended pressure spikes and lends itself to a more stable burn. The copper in the motor helps transfer heat into the grains as they burn increasing the efficiency of the burn itself.

The nozzle is a conical nozzle with a throat diameter of 15/16 inches and an expansion ratio of 6.25. This has been optimized for an altitude of four thousand feet which is approximately the launch ground altitude.



Statistics:
Apogee Alt: 10295' AGL
Ground Elev: 573' MSL
NumSamps: 5072

Displayed
☑ Raw Altitude
☐ Smoothed Alt
☑ ● Velocity

Figure 4. Test Launch Avionics Data

B. Aero-structures Subsystems

The majority of the structure of the rocket is manufactured from fiberglass composites, with the rest composed of birch plywood. All structural elements of the rocket are student designed and manufactured, with the exception of the motor retaining ring at the aft end of the motor tube.

The two main body tubes are 6-inch inner diameter fiberglass. They were manufactured around an aluminum mandrel with 7 layers of fiberglass and Aeropoxy. The forward tube is 49 inches long, and the aft tube is 47 inches. To the forward tube is fixed the coupler, which extends 6 inches into each tube and holds them together. The coupler is 1/8"-inch and serves as a load bearing part for both the ADS below and the Payload Bay above. It also contains four weld nuts to serve as a means of fastening the two body tubes together from the outside, using ¼-20 screws.

Contained in the aft tube is the motor tube, held in place by four 1/8-inch thick centering rings. The motor tube has an inner diameter of 98 mm to accommodate the SRAD Propulsion system. The aft-most centering ring also serves as a mounting point for the motor retainer, which is a threaded cap that holds in the motor case after burnout.

IO's three trapezoidal fins are mounted through the wall of the aft body tube and against the motor tube. They have a core of 1/8 inch birch plywood, covered with three layers of fiberglass and epoxy. The edges are taped with additional fiberglass to prevent de-lamination. Small epoxy fillets are also added at the body-fin interface, for additional strength.

The two-foot long nose cone is an ogive shape, with a six-inch shoulder. To make the mold, a plug was first milled from medium-density fiberboard (MDF) on a CNC mill. This plug was then used to make a female mold by placing a vacuum bag over the plug, applying mold release, and laying up fiberglass overtop. This was then covered with a layer of peel-ply and breather clothe, and finally another vacuum bag to press the fiberglass to the mold. Once the mold cured, it was sanded and smoothed with auto body filler to attain a smooth surface. This process was repeated once, for a total of two mold sections which could be mated together.

To layup the cone itself, both molds were first laid up separately. Then, while the epoxy had still not cured, the two mold sections were mated together and additional fiberglass strips were added to the seam to create one part. The inside of the tip was also filled with fiberglass shavings and epoxy to have a solid section for a more durable point.

C. Recovery Subsystems

IO has a dual-deployment recovery system with a single point of separation. As the avionics detects apogee, 4 redundant ignitors set off the primary and secondary ejection charges. The discharge separates the nosecone and pushes the drogue chute and heavy canvas parachute bag out of the body tube, shielded by Nomex fabric and cellulose insulation. The 30” drogue will deploy and restrain descent to an estimated 80 feet per second. As the avionics detects an altitude of 1500ft, two redundant cable cutters will fire to allow the 36” pilot chute and 102” main chute to deploy out of the canvas parachute bag. The main parachute will restrain the descent to an estimated 17 feet per second.

Design of the drogue followed from the IREC competition rules, which recommend a drogue descent rate in the range of 75-150 ft/s. The lower end of this range was used for a more controlled descent, and the empty weight of the rocket was estimated in order to properly size the drogue. At the time of drogue and main parachute design, the rocket’s empty weight was estimated at 52 lb. The pilot chute was introduced to the main deployment to ensure a quick and orderly deployment, to reduce the chances of tangling with the lines. Cable ties and a cable cutter restrained the opening of the canvas bag to allow for the 1500ft altitude deployment to be triggered by avionics as necessary. The recovery bay limited the size of the canvas bag and ejection charge assemblies to 16 inches in length, and 6 inches in diameter to fit in the top of the body tube. Compression and folding of the parachute into the parachute bag was necessary to get the density required to fit inside the airframe. Additionally, talcum powder is placed on the parachute to reduce friction and allow greater packing factor.

The pilot parachute was made out of 1.9-ounce grey Ripstop Nylon, 725lbs Spectra Microline, black size 92 Nylon thread, with 6 gores resulting in a semi-ellipsoid parachute. The drogue parachute was made of 1.1-ounce bright pink Ripstop Nylon, 725lbs Spectra Microline, and black size 92 Nylon thread with 6 gores making an ellipsoidal chute. The main parachute was made out of 1.9 ounce scarlet and grey Ripstop Nylon, and black size 92 Nylon thread with 18 gores making an ellipsoidal chute. Each parachute has shroud lines 1.5 times the diameter of the parachute. The gores were sewed using 5/8ths inch wide full flat felled seams, to ensure the seams were stronger than the Ripstop Nylon. The ellipsoidal chutes were modelled using MATLAB, by determining the surface area necessary for an estimated rocket size and launching conditions, and then drawing an ellipsoid, determining the midpoint of each gore section and plotting it on a 2D axis, to be sent to a laser cutter to get a template out. All of these components are connected and mounted to the bulkheads with 1/4” inch Kevlar hollow cord.

Each ejection charge consists of a latex bag containing 4F black powder and two nichrome ignitors. The latex bag is mounted in a 3D printed PLA canister with a top that breaks away as the canister fires. A canister base was drawn in SolidWorks and mounted to the recovery bulkhead, keyed with J-slots to allow 4 posts on the canister to slide in and lock, allowing for easier and safer installation and disarming of ejection charges. The recovery assemblies next to the ejection canister are covered with Nomex sheets, to protect against the hot gases and to prevent damage to vital components. The primary charge consists of approximately 5 grams of 4F black powder, and the secondary charge consists of approximately 6 grams of 4f black powder.

D. Avionics Subsystems

Background Information

The avionics team was responsible for the design of the electronics bay, programming flight computers, onboard camera footage, and implementing a telemetry system. The creation of the 2018 system was based off of the 2017 model with areas to modify in mind. The previous model was lightweight and cheap to manufacture but the hardware and integration for the system was very basic, difficult to integrate, and did not include a telemetry/GPS system. The new model was designed to improve integration time, increase rigidity and robustness of the electronics bay, and add a long-range telemetry system.

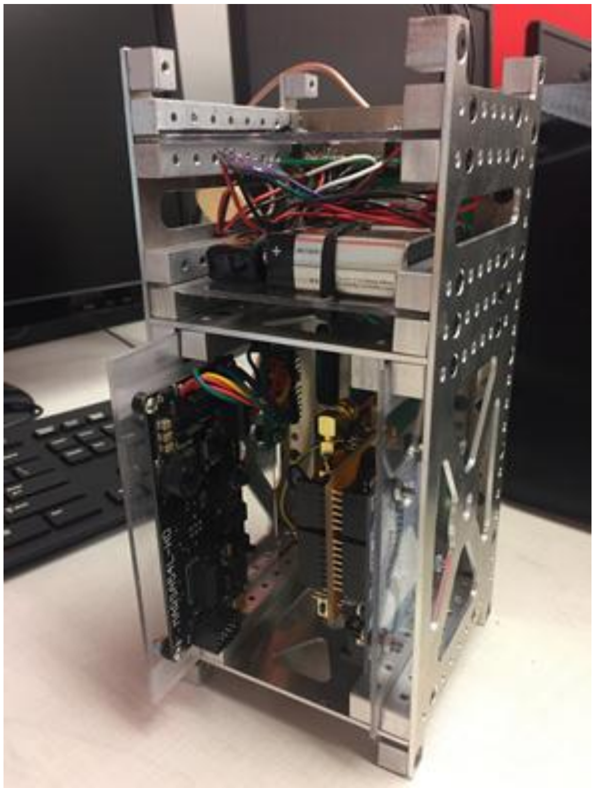


Figure 5. Avionics Bay

Flight Computers

A Stratologger CF will be used to collect data and ignite chute charges. The computer has two channels. One is for deploying the drogue chute and one is for deploying the main chute. The computer uses a barometer to detect when the rocket reaches apogee at which point, current is sent through channel one to ignite the drogue charge. Channel two is set up to also use the barometer to detect elevation at 1500 feet at which point will deploy the main chute.

A second flight computer will be used to create a redundant system barring any unforeseen damages or connectivity issues to wires, charges, or either of the flight computers. The Marsa 54L will be used as the second flight computer to collect a second data set and deploy the main and drogue chutes. The Marsa has four screw terminal channels which can be programmed in various ways to deploy the chutes. The Marsa has an accelerometer and a barometer to detect apogee and altitude. Three of the four channels will be programmed to ignite the drogue chute charge while the fourth channel deploys the main. The three channels designated to the drogue will be programmed to detect apogee differently using the Marsa software. The first channel will detect apogee using the barometer, the second channel uses the accelerometer, and the third channel uses a combination of both. The fourth channel will use the barometer to detect altitude at 1500 feet and send current to the main charge.

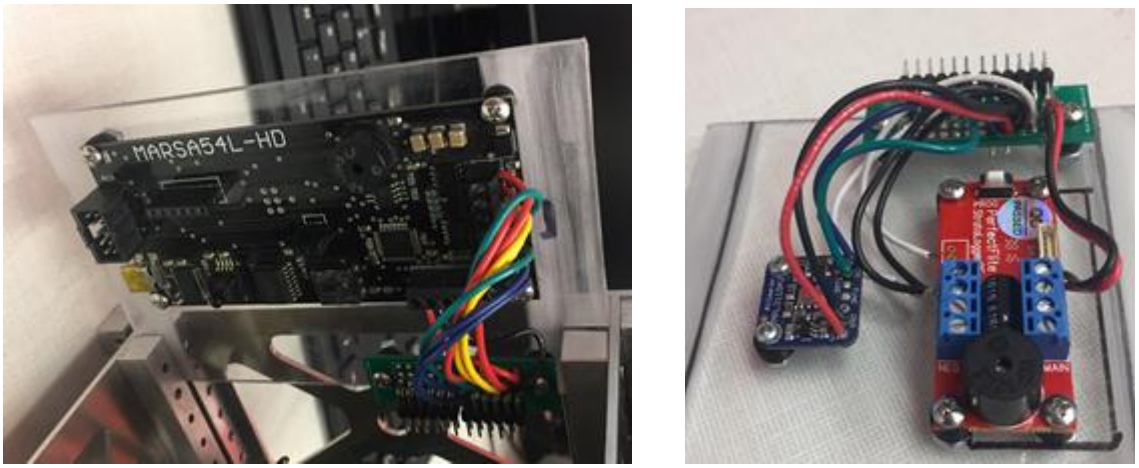


Figure 6. MARSA and Stratologger Modules

Design

The electronics are mounted on sleds which easily slide in and out of the bay for optimized storage and quick replacement of electronic components. The electronics are interconnected through a PCB that runs along the back of the bay. The sleds are connected using male right angle pins which slide into the female pins located on the PCB.

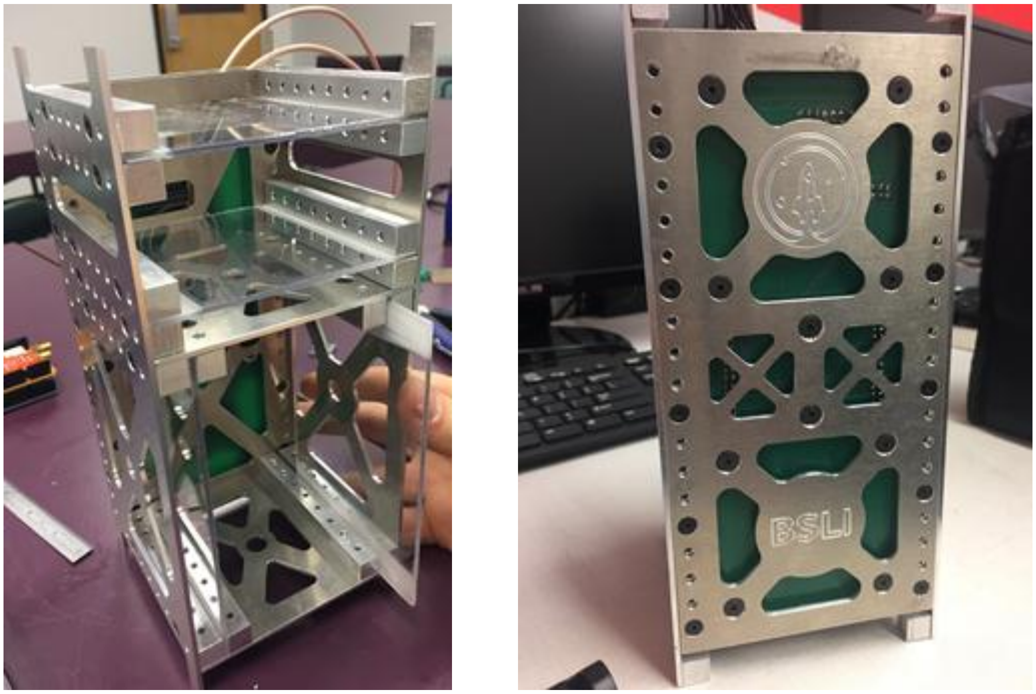


Figure 7. Fabricated Sled Design of the Avioincs Bay

Cameras

To capture on-board footage of the rocket launch, two cameras were used to give both an upward facing and a downward facing view of the flight. The type of cameras selected are Mobius ActionCam 1080p because of the high-quality video it can record and the various ways that the components can be configured to fit in and around the electronics bay. The cameras are programmed to record footage in 1080p at 30 fps. Using the 820 mAh batteries and

32 GB memory cards, the expected recording time is about an hour and a half. In past experiences, final integration of the camera systems was a problem, resulting in no on-board flight footage. To make final integration easier, the lenses are permanently mounted on the exterior of the rocket inside an aerodynamic shell. Lens extension cables are fed from the lenses to the coupler through the payload bay. The mounts for the main camera body are in the coupler area, and they are attached to the underside of the bottom payload bay bulkhead. The mounts for both the lenses and the main camera bodies were designed using SolidWorks and were 3D printed.

Telemetry

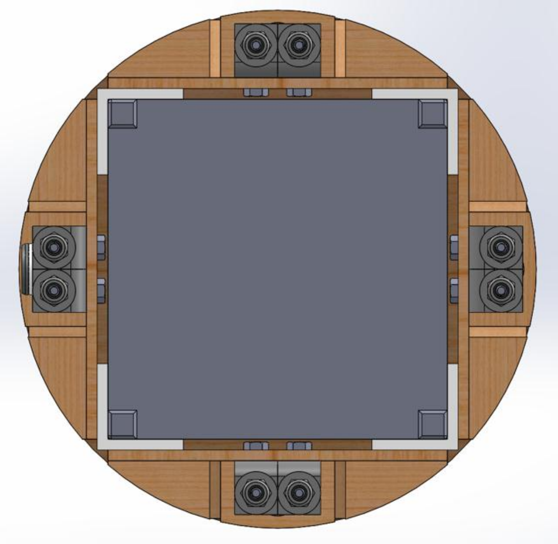
A telemetry system is a necessity for the electronics bay. The main function of the telemetry system is to obtain real time GPS coordinates from the rocket but will also be able to transmit battery voltages and altitude data. Data will be transmitted using a Dragino Lora/GPS shield and an Arduino. One module will be housed in the electronics bay connected to a GPS and Lora antenna mounted on the outside of the bay but still inside the rocket. Another module will be positioned on the ground to receive data transmitted by the sender. The two Lora modules will transmit using 900 MHz RF communication.

Integration

The electronics bay was made specifically for easy integration into the rocket. The 2U CubeSat is meant to be able to slide smoothly into the Payload Bay. Once the bay is inserted, the antennas, cameras, and ejection charges are connected to the top of the bay using circular, locking connectors. For the cameras, the lens extension cables will be connected to the camera body after the avionics bay and the payload are in and the bulkhead is secured. They will remain off until the igniters are put in, at which point they will be turned on through small holes in the body of the rocket. Finally, when the system is ready, the key switch is turned horizontal to initiate the launch sequence.

E. Payload Subsystems

The majority of the rockets internal structure was comprised of a lengthy 5U CubeSat payload bay, which housed 3U's worth of scientific experiments, and an additional 2U of avionics. The payload bay was constructed out of beech wood using a rib cage design capable of withstanding axial loads. The payload bay was designed to slide all payload experiments and the avionics bay into the rocket during integration as effortlessly as possible. To facilitate integration in the field and improve aerodynamics, the entire payload bay was designed to only mount to one bulkhead. This allowed the other end to be removed quickly for the installation of the avionics CubeSat.



The bulkhead towards the fore of the rocket, was radially mounted with six ¼-20 fasteners, which had threaded inserts mounted inside. The bulkhead was built from four layers of laser cut ¼" birch plywood glued together. The four walls of the payload bay were laser cut from 1/8" birch, and then mounted with zinc plated steel L-brackets onto the fore bulkhead. The L-brackets extended through the first two layers of the fore bulkhead and were secured with #6 fasteners. Inside the corners of the four birch walls, 1/8" PVC L-channel ran down the length of the bay, allowing the rails of the CubeSats to smoothly slide past. To prevent bowing of the payload bay, three braces extended from the walls up against the inside of the rocket body tube. Similar to the fore bulkhead, the aft bulkhead was mounted with zinc plated steel L-brackets. The aft bulkhead had large opening in the center of it, allowing easy field access to the avionics CubeSat without disassembly.

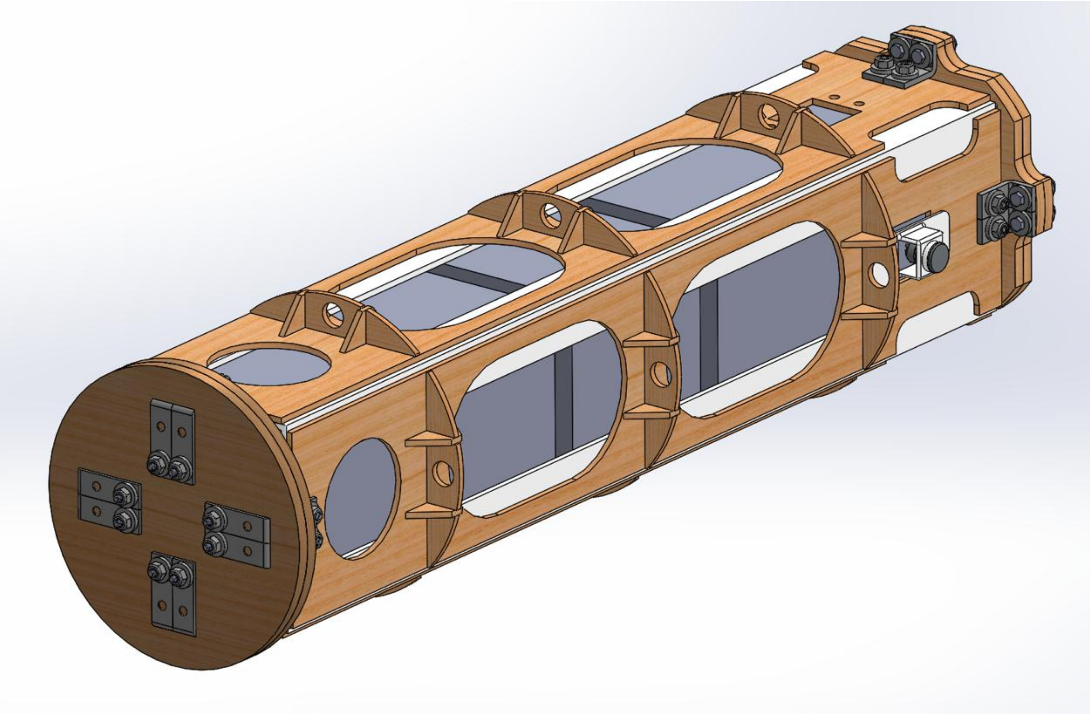


Figure 8. 5U CubeSat Payload Bay

One 1U experiment consisted of a student-built cosmic ray muon detector that was replicated from an experiment build at Massachusetts Institute of Technology. This experiment had the objective of being able to detect charged particles in the surrounding air at 10,000 ft. This project will allow the team to gain research knowledge on how charged particles change in the air as a function of altitude.

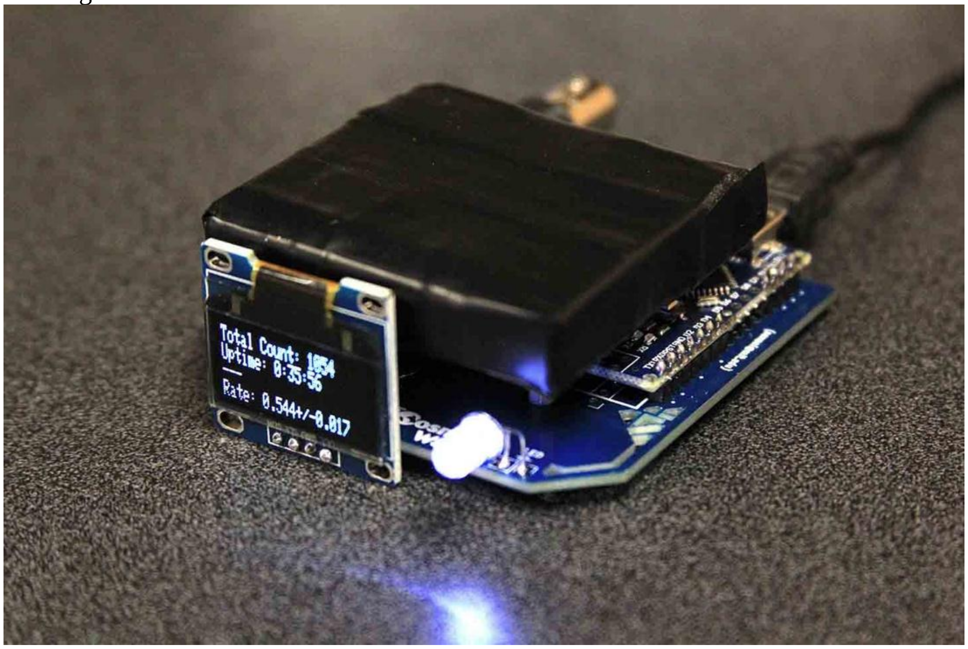


Figure 9. Muon Detector[3]

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[3] http://cosmicwatch.lns.mit.edu/detector#cosmicwatch

A second 1U experiment consisted of a student-built flight and internal environment profiling device. This device will measure accelerations and rotations of the rocket during flight. The device will also have capabilities to measure humidity, density, temperature, and pressure inside the 1U payload structure. This experiment is critical for future CubeSat projects because it will further knowledge on what the internal environment inside a CubeSat is like. By understanding the internal environment, future research project areas will be explored such as biology, neuroscience, and medical science. By profiling the flight, new designs for payload structures will be explored to hold new groundbreaking research projects. This project will ultimately give the team the capability to understand what a flight looks like from the inside of the rocket.

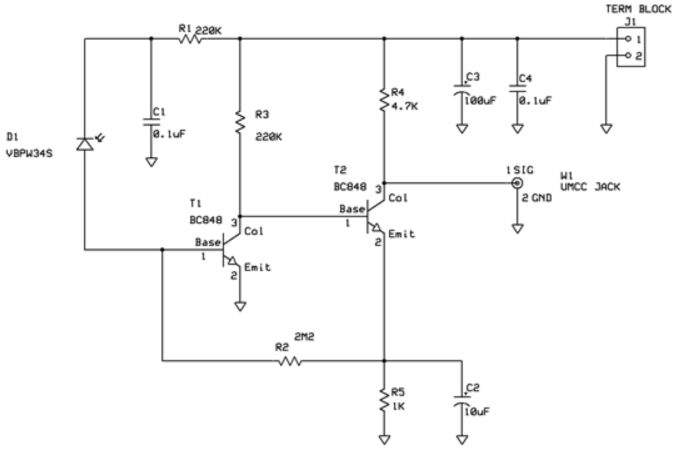


Figure 10. Circuit Schematic for Internal Environment Profiling Device

The third 1U experiment onboard was a Geiger counter. This instrument would allow the team to profile radiation at an altitude of 10,000 ft. By detecting and measuring radiation during a flight, the team could design better radiation-hardened avionics that would ultimately allow more equipment to be sent to higher altitudes. This project would provide data to allow the team to design radiation shielding for future research that would allow projects to be sent to higher altitudes.

F. Active Drag System

The design of the Active Drag System was based on the specification controlling apogee by increasing the rocket's drag at a critical moment determined by onboard simulation through flap deployment. The system allows for greater precision in reaching the target apogee by providing a degree of adaptability over the approximate methods relying on ideal conditions. To increase drag, the system deploys two flaps perpendicular to the rocket through a rack and pinion system. The overall design of the subsystem required ease of assembly by making the battery and electronics most accessible components during rocket integration. The designs of the drag flaps, housing, and bulkheads required lightweight but robust geometry and materials.

The primary design requirement for the flaps was maximized area for maximum drag effect. Several designs and deployment methods were considered like a spring loaded or pneumatic deployment, but a rack and pinion system was chosen as the flaps can deploy perpendicular to the airflow. Through Ansys CFD simulation of the rocket, the maximum load on the flaps was determined to be 68 pounds of force and a stress of 3.44 ksi. Thus, the flap material, pinion size, and motor all needed to meet this requirement. Aluminum, carbon fiber composites, and high strength plastics were considered and high strength plastic was chosen as the yield strength of 9 ksi[1] allowed for a safety factor of 3 for flap failure. The flaps were manufacturing using Fused Deposition Modeling with a grain fill of 50%. A 0.75" pitch diameter brass pinion was selected because as it would allow the flaps to deploy faster than the previously used 0.5" flap. A 12V DC Motor with a no-load speed of 146RPM and a stall torque 556 oz-in with an encoder was selected as it allowed for a deployment time of 0.5 seconds and could overpower the expected maximum torque of [insert number] caused by flap load and friction between the flap and bulkhead. However, this friction was reduced by adding a 1/16" PFTE sheet between the bulkhead and flap, reducing the friction coefficient from 0.8 to 0.1.

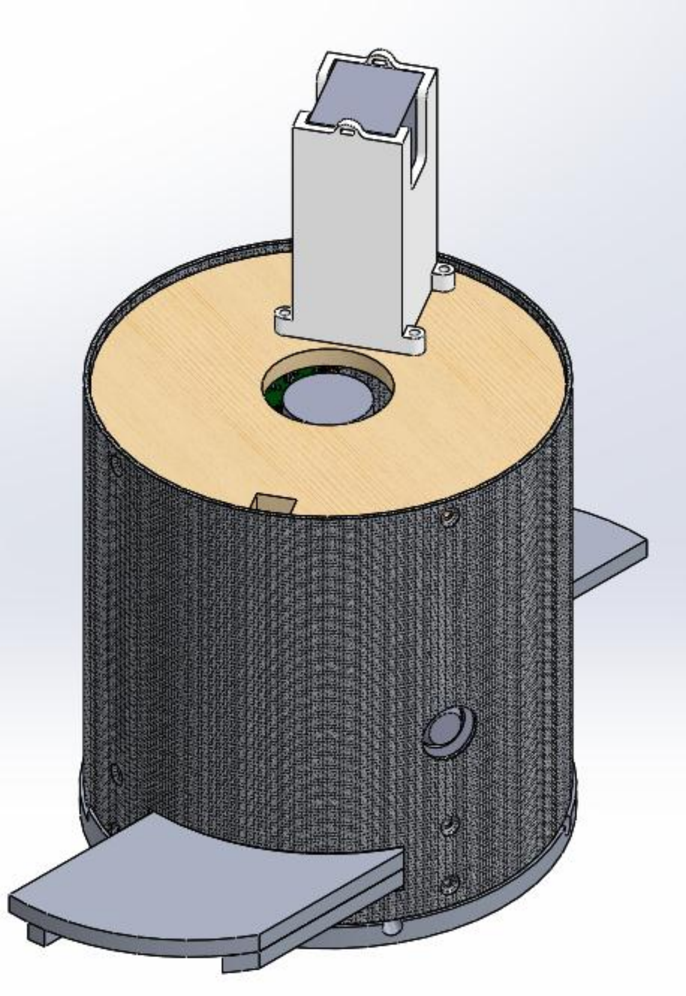


Figure 11. Fully Assembled Active Drag System (ADS)

The team chose to enclose the ADS within a cylindrical structure called the housing. The main purposes of the housing were to establish clean layers within the design of the ADS, allow the flaps to fully deploy, provide easy access to the ignition switch, prevent the ADS from rotating within the rocket tube, and transfer the compressive loads received from the flaps through the bulkheads and their fasteners. The housing used the positioning of the bulkheads, electronics base, and lid as a way to separate the ADS into two distinct modules: the lower mechanical module and the upper electrical module, each of which could be removed and worked on separately. This allowed the team to have extreme ease of access to particular regions of the ADS when problems, whether it be mechanical or electrical, occurred. The housing was designed with rectilinear channels positioned between where the bulkheads were situated so the flaps could move in and out to control the drag of the rocket and help it approach apogee as accurately as possible. The housing was also designed with a circular hole which lined up with the ignition switch of the ADS and allowed for manual control of when it was powered on/off. One major concern in the design of the housing was to remove the ability of it to rotate within the body tube of the rocket. This ability to rotate was constrained through the use of a rectilinear channel cut out from the bottom of the ADS which allowed it to fit into a metal bulkhead on top of which it rest. Along with the ignition switch and flap holes, twelve radial countersunk screw holes were implemented into the housing to attach the bulkheads and lid. These connection points are the major load-bearing regions of the structure and were an important point in choosing the material and manufacturing method used. Aluminum was previously used in the housing design but with advances in the commercial availability of additive manufacturing, the option of printing in Polylactic Acid (PLA) was examined as a way to reduce weight. The main concern in using a less rigid structure was that it might fail due to stress concentrations in the region where the metal bulkheads attached to the housing. Although the max stress around the bulkhead fasteners could not be calculated through the use of finite element analysis (FEA), the strength of the structure was verified during a wind tunnel test in which the system was fully deployed in an airflow environment similar to that of when it would be deployed during actual flight. Due to the success of this test, PLA was chosen as the material to be used in the final design of the housing. It was printed through the use of fused deposition modeling (FDM) on a Prusa i3 MK3 with 50%.

The flaps of the ADS are secured between two aluminum bulkheads that hold the flaps in place while being able to withstand the large loads involved with spaceflight. Aluminum was chosen because it is strong, easy to machine, and was readily available. The bulkheads are shaped like a (+) sign inside of an outer ring to reduce mass. Other designs that were considered included replacing the (+) sign with three beams separated by 120°much like a peace sign, and keeping the (+) sign while removing the outer ring. Simulations using SolidWorks showed that under an arbitrary load the current design could remove an appropriate amount of mass while being the strongest of the three designs. Fillets were then added to the corners to reduce stress at these 90°angles. You'll notice that the upper bulkhead also has a circular hole through its center. The hole is for the pinion that is attached to the motor to be able to reach between the two bulkheads, and engage the rack on the side of both flaps so it can drive the flaps out of the sides of the rocket.

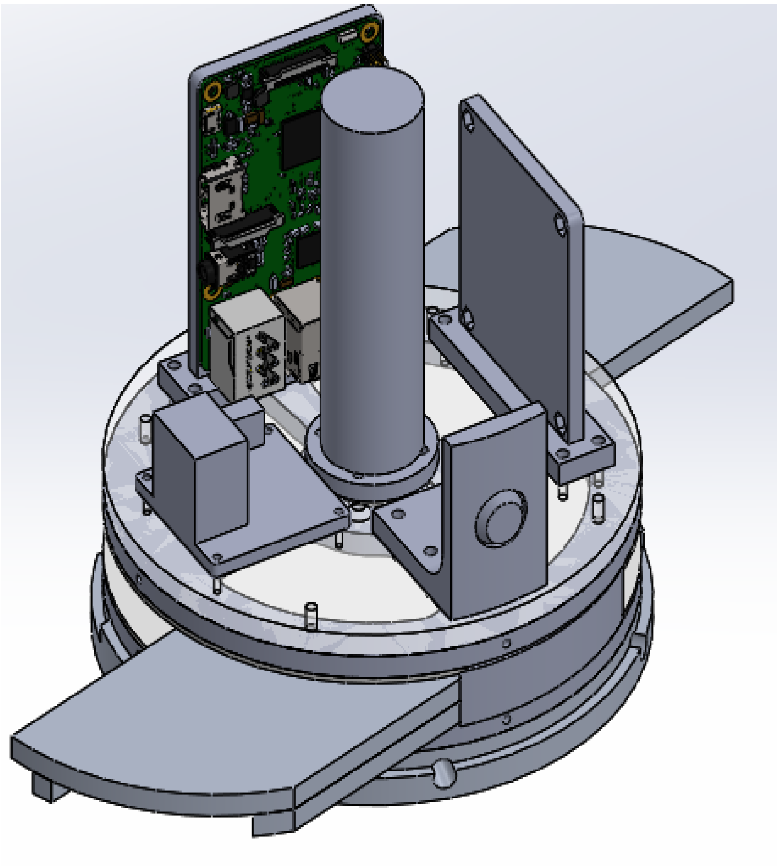


Figure 12. Internal Components of the ADS

At the top of the ADS rests the lipo battery that powers the ADS's electrical components. The battery rests on a circular lid that separates the battery from the main chamber of the ADS to create more space and prevent over-heating. The lid has a rectangular hole on its side to allow for wires to run from the battery to the ADS's electrical components. The lid also has a circular hole through its center to allow for the top of the motor to protrude, as it does not fit entirely in the housing structure of the ADS. Two zip ties were added to the lid to create a sort of handle that allows the ADS to easily be positioned in its proper location within the rocket's body tube.

The Raspberry Pi 3 Model B is the core of the electronics for the ADS. Other models of microcomputers were explored, however the Raspberry Pi beat the competitors in terms of computing power due to its quad 1.2 GHz computing cores. Due to the configuration of the wiring the Raspberry Pi requires a voltage regulator to operate normally throughout the startup process. The Sense HAT is the sensor suite that feeds the simulation the inertial, acceleration, and pressure data. The processor uses a motor encoder to interface with the motor in order to carefully move the flaps in a controlled manner in order to reduce the risk of damage to the system. In order to use the motor encoder the Raspberry Pi must use an encoder adapter to allow the wires coming off the encoder to be used with the Raspberry Pi. With the encoder attached, the motor movement can be controlled within 0.54 degrees. The motor chosen is a 12V 146 RPM which will allow the flaps to be fully deployed in 0.5 seconds.

For the electronic support boards and casings within the ADS, PLA was used with the intent of reducing overall weight of the system. The support boards for both the Raspberry Pi 3 Model B and Sense HAT were designed to be fitted with standoffs. The electronics are secured to the standoffs, leaving a space between the back of each electronic and the support board. The purpose of creating this space between them was to create a heat sink and allow the heat generated by either electronic to be released rather than building up on the electronic itself, which could – at higher temperatures – cause the electronics to overheat and fail. Though this situation is not expected, the boards were designed in such a way as to make sure this could not occur under any circumstances during flight.

The team decided to program the Raspberry Pi using C++ as opposed to the more commonly used Python. This choice was made because C++ is compiled, whereas Python is interpreted. Because of this, C++ is capable of being over an order of magnitude faster than Python in terms of computation speed. Another benefit to C++ was integration with a simulation model created using MathWorks' Simulink software.

The decision algorithm was created with simplicity in mind. To achieve this, a one dimensional flight assumption was made, thus simplifying both the complexity of the theory and complexity of computation. Also, the bulk of computation occurs during unpowered, ascending flight. On launch, the ADS begins by calculating the rocket's altitude, velocity, and acceleration from pressure and accelerometer readings. During motor burn, these values are put through a Discrete-time extended Kalman filter to reduce the influence of noise.

Simulink was used to create the simulation model for the unpowered, ascending flight. Simulink was chosen due to its simplicity and C++ code generation functionality. This simulation is used to predict both the state of the rocket during measurement as well as the maximum altitude. To calculate the measurement state, the Sense HAT's pressure sensor is used to calculate altitude and the accelerometer is used to calculate acceleration. Velocity is calculated by numerically differentiating the altitude readings, numerically integrating the acceleration readings, and then averaging the results. Both the measurement and prediction state are filtered through the Kalman filter to calculate the most probable current state. This current state is then used to seed the simulation and predict the maximum altitude. The maximum altitude prediction is then compared to an altitude-varying function that is used to reduce the possibility of over-correction, and the flaps are either deployed or retracted based on the results of the comparison. This process is repeated until apogee is detected, after which the flaps are retracted and the program ends.

III. Mission Concept of Operations Overview

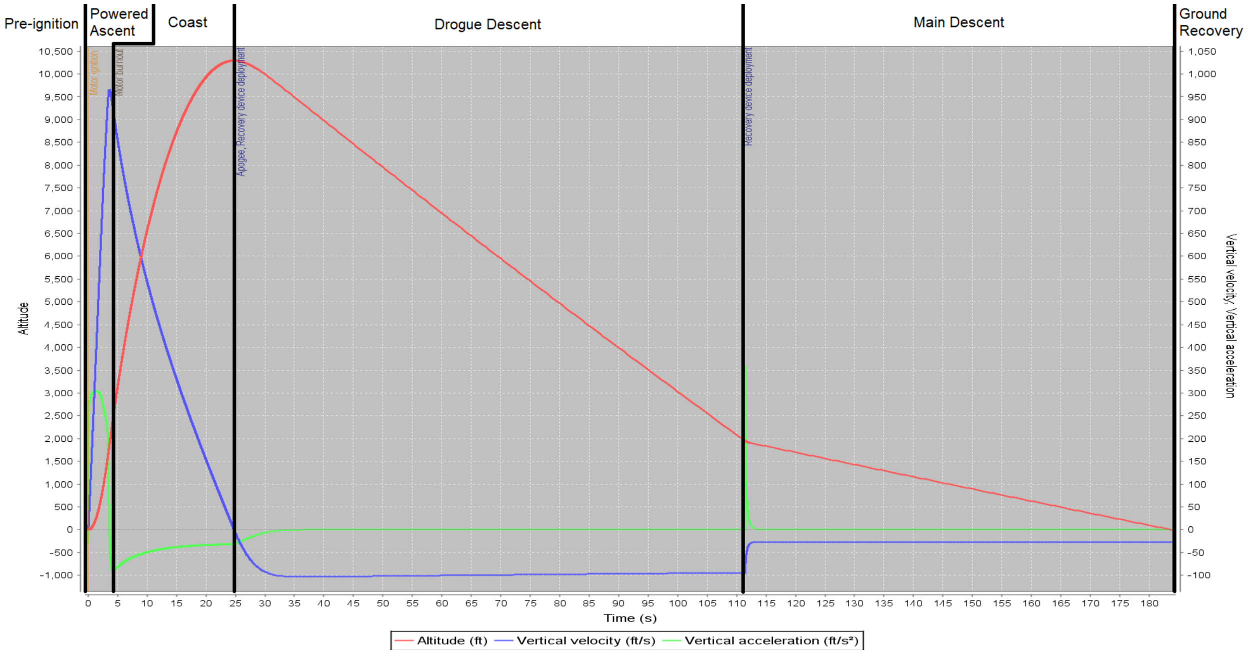


Figure 3. IO Mission Overview

Mission operations are separated into seven phases: Pre-ignition, Powered Ascent, Coast, Drogue Descent, Main Descent, and Ground Recovery. These are clearly marked at the top of Figure 3 above, which also shows predicted altitude, velocity, and acceleration over the course of the mission.

A. Pre-ignition

The beginning of the pre-ignition phase is marked by receipt of the launch card from the Range Safety Officer (RSO). This launch card indicates the vehicle has been inspected and certified to launch. Once the launch card is received, the vehicle will be transported to the launch pad and all non-critical personnel will be evacuated to a safe distance. The pad crew will consist of the project manager and all subsystem leads (Avionics, ADS, Recovery, Structures, and Payload). The vehicle will be installed on the launch rail via the two launch lugs and raised upright. When the vehicle and the launch rail have been secured in the vertical launch position, the electronics will be armed, starting with the cameras. The active drag system will then be armed, and finally the avionics and telemetry. After all electronics have been armed, the motor ignitor will be inserted and hooked up to the launch control system. The pad crew will then evacuate to a safe distance and await the RSO's permission to launch.

B. Powered Ascent

The start of the powered ascent phase is marked by the ignition signal being sent to the motor ignitor through the launch control system. This electrical signal will detonate the ignitor and start combustion of the solid fuel. The motor is expected to burn for 6 seconds, and the vehicle will be at an altitude of 2,500 feet and traveling at 925 ft/s at motor burnout. The flight computers will collect data throughout this stage and will continually monitor for their respective apogee detection conditions. The telemetry system will transmit acceleration, altitude, and GPS data to the ground station throughout this phase.

C. Coast

The start of the coast phase will be defined as the first time after motor ignition at which the acceleration of the rocket drops below zero ft/s^2 in the vertical (up positive) direction. This condition also serves as a go-ahead for the Active Drag System to begin operation. The ADS will monitor vehicle position and acceleration and use these measurements to predict apogee and adjust accordingly using mechanically-actuated drag fins. The flight computers will also continue to collect data and monitor for their apogee conditions, and the telemetry system will continue to transmit data to the ground station.

D. Drogue Descent

The start of the drogue descent phase is marked by the first successful recovery charge detonation. At apogee, there will be four events controlled by the avionics to jettison the nose cone and deploy the drogue parachute. These four events will correspond to the two recovery charges (primary and secondary) which each contain two e-match ignitors. The four e-matches will be ignited in one-second intervals, starting with the primary charge. At the end of this sequence, the nose cone will have been detached from the body of the rocket and its momentum will pull both the drogue chute and the packed main out of the recovery bay. The drogue will inflate and stabilize the rocket as it descends. At this point, the Active Drag System is retracted, disabled, and ceases gathering data. The avionics and telemetry continue to gather data and transmit it to the ground.

E. Main Descent

The main descent phase begins with the detonation of the two cable cutters holding the packed main in place. These are redundant, so detonation of either or both will cause the main chute to begin deployment. The main will inflate in an orderly fashion after being pulled out of the deployment bag by the pilot chute. This event will happen at 1500 feet, as determined by the flight computers, to slow the rocket for final descent and landing.

F. Ground Recovery

The Ground Recovery phase begins with touchdown of the rocket and ends with the successful recovery of all flight hardware. After touchdown, the telemetry system will be used to obtain GPS coordinates for the vehicle's location, which will dictate the search strategy. Once the rocket is found, the flight computers, cameras, and active drag system will be de-activated with their respective switches, and the vehicle will be returned to base camp for post-mission analysis.

IV. Conclusions and Lessons Learned

Though the *IO* project is a competition class with which the team as a whole is very familiar with, the more easily attainable altitude makes it the perfect test bed for technologies and techniques which can be improved and implemented in future projects. Of the many improvements made this year, the most notable changes came in manufacturing techniques. While previous airframes were fabricated by laying fiberglass around a cardboard tube, the team made a move this year to removable metal mandrels for tube layups. This comes with the benefit of dramatically reduced weight and form factor, and allows for greatly increased customization of the tubes.

Another notable improvement is in Ease of Assembly. Following the competition last year and the problems encountered in integration by many of the teams, an increased emphasis was placed on integration this year. This was the main driving factor behind the decision to use a unified payload and avionics bay, and the standard CubeSat format. This greatly limits the amount of time required for assembly, as the bay is a semi-permanent fixture in the body tube and the payloads and avionics can slide in and out with ease. This decision led to countless issues with integration at the beginning, but once the fit was solved, it became a very user-friendly assembly process.

Improvements in recovery have been significant. The failure of last year's tender-descender controlled chutes led to a redesign around the more reliable and redundant-capable cable cutter. Immediate results were seen from this switch at the test launch, where the recovery systems of both the team's rockets performed nominally, giving the team confidence in the longevity of this design choice.

Lastly, the Active Drag System has seen numerous improvements in weight, software, and integration. Since no data was obtained from last year's system following a failed recovery, it is difficult to ascertain all of the problems with the system, but all known problems have been addressed and the system has been greatly improved.

While *IO* serves primarily as a way to introduce new students and team members to rocketry, the project has also taught the team valuable lessons and allowed for the testing of many interesting projects.

System Weights, Measures, and Performance Data Appendix

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key

SRAD = Student Researched and Designed

v18.1

Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Date Submitted: 5/25/18

Team ID: 60

* You will receive your Team ID after you submit your 1st project entry form.

Country: United States of America

State or Province: Ohio

State or Province is for US and Canada

Team Information

Rocket/Project Name:	IO
Student Organization Name	Buckeye Space Launch Initiative
College or University Name:	The Ohio State University
Preferred Informal Name:	BSLI
Organization Type:	Club/Group
Project Start Date	8/22/17
Category:	10k – SRAD – Solid Motors

Projects are not limited on how many years they take

Member	Name	Email	Phone
Student Lead	Mark Via	via.25@osu.edu	(330) 861-4096
Alt. Student Lead	Sam Sojda	sojda.2@osu.edu	(330) 388-4427
Faculty Advisor	Dr. John Horack	horack.1@osu.edu	(614) 292-4362
Alt. Faculty Adviser	Jen-Ping Chen	chen.1210@osu.edu	(614) 247-8854

For Mailing Awards:

Payable To:	Buckeye Space Launch Initiative
Address Line 1:	201 W 19th Ave, Columbus, OH 43210
Address Line 2:	Room N350

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School	0
Undergrad	40
Masters	0
PhD	0

Male	38
Female	2
Veterans	1
NAR or Tripoli	2

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivelant organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

Rocket Rally - Put on an event at a local elementary school where team members taught students about rocketry, then participated in an Alka-seltzer rocket activity.

COSI Outreach - In planning stage of an outreach event at a local science museum, involving building and launching small Estes rockets

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	120	2' Nosecone, 49" upper body tube, 47" lower body tube
Airframe Diameter (inches):	6.25	6.25" Outer diameter, 6" Inner Diameter
Fin-span (inches):	16.25	Three fins, 5" height, 15" root chord, 4" tip chord
Vehicle weight (pounds):	38.1	
Propellent weight (pounds):	10.3	Still tentative pending motor composition decisions
Payload weight (pounds):	13	Includes (3) 3lb CubeSats and (1) 4lb Lander Technology Demonstrator
Liftoff weight (pounds):	61.4	Weight reductions in the coming weeks aim to keep this number below 60lb
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Student-built	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

1st Stage: SRAD Solid, Propellant Composition TBD, M Class, 9600 Ns

Motor is currently under development in collaboration with our local Tripoli chapter. A candidate motor will by tested March 24th (weather permitting).

Total Impulse of all Motors: 9600 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.
Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	The following were obtained from OpenRocket:
Liftoff Thrust-Weight Ratio:	6.576	
Launch Rail Departure Velocity (feet/second):	101	
Minimum Static Margin During Boost:	1.573	*Between rail departure and burnout
Maximum Acceleration (G):	9.91	
Maximum Velocity (feet/second):	1007	
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	10547	*Without Active Drag System functionality

Payload Information

Payload Description:

Payloads are currently being developed by local high schools. Our team has created a distributable CubeSat "kit" consisting of the main structural shell to our specifications, and high school teams are responsible for supplying hardware and software for their experiment to place inside. The collaboration takes the form of a competition, with multiple high school teams submitting ideas and competing for a spot on the rocket. The winning ideas will be developed into functional experimental payloads. Teams are currently in the development phase, formulating ideas and preparing to present their designs to the Buckeye Space Launch Initiative for evaluation.

Additionally, a few groups of undergrad students from the College of Engineering and SEDS at Ohio State are developing payloads.

The rocket will also feature a lander, currently being developed by a Mechanical Engineering capstone team at the Ohio State University. This lander will deploy from the nosecone after the main chute deployment, and remain attached to the parachute line. After landing, it will detach from the line and attempt to right itself. At no time will the lander separate entirely from the launch vehicle, relying on the main chute of the rocket to bring it down safely.

Recovery Information

Recovery devices will be triggered through a fully redundant COTS flight computer system, consisting of a Stratologger and a MARSA on separate power circuits, each connected to both the primary and backup ejection charges. This main ejection charge, detonated at apogee, activates the single point of separation and detaches the nosecone, deploying the drogue chute. Then, at an altitude of 1500' AGL, a second event will deploy the main chute, through the use of a cable-cutter.

Shroud line tangling problems from previous launches have been addressed by ensuring the main chute deployment bag is released into the airstream at drogue deployment rather than remaining within the body of the rocket until the section event. This will give the main chute a better chance of deploying quickly and without tangling, at the expense of a more orderly deployment.

The main chute has an elliptical cross section and a diameter of 102 inches. It has 18 gore sections and the same number of shroud lines, with a spill hole at the top.

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
4/19/18	Ground	Ejection Testing	Successful	
4/20/18	Ground	Full Integration Test	Successful	
4/21/18	In-Flight	Full-scale Flight Test	Successful	Performed with COTS Motor Hardware
	Ground	Motor Hardware Pressure Test	Successful	
	Ground	Motor Static Fire Test	Successful	
3/9/18	Ground	Telemetry Range Test	Successful	

Any other pertinent information:

This is one of two teams from the Buckeye Space Launch Initiative, at The Ohio State University. As an organization we have approximately 140 active members. We are an open organization with no requirements to join and no membership quota, simply because we do not want to exclude anyone from participating in our organization. This means that the team must run a larger scope of programs so that all team members have a chance to actively participate.

This has led to the development of two teams with different groups of students and only necessary leadership involvement, as managing the sizable teams is very difficult without the help of all experienced members. Additionally, both teams have special projects with different focuses.

The 30k team will be implementing a telemetry system which has been developed and built by students and is exceptionally more powerful and sophisticated than anything commercially available at its size and ruggedness. The range testing ability of this rocket is ideal for this system and the speeds that this rocket will travel will provide large amounts of sensor data for live transmission.

For the 10k category, submitted as a separate entry, the team has a different technological focus. In addition to teaching fundamentals to newer team members, the rocket incorporates an innovative active drag system and supports the university's capstone teams and other student organization payloads. For these reasons we are entering two teams in this year’s competition, and we do hope that we are able to continue to develop and grow both these teams of the Buckeye Space Launch Initiative. Please contact us for any clarification or questions regarding this or any other part of this entry form.

This year's rocket will feature an Active Drag System, in its second iteration for the Buckeye Space Launch Initiative. After last year's code problems, the system is being improved and re-evaluated to solve the problems which caused it to malfunction. It is hoped that the test launch in March will serve as a fully-functional test of the system. This system will attempt to lower the predicted apogee of 11,500' down to 10,000' in a real-time, adaptable manner, using variable flap deployment.

Also onboard will be an SRAD telemetry system, in addition to a COTS backup system as required by the competition rules. The SRAD system consists of and Arduino equipped with a LoRa module, GPS, and an altimeter. The ground station will provide readouts of these measurements, as well as power levels of the flight computers and recovery charge status. The COTS backup system is an Eggtimer.

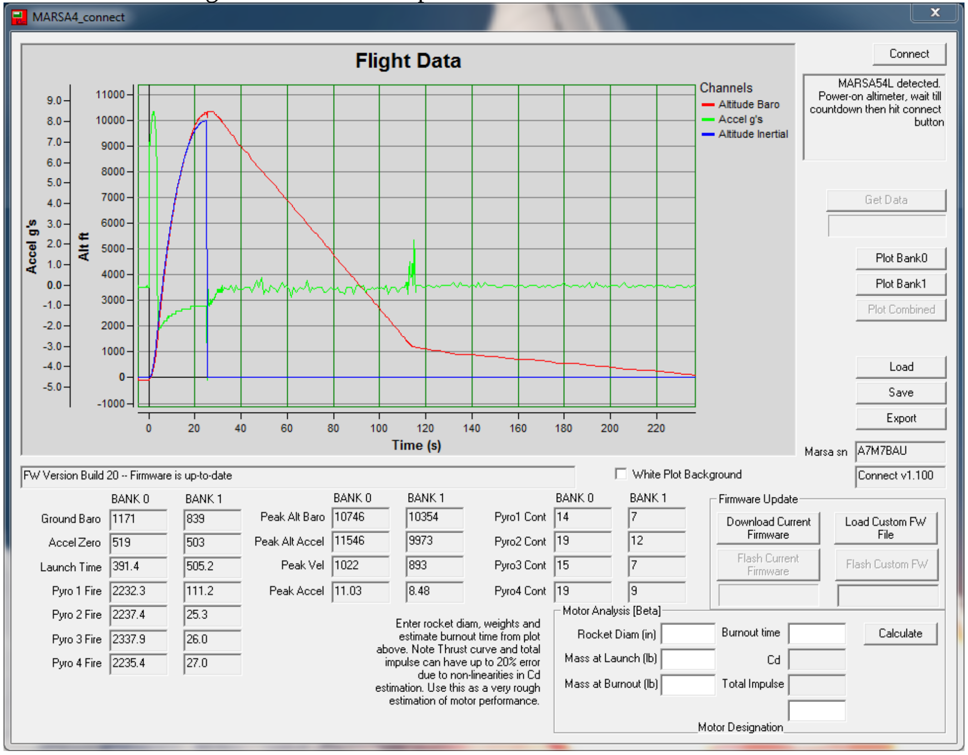
Project Test Reports Appendix

A. Recovery Test Report

The ejection charges were tested freeform on the ground, to determine the reliability of the ignitors. To begin, a homemade ignitor kit was used to prep batches to test, and, due to a manufacturing error, the reliability of these ended up being lower than 50% which was not remotely acceptable for flight. After purchasing and proving reliability of ignitors, the ejection testing began in late April, to calibrate the amount of powder required to expel the nosecone from the airframe. 5 grams of 4F black powder was determined to push the nosecone the desired distance of 10 feet away while the rocket was laying horizontal on the ground. Additional to that, the *IO* project had a test flight to prove the recovery system, which yielded a descent rate of approximately 18 ft/s, which was more than enough to safely recover the airframe without damage.

B. Propulsion Test Report

The propulsion system was tested during a test launch on April 21st. The results of the test launch can be found in the data below.



MARSA54L detected. Power-on altimeter, wait till countdown then hit connect button

Marsa sn A7M7BAU

Connect v1.100

FW Version Build 20 -- Firmware is up-to-date

	BANK 0	BANK 1		BANK 0	BANK 1		BANK 0	BANK 1
Ground Baro	1171	839	Peak Alt Baro	10746	10354	Pyro1 Cont	14	7
Accel Zero	519	503	Peak Alt Accel	11546	9973	Pyro2 Cont	19	12
Launch Time	391.4	505.2	Peak Vel	1022	893	Pyro3 Cont	15	7
Pyro 1 Fire	2232.3	111.2	Peak Accel	11.03	8.48	Pyro4 Cont	19	9
Pyro 2 Fire	2237.4	25.3						
Pyro 3 Fire	2337.9	26.0						
Pyro 4 Fire	2235.4	27.0						

Enter rocket diam, weights and estimate burnout time from plot above. Note Thrust curve and total impulse can have up to 20% error due to non-linearities in Cd estimation. Use this as a very rough estimation of motor performance.

Rocket Diam (in)

Mass at Launch (lb)

Mass at Burnout (lb)

Burnout time

Cd

Total Impulse

Motor Designation

The test launch was a proper means of simultaneously testing the rocket motor that was designed for the 10k rocket this year in addition to the flight structures and avionics. After the test launch, the data drawn from the flight computers on board allowed the team to analyze the motor profile. The motor tested in flight in conjunction with the burn sim simulation data allowed the team to accurately predict the apogee of the rocket to within 300 feet.

Hazard Analysis Appendix

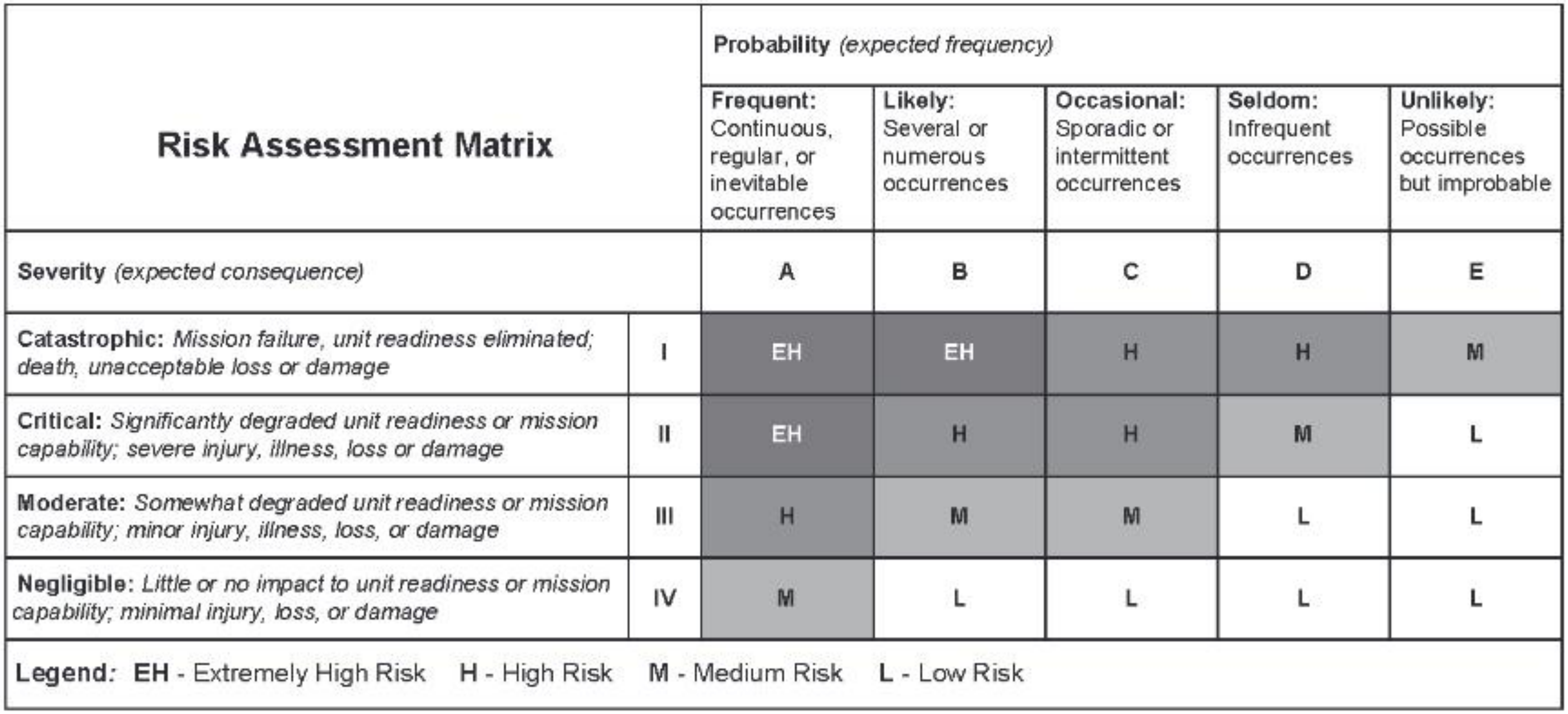
Hazard	Cause	Mitigation Approach
Hazardous Material Handling	**Fiberglass** – has potential to irritate eyes, skin, throat, and nasal passages	Personal Protective Equipment such as safety glasses, masks covering the nose and mouth, gloves, and protective sleeves must be worn at all times when handling these materials. A shop vacuum was used after every workday to remove dust and particulates from the work area. Finally, the ventilation system connected to the work area is kept running during work hours to keep the area well ventilated.
	Carbon Fiber - has potential to irritate eyes, skin, throat, and nasal passages.	
	Milled Fibers - has potential to irritate eyes, skin, throat, and nasal passages.	
	Epoxy – has the potential to be an irritant to the skin and when combined with hardener can burn.	In addition to the mitigation approach used above for the potential of these materials to be an irritant, members who use these materials must use them in a timely fashion (before the mixed solution heats up). Additionally, any leftover epoxy/hardener is left to cool down before disposal.
	Hardener – has the potential to be an irritant to the skin and when combined with epoxy can burn.	
	Acetone - has potential to irritate eyes, skin, throat, and nasal passages. Flammable	In addition to the mitigation approach used above for the potential of these materials to be an irritant, these materials are also placed in the fireproof cabinet.
	Bondo - has potential to irritate eyes, skin, throat, and nasal passages. Flammable	
	Filler Primer - has potential to irritate eyes, skin, throat, and nasal passages. Flammable	
Storage and Transportation of Propellants	**Storage** - has potential to accidentally ignite causing property damage and/or personal injury.	Storage of Propellants will be handled by Tripoli Mid-Ohio Rocketry Association until the week of the competition where we will transport them to Spaceport America.
	Transportation - has potential to accidentally ignite causing property damage and/or personal injury.	The motor grains won't be placed in the motor casing for transport so in the case of accidental ignition the energy is not directed and thus is spread over an area.

Operation of Machinery and Equipment	**Drill Press/Hand Drill** - clothing caught in revolving parts, unsecured work could spin and injure hands, scraps could be thrown into eyes.	Always use appropriate PPE (safety glasses), ensure vise is secure to prevent work from spinning, ensure the drill bit is locked securely in the chuck, wear tight fitting clothing, and remove all scraps in the work area after use.
	Angle Grinder - lacerations from attachments that break, lacerations from angle grinder kickbacks, clothing caught in revolving parts, unsecured work could spin and injure hands, scraps could be thrown into eyes, inhalation of particulates generated can be hazardous.	Always use appropriate PPE (safety glasses, dust masks), ensure vise is secure to prevent work from spinning, wear tight fitting clothing and a non-permeable full body suit, remove all scraps in the work area after use.
	Scroll Saw - lacerations from attachments that break, clothing caught in moving parts, unsecured work could catch and injure hands, scraps could be thrown into eyes, inhalation of particulates generated can be hazardous.	Always use appropriate PPE (safety glasses, dust masks), ensure material is not in contact with blade when starting the machine, always keep hands/fingers away from the path of the blade, use correct blade and tension for material being cut, wear tight fitting clothing, remove all scraps in the work area after use.
	Heat Gun - ignition of fumes or dust, burn by touching unintended areas of the heat gun, overheating of the heat gun during use, do not apply airflow directly on glass as it may crack or shatter, fumes of materials being heated may be hazardous.	Always use appropriate PPE (safety glasses, masks), ensure workplace is clean and well-ventilated, maintain air flow for cooling of nozzle by keeping nozzle away from work piece, only hold the heat gun by the plastic enclosure/handle, if using a glass surface do not linger or pause to heat up a single place for an extended time.

Risk Assessment Appendix

Determination of risk in response to each hazard is given by Table 1 which is the Army standard risk assessment matrix. The team used this standard for clarification and consistency within the team.

Table 1. The Army standard risk assessment matrix[10].



Risk Assessment Matrix		**Probability** *(expected frequency)*				
		Frequent: Continuous, regular, or inevitable occurrences	**Likely:** Several or numerous occurrences	**Occasional:** Sporadic or intermittent occurrences	**Seldom:** Infrequent occurrences	**Unlikely:** Possible occurrences but improbable
Severity *(expected consequence)*		**A**	**B**	**C**	**D**	**E**
Catastrophic: *Mission failure, unit readiness eliminated; death, unacceptable loss or damage*	**I**	**EH**	**EH**	**H**	**H**	**M**
Critical: *Significantly degraded unit readiness or mission capability; severe injury, illness, loss or damage*	**II**	**EH**	**H**	**H**	**M**	**L**
Moderate: *Somewhat degraded unit readiness or mission capability; minor injury, illness, loss, or damage*	**III**	**H**	**M**	**M**	**L**	**L**
Negligible: *Little or no impact to unit readiness or mission capability; minimal injury, loss, or damage*	**IV**	**M**	**L**	**L**	**L**	**L**

Legend: **EH** - Extremely High Risk **H** - High Risk **M** - Medium Risk **L** - Low Risk

Hazard	Possible Causes	Risk of Mishap and Rationale	Mitigation Approach	Risk of Injury after Mitigation
Explosion of solid-propellant rocket motor during launch with blast or debris causing injury.	Cracks in propellant grain	Medium, student researched and designed motor with limited simulation and experimental testing	Visually inspect motor grain for cracks, debonds, and gaps during and after assembly	Low
	Debonding of propellant from wall		Use ductile material for the motor case (Aluminum)	
	Gaps in the propellant sections and/or the nozzle		Inspect motor case for damage during final assembly before launch	
	Chunk of propellant sections breaking off and plugging nozzle		Test the designed motor composition before traveling to the competition	
	Motor case unable to contain normal operating pressure		Inspect motor case for damage after completing motor test	
	Motor end closures fail to hold		Only essential personnel in launch crew	
	Propellant burns through motor casing		Launch crew far away from launch and behind a barrier	
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Launch rail failure	Medium, student researched and designed motor and structures - no test flight only motor testing completed	Enure that the launch rail is correctly assembled and inspected before launch	Low
	Airframe fails leading to unstable flight		Used CFD, simulation, and experimentation (drop tests, motor test) to best understand stresses/forces on the airframe	
	Coupler buckles under launch forces		Reinforced coupler compared to other components as it is the only break point in the rocket	
	Motor failure causes uncontrolled launch		See - mitigation approaches used for "explosion of solid-propellant rocket motor during launch" above.	
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Vibrational failure of electrical leads	Medium, avionics and recovery systems are student developed with redundant systems. Extensive testing has been	Avionics system was operated successfully after completing a drop test simulating launch loads	Low
	Batteries not charged enough to supply current for ejection charge ignition		Batteries hold a charge that could last dozens of flights as long as they are charged correctly	
	Ejection charge not strong enough to dislodge recovery system		Ejection charge testing was completed to ensure separation at even very low pressures	

	Ejection charge fails to ignite	completed for ejection charges.	Ejection charge ignition has redundant systems so both would have to fail for no ignition	
	Accelerometer and Pressure gauges fail -leading to no recovery systems deploying		If only one sensor fails, the other should correctly deploy the recovery system. Both are rated for loads expected during launch	
	Tender descender fails leading to premature separation of rocket, recovery system, and/or payload		Tender descender has been tested to ensure it will hold under even the worst case loads	
Recovery system partially deploys, rocket or payload comes in contact with personnel	Vibrational failure of electrical leads	Low, avionics and recovery systems are student developed with redundant systems. Testing has been completed that shows a low probability of only partial deployment with current system design	Avionics system was operated successfully after completing a drop test simulating launch loads	Low
	Recovery system becomes tangled		The packing and ejection process has been tested thoroughly to ensure correct procedures	
	Accelerometer and Pressure gauges fail -leading to partial deployment		If only one sensor fails, the other should theoretically correctly deploy the recovery system. Both are rated for launch loads	
	Tender descender fails leading to main parachute not deploying		Tender descender has been tested to ensure to hold under even the worst case loads	
	Incorrect wiring during assembly		The assembly process has been completed multiple times under a strict procedure to ensure less chance of error	
Recovery system deploys during assembly or prelaunch, causing injury	Failure to properly disarm flight computers during assembly	Low, the process to properly disarm flight computers during assembly is simple and our procedures ensure to discharge any static charges before dealing with any systems.	The process to properly disarm the flight computers is simple and well known to members of the launch team	Low
	Static discharge ignites ejection charges		The launch team knows to discharge static before dealing with the rocket.	
Recovery system deploys at or near apogee,	Accidental main parachute deployment at apogee from static discharge	Low, avionics and recovery systems are student developed with	The launch team knows to discharge static before dealing with the rocket.	Low

rocket or payload drifts to highways(s)	Incorrect wiring during assembly	redundant systems. Likelihood of recovery deployment at apogee and rocket drifting to highway are low.	The assembly process has been completed multiple times under a strict procedure to ensure less chance of error	
	Tender descender failure leading to main deployment too soon		Tender descender has been tested to ensure to hold under even the worst case loads	
Rocket does not ignite when command is given but does when team approaches to troubleshoot	Motor ignites after considerable delay	Low, the team will not approach the rocket until giving it sufficient time to ignite after a hang fire. Additionally, procedures are in place to discharge static when handling the rocket.	The team will not approach the rocket until giving it ample time to have motor ignition after a hang fire.	Low
	Static discharge ignites motor		The launch team knows to discharge static before dealing with the rocket.	
Rocket falls from launch rail during prelaunch preparations, causing injury	Launch rail failure	Low, the launch rails on site are unlikely to fail. Launch rail guides are designed with a safety margin. We will not likely handle the rocket in harsh weather and care will be taken when handling it.	Ensure that the launch rail is correctly assembled and inspected before launch	Low
	Launch rod guides failure		Launch rod guides are designed to bear a much greater weight than just the rocket standing on the pad	
	Mishandling of rocket causing it to fall		All launch crew members have experience handling the rocket and will always use caution	
	Weather causes rocket to fall from launch rail		The team will not handle the rocket in harsh weather or windy conditions that could cause an accident	

Assembly, Preflight, and Launch Checklists Appendix

Equipment list

Structure:
Lower body tube
Lower bulkhead
(6x) long 1/4” -20 bolts
(10x) 1/4” lock washers
(6x) 1/4” -20 Nuts
Aft retaining ring
Rocket Motor Assembly
Upper body tube
(4x) short 1/4” -20 bolts
Nosecone
(4x) #4 Nylon sheer Pins

Payload:
Payload:
Experiment Bay Top Bulkhead
(2x) Experiment Bay Spacer Bulkheads
Experiment Bay Lower Bulkhead
(4x) 1/4” -20 nuts
(20x) 1/4” -20 wingnuts
(4x) 1/4” -20 threaded rod
(2x) Experimental CubeSat

Avionics:

Avionics Bay, Polycarbonate Sleds, Marsa 54L, Stratologger CF, 7.4 Lipo Batteries, BMP280 Altimeter, Dragino Lora and GPS Module with Arduino Uno, Key Switch, Main PCB, Mobius Cameras, 3D Printed Camera Mounts, Lens Extenders, 915 MHz Antenna

Recovery: Main Parachute bag, Drogue Parachute, Pilot Parachute, Clothes Iron, Shock Cord, Nomex Sheets, Kevlar Line Guard, 4F Black Powder, Latex Gloves, Duct Tape, Weighing Boat

ADS:

Flap/Chassis Subassembly
Motor/Battery Mount Subassembly
Motor Battery
Electronics Battery
Upper Electronics Mount
Top Cap
Raspberry Pi
SenseHat IMU
Pin Header Connector
(4x) M3-0.5 x 12mm Flathead Screws
(4x) M3-0.5 x 20mm Flathead screws
(12x) 1/8 “X 0.5” Wood Screws

Launch Checklist

(Italicized categories can be done concurrently)

Pre-integration Assembly

1. *Avionics*
    1.1. Insert electronics sleds into E-Bay CubeSat, making sure placement and orientation of each sled is correct. (See Appendix A – Avionics Sled Layout Diagram)
    1.2. Fasten sleds in place with locking mechanism
    1.3. Check all wires for loose connections and fix as necessary
    1.4. Confirm wiring and battery levels of avionics using a multimeter
    1.5. Connect batteries to avionics on-board power supply
    1.6. Test functionality of flight computers
        1.6.1. Ensure that both flight computers are programmed correctly
        1.6.2. Insert jumper cables in place of ejection charges
        1.6.3. Short circuit ejection charge terminals to test continuity
    1.7. Use key to turn switch to the OFF position, deactivating the avionics computers for integration

2. *Active Drag System*
    2.1. Screw the battery bracket onto the top wooden bulkhead using four 4-40 screws.
    2.2. Mount battery in its bracket and secure it with cable ties.
    2.3. Connect motor battery to the red and black controller chip wires.
    2.4. Activate ADS by turning key switch from vertical (OFF) to horizontal (ON) position.
    2.5. Flaps will deploy and then retract for testing purposes if the test button on the top bulkhead is pressed
        2.5.1. If flaps fully deploy and retract, proceed to step 2.6.
        2.5.2. If flaps do not fully deploy and retract, proceed to step 2.4 after 2.6.
    2.6. Deactivate ADS by turning key switch from horizontal (ON) to vertical (OFF) position.

3. *Recovery*
    3.1. Assemble Ejection Charges
    3.2. Assemble Cable Cutters

CAUTION: Take care while performing this assembly. When the ignition switch is in the horizontal position, the ADS is in the on and armed states. This could lead to a premature deployment of flaps and result in the requirement to revert to step 2.2 in the checklist.

Integration

4. *Active Drag System*
    4.1. Insert ADS into lower body tube, ensuring proper orientation.
    4.2. Align keyholes and seat ADS against wagon wheel.
    4.3. Ensure flaps have space to clear slots.

5. *Payload/Avionics*
    5.1. If functional payloads are being flown, ensure each is activated and armed.
    5.2. Remove CubeSat bay cap by unscrewing the eight nuts holding it in place.
    5.3. Insert each Payload CubeSat payload one at a time, ensuring proper orientation. Slide payloads all the way to the top of the bay and firmly seat them against the top of the bay.
    5.4. Insert E-bay CubeSat into bay, ensuring proper orientation
    5.5. Connect wires to Avionics:
        5.5.1. Connect the 12-pin recovery plug to its port in the bottom of the E-bay CubeSat
        5.5.2. Connect telemetry antenna
        5.5.3. Connect GPS antenna
        5.5.4. Connect 4-pin key switch connector to its port in the bottom of the E-bay CubeSat
    5.6. Replace CubeSat bay cap, ensuring no wires are pinched or bent.
    5.7. Fasten cap in place by screwing in the eight nuts removed earlier.

6. *Recovery*
    6.1. Attach lowest D-link to U-bolt on recovery bulkhead
    6.2. Attach highest D-link to U-bolt on nosecone
    6.3. Fasten the four main line wires to their color-coded terminals in the recovery bulkhead barrier block
    6.4. Install both the primary and secondary ejection charges in their ports on the recovery bulkhead
    6.5. Remove cable tie from main bag (while holding in place to prevent disassembly) and replace with cable tie and two safed cable cutters.
    6.6. Short the two color-coded sets of main line wires together before connecting each pair to the leads of one of the cable cutters using butt-splice connectors.
    6.7. Short the four color-coded sets of ejection charge wires together before connecting each pair to the leads of one of the ejection charge E-matches using butt-splice connectors. (See Appendix A – Recovery Wiring Diagram)
    6.8. Push loose wires down into body tube
    6.9. Cover Ejection charges with cellulose insulation
    6.10. Insert main bag into body tube and push as far down as possible
    6.11. Fold line and drogue into nosecone
    6.12. Install nosecone and hold in place with shear pins

7. *Final Assembly*
    7.1. Align both assembled body tubes and push them together
    7.2. Secure tubes with four ¼-20 bolts on coupler.
    7.3. Inspect all other external bolts on body of rocket and tighten as needed.
    7.4. Insert the assembled motor into the motor tube.
    7.5. Secure in place with retaining ring.

Pre-Flight Checklist

1. Final Rocket Checks
    1.1. Check nosecone fit by wiggling
        1.1.1. If there is play in fit, use masking tape around shoulder to tighten.
    1.2. Check rail button strength by lifting the rocket up by both rail guides
        1.2.1. If rail guides come loose or separate from the rocket, reinforce with JB Weld and reattach with longer curing epoxy
    1.3. If all the above conditions are satisfied, then move rocket to the launch pad

2. Flight Conditions
    2.1. Determine if cloud cover is acceptable
    2.2. Scan for low flying aircraft, or aircraft flying near the launch zone
    2.3. Check that wind speeds are at tolerable speeds

3. Launch Rail
    3.1. Check that launch rail is at least 10’ in length
    3.2. Check that launch rail is not bent or warped
    3.3. Check that launch rail is a 1.5”x1.5” rail
    3.4. Place rocket on launch rail
    3.5. Ensure rail angles 6° towards the wind

4. Arming
    4.1. Arm recovery system using key switch mounted outside the rocket
        4.1.1. Ensure that the MARSA reports nominal conditions
        4.1.2. Ensure that the StratoLogger reports nominal conditions
    4.2. Arm ADS by turning the key switch to the horizontal position
        4.2.1. Ensure that the ADS reports nominal conditions
    4.3. Arm cameras by using arm tool to activate the power button on both the port and starboard cameras
    4.4. Place igniter into motor so that the igniter contacts the pyrotechnic charge

  - 4.5. Tape the E-match to ensure it stays in place.

Launch Checklist

1. Evacuate all non-essential personnel
2. While in the spectator's section, have non-essential personnel point the tracking antenna towards the pad
   - 2.1. Arrange the spectators so that they are each within arm's reach of each other
   - 2.2. Always point the transceiver towards the rocket
     - 2.2.1. Follow the rocket with binoculars
     - 2.2.2. If line-of-sight is lost, pass the transceiver to another who can see it
3. Inform Launch Control Officer of flight readiness, and follow instructions
4. Ensure that spectators and fellow rocketeers are aware that a launch is taking place
5. Maintain line of sight with the rocket where possible for the entirety of the flight

Post-Launch Checklist

1. Ensure the tracker is always pointing at the rocket
2. If recovery occurred normally
   - 2.1. Drive to recovery site
   - 2.2. Find rocket using either on board RF signal or from visual contact
   - 2.3. Ensure that all ejection charges have detonated
   - 2.4. Carry the rocket to the recovery vehicle and return to base camp for inspection
3. If recovery occurred abnormally
   - 3.1. In case of ballistic recovery
     - 3.1.1. Assume rocket impacted nose first in a fully intact configuration, and that the RF transmitters will no longer function
     - 3.1.2. Acquire digging tools
     - 3.1.3. Drive to recovery site
     - 3.1.4. Attempt to locate rocket from visual contact
     - 3.1.5. If rocket is found, dig until as much of the rocket is recovered as possible
   - 3.2. In case of failure to deploy drogue or main
     - 3.2.1. Assume that RF transmitters are still operational, and that the rocket is above ground
     - 3.2.2. Follow steps for nominal recovery, but be ready to search for rocket fragments

Off-Nominal Launch Procedure

In all situations where the rocket has failed to ignite after all launch operations have been conducted, the Dis-arming and Safing procedures can be found in Appendix A

Possible Modes of Failure:

Hang Fire

1. Wait until the last rocket of the salvo is launched
2. Observe the rocket motor from a distance for at least 5 minutes from the hang fire before beginning dis-arming and safing procedure
3. Remove rocket from the pad and return to base camp for failure analysis
   - 3.1. Determine if the failure to fire stemmed from a weak igniter, or from a wiring issue in the igniter
4. If the match was not fired, then restart the checklist at **Preflight Checklist** step 4.4.
5. If the match fired but the pyrotechnic charge failed to light, then restart the checklist at **Preflight Checklist** step 4.4.
     - 5.1.1. If the pyrotechnic charge failed to light for a second time, then use a more powerful igniter
     - 5.1.2. If the third launch attempt failed, then cancel launch operations

Premature Ejection Charge Detonation

1. Wait until the last rocket of the salvo is launched
2. Follow the Dis-arming and Safing procedure with the nosecone assembly so that the remaining charge will be safed
3. Remove rocket from pad and return to base camp for analysis of failure conditions

Failure to an Ignition Charge

1. Wait until the last rocket of the salvo is launched
2. Recover rocket normally until step 2.3
3. Equip a face mask, gloves, a screwdriver, and a pair of wire cutters before approaching
4. Remove nosecone if not already separated
5. Pull shock cord line out and cut one wire on each ejection charge igniter
    5.1. **CAUTION:** Do not cut both wires at the same time

Disarming and Safing Procedure

1. Ensure that only essential personnel needed to disarm the rocket are present
2. De-activate Avionics with key switch
3. De-activate ADS with key switch
4. Remove ignition charge from the motor

Engineering Drawings Appendix

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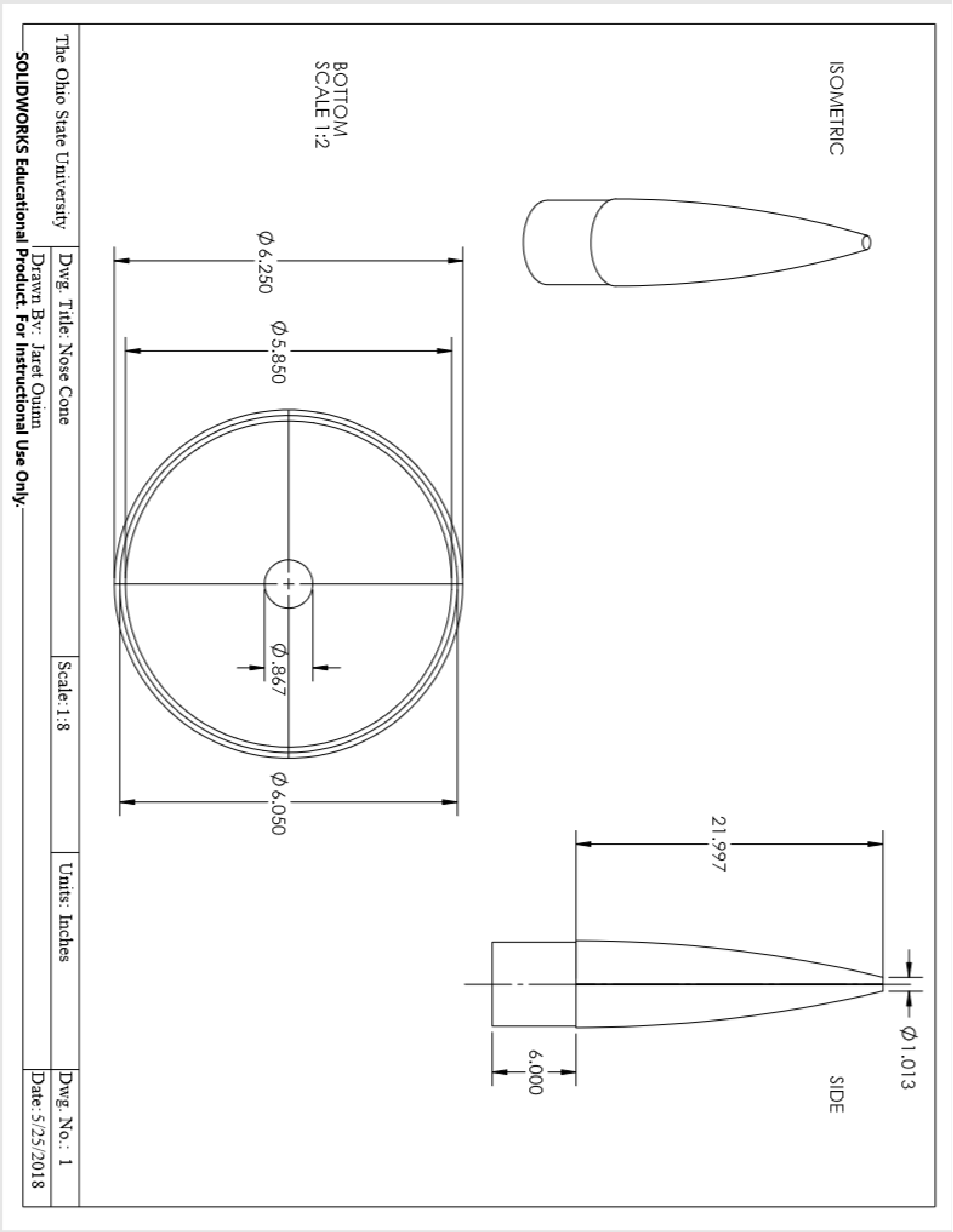
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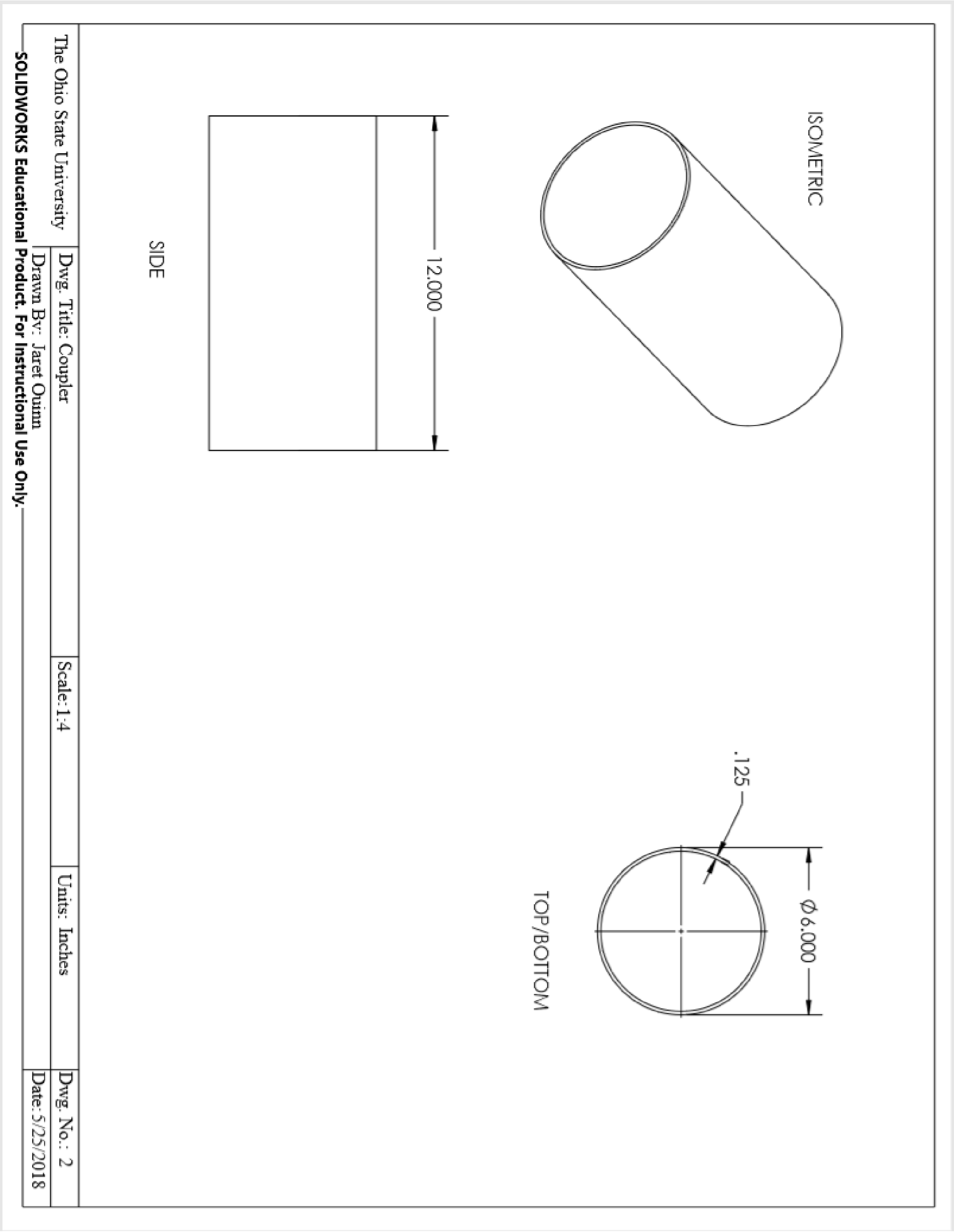
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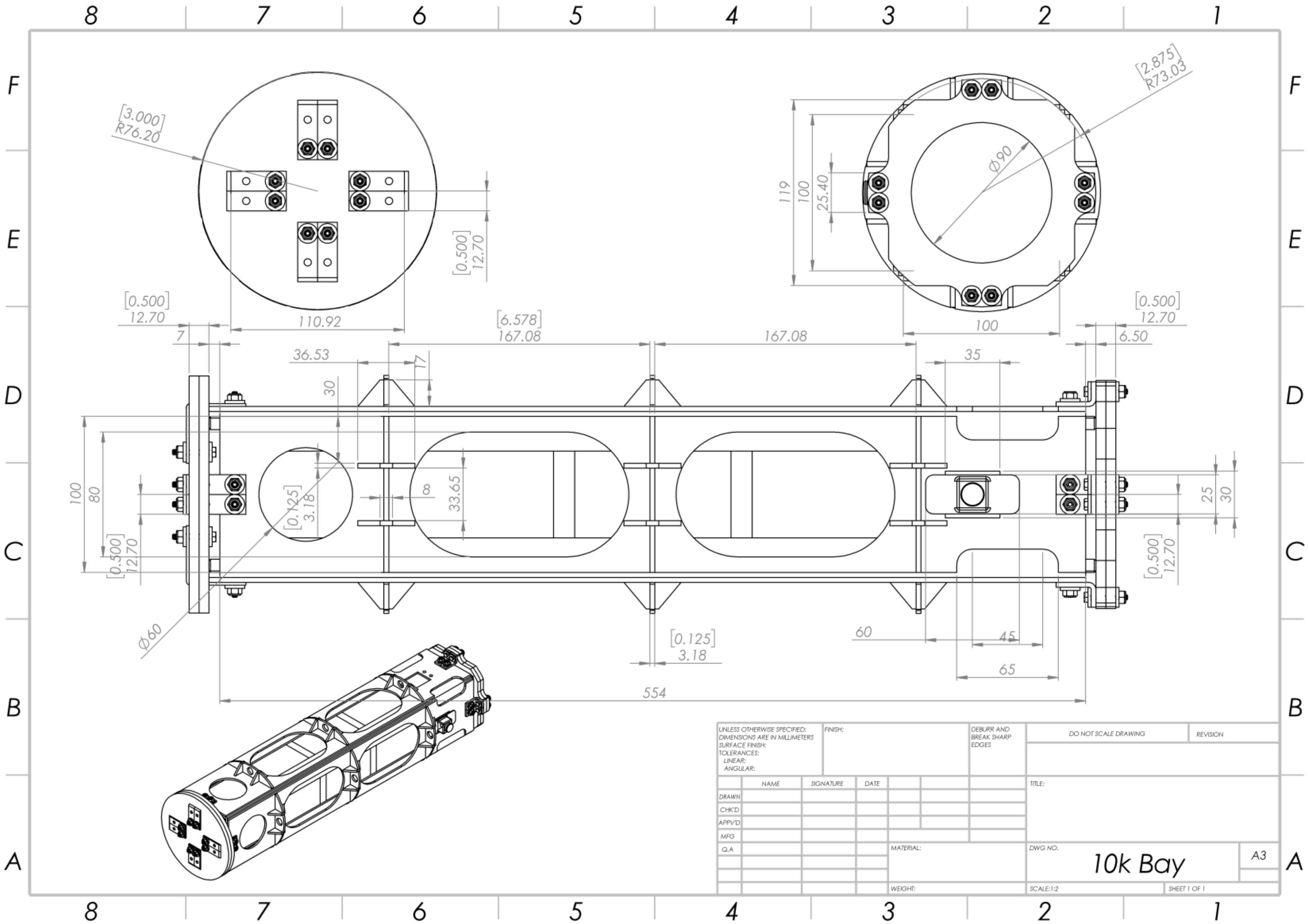
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