Water Bearer

Team 87 Project Technical Report for the 2019 IREC

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This project details the design, manufacture and testing of the RIT Launch Initiative's level 3 high-powered rocket, to compete in the 30,000 AGL apogee COTS category at the 2019 IREC. This rocket, *Water Bearer* (WB), is a 12 ft. fiberglass and carbon fiber rocket equipped with an N-5800 98mm 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. The payload, *Odysseus 0*, has data acquisition, storage, visualization and livestream capabilities for visualization before, during and after the launch. Modeling and analyses were conducted on the entirety of the rocket. Research was performed on the propulsion, aerodynamics, avionics, and recovery aspects of WB. Current models project *Water Bearer* will reach an apogee of 28,304 feet 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, seven L2 rockets, and has certified 35 members to fly L1 rockets under the National Association of Rocketry (NAR), with 40 more certifications pending completion the month after IREC. Additionally, several team members hold individual L2 and L3 high-powered rocketry NAR or Tripoli certifications.

RIT LI 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 report 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 second year attending the IREC. We will be competing in the "30,000 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 30,000 feet at a launch site in Potter, New York. This fiberglass and carbon fiber rocket encompasses a design that has stemmed from 4 years of rocket architecture, analysis, and building, as well as the lessons learned along the way. Several team members have held internships at SpaceX, Blue Origin, NASA, Lockheed Martin, as well as other notable corporations, and have been able to integrate valuable knowledge into this team and its designs. In conjunction with this year's IREC efforts, our team is conducting R&D projects that include a 100 lb. thrust liquid test engine, custom filament wound carbon fiber body tubes and transitions, and a 1300 lb. thrust hybrid rocket engine. The team plans to introduce these designs at future IREC competitions.

II. System Architecture Review

Water Bearer is a 12-foot-tall level 3 high-powered rocket. The rocket body is entirely G12 fiberglass aside from the carbon fiber transition, and is broken up into 5 sections. These sections include the booster, parachute bay, avionics bay, payload bay, and nosecone. The booster holds the Cesaroni N-5800 6 grain XL motor, and transfers the thrust through the custom boat-tail/force plate into the airframe. The boat-tail was designed to be the only structural bulkhead in the system, simplifying the structural design requirements and analysis upstream. The boat-tail also serves as the mounting point for the interchangeable fins and fillets, and the rear retention plate. The rocket encompasses a single-deployment recovery system, utilizing black powder to provide separation forces. A 5-foot drogue parachute and 14-foot main parachute will be deployed from the parachute bay. The combined effort of both chutes will allow the rocket to descend safely to earth, yet still land within a reasonable distance from the launch pad by utilizing dual redundancy Jolly Logics for main chute expansion at 1000 ft. The electronics onboard are all housed on the avionics sled, within the avionics bay. These electronics consist of a custom flight computer that utilizes 900MHz XBee Pro SX radio modules to transfer live GPS, acceleration, altitude, and gyroscope data back to a custom receiver. Components used on the custom board include: Teensy 3.6 Microcontroller, ADXL377 200g Accelerometer, MPU9250 IMU, MS5607 Altimeter, and a Venus GPS module. Other electronics in the avionics sled include an Eggtimer Proton, a redundant Eggtimer Quantum, an Eggtimer WiFi switch, and batteries. The payload of this rocket is a scientific 3U CubeSat that has real-time data acquisition, storage, and transmission for visualization before, during, and after the launch. It is complete with an independent recovery system that will guide it safely to the ground after ejection at apogee, with the help of a custom sabot design. Lastly, the nosecone is a 5:1 tangent ogive made of fiberglass with an aluminum tip. A custom shoulder was made for the metal tip that supports a threaded rod concentrically running to the bulkhead. This threaded rod not only transfers the load of the nosecone shock force, but also allows for ballasts to be easily integrated inside the nosecone if necessary for stability.

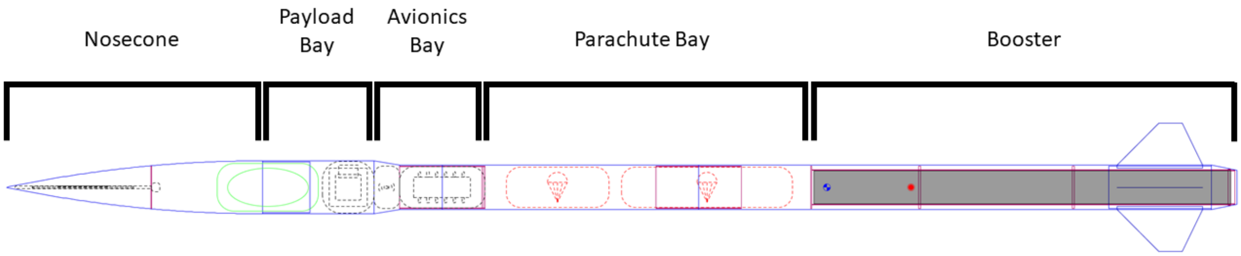


Figure 1: Rocket System Schematic

A. Propulsion Subsystems

The propulsion system of this rocket encompasses a commercial off the shelf (COTS) solid rocket motor. The motor is an N-class 98mm six grain XL Cesaroni N5800. The fuel grains are C-Star fuel mixtures and have higher specific impulse rating compared to other commercial motors of this class. Moreover, the grains are housed in a commercial phenolic liner which is located inside a second generation 98mm P98-6GXL Cesaroni motor casing. The motor delivers a total impulse of 4529 lb-s and peak thrust of 1806 lb. It will burn for 3.5 seconds with a specific impulse of 227.73 seconds. The motor was chosen due to the fact that it gave the highest peak thrust and total impulse for the 98mm class of motor casings, thus saving funds that could not be scavenged for a larger motor. A simple first design of the rocket was created using OpenRocket to determine a first approximation. Since the weight of the rocket was expected to be over 50 lb. with the payload, a 6-grain XL motor was required to reach 30,000 feet. The team then designed the rocket around this motor and made decisions that optimized apogee height above all. After all major subsystems were designed and the weights of their respective components were taken into consideration, a more accurate OpenRocket model was created. This model allowed the verification of the target altitude of the rocket.

The motor is equipped with a phenolic liner, 6 fuel grains, ceramic nozzle attachment, nozzle holder, 3 nozzle o-rings, 2 retention rings, forward insulating disk, forward closure, tracking smoke element, tracking smoke insulator, spacer, 5 grain-spacing o-rings, and an igniter. The spacer is not used in this motor because 6 grains fill up the volumetric capacity within the liner. The exterior of the phenolic liner is coated with a thin layer of lithium grease before being inserted into the casing. This is done not only for ease of assembly, but also as a safety precaution because the grease acts as a seal and minimizes the potential for leaking combustion gases. After the motor is assembled and both end caps are screwed in, the casing in its entirety is slid into the aft end of the boat tail until the lip of the casing mates to the face of the force plate portion of the boat-tail. At this point, the aft retention ring is screwed into the boat-tail using the custom tooling, which gives full motor retention. See Figure 7 in Appendix A for motor components and see figure 17 in Appendix B for the motor thrust curve.

B. Aerostructures Subsystems

A rocket is defined by its structure and shape. The shape of the rocket is critical in achieving the most aerodynamic vehicle. The structure of the rocket must be designed to sustain all loads the vehicle experiences during operation to guarantee a successful mission. The structural elements of this rocket are the booster, upper stage, carbon fiber transition, nosecone, boat-tail, fillets, and fins.

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 WB, the load is transferred from the motor casing into the force plate which is integrated within the aluminum boat-tail as a lip on the interior diameter. Aluminum 6061 was chosen for its availability, machinability and low cost. The boat-tail is epoxied into the aft end with G5000. The boat-tail transfers force into the airframe through the shoulder of the boat-tail which mates to the bottom of the lowest airframe section. The airframe material is G12 fiberglass tube that is 5 inches in diameter and 60 inches long for the booster section. Four 1” slots were cut into the bottom of the booster airframe for fin placement. These slots are 11 inches long and 0.5 inches from the bottom of the booster tube, corresponding with the designed fillets. Six centering rings are epoxied down the length of the motor tube to allow for concentricity of the motor with the fiberglass body tube. The motor tube is composed of two 30” sections. The two sections are epoxied together in the middle of the motor tube across the surface of two centering rings which are flush with the end of the tubing. From there, four more centering rings are equally spaced along the length of the motor tube to ensure concentricity throughout the entirely of the motor tube. At the forward end of the booster airframe is a 10” long 5” G12 coupler tube, epoxied and inserted 5” into the airframe, for attachment to the upper stage.

Boat-Tail

The boat-tail is responsible for transferring all developed thrust to the airframe by constraining the motor in the thrust vector direction with the retaining ring. The boat-tail is also the attachment point for fillets, allowing strong fin attachment and proper fin alignment with machined precision. A detailed manufacturing description follows below.

Machined out of a 20” long, solid 5.5” outer diameter by 1” wall thickness aluminum 6061 tube stock, this structure was cut in half, turned internally to 4.25” for motor tube clearance, 3.87” for force plate inner diameter, and 4.01” for aft motor tube ring clearance. Then, the boat tail was welded back together and turned externally to 4.995” on the 12” long shoulder for booster airframe fitment, 5.15” for outer lip mating to the bottom of the booster airframe, and then conically reduced aft of the outer lip to 4.2” over a span of 3”. The 15” long boat-tail was then brought to a 4-axis CNC in our Brinkmann Machine shop to cut slots and holes in the shoulder for fillet attachment and weight reduction. Four 0.7” wide by 10” long slots are cut at 90 degree intervals of the center axis of the boat-tail to accommodate the fin tab, fillet tabs, and attachment hardware. These slots have an interior corner radius of 3/16”. Forward and aft of these slots, two 10-32 holes are drilled and tapped parallel to the plane of the fins, 0.25” from the end of the slot and 0.2” on either side of the slot centerline. These holes are the attachment point of the fillets discussed in the following section. Offset 45 degrees from the fillet slots, four more slots are cut for weight reduction and to allow for G5000 epoxy fillets when the boat-tail is secured into the 60” G12 fiberglass booster airframe. These slots are 2.25” wide and 11” long, centered on the shoulder of the boat-tail, 0.5” from either end. These slots also have a 3/16” interior corner radius.

To take the force of the motor, a lip was designed on the inner diameter of the boat tail such that it can recieve force directly from the motor casing aft end cap. The interior face of the boat tail aft of this lip is custom threaded for attachment of the retention ring, which is treated with lithium grease to prevent galling, and screwed into the boat tail using a custom tool. The 0.59” thick retention ring is hollowed out to 3.01” inner diameter to avoid contact with the combustion gasses during the motor burn. Aluminum 6061 was chosen for the retention ring for its availability, strength, and ease of machining. With a maximum motor load of 603lbs, stress calculations were used to determine the thickness of the boat-tail lip. The equations used are below.

$$\sigma_{ring} = \frac{F}{A} \tag{1}$$

$$X_s = \frac{\sigma_{yield}}{\sigma_{ring}} \tag{2}$$

$$\tau_{edge} = \frac{F}{SA} = \tau_{epoxy} = \tau_{body} \tag{3}$$

$$Y_s = \frac{S_{strength}}{\tau_{edge}} \tag{4}$$

$$E_s = \frac{S_{epoxy}}{\tau_{epoxy}} \tag{5}$$

$$E_b = \frac{S_{body}}{\tau_{body}} \tag{6}$$

An ANSYS model was developed to confirm the force plate would not fail under expected loads. The localized Von Mises stresses were determined using a static structural analysis. The maximum thrust load was applied. The outer area of the boat-tail shoulder was treated as a bonded fixed support.

The analysis revealed an extremely high factor of safety for Aluminum 6061. All calculations yielded acceptable FOS with enough margin to account for discontinuities or improper adhesion of the G5000 High Strength Epoxy. The results are summarized in Figures 2 and 3 below.

Parameter	Hand Calculation Stress (PSI)	ANSYS Stress (PSI)
σ_{ring}	2123	1479
τ_{edge}	42.1	159
τ_{epoxy}	42.1	159
τ_{body}	42.1	159

Figure 2: Boat-tail Lip Structural Analysis

Parameter	Hand Calculation Stress FOS	ANSYS Stress FOS
σ_{ring}	13.19	18.9
τ_{edge}	665.1	176.1
τ_{epoxy}	665.1	176.1
τ_{body}	665.1	176.1

Figure 3: Boat-tail Lip Factor Of Safety

For attachment to the booster, the outer surface of the boat-tail shoulder was coated with a thin layer of G5000 epoxy, and inserted into the aft end of the booster airframe. Fillets were inserted into the airframe slots and lined up with the threaded holes in the boat tail to ensure proper alignment, After setting, the four weight reduction slots on the boat-tail were filled with G5000 fillets on the interior of the assembly for added strength. Please reference Drawing 5 in Appendix F for more on the boat-tail, retention ring, and retention tool.

Fins and Fillets

Ease of assembly and contingency to damage are the primary drivers to WB's fin/fillet/boat-tail assembly. Feedback from RIT LI's team in 2018 gave us insight to issues teams ran into such as broken and misaligned fins the day of flight. This years team decided to integrate the fins in a way that ensures perpendicular alignment as well as the opportunity to replace damaged fins on a moments notice.

Four quasi-isotropic (0/90 ± 45) solid carbon fiber fins, with rounded leading and trailing edges, bolt into custom 3D printed fillets which slide into the body tube/boat-tail slots. These fillets, printed on the Markforged Mark 2 Printer, are comprised of onyx (nylon mixed with chopped carbon fiber) with additional layers carbon fiber filament concentric rings for enhanced rigidity. Onyx was chosen for its high strength and high temperature deflection point of 145, as well as the small print layer height of the Mark 2 Printer. Eight 6-32 bolt holes along a 10" length of the fillet completes the construction of the fin-fillet assembly and guarantees alignment with the body tube. G5000 epoxy is applied to the press fit interface to mitigate air-gaps along the length of the interface. This assembly, with 3/16" rounded corners to match the machined body tube slots, press-fits into said slots where it interfaces with the aluminum boat-tail. Two 10-32 threaded holes counter sunk at the fore and aft end of the fillet, drilled parallel to the plane of the fin, are used to secure the assembly to the boat-tail. These four connection points are placed 0.25" from either end of the fillet and have a 0.2" offset from the fillet centerline. The team plans on having four "backup" fillet-fin assemblies for the competition in case of damage and WB's streamlined assembly gives the team an advantage for repairs.

Material	Number	Root Chord	Tip Chord	Span	Sweep	Thickness

Quasi-isotropic Carbon Fiber	**4**	**10”**	**2.441”**	**3.85”**	**6.453”**	**0.125”**

Figure 4: Fin Specifications

Location	Approximate Altitude Above Sea Level (ft)	Max Flight Velocity (ft/sec)	Divergence (ft/sec)	Flutter (ft/sec)
Test Flight: Potter, NY	**900**	**1727.4**	**1935.65**	**1891.2**
Competition Flight: Spaceport America	**4600**	**1757.5**	**2057.28**	**2010.04**

Figure 5: FinSim Fin Flutter Analysis

Upper Stage

Coupled to the booster airframe using a 10” long 5” G12 coupler tube is a 30” length of 5” G12 airframe. This upper stage airframe overlaps portions of the avionics bay as well as the parachute bay. This airframe section will be secured at the aft with G5000 epoxy to the coupler, and at the forward section using nylon shear pins through the avionics coupler tube (same dimensions as the booster coupler) to allow for secure attachment during flight and separation during parachute deployment.

Transition

Positioned between the upper stage and the nosecone is WB’s custom hand-laid carbon fiber transition. In the early stages of design it was decided a transition was necessary to reach desired apogee given the constraint of a 98mm motor and dimension of a 3U payload. The transition narrows the rocket body from a 6” to 5” diameter. A 6” diameter is needed to house the 10cm x 10cm x 30cm 3U payload, while the 5” section reduces the profile and thus drag forces, allowing for a higher apogee that would not have been achievable without diameter reduction given the 98mm Cesaroni motor in use. From the nosecone downward, the carbon fiber transition measures 21 inches long with a 13 inch section of 6 inch diameter, 3 inches of transition for diameter reduction, followed by 5 inches of 5 inch diameter that continues to the aft end of the rocket.

This transition piece was laid on an aluminum mandrel with a bi-axial woven carbon fiber sleeve. Continuous rotation while curing to ensure the shape was true to the mandrel was achieved by using stepper motors. after curing and upon removal from the mandrel, the transition has to be cut to size so 3D printed fixtures were made to hold the piece in place and ensure a perpendicular cut for seamless concentricity with mating parts. The transition also acts as a housing for the mechanical separation and avionics within.

Nosecone

A 5:1 6” tangent ogive nosecone was chosen as the team has had previous success with this shape in last years competition. While WB will experience over Mach 2 flight, the decision was made to use a tangent ogive rather than a Von Karman profile due to its availability from suppliers, price point, and its overall efficiency in all speed regimes. Our nosecone is 30” long, with a machined tip for more control over the tip radius and strength, compared to the conventional solid fiberglass tip with a larger tip radius.

C. Recovery Subsystems

The recovery system of the rocket is responsible for delivering the rocket back down safely once apogee or the mission has been achieved. The recovery system is a standard single bay deployment where two parachutes, drogue and main, are deployed at apogee and at 1,000 ft respectively. To keep the main parachute from opening at apogee, dual redundancy Jolly Logic Chute Release mechanisms will be utilized in series. The reason for this is that deploying a single large main parachute at apogee will cause the rocket to drift very far, causing complications when recovering the rocket. When deploying the parachute at lower altitudes, the deployment forces may be strong enough that it can cause failure of the rocket structure, increasing its complexity. This may lead to a heavier, larger rocket with greater drag. To minimize this risk, a small drogue parachute is deployed at apogee to decrease the descent velocity when the main parachute deploys. This in turn decreases the deployment forces the rocket experiences with main parachute deployment. The current design is to have the drogue parachute deploy at apogee, and the main parachute deploy when the rocket reaches 1000 ft. upon descent. The recovery system is controlled by the COTS Eggtimer flight computer. To aide in locating the rocket, GPS coordinates are transmitted over radio in real time. The computers detect when the rocket reaches apogee, and sends a signal to ignite the black powder charges located in the nosecone and parachute bays.

The black powder charges create an increase in pressure in the bay which causes the rocket to separate at velocities that deploy the parachutes. A back up black powder charge is put in place to guarantee deployment in case the parachutes do not deploy when needed. Before the deployment event occurs, 2-56 size nylon shear pins are used to keep the transition and avionics coupler attached to the upper stage of the rocket during operation. Four shear pins are used for the parachute bay. Ground deployment tests were performed to determine the amount of black powder needed for proper parachute deployment. It was determined that 5.75 grams of black powder are needed for the parachute bay, and one gram for the nosecone bay. An extra half gram of black powder is added to the backup charge for the parachute bay and quarter gram for the nosecone bay. Nomex flame blankets, 24 in. by 24 in. wide, are used to protect the recovery hardware from the black powder charges during deployment.

The avionics system consists of three separate systems, each operating independently with their own battery power supply. The deployment system utilizes 1 Eggtimer Quark and 1 Eggtimer Proton altimeter to provide redundant deployment mechanisms for deploying the parachute. Each altimeter is attached to a separate drogue and main parachute deployment charge, further providing isolation between the two systems. Both systems are armed using the Eggtimer WiFi switch.

The drogue parachute is a 5 ft diameter U.S. military pilot's reserved parachute. This type of parachute was chosen because it is meshed. The rocket was designed to house both the drogue parachute and main parachute in the same bay. Having a meshed drogue reduces or eliminates the risk of the drogue tangling with the main when deployment occurs at apogee. Only 5 ft diameter meshed parachutes were found, so that determined the size of the drogue parachute. The parachute has an approximate drag coefficient of 0.8 and reefing is used. OpenRocket was used to simulate the behavior of the rocket with the corresponding drogue parachute. The simulations were performed up to five second deployment delay after reaching apogee. Please reference Appendix B, Table 4 for simulation results.

The main is a COTS 14 ft diameter parachute made of low porosity 1.1 rip-stop nylon. The parachute is reinforced with nylon tape and webbing, and tubular shroud lines are sewn over the top of the canopy. The four- shroud lines of the parachute reduce the risk of tangling upon decent, and the overall design is more stable than cross-form or conical parachutes. The parachute has a drag coefficient of approximately 0.8 and reefing is not used. The sizing of the main parachute was determined using OpenRocket simulations, which utilize an acceptable scope of models for this application. The diameter of the parachute was analyzed with respect to the resulting deployment force and descent velocity. The simulations were performed with a deployment altitude of 1000 ft. and a rocket weighing up to 60 pounds with the drogue decent velocity included. Based on the plots, a minimum size parachute that achieved an acceptable landing velocity was chosen. Please reference Appendix B, Table 5 for main parachute performance.

During the deployment event, the body of the rocket experiences shock loads due to the impulse from the opening of the parachutes. Therefore, the structure, shock cords, and recovery hardware of the rocket must be designed and chosen to sustain the loads with a factor of safety included for margin.

Assumptions:
1. Velocity, weight, parachute area vectors are parallel
2. Particle momentum balance
3. Instant Impulse (step input) or shock load upon deployment
4. Cd of parachutes ~ 0.8
5. Calculations up to 5 second deployment delay.
6. No energy losses
7. Negligible effect from black powder charges

D. Payload Subsystems

Structures and Components

This year, the RIT Launch Initiative opted to fly a discreet, independent, internally-developed payload on the IREC rocket, in order to test multiple experimental systems for integration into future rockets and systems. The payload will deploy at apogee and descend under an independent dual-parachute system, using a 12" drogue and a 36" main parachute. The drogue and main are both ejected at 1 second after confirmed separation from the rocket, and the main is held closed by a Jolly Logic parachute release until a lower altitude. The entire structure of the payload is made of steel with aluminum accents to help with survivability during landing, and most of the internal structure is 3D printed PETG.

The first internal system being tested is a live stream camera setup. Using a 5.8GHz band and commercially available systems usually intended for drone racing, we plan on capturing real-time footage from the payload, which will then be sent back to the ground station. If this tests shows no major interference and a consistent video quality, we will integrate this technology onto future rockets, paired with more ground-based infrastructure, to allow for SpaceX-style livestreams of all of our launches, raising awareness and interest in both collegiate rocketry and aerospace STEM as a whole.

The second system being tested is a low-cost 360 camera array. Comprised of 5 SQ-12 cameras, this system is significantly more durable, easier to integrate, and less expensive than traditional 360 cameras. The footage from each camera is automatically stitched together to show a complete 360 view from inside the payload, which can then be viewed at RIT's 360 viewing conference room.

The third and most ambitious system of the payload is the PAPL (propulsively-assisted parachute landing) system. The PAPL augments the already existing recovery system to aid the payload in landing slower and softer, without the need for bulky and expensive parachutes. This system is the first step in the development process towards the integration of fully propulsive landing systems on high power rockets, which would eliminate the need for parachutes altogether, freeing up space for payloads or the ability to fly missions on smaller, less expensive motors. The PAPL will arm once it has confirmed it is outside the rocket by more than 100 feet. Then, during descent, it will constantly cross-check altitude between an altimeter onboard and a LIDAR system pointing downwards. If all safety criteria are met (GPS position, safety switches disengaged, altimeter and LIDAR measurements match, descent rate consistent with successful parachute deployment, and AOA does not exceed dangerous levels), the onboard electronics will calculate time to impact, and determine when to fire the motor to achieve a (theoretically) perfect landing at almost 0 speed. The data from the onboard electronics, specifically the LIDAR, will be collected for analysis to show the viability of such systems on future launches of full systems. Even if the PAPL is not able to fully activate due to safety interlocks, the system is designed to still collect good data that can be used to check calculations and load a simulation, to show and confirm predicted operation of the system.

Nosecone Deployment

The first event to occur upon reaching apogee for WB is ejection of the nosecone. By usage of 1 gram of black power to generate roughly 15 PSI in the nosecone volume, the pressure will allow it to eject at a velocity which causes complete separation for allocation of payload ejection just moments afterwards. The nosecone is tethered to rocket body just below the payload and mechanical separation with a shock cord that is routed around the payload. Once the nosecone has successfully deployed, mechanical separation with actuate to eject the payload with the nosecone out of the way.

Mechanical Separation

The mechanical separation system is positioned at the bottom of the 6 inch section of the transition and is responsible for the ejection of the 3U payload from its position in WB's payload bay. The payload and sabot are ejected using a 3" diameter compression spring that is loaded pre-flight and then unloaded less than a second after apogee using a servo motor and actuation arm. The chosen spring provides 13 pounds of force per inch of compression; with an estimated compression distance being 7 inches, this will provide us with ample force to overcome the weight of the payload and any frictional forces present in the system. The actuation arm is composed of a custom manufactured steel shaft and servo horn. The servo horn interfaces with a slot in the bottom of the sabot; depending on the rotation of the servo, the horn will either not line up with the slot, in which case it holds the sabot in, or the horn will line up with the slot and the spring will be allowed to push the sabot out of the rocket. The spring is contained in a 3D printed housing which also serves as a bulkhead for the sabot to rest on. Positioned below the spring housing, is the servo mounting bulkhead, which is also 3D printed and serves as the mounting surface for the servo, and below this is the transition bulkhead, which is manufactured out of ⅜ inch 6061 aluminum plate. This bulkhead is epoxied, using G5000, into the transition tube at the start of the diameter reduction section, and serves as the main mounting point for the mechanical separation system above and the avionics sled below.

E. Avionics Subsystems

The electronics for the rocket are housed on the avionics sled, within the avionics bay. A custom avionics system (N.E.B.U.L.A.) was designed to obtain a number of relevant metrics during rocket flight and log this data to a MicroSD card as well as offer real-time updates back to ground via 900 MHz radios. These metrics include: altitude, acceleration, pitch, roll, yaw, deployment continuity and GPS location. The N.E.B.U.L.A. flight computer is also capable of triggering deployments, with four deployment MOSFETs present for future rocket flights. Additional features of the board include onboard 5V and 3.3V regulators, I2C output, PWM outputs for servo control or other control devices, and headers to connect external devices to any pin of the Teensy 3.6 microcontroller. The Arduino IDE with the Teensyduino Add-on were used to program the onboard Teensy 3.6 microcontroller, and various libraries were used for the sensors mentioned above. Due to this being the first flight of the N.E.B.U.L.A. system, other COTS electronics were chosen to handle parachute deployment for the rocket. Along with the custom avionics previously described, an Eggtimer Proton and an Eggtimer Quantum with independent batteries for redundancy are used. In regards to power, 7.2V Li-ion batteries were selected, with power being remotely connected using an Eggtimer WiFi switch.

III. Mission Concept of Operations Overview

From the beginning of rocket assembly to the final rocket touch-down, 12 mission phases have been identified. The first is rocket assembly. The launch preparation station will be set up and the 5 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. The charges will be attached, batteries connected, and wires secured. Once the sled is complete, it is loaded into the avionics bay and the threaded rod is attached to the bulkheads on either end. The rod is attached to the aft bulkhead using a nut on other side of the bulkhead. The camera bay is then loaded on top of the avionics while allowing the threaded rod to pass through. The mechanical separation mechanism is then threaded onto the rod with threads in the lower bulkhead of the mechanism. The payload, enclosed in the sabot, is then used to compress the spring and then rotated until locked into place. While this is being done, the shock cords for the nosecone, sabot and spring are all routed up through the side channel of the sabot. The nosecone is then attached to the transition using 4 shear pins. The parachutes are then loaded into their bay with shock cords, quick links, swivels, and flame blankets. Finally, the avionics bay and the parachute bay are then adjoined using shear pins through the upper stage and the avionics coupler.

The payload has 3 primary systems that must be prepared for flight before final integration into the rocket. The first is the parachutes. The main and drogue parachutes have to be folded along with their shock cord, and packed into the parachute chamber. During this step, the primary and backup charges are also prepared and placed into the parachute chamber, but are not yet connected to anything. Once this stage is complete, the parachute chamber is sealed from the top using shear pins. The second system is the electronics, which are split into 4 subsections. The first of these is the COTS deployment systems, which includes the Eggtimer Quantum, backup Eggtimer Quantum, and Jolly Logic parachute release system. These are all tested and run through a testing arming sequence without any other systems or charges connected. Then comes the SRAD avionics, which are again tested and run through a test arming sequence to ensure proper operation. These are all then placed into standby mode, awaiting the final button-up. Third, the static cameras are brought online, and each one of the 5 is tested inside and outside of the body of the payload to ensure proper operation. They are armed and placed in standby mode, awaiting final button-up. Fourthly, the livestream camera is tested, integrated, and connected to its corresponding radio, which is then also armed and tested for connection. These are then placed in standby mode by connecting them through an Eggtimer WiFi switch, which will then be activated on the pad before launch. The third primary system, which is saved for as late as possible in the assembly process, is assembly and installation of the landing motor. Once this stage is started, the payload is considered and treated as a potentially dangerous system, and the assembly area is evacuated of nonessential personnel. The motor is assembled in accordance with manufacturer instructions, secured into the payload, and all final button-up procedures begin. These include, but are not limited to, connecting all batteries to their switches, connecting all igniters to their avionics, securing igniters inside of charges, and sealing the protective walls of the payload. The payload is then immediately loaded into the sabot of the rocket, and once final rocket assembly is complete, the rocket and sabot move to the pad.

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 begins arming. 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 133.9 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 N-class motor. This motor will impart thrust for 3.5 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 nosecone from the forward end. If unsuccessful, the secondary redundant charge with trigger 0.1 seconds after. This begins the sequence in which the payload is ejected using the mechanical separation. 0.5 seconds after nosecone separation, the flight computer will send the signal to the servo, which will rotate the arm, activating the compressed spring to expand and force the sabot containing the payload out of the transition. The spring-loaded sabot will unfurl like a lotus, allowing the payload to safely separate from the rocket. Once the payload is completely clear a second set of charges will activate below the transition (~1 second after apogee). The upper stage and booster section will release from the transition via black powder charges thus releasing the drogue parachute and main parachute with the Jolly Logics armed and ready. The rocket will then descend at a rate of 107 ft/s for 506 seconds with the drogue deployed. At an altitude of 1,000 feet, the Jolly Logic Releases activate and allow for the main parachute canopy to expand. After deployment, the rocket will fall at 24 ft/s for 60 seconds until it safely touches down.

Phase	Start of Phase	End of Phase
Rocket Assembly	Layout 5 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
Nosecone & Payload Ejection	Eggtimer sends signal to e-match to combust nosecone bay ejection charge	Payload is completely separated from the rocket and sabot
Drogue & Main Ejection	Eggtimer sends signal to e-match to combust parachute bay ejection charge	Drogue and main chutes 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	Jolly Logics sense altitude and actuate pin release mechanisms	Main parachute has unraveled and fully inflated
Rocket Descent - Main	Main Parachute is fully inflated	Rocket touches down safely on the ground

Figure 6: Rocket Mission Phases

IV. Conclusion and Lessons Learned

Lessons Learned

Water Bearer is the fourth high powered rocket developed by the RIT Launch Initiative team. Contrary to last year, RIT LI developed our own scientific payload in conjunction with design and construction of the rocket. With these two assemblies, RIT LI will compete in the COTS 30,000 ft. Challenge as well as the SDL Payload Challenge. While it was no walk in the park to complete this year's competition rocket, the team is thrilled with the work we've done and the significant amount we have learned for implementation in the projects to come.

One significant change we made this year was isolating the competition team to roughly 10 members compared to the 20 that were involved last year. This smaller group allowed for more productive planning and execution while discussing the details of design and overall streamlined the rocket development. However, since most of the team consists of mechanical engineers, task delegation for avionics and payload development was significantly restricted. We saw that having a more compact team was beneficial but for next years team, there has to be more variety in knowledgebase to accomplish tasks in a more streamlined fashion across all elements of the rocket.

As expected, time management is always a critical element for completion of such a large scale project. From the get go, design reviews were thrown off course, presentations lasting too long, depth of presentations were too minimal to make on the spot decisions and manufacturing was slow. One of our biggest setbacks was the acquisition of components during the manufacturing phase. The team made the mistake of ordering several parts after winter break. This was caused by the prior time management issues with design reviews during the fall semester and finalization of the rocket's design not being complete until the very last week of the semester. It is imperative that at least 75% of the rockets components be ordered prior to winter break so that manufacturing can immediately start come spring semester. Manufacturing complexity of some rocket components (boat-tail and transition) were also time setbacks but that was due to machine availability primarily. These two components were also way outside the realm of anything LI has attempted in prior years. A custom carbon fiber transition and custom solid aluminum boat-tail were significantly difficult to manufacture. The best ways to combat the time management element of LI's lessons learned is to move forward design reviews in the fall semester, have a significant portion of the rocket assembly ordered before winter break starts, and have a clear cut Gantt Chart in the spring semester for accountability of manufacturing tasks.

Lastly, a major lesson the team learned this year is that testing is essential. Theory is all fun and games until the predicted design runs into issues the week before the launch. Having a completely assembled rocket weeks before a launch is beneficial to truly assess the risks that may come about. It also allows for preliminary testing for a more accurate viewpoint on potential system failures or issues that may arise during flight. Having a complete rocket gives the team plenty of time to make adjustments if necessary before the true flight test comes about.

Conclusion

In its entirety, this rocket build taught LI how to implement a new team structure, using the skill set of each team member to their full potential, keeping on top of pressing elements of the rocket to ensure timely completion, and communicating effectively so the team as a whole can understand the task at hand. This year's team consisted of members who have been involved with LI in previous years so a well rounded basis on rocketry knowledge existed amongst everyone in comparison to last year's team that included members that were brand new to the team. Having the group this year allowed for more concise development and better collaboration because everyone had already been exposed to last years competition rocket. Certain members had been working R&D projects, such as the boat-tail, which gave LI the opportunity to implement elements which had once been foreign and overreaching for past vehicles.

The Water Bearer has been an excellent project to implement our new team structure, utilize previous R&D projects, and create a vehicle RIT can be proud of. Our older members were the glue that held the project together given their in-field experiences, previous exposure to rocketry and a desire for success and victory coming back to the IREC competition this year. The Water Bearer team has been able to work through many difficulties such as remaking a carbon fiber transition, monetary issues, delayed lead times and ineffective communication in order to complete a project which has been worked on so diligently all academic year. By bringing another vehicle to IREC, RIT LI is proving to the college and university its desire elevate RIT's reputation in the rocketry field, instill team building and collaboration in the teams younger members, and create a community of well-rounded engineers with an experience second to none. Each year RIT LI continues to gain notoriety amongst the many clubs, professors, students and community members around RIT. As a diverse team, we continue to exemplify hard work, ethical decision making, team collaboration, and act as a secure foothold for aerospace engineers at RIT.

Appendix A: Additional Subsystem Information

Figure 7: Propulsion Components

Figure 8: Drogue Parachute

Figure 9: Main Parachute

Aluminum 6061 Material Properties

σ_{yield} = 40,000 psi
$\sigma_{ultimate}$ = 45,000 psi
$S_{strength}$ = 30,000 psi
Required Factor of Safety = 5

G5000 High Strength Epoxy

Stress Rating of G5000 Epoxy = 7600 psi (Tension), 3800 psi (shear)
Required Factor of Safety = 5

G12 Fiberglass Body Tube

$\sigma_{ultimate}$ = 38,000 psi

Using (0.7x $\sigma_{ultimate}$) assumption -----> σ_{yield} = 26,600 psi
Using (0.5x σ_{yield}) assumption -----> $S_{strength}$ = 13,300 psi

Figure 10: Material Properties

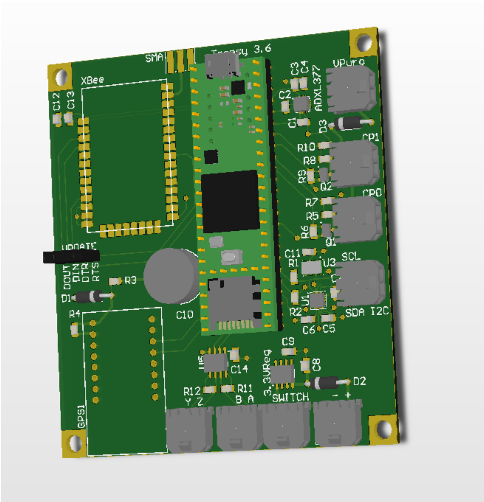


Figure 11: Nebula Custom PCB

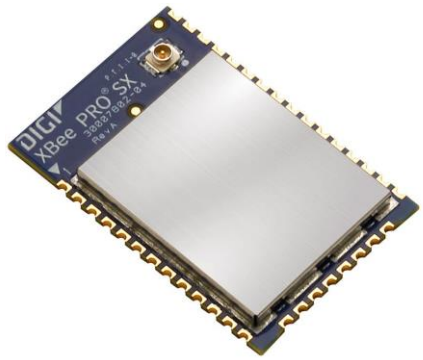


Figure 12: XBee PRO SX Radio Transceiver

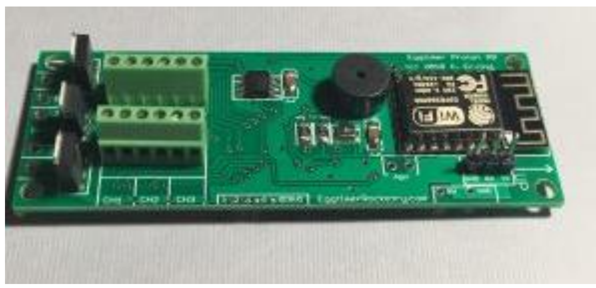


Figure 13: Four Channel Eggtimer Proton

Figure 14: Eggtimer Wifi Switch for Remote Arming

Figure 15: Two Channel Eggtimer Quantum

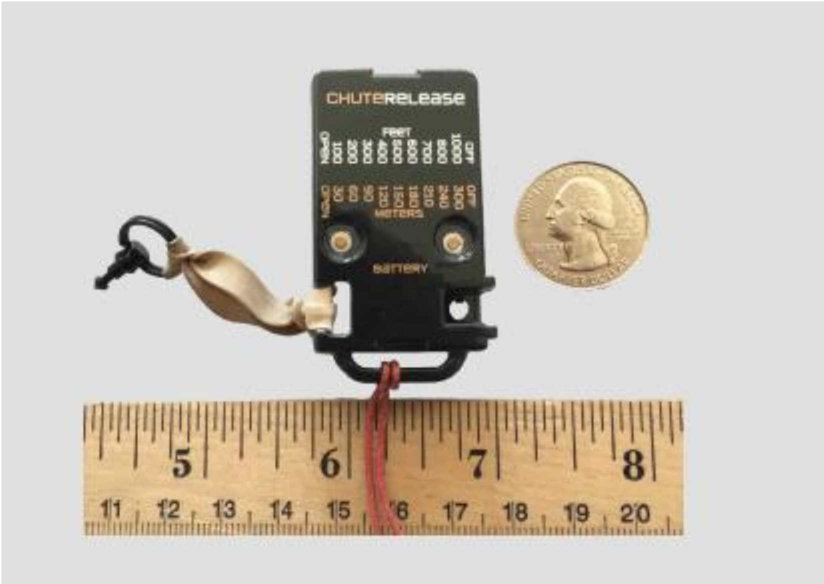


Figure 16: Jolly Logic Chute Release

Appendix B: System Weights, Measures, and Performance Data

Table 1: Rocket Parameters

Airframe Length (inches)	**144**
Airframe Diameter (inches)	**6 (reduces to 5)**
Fin-span (inches)	**12.85”**
Vehicle Weight (pounds)	**43**
Propellant Weight (pounds)	**19.88**

Payload Weight (pounds)	**9.0**
Liftoff Weight (pounds)	**84.7**
Number of Stages	**1**
Propulsion Manufacturer	**Commercial**
Kinetic Energy Dart	**No**

Table 2: Flight Parameters

Simulation Software	**RASAero II**
Launch Rail Length (ft)	**17**
Launch Angle (degrees)	**6**
Lift-Off Thrust to Weight Ratio	**17.83**
Launch Rail Departure Velocity (ft/sec)	**133.9**
Minimum Static Margin	**1.60**
Maximum Acceleration (G)	**19.66**
Maximum Velocity (ft/sec)	**1757.5**
Maximum Mach Number	**1.54**
Target Apogee (ft)	**30,000**
Predicted Apogee (ft)	**28,304**

Table 3: Propulsion Parameters

Propulsion Type	**Solid**
Manufacturer	**Cesaroni Technologies**
Casing Size	**P98-6GXL (six grain, 98 mm by 1238 mm)**
Class	**N**
Type	**N5800**
Total Impulse (lbf-sec)	**4529**
Peak Thrust (lbf)	**1806.2**
Average Thrust (lbf)	**1298.1**
Burn time (sec)	**3.49**

Loaded Weight (lbf)	**32.68**
Propellant Weight (lbf)	**19.89**
Propellant Type	**C-Star (APCP)**
Specific Impulse (sec)	**227.73**

Table 4: Drogue Parachute Recovery Summary

Drogue Parachute Diameter (ft)	**5**
Drogue Parachute Drag Coefficient	**~0.8**
Decent Velocity (ft/sec)	**107**
Deployment velocity (ft/sec)	**144.5**
Deployment acceleration (ft/sec^2)	**146.8**
Deployment velocity with 5 second delay (ft/sec)	**196.4**
Deployment acceleration with 5 second delay (ft/sec^2)	**440.9**
Shock load (lb)	**254.6**
Shock load with 5 second delay (lb)	**764.35**

Table 5: Main Parachute Recovery Summary

Main Parachute Diameter (ft)	**14**
Main Parachute Drag Coefficient	**~0.8**
Decent velocity (ft/sec)	**24**
Deployment velocity (ft/sec)	**67**
Deployment acceleration (ft/sec^2)	**252.5**
Shock load (lb)	**764.35**

Table 6: Main Parachute Shock Cord Specifications

Material	**Kevlar**
Length (ft)	**30**
Width (in)	**0.5**

Thickness (in)	**0.2**
Breaking Load (lb)	**2520**

Table 7: Drogue Parachute Shock Cord Specifications

Material	**Kevlar**
Length (ft)	**10**
Width (in)	**0.5**
Thickness (in)	**0.2**
Breaking Load (lb)	**2520**

Table 8: Nosecone/Sabot Shock Cords Specifications

Material	**Kevlar**
Length (ft)	**5**
Width (in)	**.1**
Thickness (in)	**.1**
Breaking Load (lb)	**300**

Table 9: Recovery Rigging Hardware Specifications

Hardware	**Material**	**Rated Load (lb)**
Nosecone ⅜-24 closed eye nut	Forged Galvanized Steel	500
Sabot ¼-20 closed eye nut	Forged Galvanized Steel	500
Mechanical Separation ⅜-24 closed eye nut	Forged Galvanized Steel	500
Parachute bay ⅜-16 U-Bolts	Steel	1075

Quick links	Steel	2200
Swivel links	Steel	3000

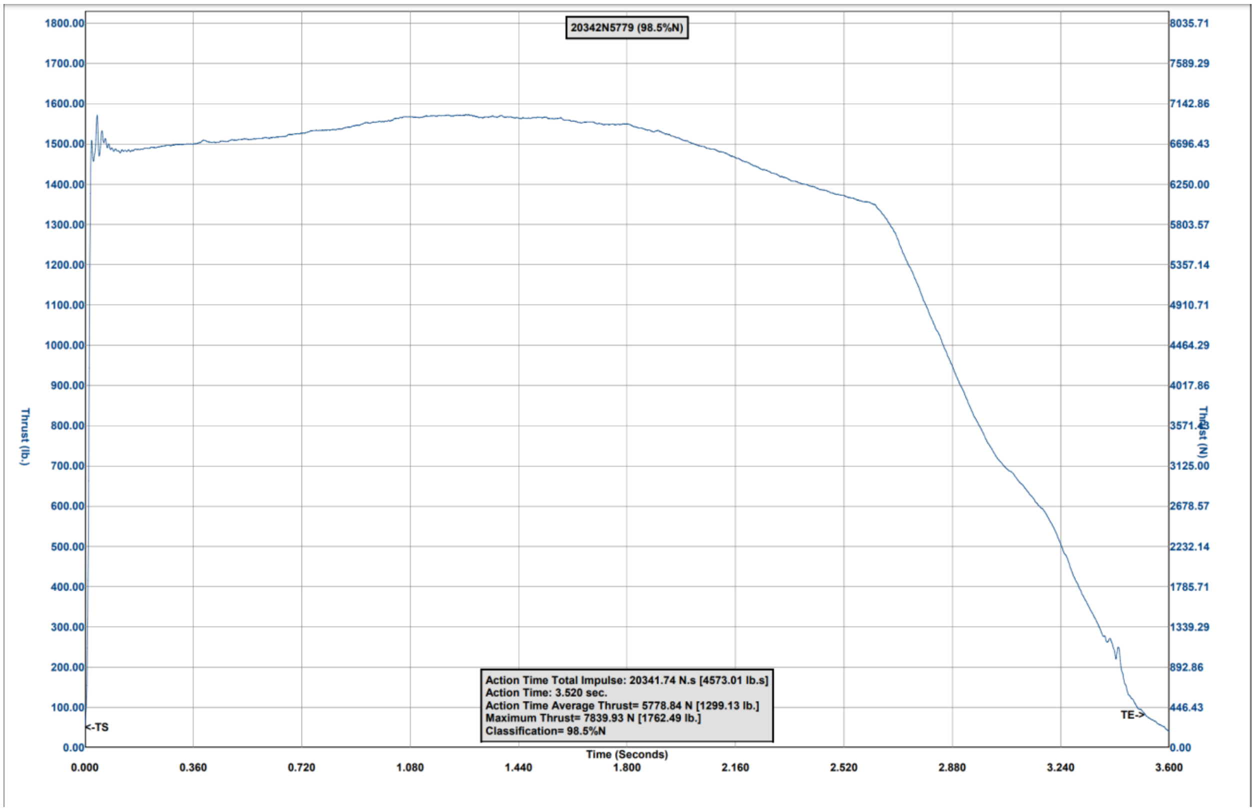


Figure 17: N5800 Motor Thrust Curve

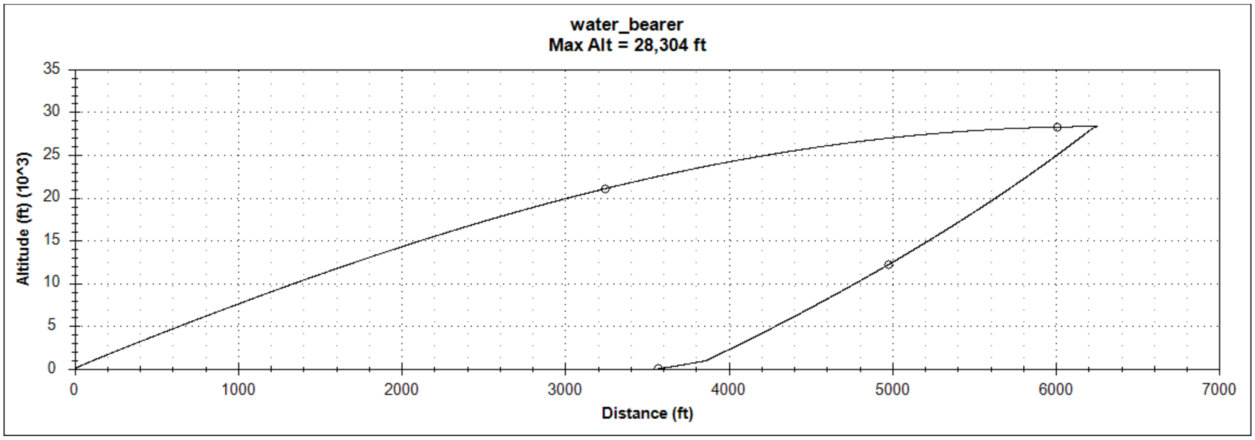


Figure 18: RASAero Flight Profile

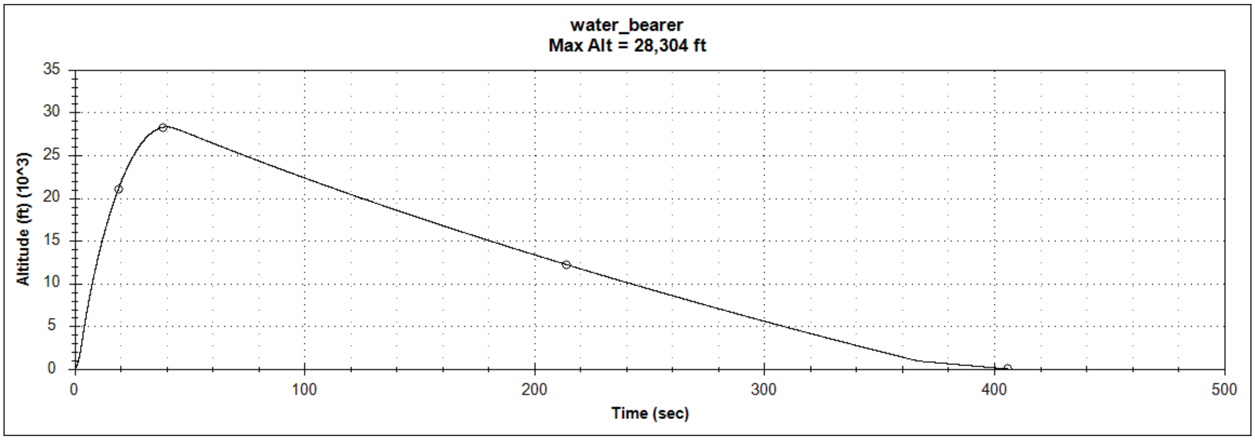


Figure 19: RASAero Flight Altitude

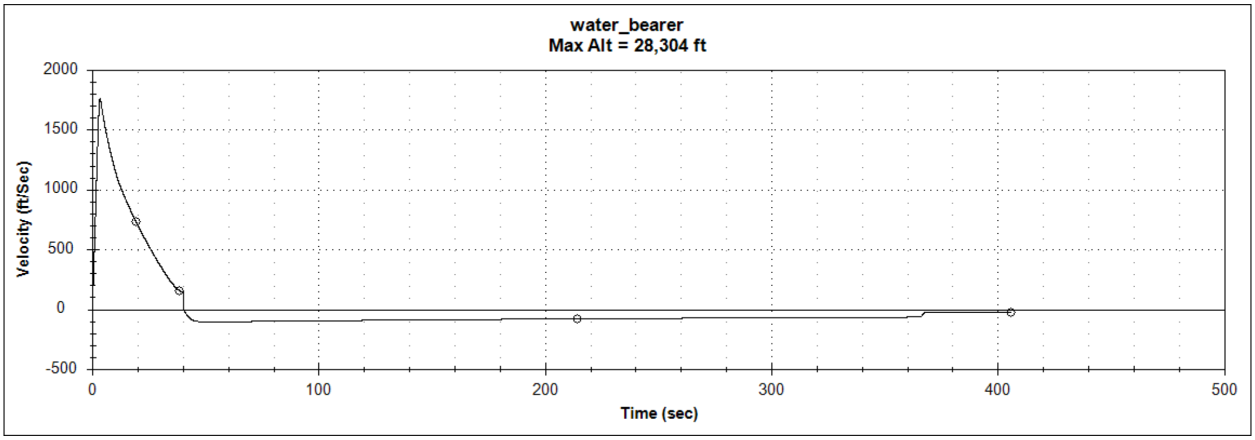


Figure 20: RASAero Flight Velocity

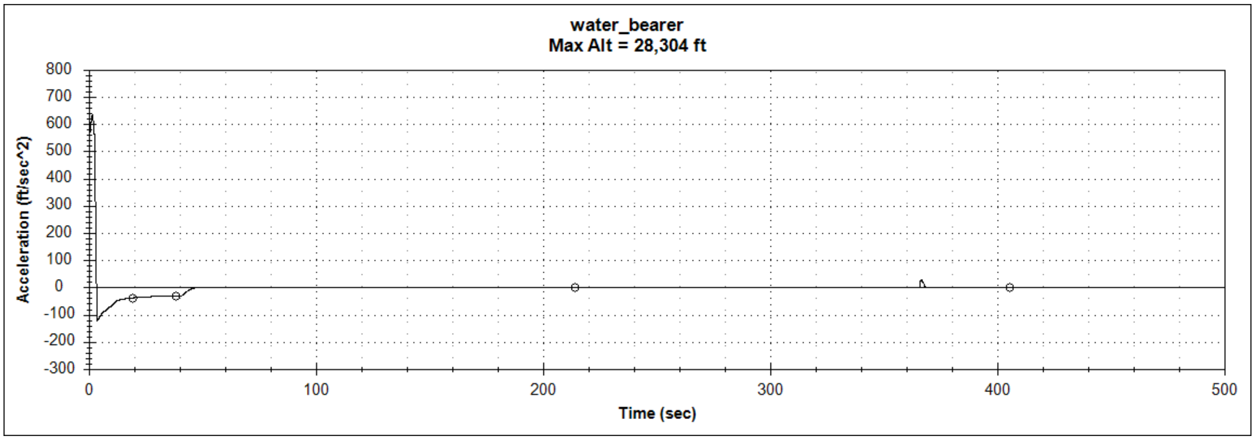


Figure 21: RASAero Flight Acceleration

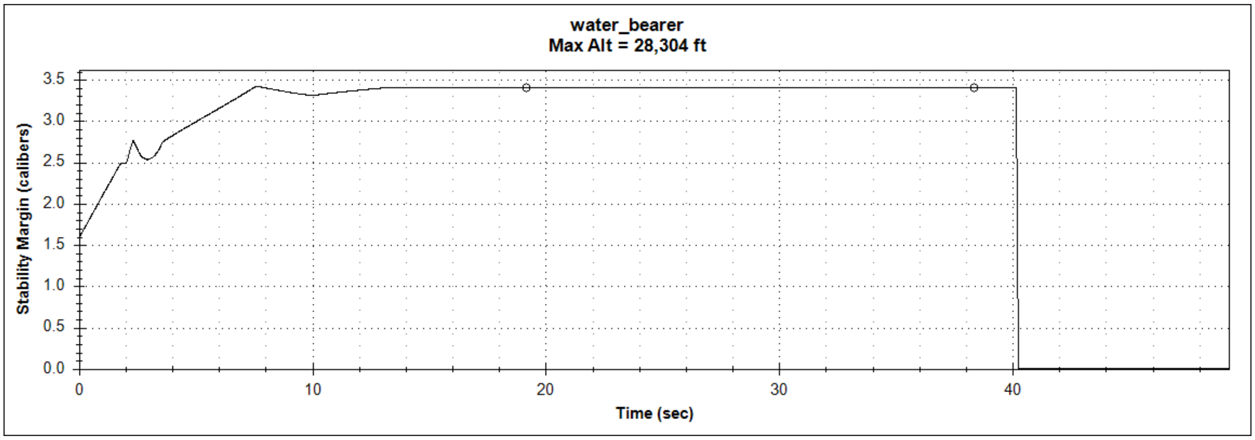


Figure 22: RASAero Stability Margin

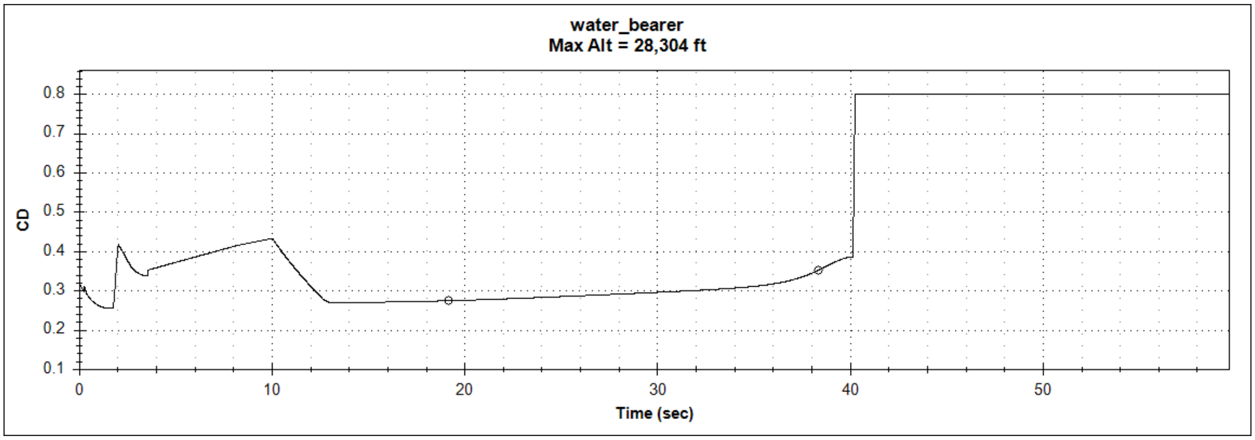


Figure 23: RASAero Drag Coefficient

Appendix C: Hazard Analysis

Team RIT Launch Initiative (87)	**Rocket/Project Name** Water Bearer	**Date** May 20, 2019		
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 D: Risk Assessment

Team RIT Launch Initiative (87)	**Rocket/Project Name** Water Bearer	**Date** 2-27-2019		
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 Team does not have experience with flyaway rail guides.	Hanging weight on rail guides reduced as much as possible	Low
	Flyaway rail guides break or slip off of body tube		Flyaway rail guide design allows for perfect alignment when loading rocket onto launch rail	
			High factor of safety on strength of rail guides, high friction surface between rail guides and outer rocket body	
Rocket does not ignite when command is given ("hang fire"), but does ignite when team approaches to troubleshoot	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 a predetermined amount of time before approaching the rocket	Very Low
	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	Misalignment of fins	Medium	During assembly, fins attached using alignment jig, bolted into the boattail	Very Low

in contact with personnel at high speed		Rocket has a high factor of safety and no control surfaces, resulting in a true flight path	with 8 bolts, and secured with bolted fins	
	Improper alignment of launch rail		Flyaway rail guides designed to detach from rocket body upon exiting launch rail	
	Damage to flyaway rail guides		Nozzle inspections during assembly of motor	
	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 recovery system deploys before exiting rocket, tangling rocket recovery systems	Failure in payload electronics	Low Multiple failsafe systems and redundancies built into payload ejection system	Payload electronics cannot deploy parachute while inside the sabot	Very Low
	Premature triggering of ejection charge		Ejection charge takes additional time after triggering to deploy	
	Sabot walls shift during launch		Payload recovery system separated by plate from rocket recovery system	

Payload recovery systems do not deploy, comes in contact with personnel	Failure in sabot identifications systems Payload electronics glitch	Medium Limited avionics testing	Backup altitude based deployment system Launch towards an area clear of personnel	Low
Main parachute deploys near apogee, rocket drifts to highway	Jolly logic chute deployment system malfunctions	Low main chute deployment system is a flight tested and common system for high powered rocketry	Proper wrapping of main chute in redundant Jolly Logic system	Very Low

Appendix E: 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. Disconnect the switches to conserve battery life.
    - 1.4. Pair mobile device to Eggtimer WiFi switch, and ensure power is off.
    - 1.5. Take the wires from the aft (parachute) bulkhead and screw them into the parachute terminals of the altimeters
        - 1.5.1. The convention is black and white for the Proton, brown and blue for the Quantum
    - 1.6. Place the ematch connector into the receptacle on the parachute bay bulkhead
    - 1.7. Using a multimeter, check continuity from the altimeters to the charge connecter
        - 1.7.1. Ensure there is no continuity between the two altimeters
    - 1.8. Take the wires from the forward (camera bay) bulkhead and screw them into the nosecone deployment terminals of the altimeters
    - 1.9. Place the ematch connector into the receptacle on the sabot bulkhead
    - 1.10. Using a multimeter, check continuity from the altimeters to the charge connecter
        - 1.10.1. Ensure there is no continuity between the two altimeters
    - 1.11. Disconnect both connectors
    - 1.12. Using a multimeter ensure continuity through the ematch
    - 1.13. Install ematches on the connector, being sure to connect one emach between the two terminals marked with black dots and the other ematch on the remaining pair
    - 1.14. Re-insert the connectors and check continuity across the altimeter leads to ensure ematch continuity once again
    - 1.15. Apply electrical tape to the top of the connector
    - 1.16. Activate N.E.B.U.L.A. custom flight computer
        - 1.16.1. Verify startup
        - 1.16.2. Verify radio communication and satellite lock
        - 1.16.3. If applicable, turn off board to save batteries

2. **Charge Preparation**
    - 2.1. Apply proper PPE per IREC specification
    - 2.2. Measure out 5.75 grams of FFFFG black powder
    - 2.3. Pour into 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 6.25 grams of FFFFG black powder
    - 2.8. Pour into 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 nosecone deployment bay, with 1 and 1.25 grams

3. **Drogue/Main Parachute Preparation**
    - 3.1. Inflate the main parachute and ensure the shroud lines are free of any tangles
    - 3.2. 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.
    - 3.3. Fold in half twice such that it resembles a pointed oval
    - 3.4. Lay the shroud lines inside the parachute, folding them in half so that the connection point is at the bottom of the parachute
    - 3.5. Fold the parachute in half lengthwise one final time, keeping the shroud lines inside like a taco
    - 3.6. Roll the parachute from top to bottom, keeping it as tight as possible
    - 3.7. Attach both Jolly Logics in series and follow instructions for deployment altitude programming

3.8. Repeat steps 3.1 - 3.6 for the drogue
3.9. Attach the long end of the main shock cord to the booster bulkhead eyebolt using a quicklink
3.10. Attach the short end of the main shock cord to the short end of the drogue shock cord using a larks head knot.
3.11. Feed the other end of the drogue shock cord through the flame blanket hole, leaving the flame blanket near that end unfolded for later use.
3.12. Attach the long end of the drogue shock cord to the parachute bulkhead using a quicklink
3.13. Attach the main parachute to the main shock cord in its designated place using a quicklink
    3.13.1. Tether each of the Jolly Logics to the quicklink using small lengths of 300# Kevlar shock cord
3.14. Attach the drogue parachute to the drogue shock cord in its designated place using a quicklink
3.15. "Z-fold" the shock cord between the main parachute and the booster bulkhead
    3.15.1. Insert this bundle into the parachute bay
3.16. Feed the main parachute into the parachute bay
3.17. "Z-fold" the shock cord between the main parachute and drogue parachute
    3.17.1. Insert this bundle into the parachute bay
3.18. Wrap the flame blanket around the drogue parachute and feed this bundle into the parachute bay, covering as much of it as possible
3.19. "Z-fold" the shock cord between the flame blanket and the parachute bulkhead
    3.19.1. Insert this bundle into the parachute bay
3.20. Leave parachute bay unattached to avionics coupler tube for later assembly

4. Booster Preparation

4.1. Build motor by following the Pro-98 instructions
4.2. 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
4.3. Apply a thin layer of lithium grease to the boat-tail threads aft of the motor
4.4. Screw the retaining into the boat-tail using the tool

5. Nosecone/Payload Bay Preparation

5.1. Attach nosecone and sabot shock cords to mechanical separation using quicklinks on either ends
5.2. Insert 4 GoPro's into camera bay, routing charge wires downward, and insert assembly into transition piece fully, making sure to align GoPro's with their respective holes
5.3. Insert mechanical separation assembly into transition, feeding servo wiring down through camera bay, and feeding shock cords up through designated holes.
5.4. Prepare Payload
    5.4.1. Connect all batteries, fold and load parachute
    5.4.2. Load and connect ejection charges
    5.4.3. Seal payload
5.5. Slide payload into sabot, seal sabot
    5.5.1. Test arm the payload to confirm good sabot connections
5.6. Insert spring into mechanical separation designated area
5.7. Using sabot-payload assembly, compress spring while lining up the servo arm and sabot keyhole, while making sure to route wiring and shock cords through the channel in the sabot
    5.7.1. Rotate sabot 90 degrees clockwise to lock into place
5.8. "Z-fold" all shock cords and insert into nosecone bay
5.9. Slide the nosecone over the sabot until it interfaces with the transition piece, keeping all cords and wiring on the interior
5.10. Secure nosecone and transition together using nylon shear pins

6. Avionics Button-up

6.1. Apply a ring of chromate tape to the inside edges of the avionics bay to serve as a gasket seal
6.2. Ensure any boards that must be turned on prior to button up are functioning
6.3. Insert the avionics rod through the camera bay and into the lower bulkhead of the mechanical separation system

6.4. Connect the power supplies for the GoPro cameras, the wiring for the nosecone deployment charges, and the servo control wiring to their respective connection points on the avionics sled
6.5. Slide the avionics sled onto the threaded rod and up into the avionics coupler tube
6.6. Secure the avionics sled into the bay by attaching both nuts onto the threaded rod on the exterior of the parachute bay bulkhead

7. Final Airframe Assembly

7.1. Attach the upper stage airframe to the avionics coupler tube using nylon shear pins

8. Pre Walkout

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

9. Pad Ops

9.1. Carefully slide the rocket onto the launch rail
9.2. Raise the rocket to the desired launch angle
9.3. Arm the altimeters by removing keys and ensure proper startup sequence
 9.3.1. Three beeps for Proton
 9.3.2. Rapid beeps for Quantum
 9.3.3. If either altimeter displays off-nominal, proceed to section 13 “clearing anomalies on the pad”
9.4. Arm payload with command from computer
 9.4.1. Wait for confirmation of arming
9.5. Clear the pad of all non-essential personnel
9.6. Insert the dowel with igniters as far up into the engine as it will go
9.7. Strip the leads of the igniters and attach them to the launch control leads
 9.7.1. Confirm they are attached in parallel
 9.7.2. Confirm they are laid out so there is no possibility of a short
9.8. Test launch controller continuity at the pad level
 9.8.1. If no continuity, proceed to section 13
9.9. Ensure one final time that all avionics are functional
 9.9.1. If not, proceed to section 13

10. Pre Launch Poll

10.1.	Avionics	Go	No Go
10.2.	Payload	Go	No Go
10.3.	Cameras	Go	No Go
10.4.	Visual Tracking	Go	No Go

11. Post Flight

11.1. Check film for approx. landing location
11.2. Check avionics for current/last known position
11.3. Proceed to landing site per IREC rules and regulations
11.4. Document the landing site/state of the rocket
11.5. Record altitude from the altimeters per IREC rules and regulations
11.6. Turn off avionics
11.7. Re-pack parachutes for ease of carrying
11.8. Return to pits/ post flight inspection

12. Clearing Anomalies on the Pad

12.1. Proton
 12.1.1. No beep pattern
  12.1.1.1. No continuity in either ematch
  12.1.1.2. Disarm altimeters

12.1.1.3. Pull rocket off rail, problem is in both bays and will likely take some time to fix

12.1.2. One beep pattern

12.1.2.1. Parachute ematch does not have continuity

12.1.2.1.1. Disarm altimeters

12.1.2.1.2. Lower rocket

12.1.2.1.3. Disassemble parachute bay

12.1.2.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down

12.1.3. Two beep pattern

12.1.3.1. Nosecone ematch does not have continuity

12.1.3.1.1. Disarm altimeters

12.1.3.1.2. Lower rocket

12.1.3.1.3. Disassemble nosecone bay

12.1.3.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down

12.2. Quantum

12.2.1. Four beep pattern

12.2.1.1. Parachute ematch does not have continuity

12.2.1.1.1. Disarm altimeters

12.2.1.1.2. Lower rocket

12.2.1.1.3. Disassemble parachute bay

12.2.1.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down

12.2.2. Five beep pattern

12.2.2.1. Nosecone ematch does not have continuity

12.2.2.1.1. Disarm altimeters

12.2.2.1.2. Lower rocket

12.2.2.1.3. Disassemble nosecone bay

12.2.2.1.3.1. If problem can be determined, fix and restart pad ops procedures, otherwise stand down

12.3. Custom avionics non-functional

12.3.1. Stand down, will require taking the rocket more or less fully apart

12.4. No continuity for motor igniter

12.4.1. Check leads for contact

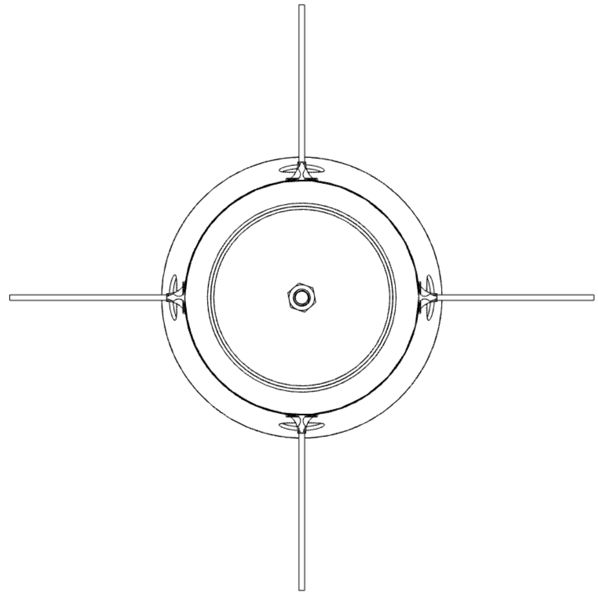
12.4.2. See LCO if other issues

12.5. Payload Eggtimer does not connect

12.5.1. See 12.1

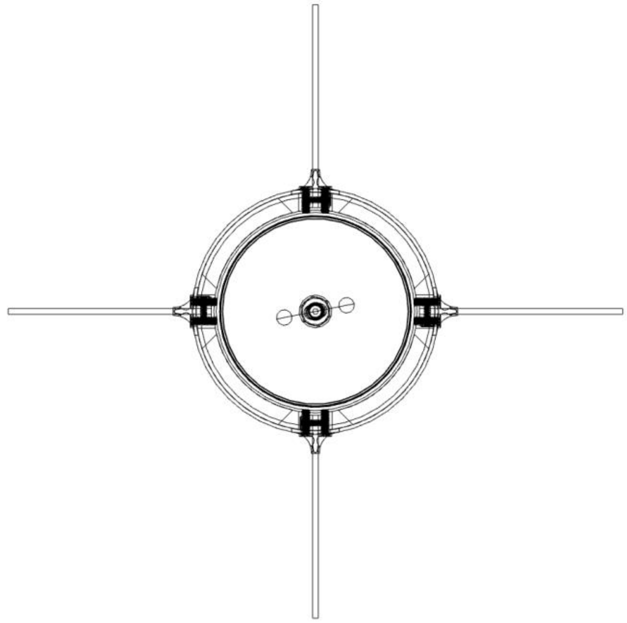
Appendix F: Engineering Drawing Appendix

Drawing 1: Rocket Assembly

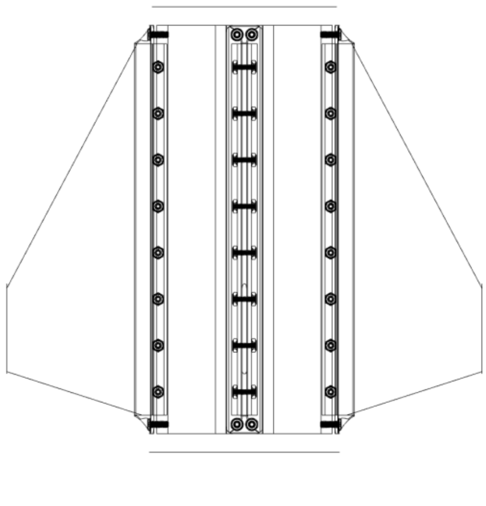


Drawing 2: Rocket Assembly Bottom View

Drawing 3: Booster Assembly

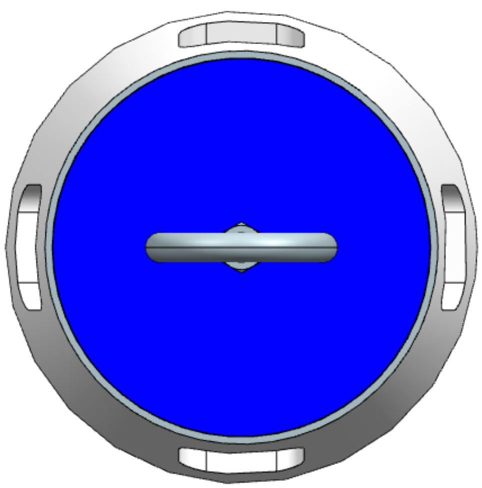


Drawing 4: Booster Assembly Bottom View



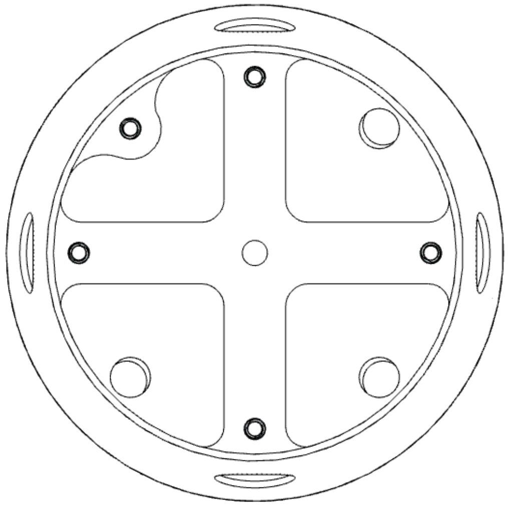
Drawing 5: Fin and Fillet assembly

Drawing 6: Avionics and Camera Bay Assembly



Drawing 7: Avionics and Camera Bay Assembly Bottom View

Drawing 8: Mechanical Separation and Payload Assembly



Drawing 9: Mechanical Separation Bottom View

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