Team 83 Project Report for IREC 2018

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This report is the culmination of a year of development and growth by UB SEDS in the design, construction, and testing of the largest rocket that has been created by the student club. Launching with a 98mm CTI motor the fiberglass airframe stands 9.4 feet tall and is broken up into two main sections. The bottom is composed of the motor, drogue parachute and the fin can, while the top contains the 3U payload, avionics, parachute deployment systems, and the main parachute. The recovery system will be controlled by a SRAD flight computer that will deploy the parachutes and provide real time GPS coordinates to the ground station. These systems will be working together to carry a payload containing multiple sensors to 10,000 feet.

Nomenclature

COTS	=	Commercial Off the Shelf
GPS	=	Global Positioning System
SRAD	=	Student Researched and Designed
PSI	=	Pounds per Square Inch
SDL	=	Space Dynamics Laboratory
SDR	=	Software Defined Radio

I. Introduction

UB SEDS offers many projects to meet the interests of all of its members. Each of these projects groups functions as their own group allowing independence within each group. Currently UB SEDS has projects in rocketry, astronomy, high-altitude weather ballooning, educational outreach, and battlebot development. UB SEDS also started UB Nanosat, which is a NASA and Air Force Research Lab funded research lab that develops satellites to be launch into space.

The UB SEDS rocketry team was divided into sub-projects focused on airframe, avionics, dynamics, recovery, and propulsion. Project tasks, such as computer modeling and fabrication are broken up across all of the team members.

We originally wanted to enter a rocket with an SRAD motor, however, due to setbacks, including receiving important infrastructure 5 months after it was ordered and development taking longer than expected the decision was made to change to a COTS motor. While a SRAD motor could have been produced for the 2018 competition the decision was made to switch to a COTS motor due to possible safety oversights that occur when a project is being rushed to completion and a lack of hands available to help development after the academic year ended. We still plan to develop rocket motors so that they will be ready for a later year.

II. System Architecture Overview

Figure 1: Section View

A. Propulsion Subsystems

For the 2018 competition a COTS rocket motor was chosen. The original goal for the UB SEDS team for IREC 2018 was to build a Student Research and Designed SRAD Motor. However, due to several setbacks and delays the decision was made in May to switch to a COTS motor. With the switch to a COTS motor taking place so late in the design process, our first choice is a CTI M3400 for three reasons. First the diameter of the motor was chosen to be 98mm due to the planned diameter of the SRAD motor that SEDS was developing. Second, the average thrust was desired to be 2400 N or greater so that the velocity of the rocket off of the launch rail was 100 ft/s or faster. Finally, the Cesaroni M3400 - WT was chosen because when compared to other motors that met the previous two requirements the M3400 produced a simulated appogee that was over 10,000 ft while still near the target altitude. If acquiring a M3400 becomes an issue due to the late change from SRAD to COTS an Aerotech M2400 will be used, Appendix A has values for the M32400 in the comments column.. Note: any calculations done assuming maximum flight conditions are assuming flight on a CTI M3400.

B. Aero-structures Subsystems

1. Upper Assembly Design

The structure consists of two 6.348 inch outer diameter composite body tubes which have a thickness of 0.1 inches. These tubes are comprised of hand laid fiberglass. This diameter was selected as it allows for adequate internal dimensions to house a 3U payload, as well as have supporting structure for a 98 mm motor mount. This also enables the use of a dual deploy recovery system, as the structure can split apart in the middle and at the nose cone to allow for drogue and main parachute deployment. The material for these body tubes was selected to be fiberglass as it provides a high strength to weight ratio and is easy to work with. A 3/16 inch relief hole is drilled in the upper body tube 1 inch down from the bottom of the nose cone shoulder.

The body tubes will be held together by a coupler which has an external diameter of 6.148 inches. This coupler is 13.5 inches in length. This was chosen to allow the coupler to sit in each body tube 6.75 inches, ensuring that it is seated over one body tube caliper length into either body tube. The coupler will be epoxied to the bottom body tube, and will permit the upper body tube to slide on and off it. The configuration will allow for easy integration of the avionics and payload, which are housed in the upper body tube. The avionics and payload sit within a removable aluminum structure which is retained by screws running through the exterior of the body tube. By having this structure be removable this greatly simplifies the avionics integration, and enables it to be worked on with relative ease. This also allows for the black powder deployment charges to be loaded safely and effortlessly.

This structure, herein referred to as the avionics payload canister, is comprised of three 6061 Aluminum bulkheads which are connected together by four quarter inch aluminum threaded rods, spaced evenly ninety degrees apart around the canister. Aluminum was chosen for this structure to allow for tapped screw holes to be placed around the exterior of the bulkheads comprising the assembly. This attachment method was selected so that the canister can be easily removed from the upper body tube. Each of the bulkheads has 8 tapped 6-32 screw holes around the exterior. These screw holes are placed at 18 degrees on either side of the rod holes. This allows for a symmetrical pattern around the exterior of the canister and body tube. There are a total of 24 steel screws which retain the canister within the upper body tube. All exterior mounting screws will have Loctite applied for final integration.

The bottom and top bulkheads have the necessary hardware for the recovery system. There are two 0.75 inch high, 1 inch diameter aluminum tubing caps which house the black powder ejection charges. These are attached to the bulkheads using ¼-20 screws. Next to the charge holders there are holes drilled in the bulkheads which allow for running wires from the flight computers. On the upper and lower bulkhead there are 1.25 inch wide ¼ inch shaft diameter steel U-bolts which allow for the parachute cords to be attached. These U-bolts are run through clearance holes and are retained by nuts on either side of the bulkhead.

Each of the bulkheads is held at a certain distance from one another on the rods using washers and nuts, which have Loctite applied to prevent them from loosening. Between the upper and middle bulkheads the avionics mount is placed and between the middle and lower bulkheads the payload is housed. The bottom of the middle bulkhead and the top of the bottom bulkhead have square recesses machined out that allow for the payload to sit within. These recesses are 0.126 inches deep and prevent the Cubesat payload from moving inside the structure.

The avionics are mounted onto a 3d-printed plate comprised of Polyethylene Terephthalate Glycol-modified plastic. This type of plastic was selected due to its high glass transition temperature. This will ensure that the expected high temperatures within the air-frame will not cause the mounting plate to become soft and lose structural integrity. This 3d-printed mounting plate is attached to the canister through two of the threaded rods. The plate has four extrusions off the sides, one at each corner, with quarter inch holes allowing the threaded rods to run parallel to the plate. On the outside of the plate at each of these corners, a washer and nut are tightened down and held in place using Loctite.

2. Lower Assembly Design

The lower fin can assembly utilizes four 0.25 in thick fiberglass bulkheads encasing the 4.1 in diameter fiberglass motor tube, with three 29.5 in threaded aluminum rods equally spaced 120° around the motor tube. These rods serve to enhance the structural rigidity of the assembly, especially along the long axis of the rocket.

These rods also serve as the mounting framework for the rail buttons. Two identical custom-machined aluminum mounts, rectangular prisms in shape, are affixed to the rods with a washer and nut either side. These mounts use two perpendicular holes, one smooth 0.25 in through-hole to slide the mount onto the rod, and one threaded hole perpendicular to the inside of the lower body tube. These threaded holes are aligned to 0.25 in holes drilled in the body tube. The airfoil-shaped rail buttons (for less drag during flight) are then screwed into the rail button mounts.

The fins are mechanically locked in place to the fin can assembly by the three lower fiberglass bulkheads. The center of these three, known as the fin centering bulkhead, has three 0.25 in by 0.527 in notches equally spaced 120° around the outer diameter of the bulkhead corresponding to a 0.25 in by 0.495 in notch in the center of each fin's inner root chord (located within the body tube). The two other bulkheads, known as the fin tab bulkheads, are similar, except they each have three equally spaced notches (0.25 in by 0.504 in) around the inner diameter. These correspond to notches 0.495 in from the ends of the inner root chord of the fin, such that the bulkheads lock down the fin from being pulled out perpendicular from the motor tube. This, combined with the fin centering bulkhead notches, ensures that the fins are mechanically locked into place. The fins and corresponding bulkheads are held to the motor tube using structural epoxy, with the joints having fiberglass cloth pressed into them. These bulkheads are also epoxied to the interior of the lower body tube to prevent the fin can from moving and to distribute the motor thrust to the body tube.

The motor is held in place by its thrust ring on the aft end, and with a ⅜ in steel threaded rod on the fore end. The threaded rod is held in place with a 4.15 in diameter, 0.5 in thick aluminum bulkhead affixed to the for end of the motor tube. The bottom 0.25 in of the motor retention bulkhead is cut to a diameter of 3.8 in to create a lip that secures the bulkhead in place laterally. The ⅜ in steel threaded rod is secured to the bulkhead with a washer and nut either side of the bulkhead, and threads into the motor casing to secure the motor. This keeps the motor held under tension and the motor tube held under compression by the motor retention bulkhead and the motor thrust ring. The motor retention bulkhead also has two 0.3 in holes to mount a 0.25 in U-bolt for the recovery system. The boat tail is secured by a 0.5 in. aluminum bulkhead located at the bottom of the fin can. The bulkhead is attached to the fin can through the threaded rods and is held on by lock nuts. This bulkhead seats inside the boat tail and has 6 6-32 tapped screw holes symmetrically around the exterior. The boat tail has a corresponding 6 clearance holes and is held on by these steel screws. The boat tail is attached after the motor is inserted and serves as a redundant motor retention method. The boat tail covers the exterior 0.5 in. of the motor casing and prevents the motor from sliding out in the event of the retention bulkhead failing.

A 3/16 inch relief hole is drilled 1 inch down from the bottom of the coupler.

3. Upper Analysis/FEA

Finite element analysis was performed on the avionics payload canister to analyze its performance under the expected loading throughout flight. Structural analysis data was set up with an acceleration of 32.9 G's to simulate maximum flight conditions with a factor of safety. Fixed supports were placed in the tapped holes surrounding the bulkheads. A distributed load of 10 lbs was placed on the bottom bulkhead to simulate the scientific payload.

The results of this test validated our aluminum structure. Maximum deformation on the body occurred in the center of the middle bulkhead and was 1.6E-2 mm. Equivalent stress was uniform at 7.5 Pa.

Analysis of parachute mechanisms was conducted by applying a 300 lb load to surface of ejection on the top bulkhead. This was done to simulate the impact of the ejection charges. All other conditions were identical to prior analyses. Results from this test proved to be similarly valid. The ejection charge and corresponding bulkhead experienced a max deformation of 5.1E-2 mm.

From these analyses we determined that the avionics payload canister would be structurally sound for launch.

4. Lower Analysis/Fiberglass Properties

Composite material testing was performed to calculate the structural integrity of the fiberglass components molded. The testing of the fiberglass was used to find the compressive strength as well as Young's Modulus. To run these tests we created sample fiberglass sheets and cut them into two sets of tabs with varying lengths for tensile and compression testing. All tabs had a cross sectional area near 0.05 square inches.

The compression tabs were tested to their breaking point. The ranging breaking points measured in pounds-force (Ibf) were divided by their corresponding cross sectional area, yielding their Ultimate Compressive Strength in PSI. The average Ultimate Compressive Strength was calculated to be 23532.2 PSI.

The compressive strength required by the body tube were calculated by multiplying the peak acceleration of the rocket and the mass of the rocket at the peak acceleration to find the max compressive load, this value was then divided by the cross sectional area of the corresponding tube. These values were then converted to pounds-force and PSI. The max load was 864.4 Ibf. The required compressive strength for the body tube and motor tube were 110 PSI and 172 PSI respectively.

The fiberglass laid was proven to be structurally reliable as the compressive strength of the fiberglass was much greater than the highest compressive strength required (23532.2 PSI compared to 172 PSI). This yields a factor of safety of 137. Since this model for strength calculations does not include the drag forces and consider buckling effects, this high factor of safety compensates for these inaccuracies in the calculations. Furthermore, as this was UB SEDS first year manufacturing our own tubes, an extremely high factor of safety was preferred to ensure that the tubes would survive flight even if there is a weak point in the layups.

The centering rings retaining the motor tube was also tested. For this test a full scale mockup of one of the ring assemblies was created and tested in compression to its breaking point. This test consisted of one of our hand laid fiberglass rings epoxied to a small motor tube and body tube segment as they are connected in the airframe. This test resulted in a breaking point of 950 Ibf. Since the max load of the rocket is only 864.4 Ibf the centering rings retaining the motor tube was proven to be sufficient.

Maximum tensile strengths for both the fiberglass motor tube and body tube were calculated, though not required, as there are no tensile forces present on the body tubes during flight. By dividing the maximum load by the cross sectional area of each tested sample, we were able to calculate a maximum tensile strength of 35086.46 PSI. In order to determine the maximum tensile force required to cause failure of the body tube or motor tube, the maximum strength was multiplied by the respective cross sectional areas. We determined the maximum force that the body tube can withstand to be 275340.57 lb. and the motor tube to be 176274.37 lb.

5. Fiberglass Components Assembly Process

To make our fiberglass body tubes we used a 6.148 inch outer diameter Blue Tube as a mandrel to wrap our fiberglass. A layer of mylar was first wrapped around the tube so that the epoxy would not cure to the mandrel. 10 rectangles of fiberglass were cut out to the length and circumference of the airframe. These layers were then wrapped around the mylar and wetted out with epoxy to create a new fiberglass tube. The start of each layer was offset in a pattern of 180 degrees, followed by 90 degrees, then 45 degrees so that no layer seams would align. On the lower body tube a layer of mylar was wrapped around the outside of the layup to create a smooth surface for airflow. For the upper body tube we decided to switch to peel ply for a smooth outer surface to reduce the need for sanding. Once cured the layups slid off the mandrel and were cut down to size. The motor tube was made following the same process but on a smaller diameter phenolic tube.

Centering rings for the fin can were cut out of sheets of our own fiberglass. These sheets were made with 25 layers of fiberglass laid on a sheet of wax paper to prevent adhesion with the build surface. Centering rings were then cut out with a Dremel and a band saw following a template from our CAD model. The fins were originally going to be made out of a similar sheet of fiberglass but we decided to use commercial off the shelf fiberglass for the fins over concerns about the aerodynamic forces during flight.

The remaining fiberglass components, the coupler, boat-tail, and nose cone, all had unique geometries specific to our rocket design. To fabricate these parts custom mandrels were designed and 3d-printed. The coupler was made by wrapping fiberglass around a 3d printed tube as a mandrel, utilizing the same procedure as with the airframe tubes.

For the boat-tail a mandrel was generated using the CAD model for the boat-tail that was designed to improve our aerodynamics. This mandrel was 3d-printed in PLA and prepared for use with coats of wax and a release film. Two shapes of fiberglass were used in the the 10 layer layup. The main shape was a semicircle with tabs on each end. The main section folded around the slope of the mandrel while the tabs would fold over to form the shoulder and the flat end of the boat tail. Circles of fiberglass were put on the flat end tabs to keep them in position and to increase strength. Three pieces of peel-ply were laid over the fiberglass for a smooth finish. This gave a one piece fiberglass boat-tail. The screw holes and motor hole were then cut out once cured.

The profile of the nose cone was generated using equations for a Von Karman nose cone. The mandrel for this object needed to be designed in multiple pieces due to build volume restrictions on our 3d printer. Once printed each piece was fit together, then prepared the same way as the boat-tail mandrel. The fiberglass was cut to form a single piece layer; three leafs of the nose cone profile connected to a rectangle the length of the shoulder circumference. For each layer the shoulder was wrapped around first then each leaf of the nose cone profile was folded up into place, rectangles of fiberglass were then placed over the seams between each leaf for added strength. After ten layers, peel-ply was placed to give a smooth surface. When test fit on the body tube, there was an expected gap between the end of the nose cone curve and the outside of the body tube. A thick epoxy was used to fill this gap then sanded to create a smooth transition between nose cone and body tube. A fiberglass bulkhead with a steel U-bolt was then epoxied into the shoulder for the recovery harness.

C. Recovery Subsystems

1. Parachute Design

The recovery system consists of drogue and main parachutes, which are deployed through primary and backup deployment events. Located in the middle of the rocket, the drogue deployment charge will separate the rocket into two halves at apogee. Holding these two halves of the rocket together will be 50 feet of ¼ ” tubular Kevlar, which has a tensile strength of 9,500 lbs. The drogue parachute will be secured to the recovery harness ⅓ of the length of the recovery harness (16.67 feet) from the top half of the rocket. The main parachute ejection charge will fire at 1250 ft., with the backup charge set to deploy at 1100 ft. At this point, the nose cone will separate from the upper tube, connected by another 50 ft of ¼” tubular Kevlar. This separation will pull the main parachute out of the rocket, being attached to the shock cord 16.67 feet from the nose cone.

Both parachutes are made of Ultra-Low Porosity Ripstop Nylon. This material was chosen as it complies to Military Specification MIL-C-44378, now PIA-C-44378, and has a breaking strength of 45 lbs. Both parachutes are of a hemispherical design, with a drag coefficient of .62 [1]. The drogue parachute was sized such that the steady state descent velocity would be 120 ft/sec, resulting in a parachute 22.8” in diameter. The main parachute is 111” in diameter, resulting in a descent velocity of 25 ft/sec. In order to calculate the descent velocities listed above, the rocket was assumed to be in a steady state fall, such that the only forces acting on it were gravity and the drag force generated by the parachute. As these forces act in opposite directions, they were set equal to each other, and the required parachute areas were determined.

Each parachute consists of 8 gores sewn together using a short straight stitch pattern. After each gore seam was stitched, the seams were butterflied open and bias strips were top-stitched along each side of the seam, reinforcing it. Bias strips are lengths of material cut at a 45 degree angle from the grain of the fabric (along the “bias”); this is done with non-stretchy materials because at 45 degrees from the grain the material becomes significantly more flexible. By adding the bias strips along the butterflied gore seams in this way, non-simultaneous failure modes were built in to verify that the parachutes will continue to function after deployment.

In the case where total failure did occur, the initial impact would rip open the straight stitch holding the gores together, but the seams would still be held together with the bias strips, which would flex to their maximum extension before the seams holding them began to fail. This tiered approach to the failure modes is intentional because the maximum shock experienced in parachute deployment lasts for a fraction of a second, and the time needed to flex the bias strips should ensure that the parachute will not fail during deployment.

Shroud lines were then sewn onto the parachute, and when possible, they were aligned with the gore seams to make the parachute even stronger. These lines were made of ½" tubular nylon, with a breaking strength of 2,000 lbs. Six lines were sewn onto the drogue parachute, while 8 lines were used for the main. The additional two shroud lines were used on the main in order to reduce the loading on each line. Additionally, whenever possible, lines opposite of each other were sew on from a single length of nylon to help distribute the load more symmetrically around the parachute and reduce the number of seams, which cannot withstand as much load as the tubular nylon. Finally, the shroud lines were secured together around a swivel rated for 3,000 lbs. to ensure they do not become tangled and to comply with SA Cup regulations.

2. Avionics

Our avionics consist of the following subsystems:

- Primary SRAD flight computer with GPS telemetry.
- Raspberry Pi SRAD camera system.
- Secondary COTS flight computer.
- Secondary COTS GPS tracker.
- Tertiary SRAD RDF tracker.
- Bottom section SRAD RDF tracker.

We based our initial flight computer design on an Arduino Uno, however we quickly ran out of available program storage space and upgraded to a Teensy. The sensor modules that we are using include a BMP280 barometric pressure sensor, an ADXL345 accelerometer, a MTK3339 GPS module, and an XBee-PRO 900HP 10kbps radio.

In order to provide optimal apogee detection we implemented a Kalman filter. Our Kalman filter combines our sensor measurements with a dynamics model to improve state estimation above what either source could do alone. Our Kalman filter combines sensor inputs from the barometer and accelerometer along with a simple quasi-one dimensional model to estimate our position, velocity and acceleration and improve on our apogee detection capabilities. The Kalman filter is a linear estimator but rocket dynamics are inherently nonlinear. Drag , which is a function of velocity squared, and rotational kinematics are both nonlinear elements. We can avoid the nonlinear element of drag in apogee detection because at apogee the rocket's velocity is near zero. Any near zero velocity squared will send the drag down to being extremely small. Additionally, if our Kalman filter is running fast enough we can approximate rotational kinematics as linear and ignore them as well. These two assumptions, while imperfect, allow us to structure rocket dynamics in the linear form that a Kalman filter needs. Through proper tuning the Kalman filter is able to provide more accurate apogee detection for improved recovery abilities.

Our flight computer provides live telemetry, including altitude, velocity, acceleration, battery voltage, and GPS coordinates to a receiving station on the ground, which displays this information and plots the rockets current position on a map. We elected to go with an XBee radio after considering many other systems because the XBee is very simple to use, advertises long range, and is fairly affordable.

Video is provided by a Raspberry Pi camera connected to a Raspberry Pi Zero. The Raspberry Pi both records and live streams the video feed from the camera, using custom Python software written with the help of the picamera library. The Raspberry Pi creates its own wireless network, which the ground station will connect to in order to receive the video stream.

Power to the avionics subsystems will be provided by a set of 7 Lipo Batteries:

- 1 1100mAh 3S LiPo battery for the primary SRAD flight computer electronics power.
- 1 1100mAh 3S LiPo battery for primary flight computer ignition power (see below).
- 1 9V battery for secondary flight computer.
- 1 1200mAh 1S LiPo battery for secondary GPS tracker.

- 1 2500mAh 1S LiPo battery for camera system.
- 2 400mAh 1S LiPo batteries for the SRAD RDF trackers in the avionics bay and bottom section.

We chose to have a seperate power supply for the flight computer's ignition circuit in order to provide higher reliability in the event of an igniter short. Another way of solving this issue would be to include a large capacitor that could power the flight computer if the igniter shorted, but we chose to use two batteries for now since it lead to a simpler design.

3. Ejection Charge Calculations

Black powder ejection charges will be used to deploy both the main and drogue parachutes. In order to ensure that the parachutes are deployed, two charges will be used for each parachute, a main charge and a backup charge. When the black powder is ignited, it will create a high pressure gas, which will break the shear pins holding the rocket together, force the rocket to separate, and pull the parachute out. In order to determine the appropriate amount of black powder to use in the main ejection charges, *Modern High Power Rocketry* [2], was consulted. Using the formula shown below, predicted amounts of black powder were calculated. These equations calculate the amount of black powder required to produce 15 pounds per square inch (psi) on the rocket bulkhead. To verify that these quantities would be sufficient, ground testing was performed, where the parachute was packed in the rocket as it would be during flight, and the ejection charge was ignited. After testing, it was determined that there was insufficient pressure in the fore body tube containing the main parachute, and the amount of black powder being used would have to be increased. It was decided to increase the internal pressure to 20 psi of pressure, which requires 4.33 grams of black powder. Ground testing was again performed, and it was determined that this new pressure was sufficient.

For the backup ejection charges, it is imperative that they deploy the parachutes if need be. Therefore, it was decided that they should produce a higher pressure than the main charges. The backup charge for the fore body tube was thus designed to produce 24 psi, requiring 5.33 grams of black powder. For the aft body tube, 19 psi was required, meaning that 5.41 grams of black powder were necessary.

Taken from *Modern High Power Rocketry* [2]:
Black powder needed for separation in grams = (Inner Diameter of Body Tube)^{2}x (Length of Body Tube)x0.006

Fore Body Tube Primary Ejection Charge:
$(6.148 \text{ in.})^2 \times (14.69 \text{ in.}) \times (0.006) = 3.33$ grams

Aft Body Tube Primary Ejection Charge:
$(6.148 \text{ in.})^2 \times (17.9 \text{ in.}) \times (0.006) = 4.06$ grams

D. Payload Subsystems

Payload consists of a 3U box that will contain the scientific payload and ballast to meet the required 8.8 lbs. The payload will be a low cost UHF Communications radio developed by the University at Buffalo Nanosatellite Laboratory. The radio provided the opportunity for high precision range finding for CubeSats, allowing for both orbit determination and TLE cross-tagging identification. While short and medium range testing has been completed, long range and high speed testing is desired to improve confidence this system will work on orbit. All software was developed in house and the hardware is run on Lithium AA batteries. The main hardware components are:

1. Si4464 Radio Frequency Integrated Circuit (RFIC) - chosen for wide frequency range coverage, allowing for both VHF and UHF. (operates using Gaussian Frequency Shift Keying)

2. MSP430 Microcontroller - chosen for radiation resistant FRAM (key for on orbit operations)
3. Temperature Compensated Crystal Oscillator - provides reference frequency even in wide range of thermal environments.

This payload will not interfere with any operations on the rocket. Ideally the range measurements will be compared with GPS based ranges because the payload was designed to operate on orbit, it will be perfectly capable of surviving launch prep and the launch itself.

A small software based GPS module (utilizing either an RTL-SDR or maybe even a B200 mini SDR) may be incorporated depending on the laboratory. It would serve as proof of concept for the planned use of an SDR as a GPS module, and could also provide us with the reference GPS ranges. Another data collection that could be retrieved in the rocket flight is a test of Doppler shift correction, though it might be difficult given how short the flight is.

II. Mission Concept of Operations Overview

Toc is designed to be launched to 10,000 feet in the air, and contains a dual deploy recovery system with main and drogue parachutes. Below can be found the mission concept of the rocket, from arming to recovery.

1. With the rocket loaded onto the launch rail and the igniter installed, a member of the team will arm the rocket. As soon as data is received from the radio, the SRAD flight computer is armed. At this point, telemetry data starts being sent back to the ground. The recovery systems are also turned on and armed, and begin collecting pressure data. The avionics system is ready to collect data on the pad. The propulsion system is unignited and sitting waiting for ignition. Right before the end of this phase, the ground station will begin pinging the payload, causing the payload to respond and send a signal back to the ground station. Lastly, the aero-structure system will allow the rocket to stand upright on the pad.
2. The next phase of operation is the ignition of the motor. This phase starts when the fire button has been pressed by the range safety officer. The ignition phase ends when the engine begins to exhaust hot gas. The propulsion system will be ignited and start to generate thrust for the rocket. At this point, the avionics will begin to store the incoming telemetry from the rocket. The recovery systems will be on and ready for the recovery stages, while continuing to collect pressure data. The aero-structure system will hold the rocket upright for the launch. The payload will continue to function as in the previous phase.
3. Liftoff follows ignition and is signified by the rocket moving upwards on the launch rail. Liftoff is complete when the rocket leaves the launch rail. The propulsion systems will be generating thrust to allow the rocket to climb in altitude. The avionics system will continue to collect data, while the recovery system will continue operating as in the previous mission phase. The aero-structure system will maintain stable flight off the launch rail. Again, the payload will continue sending a signal back to the ground station throughout this flight.
4. The rocket then enters the powered flight phase. During this time it is being propelled by the solid propellant motor off the rail unil burnout of the motor. The propulsion system will continue to create thrust, sending the rocket upwards. The recovery system is still armed and collecting pressure data. The avionics will measure various flight parameters during this phase, and the aero-structure will ensure the rocket maintains structural integrity during this phase. The recovery system will continue monitoring the air pressure during this phase, and the payload will continue sending a signal back to the ground station. This phase ends when the motor ceases producing thrust.
5. After burnout of the motor, the rocket will glide to an apogee of 10,000 feet, being slowed by gravity along the way. The propulsion system has burned to completion, and will thus no longer produce any thrust. The avionics and recovery systems will continue collecting data. The aero-structure will continue to perform the same task as it did during the powered flight phase. As with all previous steps, the payload will continue sending back a signal.

6. The first recovery event occurs at apogee, when the drogue parachute is deployed, with a redundant charge firing 1 second after apogee. This phase begins with the recovery system firing the first separation charge, separating the rocket body in two components and pulling out the drogue parachute, and ends when the drogue has been deployed. During this phase the avionics will continue to collect data, and the aero-structure will separate into two conjoined pieces. Finally, the payload will continue sending a signal back to the ground station.
7. The rocket then freefalls, slowed by the deployment of the drogue parachute, at a rate of 120 ft/sec, until the second recovery event, which occurs at 1,250 feet. The avionics system collect further data on the flight until the second recovery event. The aero-structure works in conjecture with the drogue parachute to slow the rocket by creating drag due to the separated rocket body. Again, the payload will continue sending back a signal during this phase.
8. At 1,250 feet the primary separation charge fires, deploying the main parachute. A backup charge fires at 1,100 feet in order to ensure the main parachute is deployed. This event is very similar to the drogue deployment, with the nosecone separating from the rocket body, pulling the main parachute out at the same time. Once the main parachute is deployed, it will slow the rocket's descent down to 25 ft/sec. During this phase the avionics continue to collect data. The aero-structure again separates following the deployment of the main parachute, and the payload will continue to send back a signal to the ground.
9. The rocket will continue to descend with both parachutes deployed until in impacts the ground. After impact, the project team will safely recover the rocket. The avionics will stop storing data after landing is detected. All other systems will be intact on the ground waiting for recovery. Upon landing, the ground station will cease sending a signal to the payload, resulting the the payload no longer sending back any signal.

Throughout the flight, the electronics will be sending GPS data from the rocket back to the ground in real time. Figure 2 below is a flowchart showing the mission described above.

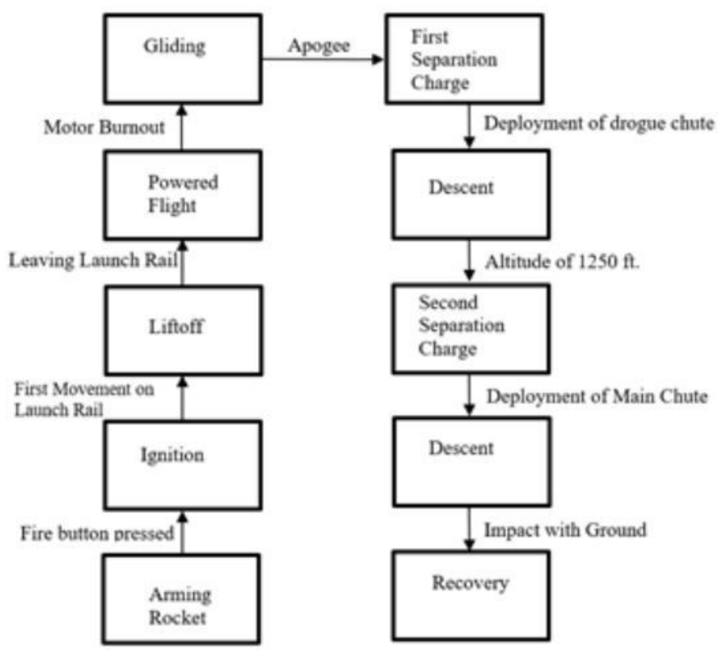

Figure 2: Mission Flowchart

III. Conclusions and Lessons Learned

The road to IREC 2018 has been a learning experience for UB SEDS and has allowed for growth that has not been seen for a few years, especially from participating in IREC 2017. During this growth there was a lot learned though not only the successes, but also the failures. Previously, focusing on the design, construction, and the flights of level 1 and 2 high powered rockets, IREC was a big step up. Part of this change was the need to look at designing the rocket from scratch, rather than using a template that has been passed down from year to year. Working with an almost entirely fiberglass rocket created new challenges that had to be addressed in the design and manufacturing phases. From proper adhesion methods to cutting the fiberglass, new methods had to be learned.

The electronics team started from COTS flight computers and from there has had to develop code, circuit design, and construction skills. In terms of testing, one of the most important things that we learned was how to communicate with campus officials when performing recovery tests and other tests that require increased administrative knowledge. Beyond communication, the proper documentation of each test along with the generated information became more useful and allowed for both additional tests and a better understanding from each test.

From a management perspective it was interesting to see how different the club and its members are now from when the group began the competition, however the lesson that may make the largest impact on future competitions is the realization that while long term planning is important, if enough attention is not given to present events some things can fall between the crack and cause problems. From the design process, not enough attention was paid to small details and the team really needed to break up into subgroups earlier in the process.

Part of the transition of information was from the graduating seniors along with other more experienced members of the club was the involvement of many different group members in the writing of the 2018 technical Report. This has allowed for the rising freshman and sophomores to ask questions about what is going on with the part of the report they are responsible for. Also this being only the second year for UB SEDS competing in a large competition, many of the underclassmen were working side by side with the upperclassmen in the design and construction process. Focusing on hands on experience allows for the underclassmen to be involved, maintains interest and helps the effort as a whole with the generation of new ideas to solve problems and distributes the work load more evenly. Additionally, besides relying completely on information passed down verbally a document was created by the previous rocketry lead detailing everything from vendor information to resources on different aspects or rocketry construction.

Appendix A: System Weights, Measures, and Performance Data

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	112.4	Calculated using Autodesk Inventor 2017
Airframe Diameter (inches):	6.15	Calculated using Autodesk Inventor 2017
Fin-span (inches):	22.55	Calculated using Autodesk Inventor 2017
Vehicle weight (pounds):	36.6	Calculated using Autodesk Inventor 2017
Propellent weight (pounds):	7.7	From Manufacturer (8.1 for M2400)
Payload weight (pounds):	8.8	
Liftoff weight (pounds):	53.1	(53.5 for M2400)
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Commercial	See last section for more details
Kinetic Energy Dart:	No	

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

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1st Stage: Cesaroni Pro 98, 9994M3400-P, M Class,  9994 Ns
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Total Impulse of all Motors: 9994 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	12.9	(10 with M2400)
Launch Rail Departure Velocity (feet/second):	115	(101 ft/s with M2400)
Minimum Static Margin During Boost:	1.6	(1.78 with M2400)
Maximum Acceleration (G):	15.6	(10.4 G with M2400)
Maximum Velocity (feet/second):	1162	(912 ft/s with M2400)
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	12871	(10052 ft. with M2400)

Appendix B: Project Test Reports

Date	Name	Description
	Avionics	
2018-02-16	Apogee Test 1	Tested apogee detection code by strapping flight computer to a racing drone to simulate launches. Found that apogee detection was very late. Cause was later found to be incorrect configuration of the Kalman filter noise values.
2018-03-12	Apogee Test 2	Same setup as before, except with proper Kalman noise values. Apogee was accurately detected once, but we were not able to reproduce the result. Apogee was frequently not detected at all. Cause was found to be a faulty accelerometer that was reporting a constant acceleration of 25g.
2018-03-12	Apogee Test 3	Same as before with a different accelerometer. Apogee detection was accurate and consistent through repeated tests.
	Airframe	
2018-05-10	Fiberglass Compression Test	Five compression samples were prepared using a flat, 10 layer, layup to mimic the thickness of the body tube. Fiberglass tabs were then epoxied to each sample to allow the jaws of the testing fixture to grip the samples. The prepared samples were then placed in the fixture, one by one, and compressed to failure.
2018-05-10	Fiberglass Tensile Test	Five tensile samples were prepared in the exact same way as the compression samples, only roughly 2 inches longer. Samples were then loaded into the testing fixture and tested to failure.
2018-05-21	Fiberglass Shear Test	A full-scale model of the body tube, motor tube, and a single mounting ring were epoxied together. The model was then compressed to failure in order to test the maximum shear forces that the epoxy would be able to withstand.
	Recovery	
2018-05-11	Ground Testing of Recovery System 1	Recovery system was rigged and packed as it would be prior to flight, and main and backup charges were detonated from a safe distance to ensure proper separation of body tube. Drogue successfully separated, while main did not deploy as planned.
2018-05-23	Ground Testing of Recovery System 2	As the main parachute failed to separate properly during the first test, the main parachute was again tested, this time using 4.33 grams of black powder. Main parachute then separated as intended.
	Other	
2017-20-10	38mm motor test	Static test fire of 38mm SRAD solid motor - Successful
2017-28-10	Launch with 38mm Ex	Rocket launch with 38mm EX motor -Motor Successful
2018-17-5	98mm Hydrotest	Hydrostatic test of SRAD 98mm motor casing, water leaked through seal at 800 psi, goal was to reach 1000 psi, failure
2018-1-1	Airframe rocket test	Goal was to launch a small SRAD airframe - Launch Cancelled due to Weather
2018-28-4	Full Scale Launch	Goal was to launch Competition airframe - Launch Cancelled due to Weather

Appendix C: Hazard Analysis

An analysis of the hazards posed during the design, construction, and launch of the UB SEDS entry into IREC 2018 highlighted specific hazards which need to be addressed. Each hazard will be outlined and a mitigation approach shall be defined.

A. Propellant

1. Hazard: The propellant aboard the rocket is solid composite propellant composed of ammonium perchlorate, metal powders, and synthetic rubber. The motor and reload kits are classified as Class 1.4C explosives and the main hazard posed is that of fire.
2. Handling: Propellant handling shall be as per the guidelines in the Safety Data Sheet. They are to be kept away from heat, sparks, and flame. Contamination within foreign substances it to be avoided. The propellant should not come in contact with eyes, skin, or clothing. It should also not be consumed in any way.
3. Transportation: The shipment of high power motors is regulated under 49 CFR Subchapter C Hazardous Materials Regulations. A HAZMAT label is required.
4. Storage: Propellant is to be stored in a cool, dry place away from sources of heat, spark, or flame. Ideally, it is to be kept in its shipping packaging until use.
5. Mitigation Solution: UB SEDS stores its propellant in the original unopened packaging. Hazardous materials are stored in a metal cabinet separate from all other materials in which the contents are clearly labelled. The high powered motor reload will need to be assembled before launch according to the RMS-98/2560-15360 instructions. All propellant will be transported to Spaceport America by car with the rocket; it shall be placed in its own storage container with other hazardous materials that will remain under the supervision of the team leader or a designee.

B. Black Powder

1. Hazard: Black Powder is used in small quantities on the UB SEDS rocket as a separation charge. Composed of potassium nitrate, sodium nitrate, charcoal, sulfur, and trace quantities of graphite, black powder is a Class 1.1 explosive. Under this classification, the hazard of concern is the possibility of a mass explosion.
2. Handling: Black powder is to be kept away from friction, impact, and heat. Food, drink, and tobacco should be kept away to prevent contamination. While deemed an unlikely route of exposure, black powder should not be consumed or inhaled, nor should it come in contact with the eyes.
3. Transportation: Black powder must normally be shipped with a HAZMAT Class 1.1 explosives label. If in limited quantities, it may also be transported as "Black powder for small arms."
4. Storage: Black powder should be stored in a cool, dry place.
5. Mitigation Solution: Black powder is to be transported to Spaceport America by car in a container of hazardous materials that will remain under the supervision of the team leader or a designee. Additionally, when being handled face shields will be worn by members of the team who are in direct contact with the Black Powder.

C. Igniters

1. Hazard: The igniter will be a First Fire ignitor included in the purchase of the solid composite rocket motor. It is composed of Ammonium or Potassium Perchlorate, carbon black and carbon fibers in a flammable binder. Appearing as two wires leading to a single fuse head dipped in rubbery, silvery-grey composition, the igniters are classified as low-risk explosives (Class 1.4S).
2. Handling: Igniters are to be kept away from heat, sparks, and flame. Contamination with foreign material should be avoided. They should not come in contact with the eyes, skin, or clothing, nor should they be consumed orally.
3. Transportation: A HAZMAT Class 1.4S warning is required for shipping.

4. Storage: Igniters are to be kept in a cool, dry place away from sources of heat, spark, or flame. Ideally, they should be kept in their shipping packaging before use.
5. Mitigation Solution: UB SEDS stores its igniters in the cardboard packaging of the motors with which they come. They are stored in a metal cabinet away from non-hazardous materials. As a result, unintended contact
or consumption will be avoided. During transport to Spaceport America, they will be stored in the same storage container of hazardous materials under the supervision of the team leader or a designee.

D. Electronic Matches:

1. Hazard: Electronic matches are devices used to ignite another substance in this situation, black powder, by means of an external current. They are Class 1.4S explosives. They work in the same was as igniters and have the same appearance.
2. Handling: Electronic matches are not to be altered and should be kept in their packing until they are to be used. Personal protective equipment consists of safety glasses. No smoking should be permitted when using electronic matches, and they should only be used in well-ventilated areas away from heat, sparks, open flames, or hot surfaces. If used properly, electronic matches do not pose a health hazard. However, inhalation, as well as ingestion, skin contact, and eye contact should all be avoided.
3. Transportation: As a Class 1.4S explosive, appropriate warnings or placards are required during Shipment.
4. Storage: Electronic matches are stable and will not ignite under normal environmental conditions. They should not be stored in temperatures above 120°F. Additionally, the exposure to friction, shock, open flames, smoking or other accidental ignition sources, strong RF fields, or static discharge should be avoided.
5. Mitigation Solution: UB SEDS stored electronic matches in a metal cabinet away from non-hazardous materials. As a result, unintended contact or consumption will be avoided. During transport to Spaceport America, they will be stored in the same storage container of hazardous materials under the supervision of the team leader or a designee. Examining the environmental conditions are the Spaceport, the record temperature in nearby Truth or Consequences, NM is 108°F. As a result, the probability of any further steps being necessary to maintain a sub-120°F safe storage temperature is minimal.

E. Li-Po Batteries:

1. Hazard: If used properly, lithium polymer batteries pose no risk; they are hermetically sealed, so their contents are not able to come into contact with the user. However, if misused, they may release a flammable
gas or burst.
2. 2. Handling: Batteries are not to be swallowed, exposed to water or fire, short-circuited, or overcharged. Under no circumstances are they to be pierced.
3. Transportation: Shipping is permitted in limited quantities and within packing strong enough to ensure that the batteries will not be crushed. Appropriate DOT labels are required for shipment.Storage: Ideally, batteries are to be stored at room temperature (approx. 20°C). They should not experience rapid changes in temperature, nor or they to be directly exposed to sources of heat or sunlight.
4. Mitigation Solution: UB SEDS currently stores its lithium polymer batteries in a metal drawer. The drawer's construction prevents any possible crushing of the contents and the room that it is housed in is maintained at temperature well within the limits of the batteries. During transport to Spaceport America, the batteries will be placed in their own container that cannot be violated by piercing or crushing. Transport will be achieved by car in a temperature-controlled cabin. Should outside temperatures be considered unsafe when the car is not in use, the batteries will be carried by a member of the UB SEDS team into a cooler environment. If any signs of a violation of the battery is found, or any concerns regarding their reliability and safety are raised, the battery will be swapped for a replacement.

Appendix D: Risk Assessment

Hazard	Possible Causes	Risk of Mishap and Rationale	Mitigation Approach	Risk of Injury after Mitigation
Deployment of recovery system on launch rail	Electronics are short wired causing deployment	Medium. Pyrogen charges are used in the rocket that could cause injury. Limited testing with electronics.	Inspect wiring before installing electronics bay.	Low
	Incorrect Pressure Reading		Ensure proper functioning of sensors of sensors and flight computer	
	Improper arming/installation of electronics		Instruct launch crew of proper installation and arming of electronics.	
No signal for armed system	Improper wiring	Low. The electronics will not work without power and lack of signal demonstrates that they are not working so no charges will be ignited.	Inspect wiring before installing electronics bay.	Low
	Malfunction of the electronics		Inspect electronics before use.	
Rocket falling off launch rail injuring personnel	Improper Installation of rocket on Launch Rails	Low. The rocket will weigh considerable amount, but the project team will utilize on-site tools to install rocket on launch rail.	Instruct launch crew on proper installation of rocket.	Low
	Improper installation of launch lugs		Test launch lugs with full weight of rocket before putting rocket on launch rail.	
Failure to ignite motor	Malfunction of the igniter	Medium. The solid propellant is made of explosive material and approaching the unfired motor can be dangerous unless range is powered down.	Inspect igniter before installation.	Low
	Insufficient power supplied to igniter.		Check with range safety officer that the range can supply required voltage.	
	Improper installation of igniter		Inspect the igniter's installation for proper use.	
Explosion of Rocket Motor on	Cracks in propellant	Low. Off-the shelf motor is being used	Inspect motor prior to launch.	Low

Ignition launching debris		with reusable motor casing. Off the shelf motors are well tested before certified by rocketry association.		
	Debris in nozzle		Inspect motor prior to launch.	
	Weakness in motor casing		Inspect motor casing prior to launch.	
Deviation from path at high speed	Instability of Rocket	Medium. The rocket at high speeds is uncontrollable and can cause severe injury.	Simulate rocket performance and perform stability calculations.	Low
	Severe Weather		Do not launch if weather is not in accordance with launch rules.	
Explosion from separation charge launching debris	Excessive explosive material used	Medium. Separation charges firing occurs at high altitudes, but the shrapnel can fall and hit personnel.	Use required amount of explosive material and no more.	Low
	Over pressurization in body tube		Use required amount of explosive material and no more.	
	Weakness in body tube		Inspect body tube before launch.	
Separation of rocket components	Improper tethering of components	Medium. Rocket components can be separated during flight and hit personnel. Limited testing done in tethering components together.	Carefully inspect the joining of component by knots and other hardware.	Low
Failure of parachute deployment	Malfunctioning of recovery system	Low. The parachute deployment will not slow the rocket's descent, but air resistance will still slow rocket and the long fall will allow for injuries to be avoided due to noticing where the rocket is falling.	Test recovery system on the ground before launching.	Low
	Improper packing of parachute		Inspect parachute packing before launch.	
Early deployment of drogue parachute in flight	Malfunctioning of electronics	Low. Too early of deployment may cause parachute to rip. Also, it may cause unwanted loading on body tube	Inspect and test electronics prior to launch.	Low

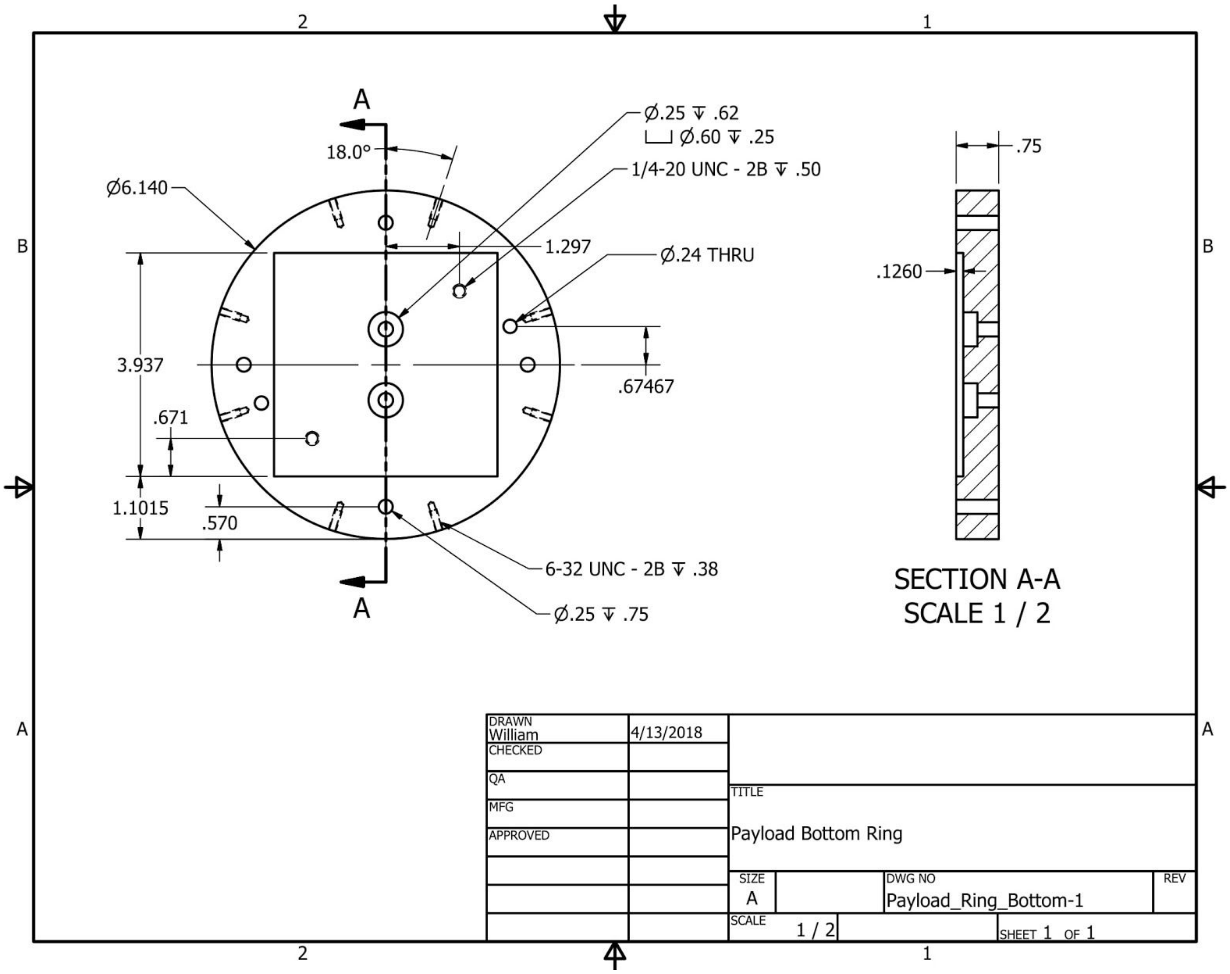
		due to deployment at higher total pressure.		

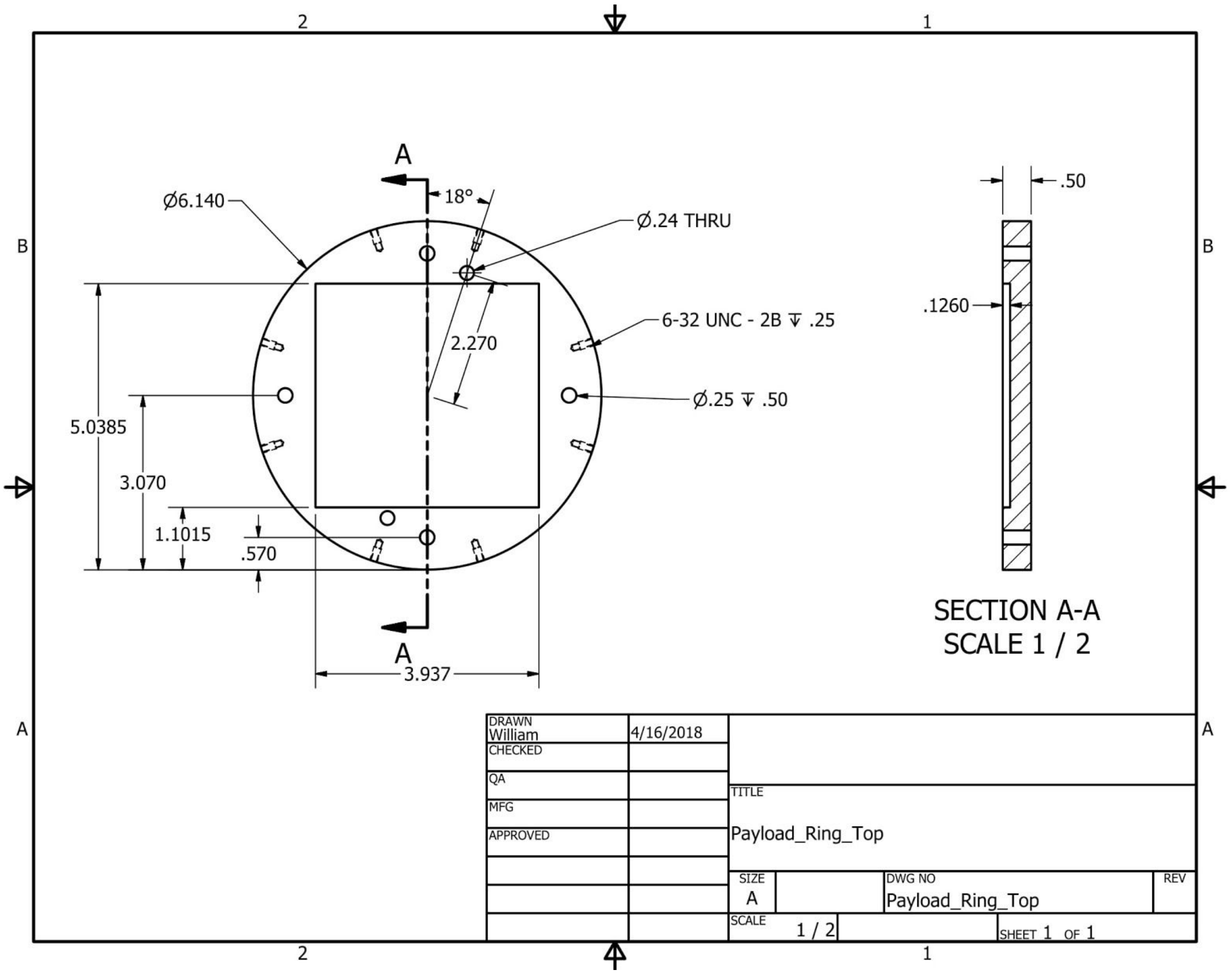
Appendix E: Assembly, Preflight and Launch Checklists

1. Insert the payload into the avionics payload canister.
2. Check all connections in the electronics bay so that they are fully and firmly connected.
3. Check the voltage of all batteries with a multimeter to make sure that they are fully charged.
4. Make sure all the electronics are turned off and connect the batteries to the system.
5. Attach 1-inch tubular nylon shock-cord to the top bulkhead of the avionics payload canister and to the nosecone, running the cord through the upper body tube.
6. Attach the drogue chute between the lower bulkhead of the avionics payload canister and the lower section with approximately 30 ft of shock cord, pack properly into the coupler.
7. Zero the scale including the measuring cup, precisely measure 4.33 grams of black powder for upper separation charge, 4.06 grams for the lower separation charge. Also measure 5.33 and 5.41 grams for the upper and lower backup charges.
8. Disconnect the power if not already, and connect the e-matches to the flight computer, then insert a charge into each cap.
9. Fill the remaining cap space with inflammable insolation, using masking tape, tape the cap shut.
10. Mount the avionics payload canister into the upper section of the rocket.
11. Attach the main parachute by the quick links to upper section's shock-cord with approximately 50 ft of shock cord, roll, pack, and cover the parachute with the Kevlar protector.
12. Insert the nosecone and main parachute into the upper section, and fasten with 4 2-56 3/16" long shear pins 90 degrees apart.
13. Connect the upper and lower sections, and fasten with 4 2-56 3/16" shear pins 90 degrees apart.
14. Thread the steel rod into the top of the motor, slide the motor in the motor mount tube, and secure the retainer ring to the threaded rod, fasten with washers and lock nuts.
15. Attach the boat tail
16. Mount the rocket onto the launch rail using the launch lugs.
17. Insert the ProFire ignitor into the motor and connect to the ignition system.
18. Raise the rocket and launch rail into the proper launch angle.
19. Turn on the electronics bay, listen for computer continuity and proper settings.
20. Verify that telemetry is being received from the primary flight computer.
21. Verify that video is being received from the camera system.
22. Check continuity of launch system.
23. Clear site for launch.

Note: In the event of the required disarming of the rocket, undo steps 16 through 19 in receding order, then disconnect the battery.

Appendix F: Engineering Drawings

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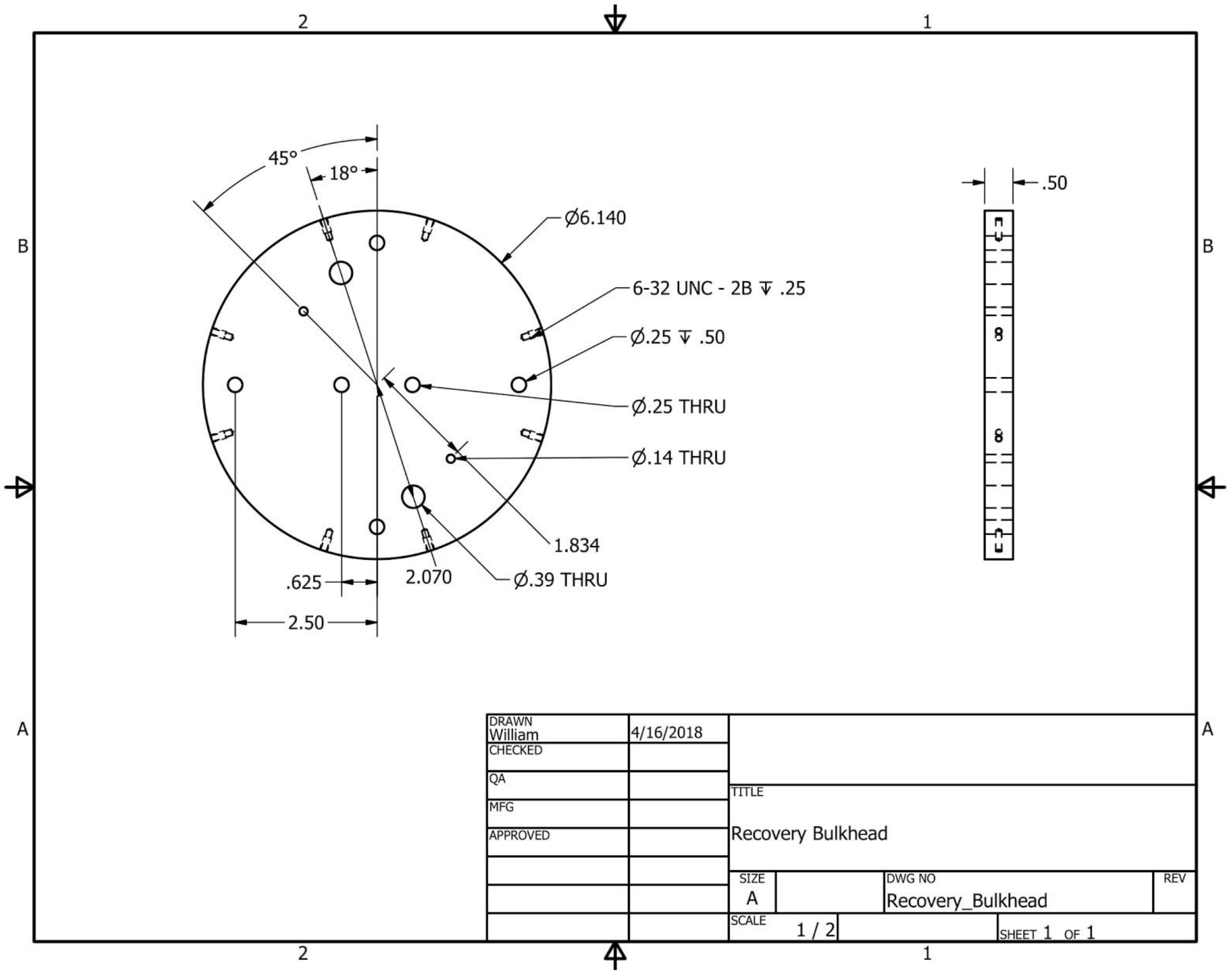

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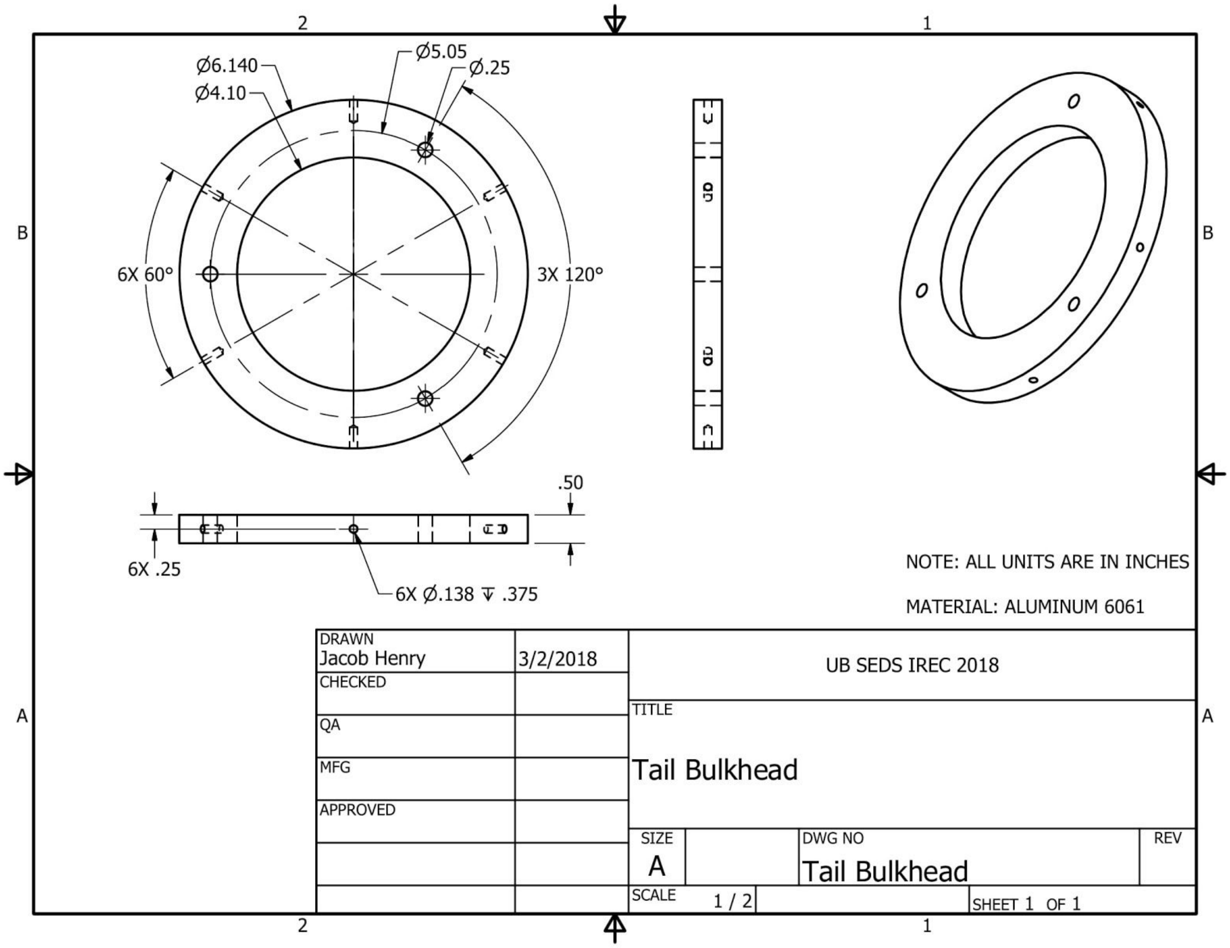
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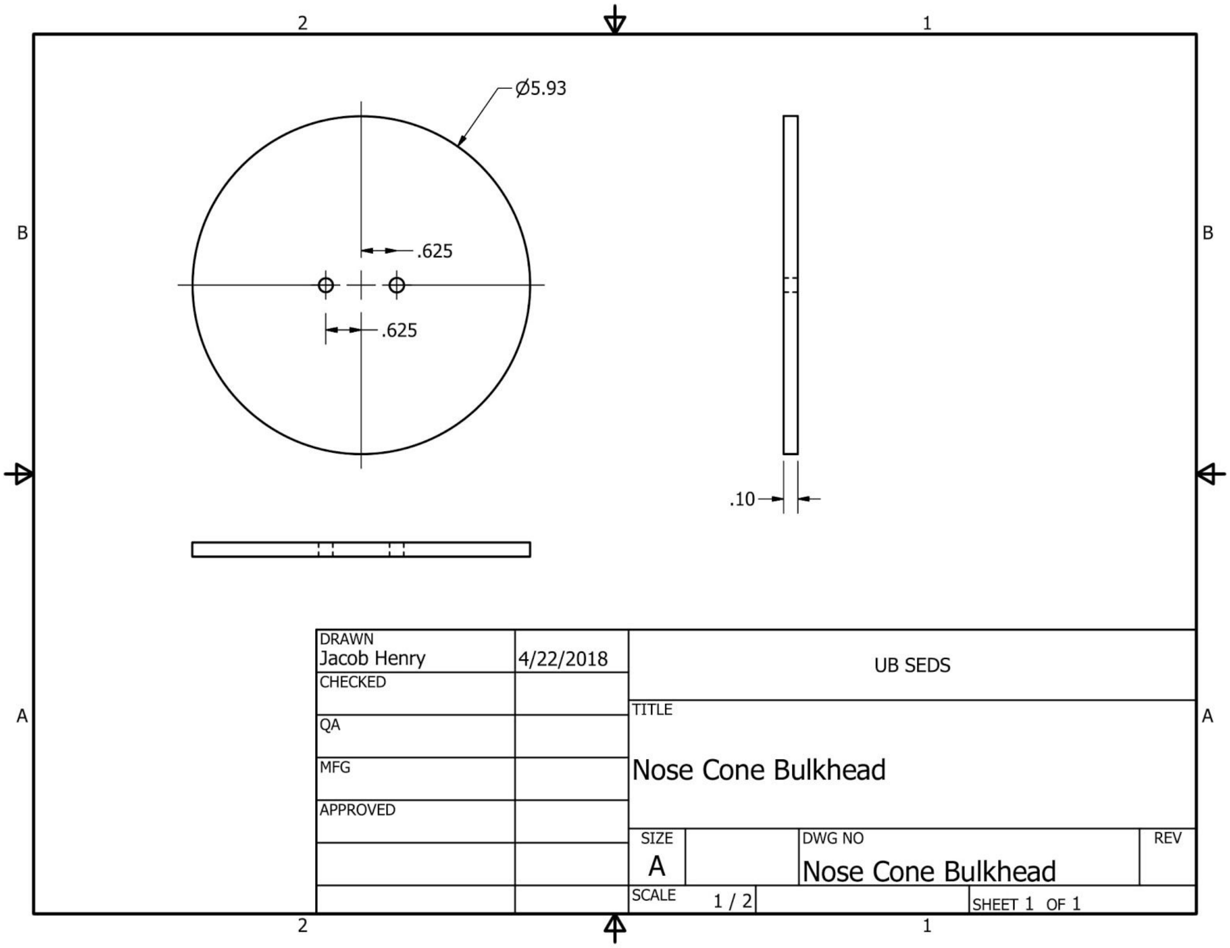
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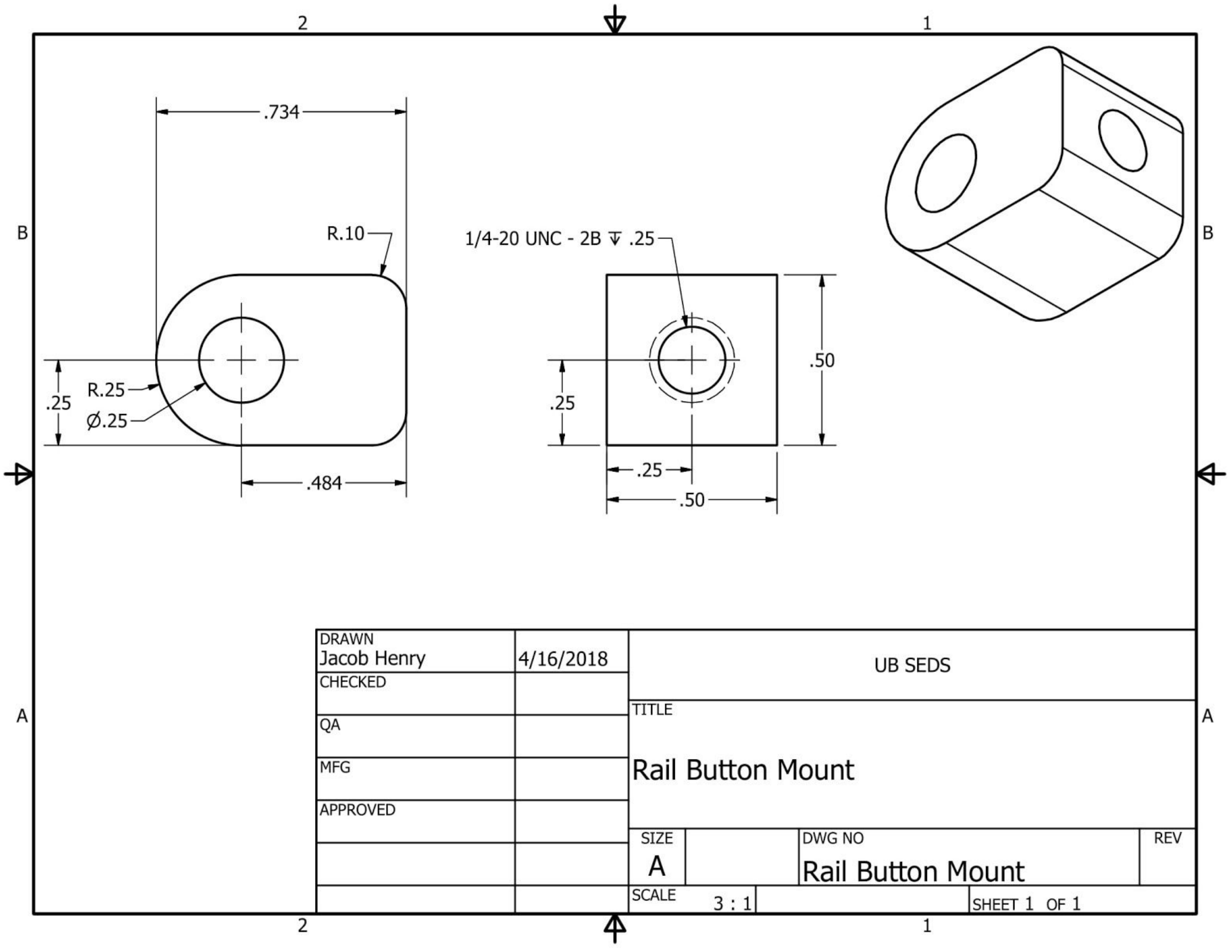

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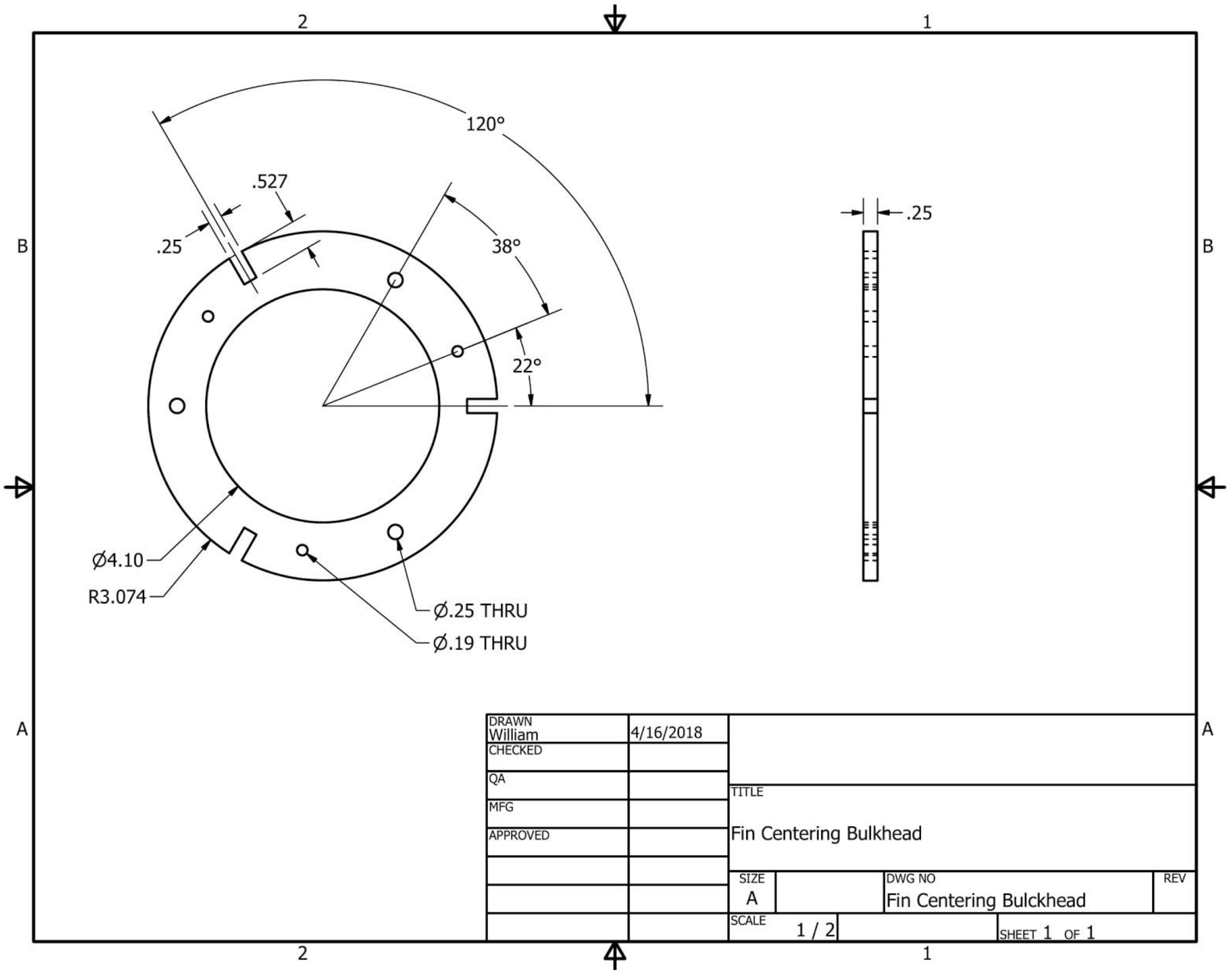
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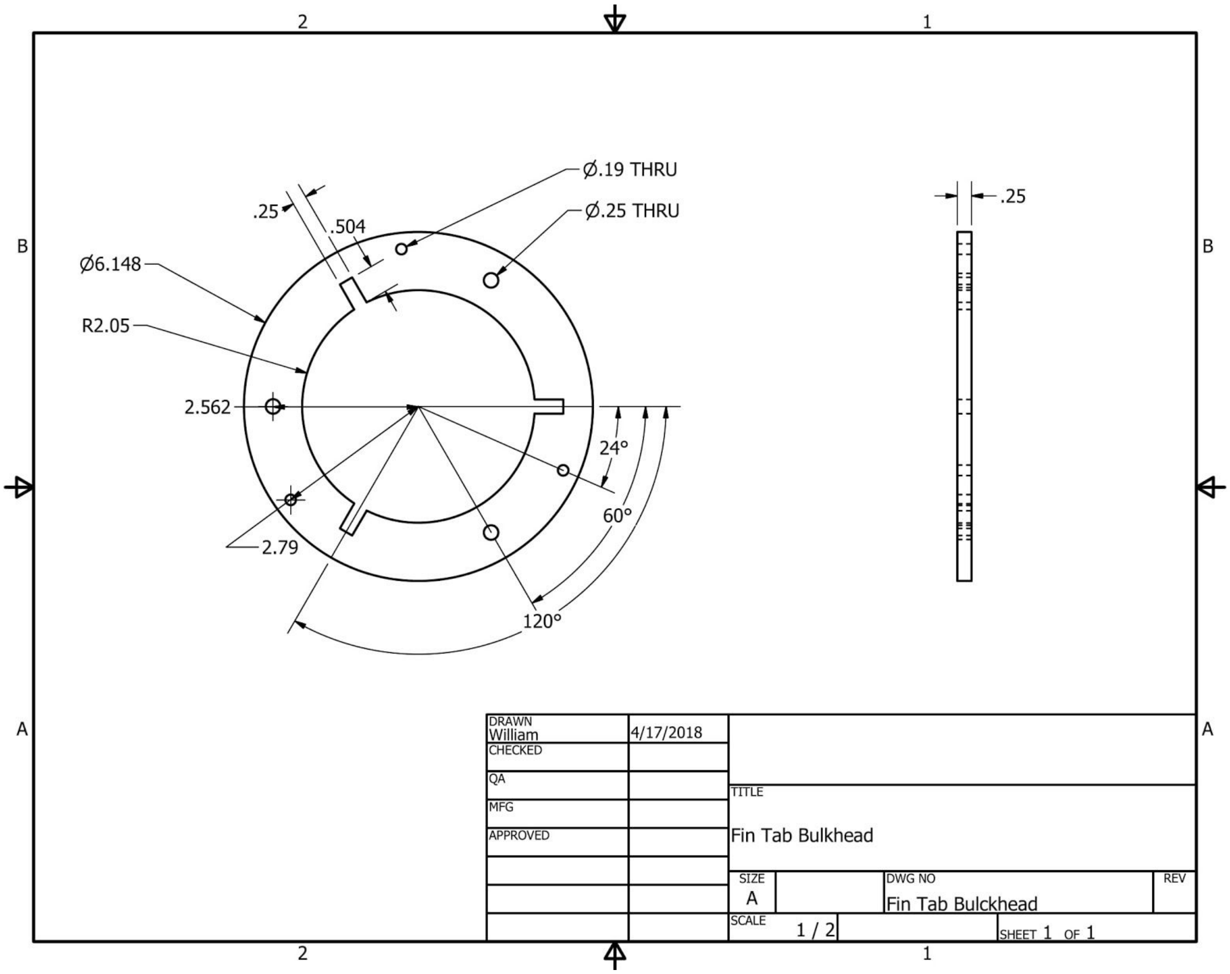

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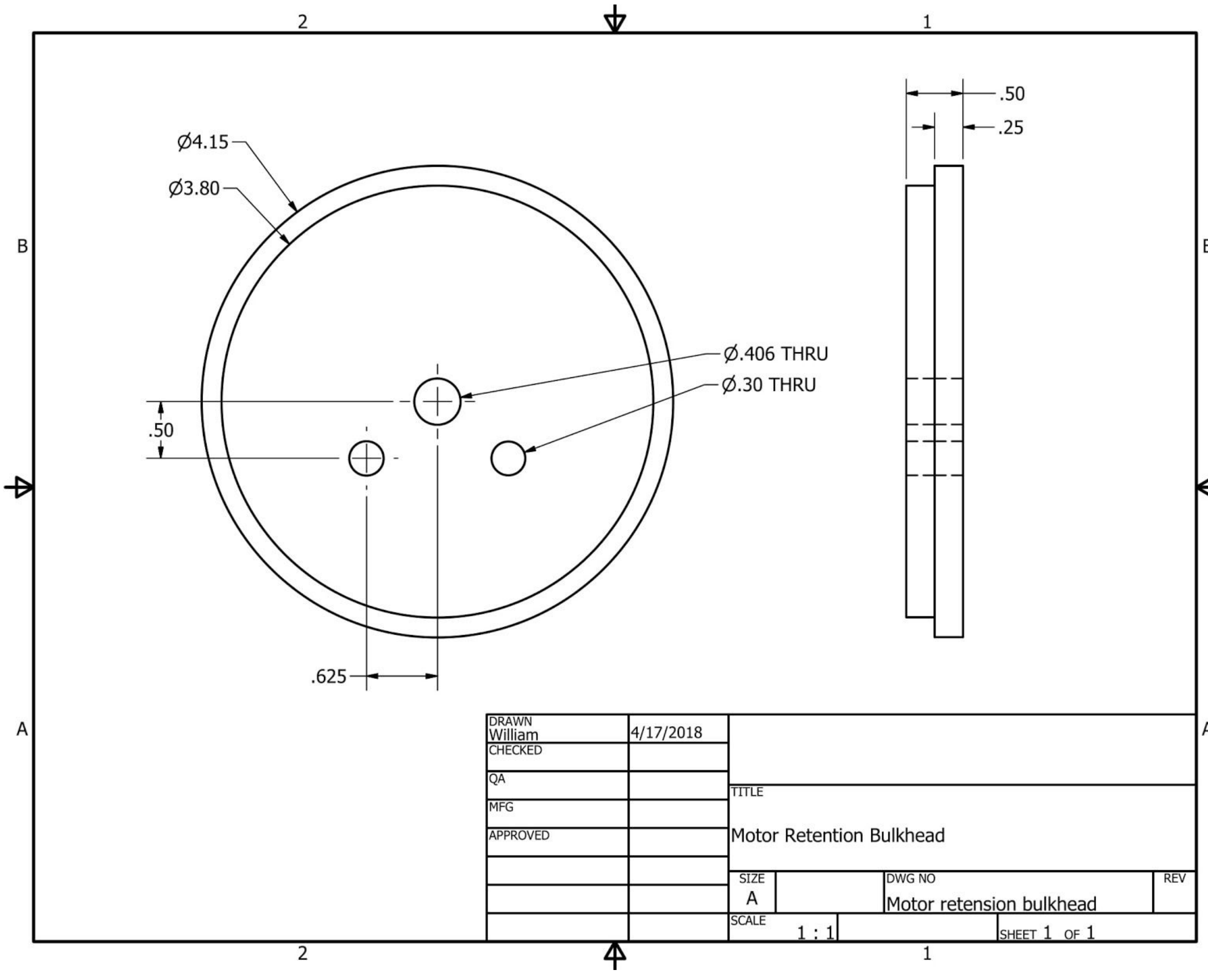

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References

[1] Knacke, Theo W, "Parachute Recovery System Design Manual" 2nd ed., Para Publishing, Santa Barbara, California, 1992, Chap. 5

[2] Canepa, Mark, "Modern High Power Rocketry 2." 1st ed., Trafford Publishing, Victoria, British Columbia, 2005, Chap. 6