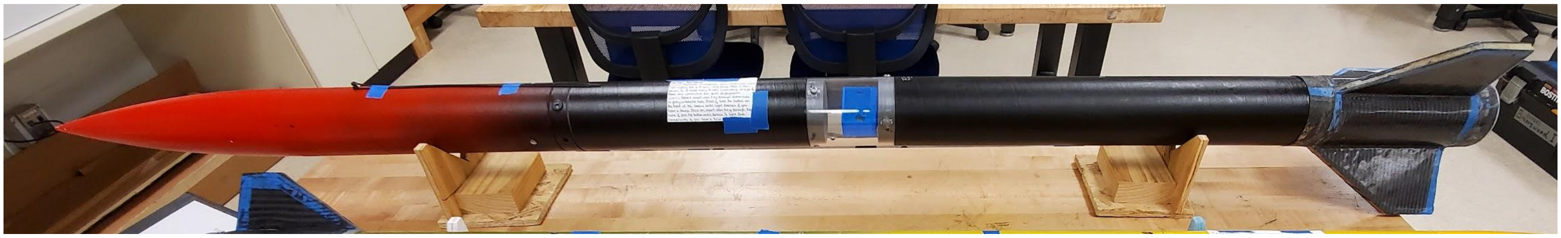
1 Pound / 1 Mile Post Mission Analysis

Saturn VI



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Abstract

Within our Post Mission Analysis of the *Saturn VI* 1-Pound/ 1-Mile vehicle, we have made a culmination of the ideas, decisions, and manufacturing processes that our team -- both this year's Transonic 2nd/3rd team and last year's 1-Pound/1-Mile teams -- have experienced throughout both this year and last. Included is an overview of our team's mission, a timeline of specified deadlines, details about the building process, and final preparations in order to launch a vehicle that would take a payload of 1 pound to an altitude of 1 mile.

Problem Statement

As a team, we came to the conclusion that our overall mission for our 1-Pound/ 1-Mile rocket was to research and manufacture an aircraft that would reach an apogee of 1 mile with a 1 pound payload. We also planned to record the flight and successfully recover the craft while staying under a 1000 dollar budget. Furthermore, in order to get a better understanding of what our teams should accomplish and how to go about it, we decided upon making individual component team mission statements. Our propulsion mission was to use a K240 engine to propel our rocket to a height of 1 mile and to construct a retention system to keep the engine retained during flight. For our avionics mission, we wanted to wire and program an altimeter that would work with recovery to deploy a drogue parachute at apogee, and a main parachute at 500 feet all the while recording our altitude. The payload mission was to install a 1 pound payload and successfully retrieve and view the data that recorded the flight from within the rocket. And finally, our airframe mission was to...

Timeline

Our timeline consists of two years of work of which one was interrupted by Covid. Our work was predominantly accomplished in the first year of the school's second semester (2019-2020), while the second year (2020-2021) was used to finish some finer details of construction. In order to construct the rocket, we had to dedicate the beginning of the semester to researching aerodynamics and component team requirements, which was followed by 3 weeks of finding specific components needed for each team to function.

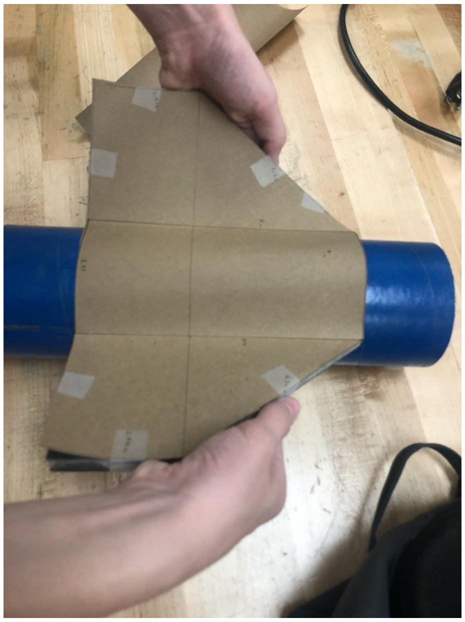
Components

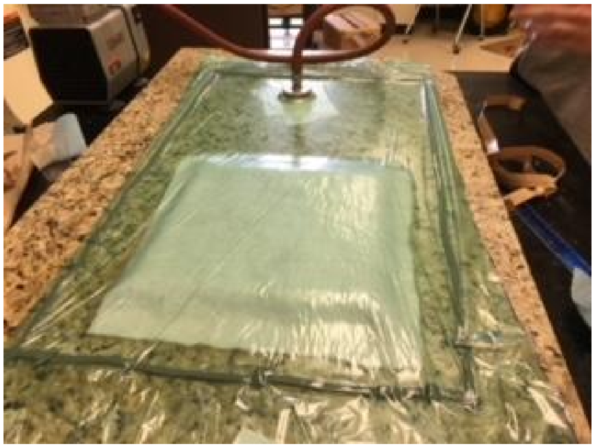
The components of our rocket are accounted for by our airframe, recovery, avionics, payload, and propulsion.

Airframe:

- Nosecone:
    - Friction fitted to the body tube.
    - Made of Polypropylene.
    - Fiberglass bulkhead 0.250 inches thick
    - Added bulkhead with 500 pound rated eye bolt.
- Bluetube:
    - 4 inch diameter
    - Three sections
    - Fore tube
    - Switch band 1 inch
    - Aft tube with bulkhead for dual deployment and 500 pound u-bolt.
- Fincan:
    - Carbon fiber composite
    - Fins were 0.500 inches thick once all layers were on and laminate epoxy cured.
    - This was first made in the summer before the 2020-2021 school year and it started with the wrapping of a covered body tube with three sheets of carbon fiber. We then wrapped the carbon fiber with heat shrink tape and used a heat gun to compress the epoxy. After this dried, we began to work on the fins themselves, layering composite and foam core with epoxy in between all layers and then using a vacuum seal to pull the epoxy. After curing, we cut down the carbon fiber mess into a square with a bandsaw and then took it to the water jet to cut out the correct fin shape. After this we would attach one fin at a time to the fin can with epoxy and use a jig to align all the fins to each axis. Because the single attachment point to the fin

can is weak, a tip-to-tip method was done to strengthen the attachment. This was done by cutting out carbon fiber section pieces that had the shape of the area in between to fins. After the two different directions of carbon fiber weaves were cut, we epoxied the sheets to the fin can and used rollers and brushes to spread the epoxy evenly. We then put a mylar layer on top to apply even compression to all areas, and then wrapped the entire assembly with a vacuum bag, being careful to seal all gaps in the bag. We then pulled a vacuum and let the epoxy cure, repeating the process to the other two sides of the fins. This left quite a few deposits of epoxy and excess bleeder fabric that needed to be dremeled off, however, this process was not done perfectly and led to an increase in drag.





- Lumedyne nuts:
    - These were ordered to prevent the separation of the two parts of the body tube that need to remain together so that the back powder charge could only blow out one end of the tube instead of breaking off in two places which would not have allowed the deployment of the main parachute.
    - No shearing of the pins, all worked without fail.

Recovery:

- Drogue Parachute:
    - This two-foot rocket man chute allowed the descent rate to slow down enough to where when the main chute deployed at 800 feet, the opening force wouldn't tear out bulkheads and it would also reduce drift by deploying closer to the ground.
- Main Parachute:
    - This 10-foot rocket man parachute would slow the rocket down to a descent rate of 15 feet per second, leading to a very slow and elegant landing. We chose this because of availability and the known Cd value of 0.96, which would help calculate the drag and descent rates.
    - Opening force from parachutes calculated from knacke parachute manual with the equation F=Area*Dynamic Pressure*Geometry coefficient*Force Reduction factor. After finding these values for a ten-foot parabolic chute (closest shape in the manual to what we have) we found an exact value of 78 pounds. This value was then doubled as a safety factor and then we built our hardware to withstand this force.
- Black Powder Charges:
    - One charge was for the drogue chute which would require less because it was a smaller volume, and another for the main chute that required a larger charge because it had a larger volume. The exact amount was based on the calculation of volume found in stage two.
- Packing:
    - The drogue chute only required a small amount of packing skill because it was so small. We did still have to attach the nomex sheet to the kevlar shock cord to avoid burning of the parachute.

- The main chute required practicing to pack and even at our final pack it was still a tight fit. However, the recovery charge that pressurized the container was enough to deploy the parachute at 800 feet at an estimated descent rate of 15 feet per second.
- Kevlar Shock Cord:
    - The length of the shock cord was encouraged to be two to three times the length of the rocket. Due to the availability of this easy access material that had worked in the past and was rated for far more than our opening force. We also took into account the fact that kevlar is heat resistant and would not burn when the deployment charge blew.
- Unexpected at Stage Two:
    - The shear pins that we had chosen to constrain the nose cone were discouraged from use in stage two and instead friction fit was encouraged. After the safety officer convinced us to just use friction fitting, we had to wrap the nose cone in tape in order to make the fitting between the two pieces a little more snug.
- Unexpected at Stage Three:
    - The electronic connections needed to be checked in stage two. The range safety officer was concerned about the wires touching so we had to rewire the connections to the altimeter. This was then not checked one last time at stage two and when we attempted to turn on the altimeter at stage three, it would not turn on and we had to open the bulkhead and rewire the altimeter making sure all connections were in their correct position.

Avionics:

- RRC3 Sport:
    - Capable of dual deployment and was programmed to do so.
    - Our first deployment charge was meant for our drudge parachute and was set to go off at apogee, but in actuality, it went off just a little after due to a delay in pressure difference and reading time.
    - The second deployment charge was meant for our main parachute and was to be used as our main way to slow down our rocket. This charge was set to go off at 500 feet and successfully did so.

    - The altimeter also has an external program that allows us to get additional information over our flight.
- <u>9 Volt Duracell Battery:</u>
    - Recommended battery to use for the RRC3 sport.
    - Sufficiently powered the altimeter for ample time before, during, and after the flight.
    - Was wrapped in tape in order to help friction fit the battery inside the battery holder.
- <u>Battery Holder:</u>
    - Printed out of TPU and specifically designed for the 9-volt Duracell battery.
    - TPU was used in order to help absorb some of the shock and forces that are exerted onto the battery throughout the flight.
- <u>Wires:</u>
    - One 10 inch and one 24 inch wire were used to connect the altimeter to the deployment charges.
    - The 10-inch wire was used to connect to our drogue parachute chamber, and the charge was located just outside of the bulkhead. The launch requirement was 6 inches outside of the area where the charge would be located.
    - The 24-inch wire reached from our altimeter to 6 inches outside the top of our nose cone.
- <u>Switch:</u>
    - A rotary switch was used.
    - Wires were soldered on and were connected to the altimeter to turn it on.
    - The switch was epoxied into our switch band.
- <u>Switch Band:</u>
    - A 1-inch long piece of body tube was connected to the outside of our E-Bay coupler tube.
    - Contained three vent holes each with a diameter of 0.250 inches in order to allow the altimeter to get a corrected pressure reading.
    - Also contained our altimeter switch.
- <u>Bluetube Coupler:</u>
    - Was 8 inches long.
    - Had two fiberglass bulkheads on either end. Both 0.250 inches thick.
- <u>Fiberglass Bulkheads:</u>

- Each bulkhead was 0.250 inches thick.
- One bulkhead had a U-bolt attached to it and was connected by nuts with washers to help spread out the force exerted on it due to the shock cord and parachute.
- The other bulkhead had an eye-bolt connected to it, but only had a nut and no washer.
- No washer was used because there was less force exerted on it and because we didn't have one big enough to be effective.
- Each bulkhead also contained holes for our allthreads to go through so they could be connected and secured in place.

- U-Bolt:
  - We used a u-bolt on our main parachute side because there would be a greater opening force, and the u-bolt could spread out the force exerted on the bulkhead.
  - We used a u-bolt with a strength rating of 500 pounds
  - Our opening force was calculated and projected to be 78 pounds and so our u-bolt held up through recovery.
- Eye-bolt:
  - Our eye-bolt was connected to our drogue parachute shock cord and was used because there would be less of an opening force.
  - Our eye-bolt was rated to a strength of 500 pounds.
  - The opening force of our drogue parachute was 76 pounds, we were able to have a successful recovery here too.
- Sled Holders:
  - 3-D printed out of PLA.
  - Printed with holes to screw in our sled, and with holes to connect the sled to allthreads.
  - Printed out of PLA because there would be little to no force exerted on them.
- Mounting Hardware:
  - Plastic standoffs were used to keep the altimeter up off of the sled so it could get accurate readings and to keep the electronics from touching the sled.
  - Small metal nuts and bolts were used to connect the battery holder to the sled.

- ABS Sled:
    - Cut out of ABS because there would be little to no force exerted on them.
    - Made from a sheet of ABS that was 0.100 inches thick.
    - Holes drilled into the sled in order to mount the hardware and attach the sled to the sled holders.
- Allthreads:
    - They were made out of aluminium.
    - Two were used and each one was 8.500 inches long.
    - They had a diameter of 0.250 inches.
    - Rethreaded after we cut them to size.

- Unexpected at Stage Two:

    - Wire connections from the switch to the altimeter were cut and shortened in order to reduce the chance of it touching another wire and hurting our electronics, or causing the deployment of our parachute to be early.

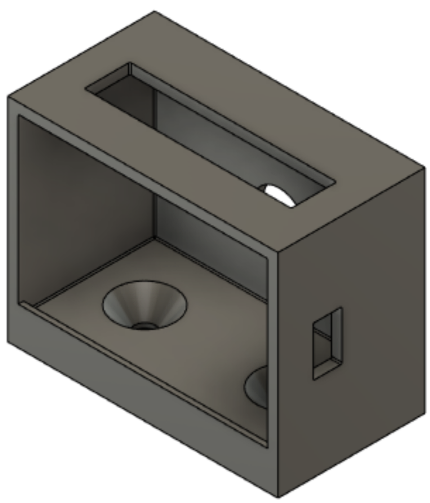
- Unexpected at Stage Three:

    - The electronic connections needed to be checked in stage two. The range safety officer was concerned about the wires touching so we had to rewire the connections to the altimeter. This was then not checked one last time at stage two and when we attempted to turn on the altimeter at stage three, it would not turn on and we had to open the bulkhead and rewire the altimeter making sure all connections were in their correct position.

Payload:

- GoPro:
    - HD Hero Original
    - 3.400 ounces
    - Wide lense

- Camera Case:
    - Printed out of TPU.
    - The flexible design allows for easy insert and removal of the camera while keeping it secure.
    - TPU is also effective at absorbing shock.
    - Holes are designed at the bottom for screws to attach to the coupler.
    - There is a rectangular hole in the top of the case so that one can access the power button.



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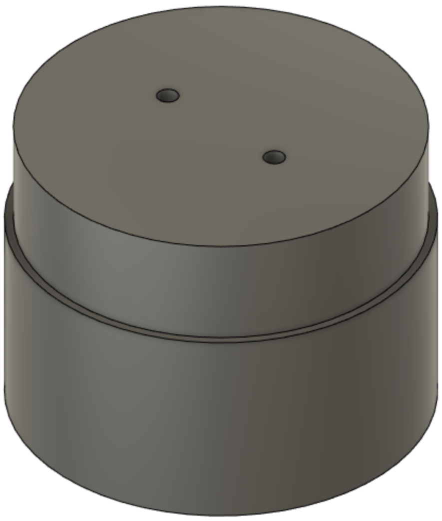
- Camera Case Screws:
    - 2.250 inches, longer than needed, but plenty of room in the coupler so it does not interfere.
    - Thread diameter: 0.240 inches

- Washers:
    - Located within the bottom couple, two were used on each screw to spread the force along the coupler.
- Nuts:
    - Like the washers, these were within the bottom coupler.
    - Used to secure the screw and washer to the coupler.
- PETG Couplers:
    - Printed out of PETG for a durable material.
    - Hollow to allow access to nuts and screws.
    - Two holes for screws that would secure the case to the coupler.
    - Connects the polycarbonate tube to the main body.
    - Two couplers

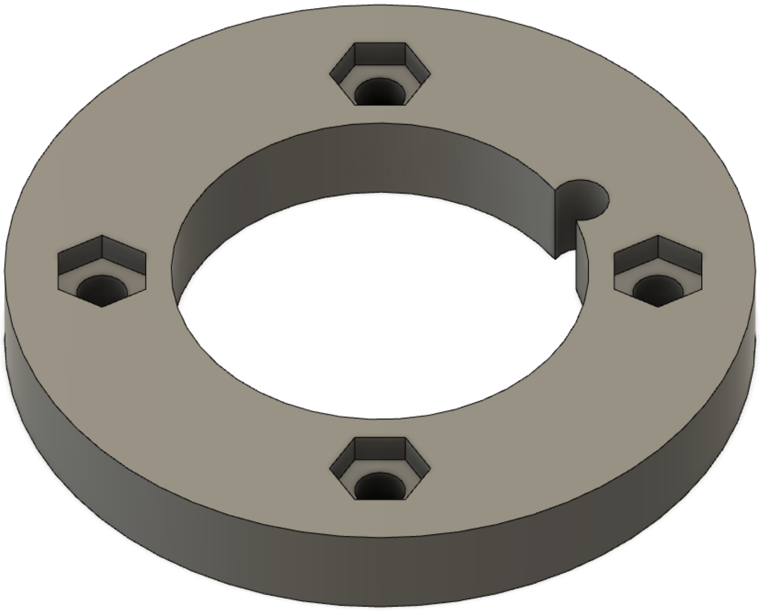


- Threaded Inserts:
    - Drilled with 15/64 inch drill bit.
    - Three placed in each coupler.
    - Screws would go through holes in the polycarbonate tube and into the inserts in the couplers.
- Coupler Screws:
    - These would attach the polycarbonate and couplers to each other.
    - Six screws of three different sizes were used (two of each size). There were different sizes because some wouldn't fit in the threaded inserts due to

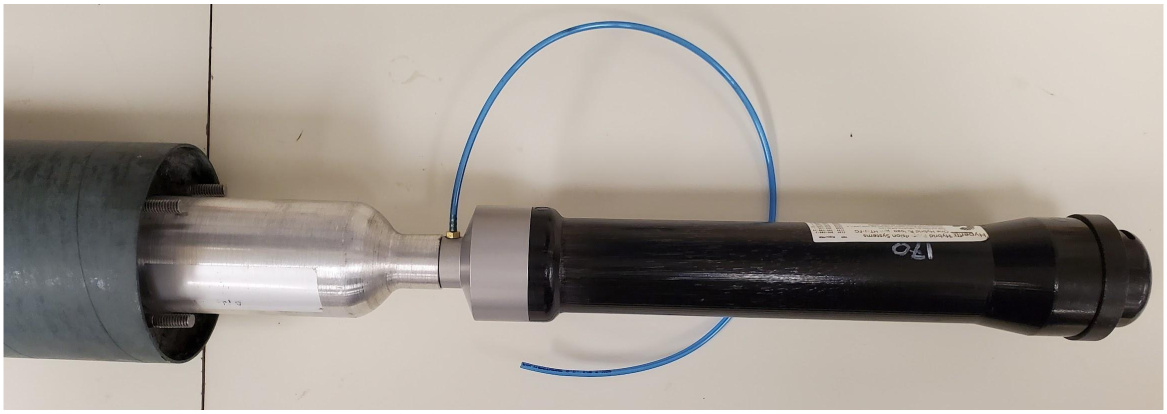
there being excess PETG after we melted holes in the coupler to install the inserts.
    - Screw sizes: 1.212 inches in length, 0.181 inch thread diameter; 0.675 inches in length, 0.250 inch thread diameter; 0.500 inches in length, 0.250 inch thread diameter.
- Polycarbonate Tube:
    - 5 inches long
    - 0.125 inches thick
    - OD: 4.014 inches; ID: 3.750 inches
    - Weight: 5.340 ounces
    - Clear to allow the camera to record within the rocket.
    - Polycarbonate is very strong (tensile strength is 9000 pound-force per square inch).
    - Two small holes were positioned to allow the Allen key to turn on the camera, and to start the recording.

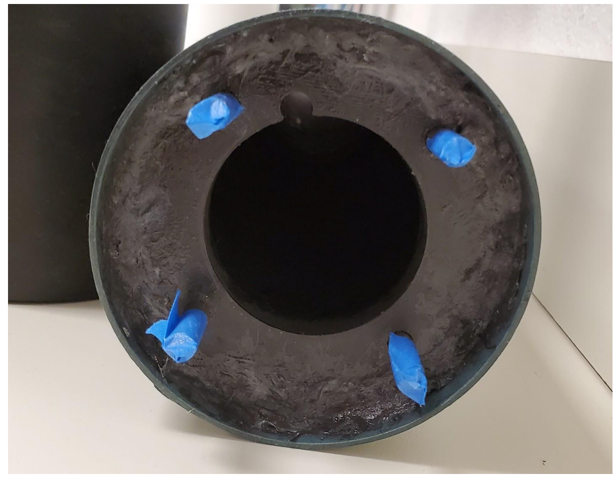
Propulsion:

- Hypertek K240 Engine:
    - We went with the K240 over the L550 because it kept us comfortably within our altitude margin. When we simulated flight with the L550, the rocket would go significantly higher than the required 5280 feet.
    - 5.600 seconds of burn time and 425 Newtons during max thrust.
    - Three o-rings are in this system, one to seal the ox tank to the injector bell, one to seal the fuel grain to the injector bell, and one inside the injector bell which is used to seal the fill stem while the ox tank is being filled.
- Retention System:
    - The Retention system used experimental carbon fiber epoxy to hold the retention system into the body tube.
    - Carbon Fiber onyx retention ring with countersunk bolts made up the retention ring keeping the motor from shooting through the rocket.

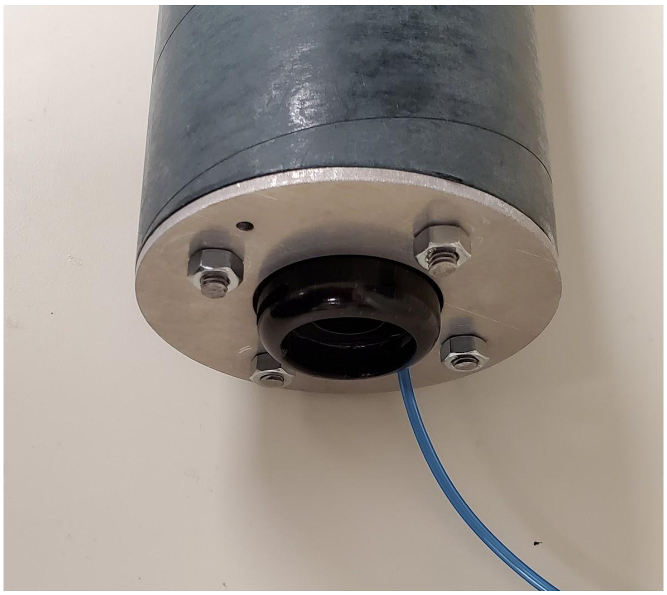


    - Carbon fiber onyx fuel grain spacer allows the retention system to clamp down on the fuel grain and hold it in place, (using the aluminum thrust plate to clamp down).
    - An ⅛ inch aluminum ring is used on the aft end of the rocket to keep the motor from shooting out the back when we deploy our parachutes.
- <u>Fuel Grain Analysis:</u>
    - When we flew our rocket we noticed that it sounded and looked like the most powerful K240 burn, but after mass analysis, we realized that it only burned a fraction of the mass it was supposed to burn.
    - In the end, the fuel grain only burned around ⅓ of the mass (2.469 ounces, or 70 grams) it was supposed to burn (7.055 ounces, or 200 grams).
- <u>Retention System Pictures:</u>



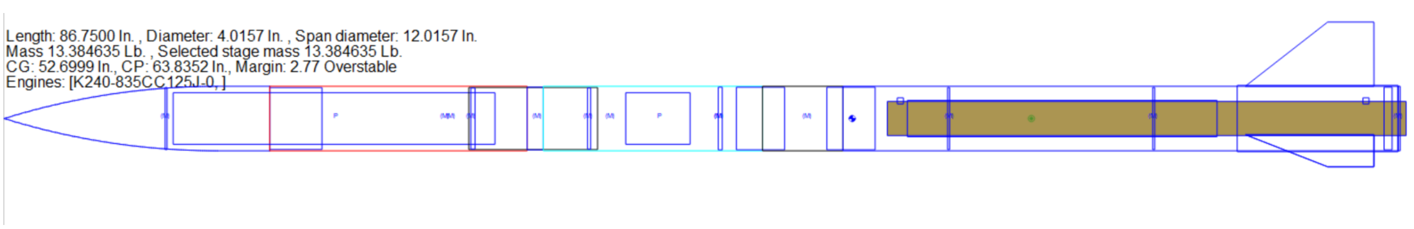


Graphic of Carbon Fiber Epoxy used to adhere Onyx retention ring to the body tube.



Aluminum retention plate and nuts installed, fully securing the motor.

RockSim/RASAero



The RockSim and RASAero simulations are the foundation of designing any rocket. RockSim gives us a variety of data based on our rocket (e.g., center of mass, center of pressure, weight, etc.) and its flight (e.g., drift, max velocity, apogee). RASAero gives us accurate drag coefficients based on rocket aerodynamics that we use to modify drag data in Rocksim. However, we didn't use RASAero for our 1-Pound/1-Mile mission.

The *Saturn VI* had a plethora of components that needed to be tracked and inputted into RockSim, and we had to make sure that the locations and relative CMs of each component were accurate. Simulations were run to find the

Launch Day Stage 1/2

- A new battery was placed inside of our E-Bay and friction fitted into the holder before we started our FRR review.
- Shear pins were removed because the calculation for the amount of black powder we needed was much more complicated, and a friction fit was more reliable and less black powder was required.
- A bolt that helped hold together our polycarbonate tube to the coupler ended up getting in the way of our rail guides and interfered with the launch rail. The bolt was left in but created a weird angle on the launch rail.

Launch Day Stage 3

- We attached a card to the rocket's body tube displaying information on how to turn on the altimeter and camera for flight.
- Black powder was loaded, the E-bay was tested, and the camera was tested before the rocket left for the launch rail.

Conclusion

- <u>Flight Analysis:</u>
    - The rocket took off and went about half a mile (2500 feet) before it reached apogee and deployed the drogue parachute. Afterward, the rocket came down at a velocity that we are unsure of because our altimeter didn't record velocity or acceleration, but our main parachute deployed at 800 feet to continue to slow the rocket's fall. Upon landing, we found that the electronics worked and our charges deployed to allow for a successful recovery. We also discovered that our rocket didn't go as high as planned.
- <u>Expected vs Outcome:</u>

- We expected our rocket to reach a height of 1 mile but data showed only went half the expected altitude.
- We expected for our engine to burn all the fuel, but we only got around ⅓ the efficiency.
- Video footage that we captured with our GoPro was much better than we expected, and we were able to clearly see each stage of recovery in the video.
- The actual data found may not be accurate because the seal of the avionics bay could have been unsealed and let hot gasses inside, disrupting maximum values recorded by the altimeter.

- Changes for Repeated Mission:
    - Check that our designs are final before we cut our components so we don't waste material.
    - Check what direction our 3D printed components are printed for the best strength rating for its desired use. This specifically applied to the PETG couplers that had to stand up to the opening force