Blackout

Team 74 Project Technical Report for the 2021 IREC

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Abstract

This project details the design, manufacture and testing of the RIT Launch Initiative's level 3 high-powered rocket, to compete in the 10,000 AGL apogee COTS category at the 2021 IREC. This rocket, *Blackout*, is a 10.5 ft. completely custom carbon fiber rocket equipped with an M-2020 75mm Cesaroni solid motor. The rocket is designed to deploy a 3U CubeSat scientific payload at apogee, which will descend with its own independent recovery system. Modeling and analysis were conducted on the entirety of the rocket. Research was performed on the manufacturing, propulsion, aerodynamics, avionics, and recovery aspects of *Blackout*. Current models project *Blackout* will reach an apogee of 10,104 ft. AGL.

Nomenclature

F_d = *Drag Force*
W = *Weight of Rocket*
m = *Mass of Rocket*
a = *Acceleration*
C_d = *Drag Coefficient*
ρ = *Free Stream Density of Air*
A = *Projected Parachute Area*
g = *Gravity*
F = *Force*
SA = *Surface Area*
σ = *Normal Stress*
Xs = *Normal Stress Factor of Safety*
σ_{yield} = *Normal Yield Stress*
σ_{ring} = *Normal Stress on Ring*
$\sigma_{ultimate}$ = *Ultimate Strength*
τ = *Shear Stress*
τ_{edge} = *Shear Stress on Inner Edge*
$\tau_{bodytube}$ = *Shear Stress of Body Tube*
τ_{epoxy} = *Shear Stress of Epoxy*
Ys = *Shear Stress Factor of Safety*
Es = *Epoxy Factor of Safety*
Bs = *Body Tube Factor of Safety*
$S_{strength}$ = *Shear Strength*

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I. Introduction

The RIT Launch Initiative is a multidisciplinary student organization that applies the principles of rocket design and manufacturing for learning and competition. The team aims to prepare students for excellence in aerospace, to conduct novel research and development, and put RIT at the forefront of the emerging space push. This year the team has expanded, introduced numerous new projects, and made great strides towards becoming a leading competition team in the college of engineering here at RIT. The team has successfully flown three L3 rockets, ten L2 rockets, and has certified over 70 members to fly L1 rockets under the National Association of Rocketry (NAR). Additionally, several team members hold individual L2 and L3 high-powered rocketry NAR or Tripoli certifications.

RIT Launch is split into 5 primary project teams, each consisting of 6 to 20 members, the IREC competition rocket being one of these. The IREC team is then split into 5 critical departments; booster, recovery, avionics, payload, and sustainer. Each of these departments consist of a single department head and multiple student engineers. Each of these department heads reports to the project lead and deputy project lead, who, along with the system integrator and safety officer, oversee full development of the project. The project as a whole also reports to the executive board, which consists of technical experts that review designs; the project manager who oversees timelines and development work; the treasurer who coordinates funding, sponsorships, and purchasing; and the chief safety officer, who oversees safety, operations, and training of members.

This will be the team's third year attending the IREC. We will be competing in the "10,000 ft AGL apogee with commercial-off-the-shelf (COTS) solid or hybrid rocket propulsion system" category. The rocket that will be flying has a solid propulsion system, great structural integrity, and will have been test launched to over 10,000 feet at a launch site in Potter, New York. This custom carbon fiber rocket encompasses a design that has stemmed from 6 years of rocket architecture, analysis, and building, as well as the lessons learned along the way.

Figure 1. Blackout's External Geometry and Appearance

II. System Architecture Review

Blackout, standing at 10.5 ft and weighing 64.125 lbs. fully loaded, is RIT Launch's first level 3 high-powered rocket with a completely custom aero-structure and SRAD flight computer. The rocket is broken up into three main sections: nose cone, sustainer, and booster. Within the nose cone the drogue parachute is located. The sustainer contains all the avionics and the payload. The booster contains our main parachute, the Cesaroni M2020 6 grain motor, fin/fin can, boattail. and motor retainer. The nose cone, body tubes, fins, and boattail were custom carbon fiber designed parts and manufactured in house using a multitude of different methods detailed below.

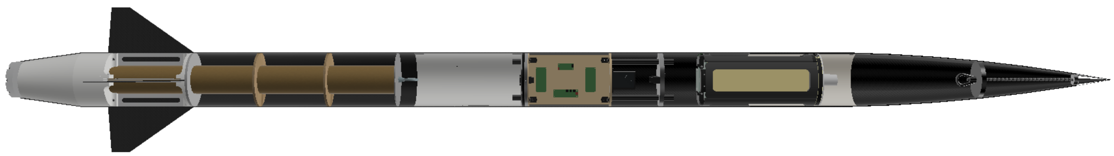


Figure 2. Blackout's Internal Configuration

The avionics sled, positioned in the center of the rocket, consists of a student-developed flight computer S.P.I.C.A, which records altitude, acceleration, temperature, pressure, pitch, roll, yaw, GPS coordinates, and can also be used to ignite e-matches. Additionally, an eggtimer quark, a Stratologger Perfectflite, a BeeLine GPS, and an Akaso EK7000 Action Camera are also located on the sled. Because carbon fiber tubes are not RF transparent, the radio antenna and receiver for the GPS are flush mounted to the external section of the tube providing little to no drag and position lock.

Table 1. Key Technical Specifications

Specification	Value	Target	Units
Airframe Length	125	-	in.
Airframe Diameter	6.2	6.17	in.
Liftoff Mass	64.125	-	lb.
Peak Thrust	2,680	-	N.
Max Velocity	837	<1000	ft/s
Motor	Cesaroni M2020	-	-
Predicted Apogee	10247	10000	ft.
Thrust/Weight Ratio	6.9	>5	
Rail Departure Speed	90.7	100	ft/s
Stability Margin	1.6	>1.4	caliber s
Drogue Descent Rate	90.4	>75	ft/s
Main Descent Rate	21.3	<33	ft/s

A. Propulsion Subsystems

Motor

The propulsion system of this rocket encompasses a commercial off-the-shelf (COTS) solid rocket motor. The motor is an M-Class 75mm six grain Cesaroni M2020. This motor provides sufficient force to reach the required off-the-rod velocity, and the impulse to reach the target altitude of 10,000 ft. Initial simulations using OpenRocket, had us using a stronger motor when we were not clear on the final mass. However, when manufacturing was close to finishing, our total mass for certain subcomponents was lighter, thus allowing us to use a smaller motor.

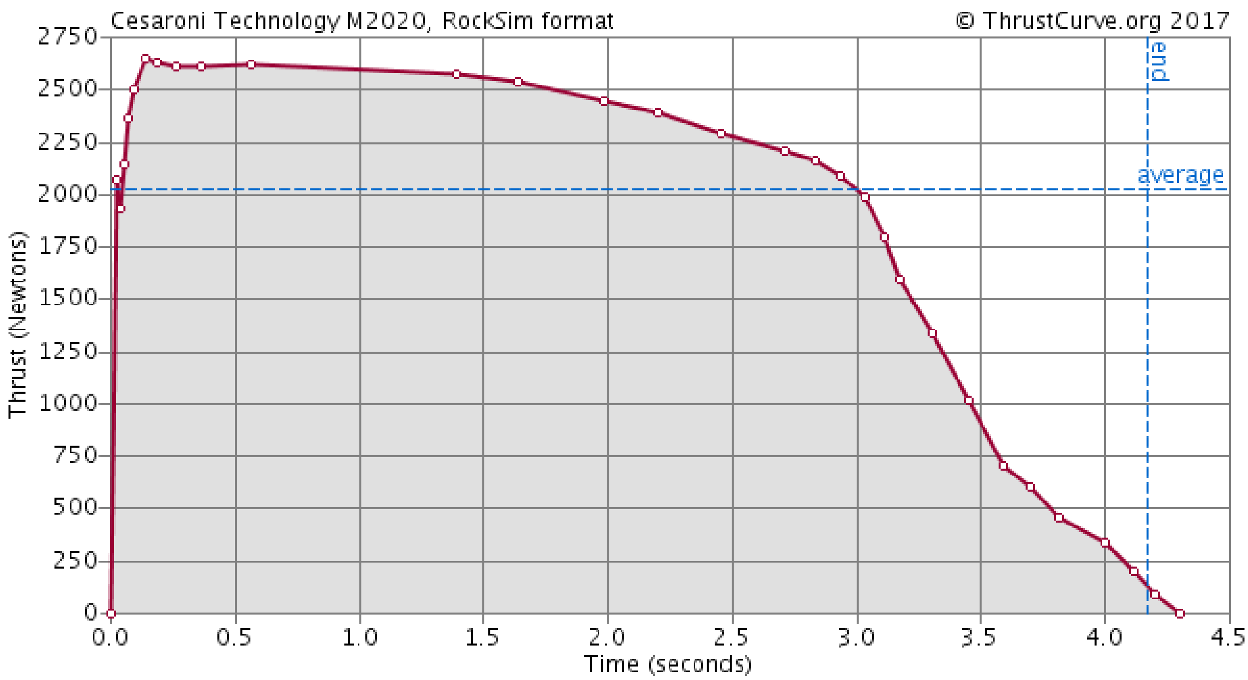


Figure 3. Thrust curve of COTS M2020 Motor

B. Aerostructures Subsystems

Nose cone

A 4:1 6” tangent ogive nose cone was chosen as the team has had prior success with this similar shape in previous rockets. Our nose cone is 35” long, made in-house using carbon fiber, with a machined tip for more control over the tip radius and strength, compared to the conventional solid carbon fiber tip with a larger tip radius.

To produce our own carbon fiber nose cone, we used a split mold method to give us the best exterior surface. In this method, we split the nose cone in half and produce two equal patterned molds. To create larger molds, MDF boards were assembled together in a large stack and using wood glue and clamps, we created a large homogenous piece. We then used a Shopsabre CNC router to rout each half of the mold, before sanding and finishing with primer. Once the mold was primed, up to 5 layers of mold release were applied before applying carbon fiber. To produce sufficiently strong parts, multiple layers were combined to create one thicker homogeneous layer. With both molds laid-up, we carefully brought them together, creating one part. To ensure the carbon fiber was pressed against the mold, a long party balloon was blown up in the interior thus pressing the carbon fiber.

Figure 4. One half of nose cone mold routed from medium density fibreboard

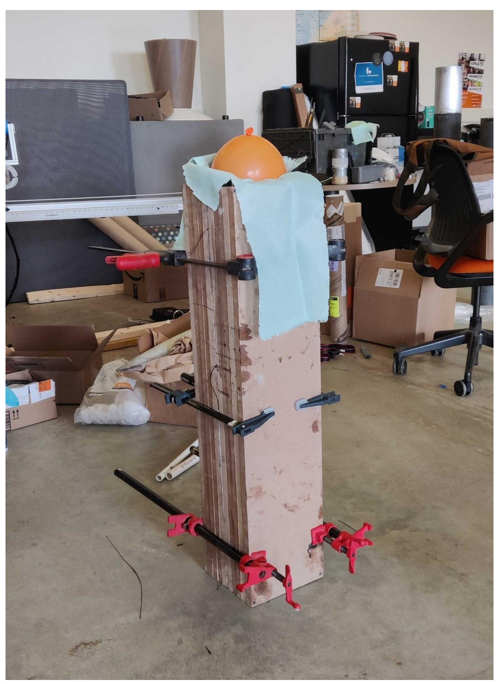


Figure 5. Nose cones mold together in one piece.

Body Tubes

Body tubes for rocketry make up the airframe of the rocket. They house and secure all other subsystems; payload, avionics, motor, and parachutes. In rocketry, these airframes are made from a large list of different materials, composites being a preferred choice for their high strength to weight ratio and low cost to manufacture or purchase outright. For many previous rockets, the team has relied on purchasing body tubes from manufacturers. However, RIT launch was able to secure the use of a filament-winding machine this year. Filament-winding is a fabrication technique mainly used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). This process involves winding filaments under tension over a rotating mandrel. The mandrel rotates around the spindle (Axis 1 or X: Spindle) while a delivery eye on a carriage (Axis 2 or Y: Horizontal) traverses horizontally in line with the axis of the rotating mandrel, laying down fibers in the desired pattern or angle to the rotational axis. The most common filaments are glass or carbon and are impregnated with resin by passing through a bath as they are wound onto the mandrel. Once the mandrel is completely covered to the desired thickness, the resin is cured. Once the resin has cured, the mandrel is removed or extracted, leaving the hollow final product. The team conducted numerous trials to identify the best procedure for producing usable tubes, from prepping the mandrel, to the wrapping and drying process, to removal and finishing. Initially, problems arose from the angle of wrap slipping on the mandrel, bunching at the end of the mandrel, the epoxy infusion levels, and then being able to remove the finished wrap from the mandrel. After much trial and error, we found that doing the three wraps gave the strongest tube and prevented slipping; first a 60 degree wrap, then a 90 degree, and finally another 60. We also learned that applying mold-release and one layer of mylar to the mandrel produced the best results for removing a finished tube, while still allowing for the carbon fiber to wrap without slipping. The final big lesson learned was using liquid nitrogen to cool and contract the aluminum mandrel, allowing for the cured wrap to easily slide off.

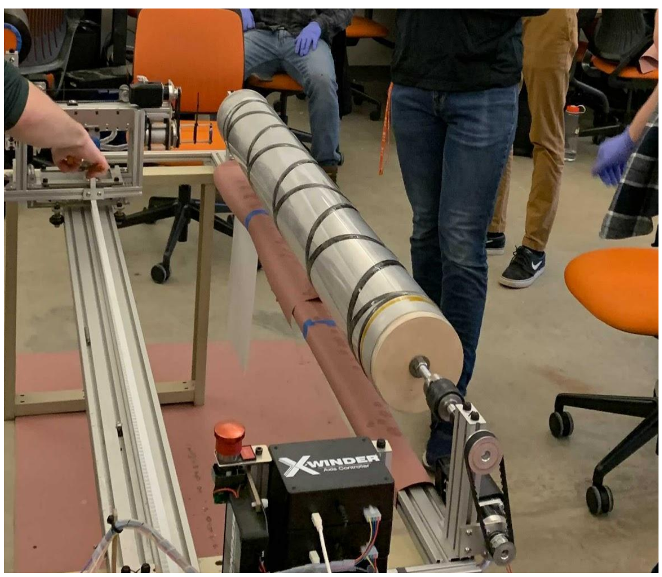


Figure 6. First stages of carbon fiber wrap, following the application of mold release and mylar.

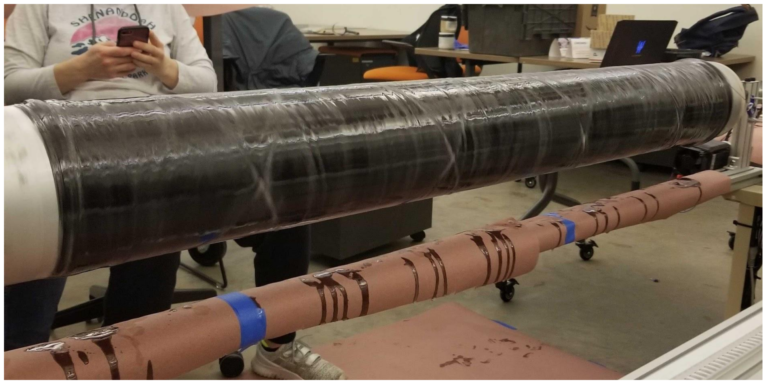


Figure 7. Newly completed wrap on the mandrel.

Figure 8. Carbon fiber tube after peel-ply and heat shrink have been removed.

Figure 9. Pouring liquid nitrogen into the mandrel to remove the wrap.

Figure 10. Carbon fibre tubes cut to length and sanded.

Figure 11. Final coat of polyurethane spray for a smooth finish.

Booster

The booster houses the engine or motor of the rocket. It is responsible for transferring the developed thrust from the motor into the rocket structure and fixing the engine in place. For *Blackout*, the load is transferred from the motor casing into the aluminum motor retainer which is integrated within the carbon-fiber boat tail as a lip on the interior diameter. The booster contains the fin can, motor mount tube, centering rings, integrated boattail, and motor retainer. The boattail assembly was epoxied together with the fin can, motor mount tube and centering rings, before the assembly was inserted into the booster airframe. To allow for seamless transition from the boattail to airframe, one final layer of carbon fiber was laid up over the connection seam. This approach still leaves a cosmetic seam, as the two carbon fiber manufacturing patterns leave two different distinct patterns, however they still act as one homogenous piece. Fin slots were then made via a two-method approach; 1. marking perfect slots using a jig and laser cutter to mark the carbon fiber, 2. cutting the carbon fiber using a dremel with an abrasive cut-off wheel. Finally, after fins were cut, they were epoxied into place and a small fillet of black epoxy was applied. In any application of epoxy, G5000 two part rocket epoxy was used.

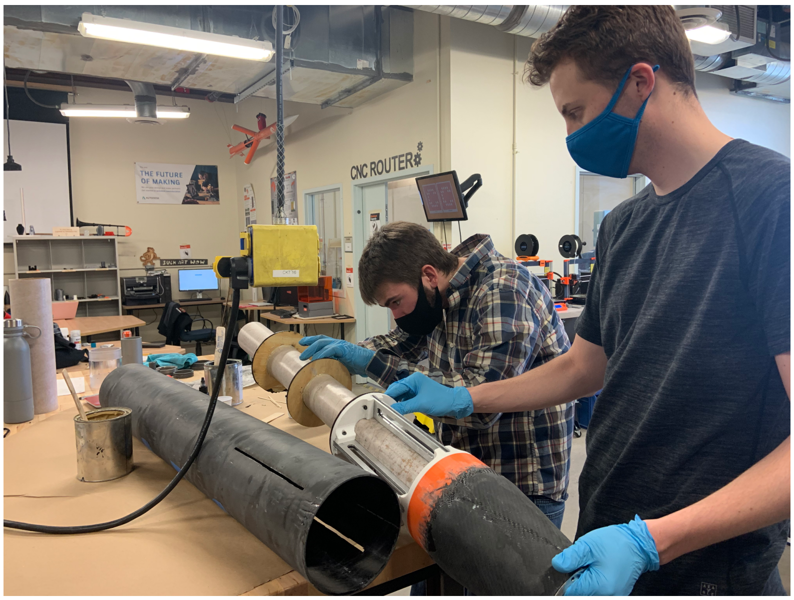


Figure 12.   Epoxing and assembly of booster section

Figure 13. Completion of booster section

Boattail

For *Blackout*'s boattail, initial design and thought had us using the X-winders fourth axis option, to create either the boattail separately or the boattail integrated with the rest of the airframe. However, both options were discarded after much debate over feasibility and quality, and instead we opted to create the boattail with the more traditional lay-up method. To do this, first we create a plug/mold. Traditionally these are removed after the carbon fiber shape has been made, however, in our case it was simpler and beneficial to keep the plug. This allowed for faster manufacturing, easier integration with the motor retainer, and use as a coupler for assembly. In our design we 3D-printed the plug since we wanted a lightweight material that could be manufactured as quickly as possible. Once made, the lower section of the motor retainer was glued to the bottom of the boattail, giving us the final shape of the "plug" for the boattail. For the lay-up method for composites we start by cutting the rough shape of the part out of dry carbon fiber cloth. We cut out multiples of the boattail shape at different sizes, to build up thickness when laid up. Next, application of slow-curing resin to the plug and then application of a first layer of carbon fiber allowed for the dry cloth to infuse with the epoxy but also adhere to the plug and motor retainer. Further application of epoxy and carbon fiber was applied until the proper shape and thickness was acquired. Finally, we tightly wrapped nylon peel-ply around the entirety; we used Nylon Peel Ply in order to create a smooth, consistent surface finish once the curing process is completed. At this point, we let it sit and cure, however another, final, step is to apply breather cloth and vacuum bag the shape, thus giving an even better surface finish and to evenly distribute the epoxy through the cloth. This last step wasn't taken because it was unnecessary, since a final layer of carbon fiber would be applied after assembly with the body tube, and because Launch was unable to secure a proper vacuum pump. Once cured, heavy sanding is required and any extraneous pieces cut off. The boattail was assembled with the rest of the motor retainer and body and a final layer of carbon fiber was applied to create a seamless transition. For the initial layers of dry carbon fiber we used commercial grade 3K 2x2 Twill Carbon Fiber Fabric/Cloth; for the final layer, in order to produce the seamless transition, we used 3K Hexagonal Weave. We used West System 105 Epoxy Resin® / 206 Slow Hardener® for this lay-up.

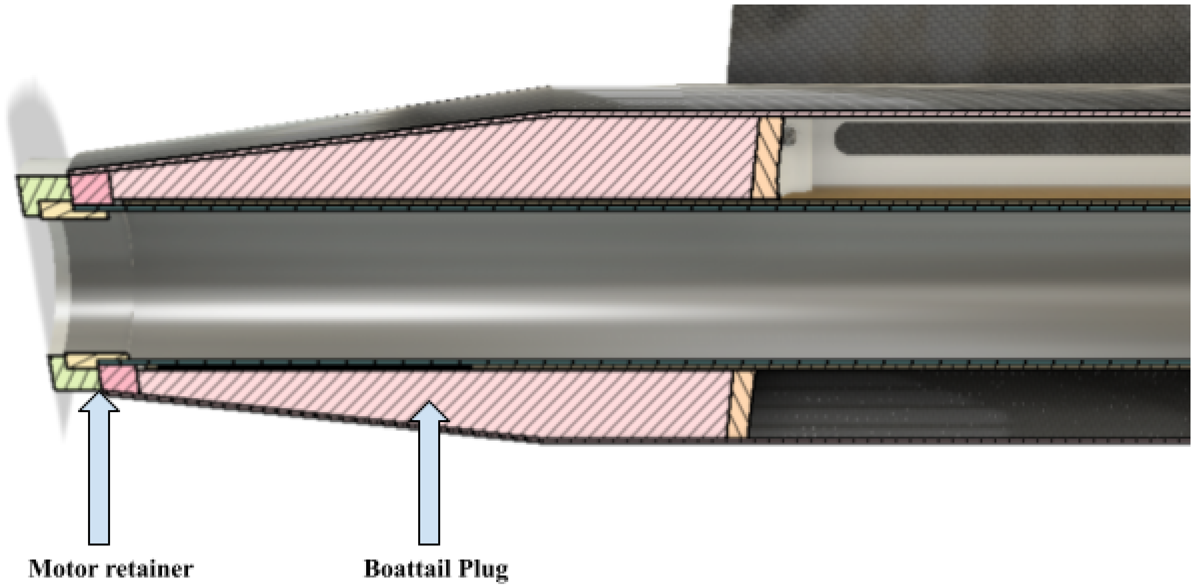


Figure 14. Cross sectional diagram of the Boattail

Figure 15. Boattail being wrapped

Motor Retainer

Blackout's motor retainer consists of two custom machined Al6061 components. The thrust ring piece was machined using a CNC lathe and a 2-axis mill while the retainer piece was machined on a 3-axis mill. The ring is the interface in which load is transferred into the air frame and was analyzed using an ANSYS mechanical simulation; all results were within margins. The ring was epoxied in place during the boattail wrapping process while the retainer piece was bolted on using eight (8) socket head cap screws, with stainless steel helicoils installed into the ring piece to prevent bolt tear-out.

Figure 16. Assembly of the carbon fiber boattail with motor retainer

Fins and Fin Can Assembly

Located internally near the aft end of the airframe is the fin stability structure or fin can. The section consists of 8 slotted aluminum supports, 2 FDM 3D printed caps made of Acrylonitrile butadiene styrene (ABS), and 16 8-32 cap screws. The rectangle supports are 6061 aluminum milled to 0.125" thick, with ½" slots in the center for weight reduction. Holes are drilled and tapped for 8-32 screws. The end caps are composed of ABS. This material was chosen due to its cost effectiveness, toughness, and thermal resistivity. The primary function of this component is fin rigidity and structural integrity. In assembly, the aluminum rectangles are inserted into the slots of the printed endcaps. The screws are then inserted into the tapped holes and tightened. Once assembled, the can is slid into the aft end of the rocket lining it up with the fin slots. The fins were cut out of 0.125" precision pressed carbon fiber sheets on the CNC router to our desired geometry. The fileted edges were done manually on a belt-sander for increased function and appearance. Once manufactured, the fins were brushed with epoxy on the root chord and tab, then inserted into the fin slots until flush with the airframe. Fillets were then applied for improved aerodynamics and a finer finish.

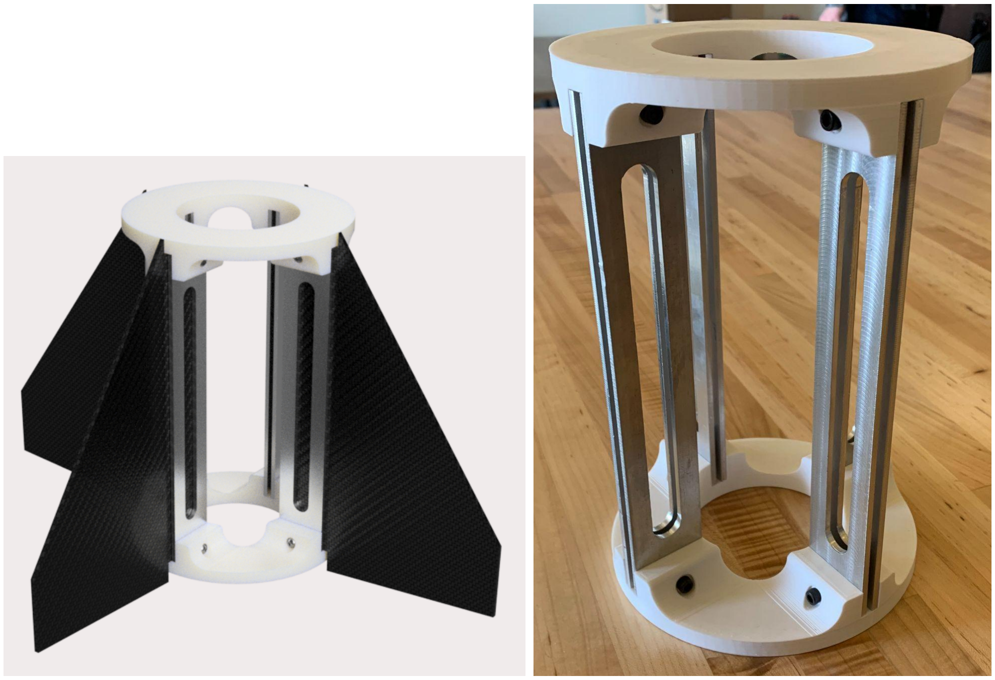


Figure 17. Fin Can.

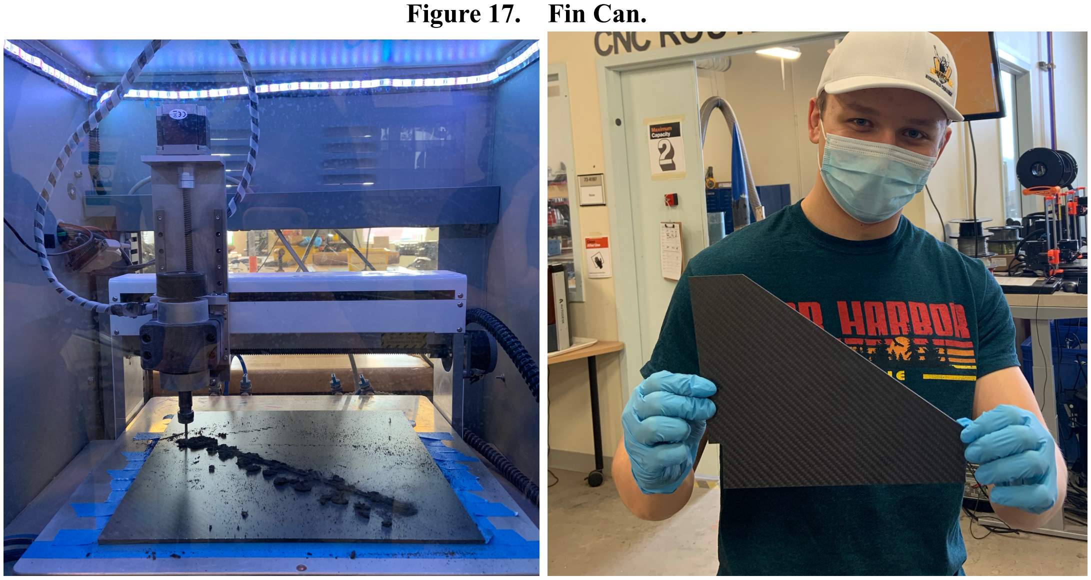


Figure 18. Carbon fiber fin Fin

C. Recovery Subsystems

The launch vehicle is single-state and is wholly recoverable by parachute. The parachutes used are the "Rocketman Ultra Light Parabolic" models made of Ripstop Nylon, with a C_d of ~0.97. The drogue and main chutes are 3 and 12 feet in diameter, respectively. These parachutes are widely used and respected. The deployment system is a standard two-bay deployment, where two parachutes, drogue and main, are deployed at apogee and at 1,200 ft (by descent), respectively. GPS coordinates are transmitted over radio in real time. A drogue chute is necessary because if the main chute were solely deployed, then the deployment forces could destroy the launch vehicle. This is mitigated by including a small drogue chute, which decreases the forces to acceptable levels. The main chute is stored in the lower body tube, and deploys by the action of the upper body tube separating from the lower body tube, which will pull the parachute out. The drogue is stored in the custom carbon fiber nose cone and deploys by the action of the nose cone separating from the upper body tube, which will pull the parachute out. Both the nose cone and lower body tube are connected to the upper body tube with a nylon recovery harness. The recovery harness has a length of 55 feet for the drogue, and the main has a length of 55 feet. To prevent premature nose cone separation, nylon shear pins were added to the upper body tube where they would "press" against the nosecone coupler tube and booster coupler tube. 7 pins of the 2-56 type were used for both separation points. The proper deployment altitudes are determined by the flight computer's altimeter. Deployment is done using 4F Black Powder charges, which, when ignited, increase pressure and facilitate separation. Through deployment testing, it was found that 4 grams are necessary to release the drogue chute, and 3 grams are necessary to release the main chute. To prevent the black powder charges from lessening the structural integrity of the recovery harnesses, or parachutes, small flame blankets are used to protect them. In the event the initial black powder charges fail, redundant charges with 20% more black powder (4.8 and 3.6 grams respectively) are in place. Redundant charges would fire 100 feet by descent after the primary charges (9,900 and 1,100 feet, respectively).

Assumptions:
1. Velocity, weight, parachute area vectors are parallel
2. Particle momentum balance
3. Instant Impulse (step input) or shock load upon deployment
4. C_d of parachutes ~ .97
5. Calculations up to 5-second deployment delay.
6. No energy losses
7. Negligible effect from black powder charges

Figure 19. Deployment testing.

D. Payload Subsystems

This year, the RIT Launch Initiative had decided to work with RIT SPEX to develop a scientific payload for competition. However, due to the pandemic and poor leadership from SPEX, SPEX notified the team that they would not be able to deliver a payload. Thus, we found ourselves with little time to internally develop a proper scientific payload for *Blackout.*

Nonetheless, in a short amount of time we put together a fun and small experiment and payload container. From our local brewery, two Genesee beers were secured in a plywood and steel payload housing and attached via recovery hardness to a secured bulkhead. The fun payload goal is to test temperature fluctuation from initial liftoff, apogee, and finally landing.

E. Avionics Subsystems
Avionics Bay

The avionics bay is located in the upper body tube of the rocket. It consists of an aluminum bulkhead on either end of the camera bay, arming switch, and avionics hardware. Two threaded rods run the length of the avionics bay to align and hold the system together. The total distance between the outside of either bulkhead is 16”. The top bulkhead is 0.5” thick, and is fixed inside the tube with rocket epoxy. Standard hex nuts screwed onto the threaded rods secure the rest of the avionics bay to this fixed bulkhead. This is done so the camera and avionics hardware can be easily removed. The bottom bulkhead is 0.75” thick, and can be removed as well. Each bulkhead has 2 DB9 connectors that allow for the avionics wiring to pass through the entire bay without impacting the ability to build the pressure required for deployment. Each bulkhead also contains a threaded eyebolt, so as to attach the parachute shroud lines and recovery harness.

The arming switch is part of our remove before flight (RBF) system. The deployment charges are indirectly wired through these switches, which are fixed into the airframe so that we can turn the switches from outside the rocket. This ensures that our system will not be armed until the rocket is on the pad and ready to launch, ensuring the safety of our engineers. Next to the RBF switches is our camera housing, consisting of an Akaso EK7000 Action Camera and a custom-designed camera housing that has been 3D-printed from PLA. A single hole precisely cut into the airframe allows for the camera to capture unobstructed footage. As the avionics bay is inserted into the tube, the camera is pressed down into the housing. When the lens aligns with the hole, the springs push the camera forward until the camera body is flush with the inside of the body tube, locking the camera in place. The avionics sled sits between the camera housing and above the removable bulkhead. It is non-structural and built from ⅛” thick birch plywood. The main purpose of the sled assembly is to house the avionics hardware, which will be discussed in the sections below.

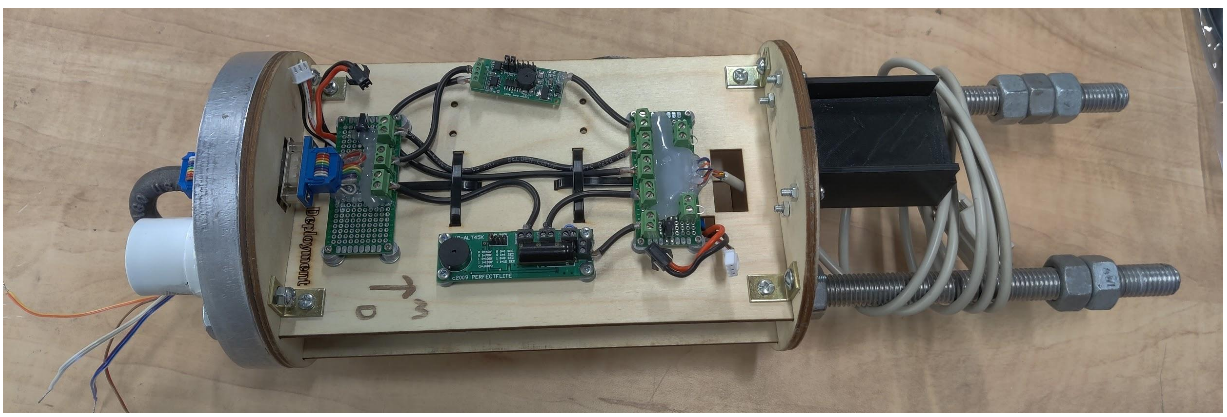


Figure 20. Bird’s eye view of assembled avionics bay (without fixed bulkhead).

Deployment and Data Collection

The deployment of the main parachute is handled by the Eggtimer Quark with a Stratologger PerfectFlite as redundancy. For data collection, a custom flight computer (S.P.I.C.A.) was designed to obtain telemetry for the rocket as well as to detect apogee. Telemetry for the rocket includes pressure, temperature, altitude, acceleration, pitch, roll, yaw, and GPS position. To obtain pressure, temperature, and altitude, two different altimeters are used with a max measurable altitude of 120,000 feet. To obtain acceleration, pitch, roll, and yaw, a 9 Degree-of-Freedom Inertial Measurement Unit (IMU) is implemented. Due to the IMU’s limited dynamic range of 16G for acceleration, an additional 100G 3-axis linear accelerometer is added to measure higher forces. For tracking purposes, a GPS module with an additional active antenna is used. Telemetry for the rocket is stored on the S.P.I.C.A. using a SPI Flash memory chip, and data is also transmitted in real-time with a 900MHz transceiver. While not used until further testing is performed, the S.P.I.C.A. also has four deployment channels with continuity sensing. Since the airframe is made of carbon fiber, an RF-blocking material, external antennas are mounted to the outside of the rocket for the

900MHz transceiver and the GPS. Since this is the first flight for the flight computer, the BeeLine GPS, a board capable of tracking up to over 40 miles was chosen to act as a backup tracking device.

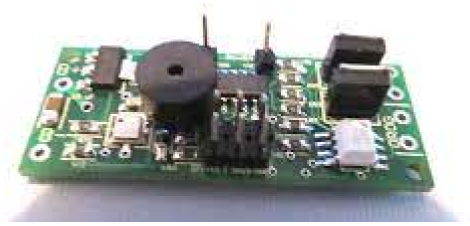


Figure 21. Eggtimer Quark.

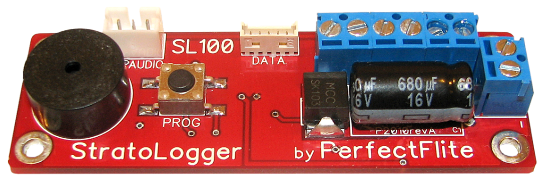


Figure 222. StratoLogger by PerfectFlite.

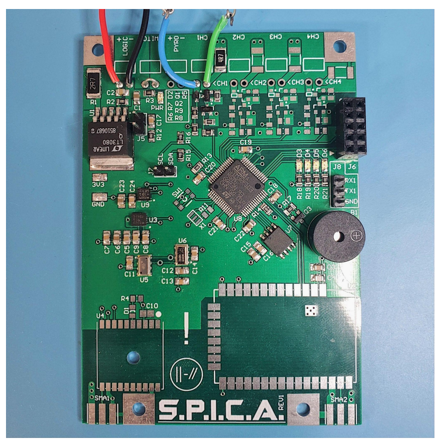


Figure 23. Custom flight computer (S.P.I.C.A.).

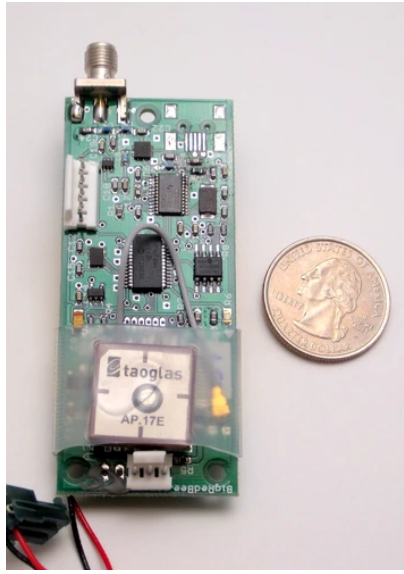


Figure 24. Beeline GPS

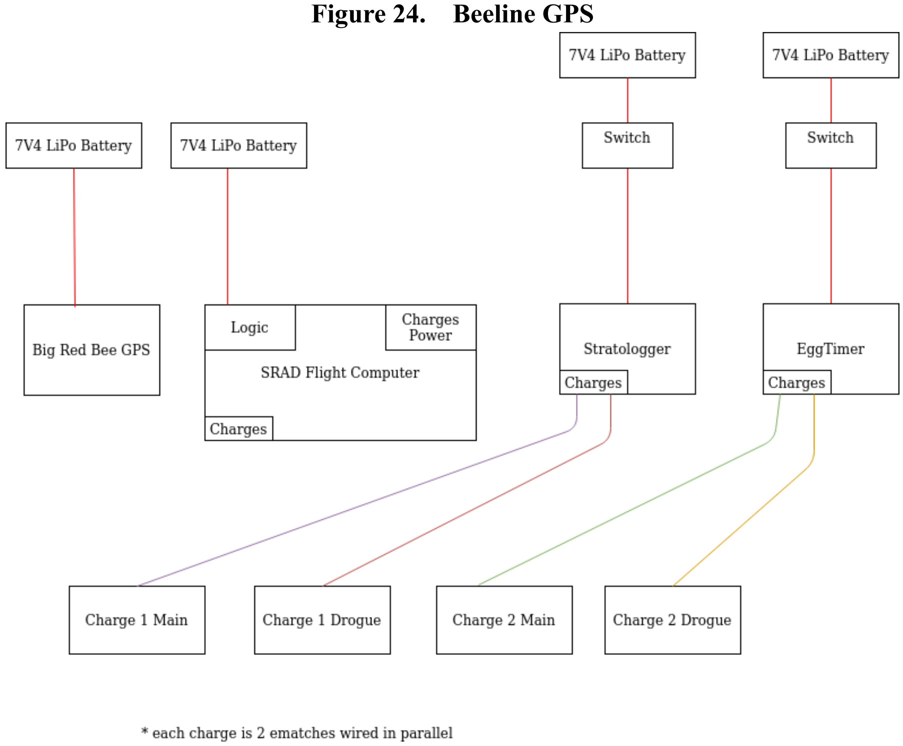


Figure 25. Wiring diagram for both deployment and data collection boards.

Ground Station

A custom ground station software was designed to report log and telemetry data from vehicles and payloads. Its main functions are telemetry parsing, logging the data in a readable format, and displaying the numbers. For *Blackout*, the variables being tracked are uptime, altitude, latitude, longitude, acceleration, angular velocity, and the magnetic field direction. In order to retrieve data from the flight computer, the receiver reads this information from an XBee transmitter and then forwards it as a UDP packet to the ground station using the onboard Ethernet chip. Additionally, the receiver also outputs any bytes received on the XBee transmitter over its USB serial. The ground station then parses the telemetry data into a readable format before displaying it and logging it in a non-volatile location. This allows the data to be viewed and analyzed later in the case of a failure. The software was implemented in C++ and is compatible with any Linux distributions.

Figure 26. Ground station dashboard for tracking live telemetry data.

III. Mission Concept of Operations Overview

From the beginning of rocket assembly to the final rocket touch-down, 11 mission phases have been identified. The first is rocket assembly. The launch preparation station will be set up and the 3 main sections of the rocket will be laid out. The sub teams will simultaneously prepare the motor, avionics, and parachutes. The motor components will be prepared and assembled on a clean surface. It will then be loaded into the booster and secured via rear retention in the boat-tail. The avionics sled will come with all electronics mounted on it. The black powder will be loaded and sealed into their canisters with an e-match embedded and connected to the DB-9 passthrough. The charges will be connected via the passthroughs, batteries connected, all wires secured, and camera connected. Once the sled is complete, it is loaded into the avionics bay and the two threaded rods are attached to the bulkheads on either end. The rods are attached to the bulkheads using nuts on the other side of each bulkhead. The payload is then secured to the drogue's shock cord via a separate shock chord and then loaded into the bay. While this is being done, the shock cords for the nose cone and drogue are routed up through the side channel of the payload. The parachutes are then loaded into their respective bays with shock cords, quick links, swivels, and flame blankets. The nose cone is then attached to the upper body tube using 7 shear pins. Finally, the avionics bay and the booster are then adjoined using shear pins through the upper stage and the booster coupler.

The fully assembled rocket will be carried to the pad by several team members. The rail will be lowered and the rocket launch lugs will be aligned with it. One member supporting the booster, one member supporting the nose cone, and one spotter will carefully slide the rocket onto the rail. Once the rocket is at the bottom of the rail, the rail will be raised and oriented to a specific angle depending on the launch conditions. The rocket will be locked down and the igniter will be inserted into the booster. Then arming begins. It will go through its starting sequence and once it reaches steady state, the egg-timer will be armed. After it finishes its sequence, both keys will be removed, locking them in place. The team will return to safety and when cleared for launch, a wireless signal will be sent to the igniter. If it is a successful ignition, smoke will appear from the bottom of the rocket and shortly after the rocket will begin lift-off.

The lift-off on the rail is considered a phase because of its critical importance in achieving a stable flight. A minimum velocity of 42 ft/s must be achieved off the rail and this rocket should reach 96 ft/s. If this velocity is achieved and the rocket is no longer in contact with the rail, this phase will be completed. The rocket will now ascend due to the thrust force imparted by the M-class motor. This motor will impart thrust for 4.2 seconds until the 6 fuel grains are completely exhausted. Once they are burned out, the motor burn phase comes to an end. The rocket now abides by the laws of projectile motion and its performance will depend on the initial burnout velocity and weather conditions such as wind. When gravity and drag finally bring the rocket's vertical velocity to zero, it will have reached apogee.

After the rocket reaches apogee, the pressure readings of the eggtimer will trigger a switch to open the circuit that sends current into the e-match. The e-match will ignite the black powder charge and the pressure force will push the nose cone from the forward end. If unsuccessful, the secondary redundant charge will trigger 0.1 seconds after. This begins the sequence in which the payload is ejected as it's pulled out of the tube by the drogue. The rocket will then descend at a rate of 90 ft/s for 100 seconds with the drogue deployed. At an altitude of 1,200 feet, the pressure readings of the eggtimer will trigger another switch to open a circuit that sends current into the e-match. The e-match will ignite the black powder charge and the pressure force will push the booster and upper stage away from each other, thus releasing the main parachute. After deployment, the rocket will fall at 21.7 ft/s for 50 seconds until it safely touches down.

Phase	Start of Phase	End of Phase
Rocket Assembly	Layout 3 major rocket sections	Rocket is completely assembled with all mechanical and electrical components
Load Rocket onto Rail	Rail is lowered and launch lugs are aligned and slid onto rail	Rocket is upright and self-supported in launch-ready position
Arming Avionics	Rocket is upright and self supported in a launch ready position, all nonessential personnel leave the launch area	Final arming personnel leave the pad in a safe manner once they have confirmed that all systems are armed and operating as expected
Ignition	All personnel are at a safe distance & wireless ignition signal sent to pad	Successful ignition signified by smoke leaving bottom of motor
Liftoff from Rail	Rocket has started upwards momentum	Rocket reaches stable exit velocity and no longer contacts launch rail
Rocket Ascent - Motor Burn	Rocket no longer contacts rail	Propellant grains completely burned

Rocket Ascent - Cruise	Motor no longer providing thrust	Apogee is reached
Nose Cone & Drogue Ejection	Eggtimer sends signal to e-match to combust nose cone bay ejection charge	Drogue and payload are pulled from body tube and drogue inflated
Rocket Descent - Drogue	Drogue is fully inflated	Rocket has reached programmed altitude for main parachute deployment
Main Parachute Deployment	Eggtimer sends signal to e-match to combust main parachute bay ejection charge	Main parachute has unraveled and fully inflated
Rocket Descent - Main	Main Parachute is fully inflated	Rocket touches down safely on the ground

IV. Conclusion and Lessons Learned

Lessons Learned/Conclusion

In the team's history we have mostly focused on avionics and payload. This year's rocket was a significant departure from the past, as we focused heavily on the aerostructure and developing the tools and skills to create complex composite parts. Our naivety on how difficult this would be led us, initially, to have far loftier goals for this rocket, which included custom cameras, custom remove before flight tags, a far more advanced ground station, and integrated umbilical connection for liftoff. The pandemic also certainly hampered all efforts and in some sense prevented SPEX from producing a scientific payload. However, through all the struggles, the team has gained tremendous knowledge on manufacturing composite parts. We demonstrated that we could create custom composite airframe parts that were strong yet lightweight parts and also looked fantastic. We made many mistakes but were able to learn from these pitfalls and what to avoid for future projects.

The IREC team was definitely hindered due to the pandemic. We saw a major loss in skilled team members, resources, funding, and focus through the year, but through the pain, we have set up next year's rocket to be incredibly successful. We hope that the lessons learned through this project will be beneficial to the team and to any future projects.

Appendix A: System Weights, Measures, and Performance Data

Table 2: Rocket Parameters

Specification	Value	Target	Units
Airframe Length	125	-	in
Airframe Diameter	6.2	6.17	in
Fin-span	6	-	in
Vehicle Weight	35.625	-	lb.
Propellant Weight	15.5	-	lb
Payload Weight	13	>8.8	lb
Liftoff Weight	64.125	-	lb
Number of Stages	1	1	-
Propulsion Manufacturer	Cesaroni	-	-

Table 3: Flight Parameters

Specification	Value	Target	Units
Simulation Software	OpenRocket	-	-
Launch Rail Length	17	-	ft
Launch Angle	0	-	degrees
Lift-Off Thrust to Weight Ratio	6.9	>5	-
Launch Rail Departure Velocity	96	100	ft/s
Minimum Static Margin	1.6	>1.4	-
Maximum Acceleration	272	-	ft/s^2
Maximum Velocity	844	<1000	ft/s
Maximum Mach Number	0.77	-	-
Predicted Apogee	10249	10000	ft

Table 4: Propulsion Parameters

Propulsion Type	Solid
Manufacturer	Cesaroni Technologies
Casing Size	P75-6 Grain
Class	M
Type	M2020
Total Impulse (N-sec)	8,429.4
Peak Thrust (N)	2,680.4

Average Thrust (N)	2,020
Burn time (sec)	4.2
Loaded Weight (kg)	7.1
Propellant Weight (kg)	4.35

Table 5: Drogue Parachute Recovery Summary

Drogue Parachute Diameter (ft)	3
Drogue Parachute Drag Coefficient	~0.97
Decent Velocity (ft/sec)	89.9
Deployment velocity (ft/sec)	101.6
Deployment acceleration (ft/sec^2)	103.7
Deployment velocity with 5 second delay (ft/sec)	107.6
Deployment acceleration with 5 second delay (ft/sec^2)	109.8
Shock load (lb)	21.2
Shock load with 5 second delay (lb)	23.8

Table 6: Main Parachute Recovery Summary

Main Parachute Diameter (ft)	12
Main Parachute Drag Coefficient	~0.97
Decent velocity (ft/sec)	21.4
Deployment velocity (ft/sec)	90
Deployment acceleration (ft/sec^2)	264
Shock load (lb)	799

Table 7: Main Parachute Shock Cord Specifications

Material	Kevlar
Length (ft)	55
Width (in)	0.5

Thickness (in)	0.2
Breaking Load (lb)	4000

Table 8: Drogue Parachute Shock Cord Specifications

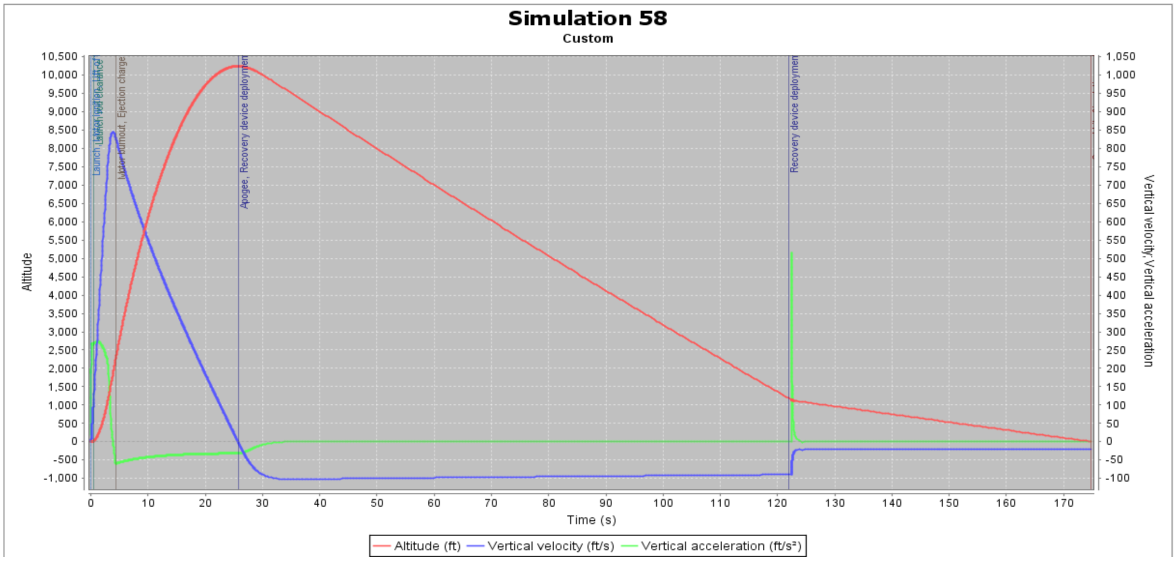
Material	Kevlar
Length (ft)	55
Width (in)	0.5
Thickness (in)	0.2
Breaking Load (lb)	4000

Table 9: Black Powder Specifications

Type	FFFF
Drogue Mass (g)	4
Main Mass (g)	3
Drogue Backup (g)	4.8
Main Backup (g)	3.6

Table 10: Shear Pin Specifications

Material	Nylon
2-56	7



Appendix B: Hazard Analysis

Team RIT Launch Initiative (74)	**Rocket/Project Name** Blackout	**Date** May 13, 2021		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Black powder stores come in contact with ignition source and explodes	Ignition sources around black powder	Very Low Black powder stored in flame-resistant containers	Keep ignition sources away from black powder and/or in protective container	Extremely Low
Motor grain comes in contact with ignition source and catches fire	Ignition sources around motor grain	Very Low Motor grain stored in flame resistant protective container until moments before assembly	Keep ignition sources away from motor grain and/or in protective container	Extremely Low

Appendix C: Risk Assessment

Team RIT Launch Initiative (74)	**Rocket/Project Name** Blackout	**Date** 2-27-2021		
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 flying debris causing injury	Cracks in propellant grain	Low COTS motor with documented and in-flight testing, assembled by an experienced flyer	Visual inspection of grains and all parts during assembly	Very Low
	Debonding of propellant from wall		Each assembly step checked by two personnel other than the assembler	
	Gaps between propellant sections and/or nozzle		Inspection of motor casing for residue buildup by an experienced professional after each use	
Recovery system deploys during assembly or prelaunch, causing injury	Shortage between avionics and battery systems	Low COTS Recovery system has been designed with multiple redundant safety systems to prevent premature deployment	Wifi switches used to arm deployment systems away from the rocket, allowing personnel to be far away from any possible accidents	Very Low
	Gust of wind triggers barometric pressure sensors			
Rocket falls from launch rail during prelaunch, causing injury	Rocket not properly secured to launch rail during initial loading	Medium With such a heavy rocket any twisting of the rocket could break a button off	Hanging weight on rail buttons reduced as much as possible	Low
	Rail Buttons Break off		Minimum amount of people attaching rocket to rail	
			High factor of safety on strength of rail buttons, high friction surface between rail guides and outer rocket body	
Rocket does not ignite when command is given (“hang fire”), but	Improper motor assembly	Low COTS igniters and motors tend to not hang fire, but will either fire or not	In the event of a fire failure, the launch system will be fully disarmed and launch personnel will wait	Very Low

does ignite when team approaches to troubleshoot			a predetermined amount of time before approaching the rocket	
	Igniter failure		If an igniter failure occurs, personnel will wait a predetermined amount of time before approaching the rocket to replace the igniter.	
			Redundant high grade igniters	
	Unsafe personnel approaching tactics		Personnel approaching hang fire rockets should wear PPE, and the number of personnel should be limited to as few as possible	
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Misalignment of fins	Medium Rocket has a high factor of safety and no control surfaces, resulting in a true flight path	During assembly, fins attached using alignment jig, bolted into the boattail with 8 bolts, and secured with bolted fins	Very Low
	Improper alignment of launch rail		Flyaway rail guides designed to detach from rocket body upon exiting launch rail	
	Damage to or misalignment of nozzle		Personnel safely distanced from launch pad as defined by RSO	
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Ejection charge does not fully deploy recovery systems	Low Rocket deployment systems have been tested on the ground and in flight to guarantee the deployment system will deploy with a factor of safety	Ejection charges stronger than needed to deploy	Very Low
	Electronics fail to trigger deployment charges		Redundant ejection electronic systems	
	Electronic match does not go off, ejection charge not triggered		Redundant ejection charges with independent electronic matches	

			on each part of the recovery system	
	Nylon screws do not sever properly during ejection		Rocket launch takes place away from personnel and launched away from direction of personnel	
Recovery system partially deploys, rocket or payload comes in contact with personnel	Parachute becomes tangled in shock cord	Low Rocket deployment systems have been tested on the ground and in flight to guarantee that the deployment system will deploy with a factor of safety	Shock cord is packed separately from the parachute in a way to prevent tangling	Very Low
	Parachute does not fully extend, becomes tangled in itself			
	Ejection charge causes damage to the components of the recovery system		Parachute is packed loosely and packed just before launch to prevent creasing	
			Large flame blankets installed on shock cord between parachute and charges to protect them, kevlar shock cord used to prevent burning	
Ejection charge burns a hole into parachute, rocket falls at faster rate than expected, injuring personnel on ground	Ejection charge burning powder hits parachute	Low Measures taken to prevent powder on parachutes	Flame blankets placed between ejection charges and parachutes	Very Low
Payload becomes loose and separate from the rocket falling without a chute	Failure in recovery harness	Low Recovery harness is inspected before launch	Payload should not experience much snatch for	Very Low
	Sabot walls shift during launch		Payload should not be able to move a during ascent	

Main parachute deploys near apogee, rocket drifts to highway	Deployment system malfunctions	Low main chute deployment system is a flight tested and common system for high powered rocketry	Proper ground testing and proper wiring	Very Low

Appendix D: Assembly, Preflight, and Launch Checklists

1. **Avionics Preparation**
    - 1.1. Test three batteries, they should each be at or above 7.2V
    - 1.2. Attach the switch and battery leads to the two altimeters and power them on
        - 1.2.1. Confirm the altimeters enter startup sequence
    - 1.3. Start the custom ground station
        - 1.3.1. Verify that the config file is set to Blackout
        - 1.3.2. Run the script to start the ground station
        - 1.3.3. Verify using mem_view to see that the correct variables are being tracked
    - 1.4. Activate S.P.I.C.A. custom flight computer
        - 1.4.1. Verify that the buzzer activates
    - 1.5. Activate the receiver board
        - 1.5.1. Verify that the LEDs are flashing
    - 1.6. Verify network connection between receiver and ground station
        - 1.6.1. Ethernet cable connected to ground station and receiver
        - 1.6.2. Receiver responds to pings from the ground station
    - 1.7. Verify ground station receiving packets from the receiver
        - 1.7.1. Ground station shared memory is being updated with new packets
        - 1.7.2. Uptime measurement is increasing at an approximately expected rate
    - 1.8. Verify packets are being logged by the ground station
        - 1.8.1. Ground station has created and partially populated and telemetry log files
    - 1.9. Insert the sled into the rocket
    - 1.10. Verify GPS lock is acquired
        - 1.10.1. Received latitude and longitude are updating and are approximately correct
2. **Charge Preparation**
    - 2.1. Apply proper PPE per IREC specification
    - 2.2. Measure out 4grams of FFFFG black powder
    - 2.3. Pour into the drogue parachute primary charge cup.
    - 2.4. Insert the primary parachute ematch (designated by the black dots on the connector) into the powder
    - 2.5. Crumple paper into a ball and insert into the charge cup on top of the powder

2.6. Seal the cup with a layer of painters tape
2.7. Measure out 4.5 grams of FFFFG black powder
2.8. Pour into drogue parachute backup charge cup
2.9. Insert the backup parachute ematch into the powder
2.10. Crumple paper into a ball and insert into the charge cup on top of the powder
2.11. Seal the cup with a layer of painters tape
2.12. Repeat steps 2.2-2.11 for the main parachute deployment bay, with 3 and 3.5 grams

3. **Booster Preparation**
3.1. Build motor by following the Pro-98 instructions
3.2. Slide the motor into the booster being sure that the thrust ring of the motor is flush with the thrust lip of the booster boat-tail
3.3. Apply a thin layer of lithium grease to the boat-tail threads aft of the motor
3.4. Screw the retaining into the boat-tail using the tool

4. **Avionics bay/Payload bay Preparation**
4.1. Prepare avionics sled and secure dynamic bulkhead
4.2. Connect fixed bulkhead wiring to sled and connect wires to arming keys
4.3. Connect camera to phone, and secure in camera holder
4.4. Slide avionics sled into the bay, securing with nuts on the top bulkhead.
4.5. Prepare Payload
4.5.1. Connect charge cap wires to bulkhead pass throughs.
4.5.2. Load and connect ejection charges
4.5.3. Connect shock cord to eyebolt on top of payload via quicklink
4.5.4. Attach other end of shock cord to the avionics fixed bulkhead via quicklink
4.6. Slide payload into bay

5. **Drogue/Main Parachute Preparation**
5.1. Inflate the main parachute and ensure the shroud lines are free of any tangles
5.2. Lay out the parachute so that it is perfectly symmetrical, with the two side leaves folded in half and the two remaining leaves stacked on top of each other.
5.3. Fold in half twice such that it resembles a pointed oval
5.4. Lay the shroud lines inside the parachute, folding them in half so that the connection point is at the bottom of the parachute
5.5. Fold the parachute in half lengthwise one final time, keeping the shroud lines inside like a taco
5.6. Roll the parachute from top to bottom, keeping it as tight as possible
5.7. Repeat steps 3.1 - 3.6 for the drogue
5.8. Attach the long end of the main shock cord to the booster bulkhead eyebolt using a quicklink.
5.9. Attach the short end of the main shock cord to the eyebolt on the dynamic bulkhead at the bottom of the avionics bay using a quicklink.
5.10. Attach the main parachute to the main shock cord in its designated place using a quicklink and swivel link
5.11. Attach the long end of the drogue shock cord to the nose cone bulkhead eyebolt using a quicklink.
5.12. Attach the short end of the drogue shock cord to the eyebolt on the eyebolt on top of the payload .
5.13. Attach the drogue parachute to the drogue shock cord in its designated place using a quicklink and swivel link.
5.14. “Z-fold” the shock cord between the main parachute and the booster bulkhead
5.14.1. Insert this bundle into the parachute bay

5.15. Feed the main parachute into the parachute bay
5.16. Wrap the flame blanket around the main and feed this bundle into the parachute bay, covering as much of it as possible
5.17. "Z-fold" the shock cord between the flame blanket and the parachute bulkhead
 5.17.1. Insert this bundle into the parachute bay
5.18. Repeat steps 5.14 - 5.17 for the drogue

6. Final Airframe Assembly

6.1. Attach the nose cone to the upper stage using nylon shear pins
6.2. Attach the upper stage to the booster using nylon shear pins

7. Pre Walkout

7.1. Check motor igniter continuity
7.2. Using electrical tape, affix two engine igniters to the end of a long skinny wooden dowel
7.3. Run final simulations to ensure proper weight and launch angle

8. Pad Ops

8.1. Carefully slide the rocket onto the launch rail
8.2. Raise the rocket to the desired launch angle
8.3. Arm the altimeters by removing keys and ensure proper startup sequence
 8.3.1. Three beeps for Perfect flight
 8.3.2. Rapid beeps for Quantum
 8.3.3. If either altimeter displays off-nominal, proceed to section 13 "clearing anomalies on the pad"
8.4. Arm payload with command from computer
 8.4.1. Wait for confirmation of arming
8.5. Clear the pad of all non-essential personnel
8.6. Insert the dowel with igniters as far up into the engine as it will go
8.7. Strip the leads of the igniters and attach them to the launch control leads
 8.7.1. Confirm they are attached in parallel
 8.7.2. Confirm they are laid out so there is no possibility of a short
8.8. Test launch controller continuity at the pad level
 8.8.1. If no continuity, proceed to section 13
8.9. Ensure one final time that all avionics are functional
 8.9.1. If not, proceed to section 13

9. Pre Launch Poll

9.1.	Avionics	Go	No Go
9.2.	GPS	Go	No Go
9.3.	Cameras	Go	No Go
9.4.	Visual Tracking	Go	No Go

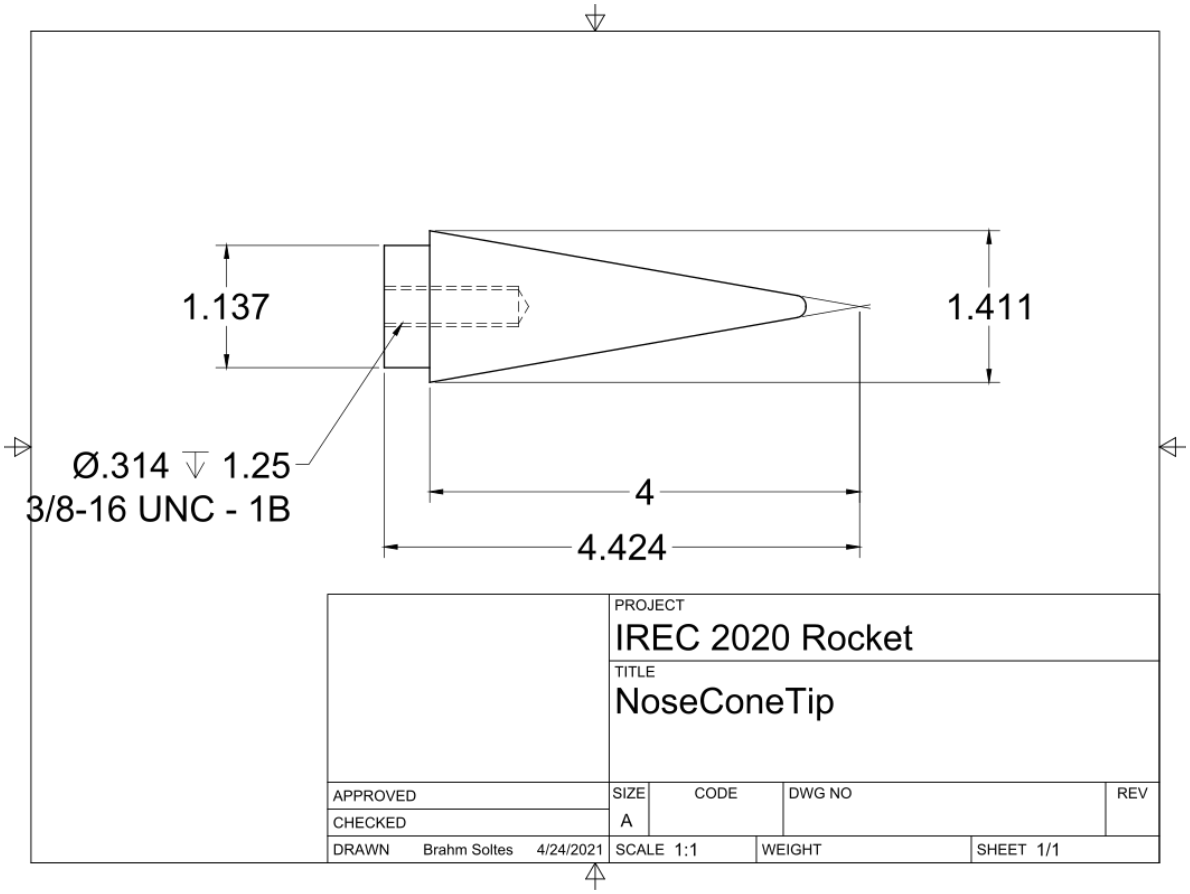
10. Post Flight

10.1. Check film for approx. landing location
10.2. Check avionics for current/last known position
10.3. Proceed to landing site per IREC rules and regulations
10.4. Document the landing site/state of the rocket
10.5. Record altitude from the altimeters per IREC rules and regulations
10.6. Turn off avionics
10.7. Re-pack parachutes for ease of carrying
10.8. Return to pits/ post flight inspection

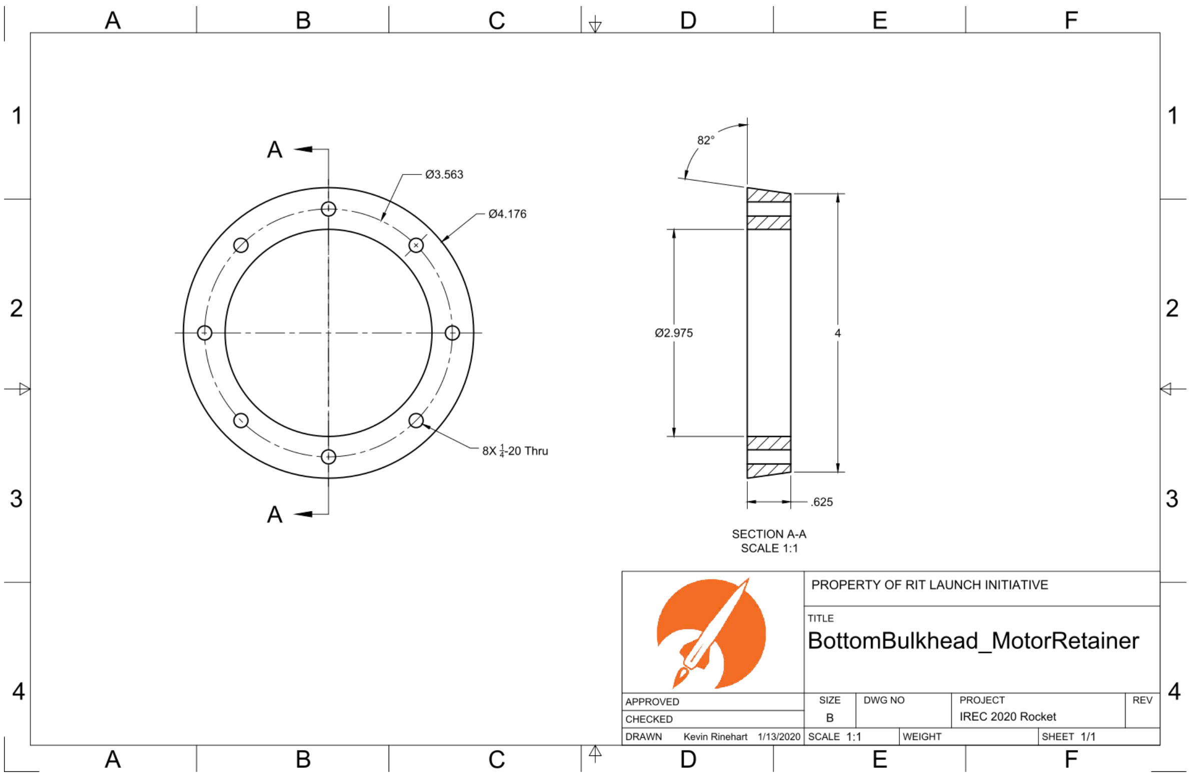
11. Clearing Anomalies on the Pad

11.1. Perfect Flight
    11.1.1. No beep pattern
        11.1.1.1. No continuity in either ematch
        11.1.1.2. Disarm altimeters
        11.1.1.3. Pull rocket off rail, problem is in both bays and will likely take some time to fix
    11.1.2. One beep pattern
        11.1.2.1. Main parachute bay ematch does not have continuity
            11.1.2.1.1. Disarm altimeters
            11.1.2.1.2. Lower rocket
            11.1.2.1.3. Disassemble main parachute bay
                11.1.2.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down
    11.1.3. Two beep pattern
        11.1.3.1. Nosecone ematch does not have continuity
            11.1.3.1.1. Disarm altimeters
            11.1.3.1.2. Lower rocket
            11.1.3.1.3. Disassemble nosecone bay
                11.1.3.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down
11.2. Quantum
    11.2.1. Four beep pattern
        11.2.1.1. Parachute ematch does not have continuity
            11.2.1.1.1. Disarm altimeters
            11.2.1.1.2. Lower rocket
            11.2.1.1.3. Disassemble parachute bay
                11.2.1.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down
    11.2.2. Five beep pattern
        11.2.2.1. Nosecone ematch does not have continuity
            11.2.2.1.1. Disarm altimeters
            11.2.2.1.2. Lower rocket
            11.2.2.1.3. Disassemble nosecone bay
                11.2.2.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down
11.3. Custom avionics non-functional
    11.3.1. Stand down, will require taking the rocket more or less fully apart
11.4. No continuity for motor igniter
    11.4.1. Check leads for contact
    11.4.2. See LCO if other issues
11.5. Payload Eggtimer does not connect
    11.5.1. See 12.1

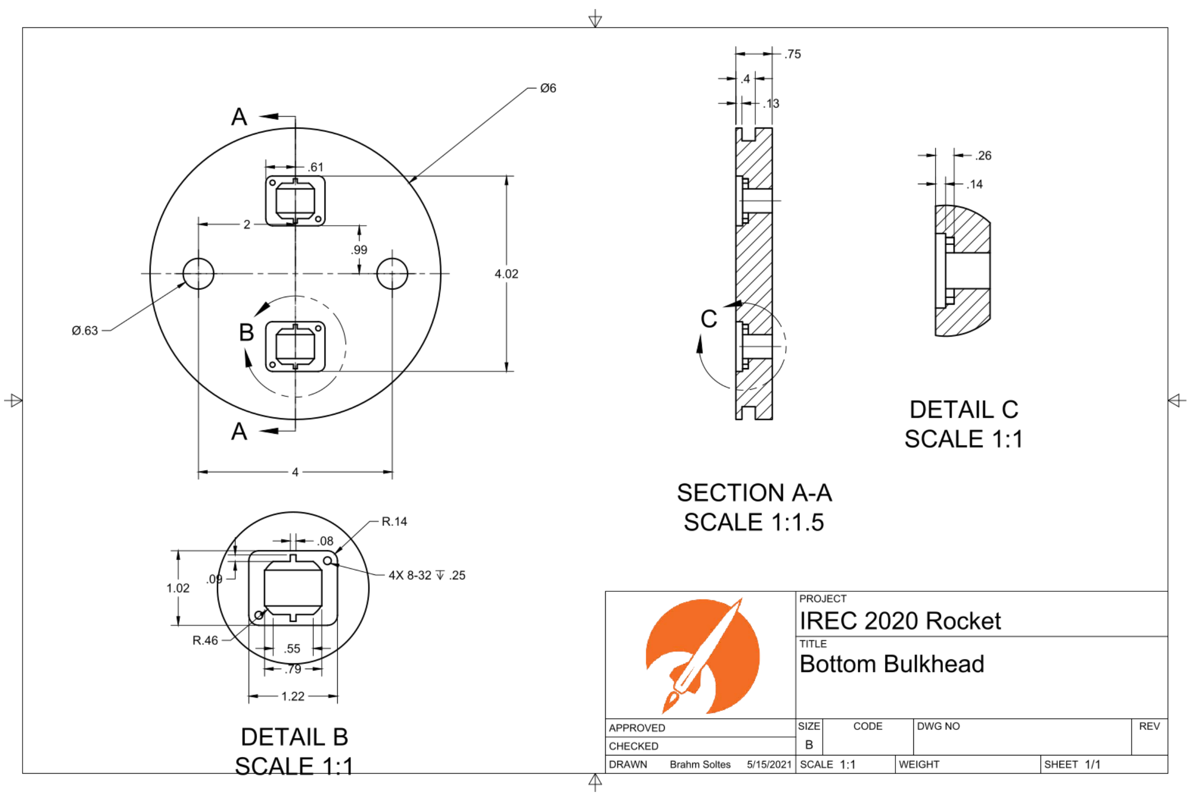
Appendix Ee: Engineering Drawing Appendix



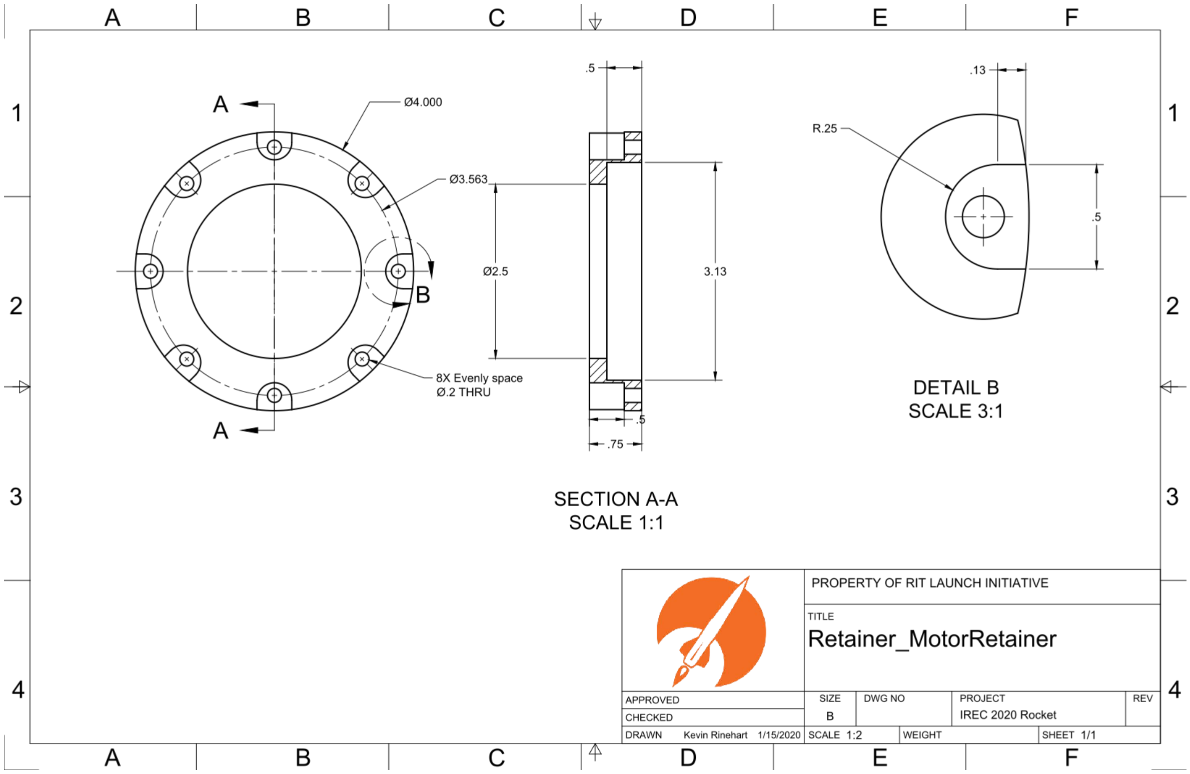
Drawing 1. Nose cone Tip.



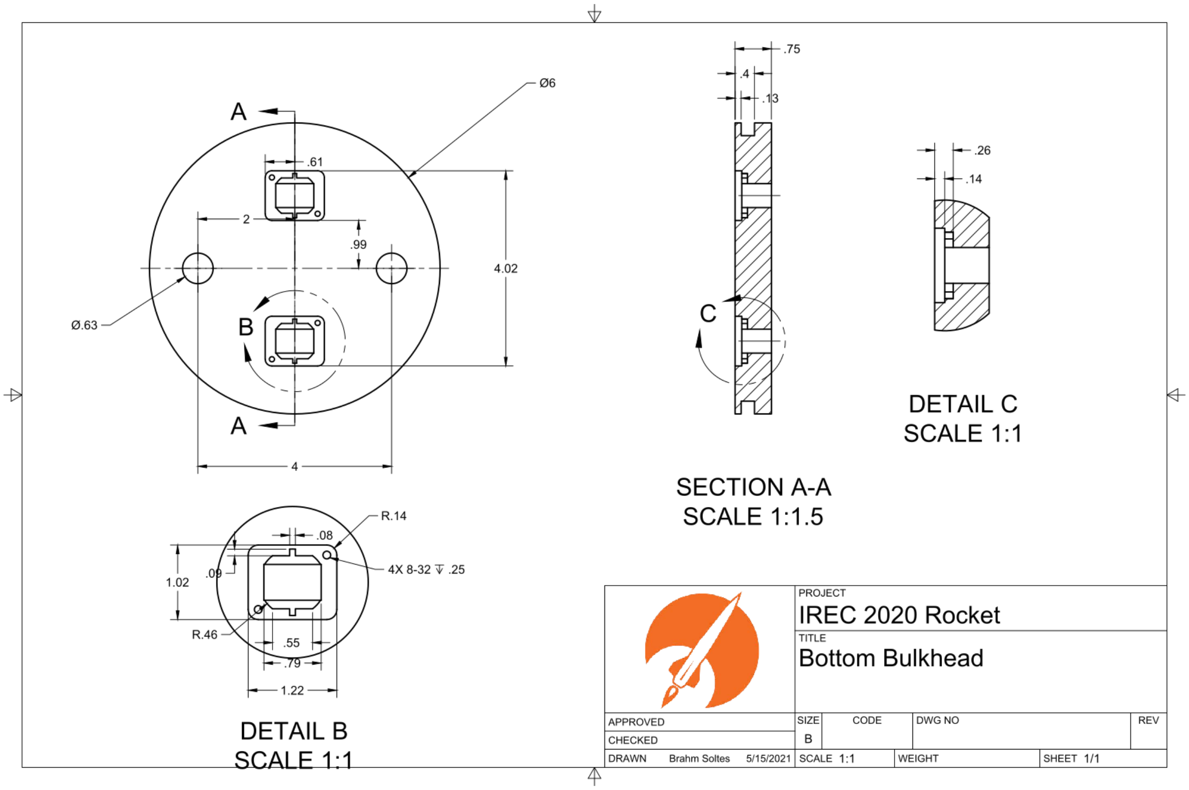
Drawing 2. Bottom half of Motor Retainer.



Drawing 3. Dynamic Bulkhead



Drawing 4. Motor Retainer Top Half.



Acknowledgments

The authors would like to thank the following for their contributions to the project:

Michael Buffalin for supporting our team and providing the space and equipment necessary to successfully complete the project.

Kate Gleason College of Engineering for supporting our second IREC competition and helping us complete all the required school documentation.

Upstate Research Rocketry Group for providing experienced rocket knowledge, launch memberships, and a launch site for our test launch.

All parties who donated to RIT LI's crowdfunding campaigns

Team Members:
Brahm Soltes for designing the rocket, manufacturing the body tube, nose cone, boattail, and half of the motor retainer.

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