Transonic Post Mission Analysis

Exodus

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Abstract

Within this Post Mission Analysis of the *Exodus* Transonic vehicle is a culmination of the ideas, decisions, and processes that our team — the 2nd/3rd Period Transonic team — experienced throughout the year. Included is an overview of our team's mission, a timeline of specified deadlines, a breakdown of component decisions, a dissection of our building processes, and any final preparations before launch day; also, an analysis of each stage at Smith Point, *Exodus*'s performance during flight, and any identified failure points will be addressed.

Objective Of Vehicle

The *Exodus* rocket was designed to achieve the Transonic mission: surpass Mach 1 (1125 ft/s) while staying under the altitude limit of 13,000 ft. Logically, a rocket reaching Mach 1 would experience stresses that are magnitudes higher than that of a 1lb/1mile rocket. As a result, we concluded that proving our materials wouldn't buckle was as important as efficiently designing each component. Understanding the mission requirements served as a guide that steered us toward choosing the right materials and components.

Yearly Projection of Transonic Mission

- Fall Semester
  - Develop Math Model (simultaneously finish designing and building 1lb/1mile)
  - December - begin Preliminary Design Review for Transonic vehicle and continue research
- Spring Semester
  - Research and design until CDR in late February.
  - Begin construction on Fin can February-March; because it's a mission critical component, as well as complex and time-consuming, we made sure to start early so we have time to adjust for mistakes.
  - March through May consisted of construction and acquisition of hardware from vendors:
    - Build Electronics and hardware insertion.
    - Develop procedure for tapping retention system.
    - Finish modifying the body tube and then have the vehicle painted in May.
    - Tested strength of launch lugs and retention system, release mechanism in the Jolly Logic, and data collection in the Stratologger.
  - Work on the FRR as we are constructing the rocket, and finished FRR week of launch.
  - Prepare tool boxes and last minute preparations week before Launch.

Airframe

Airframe Team Object

- The Airframe team will design a 3” diameter vehicle that will minimize drag, surpass Mach 1, and choose materials that will withstand the aerodynamic forces experienced during flight.

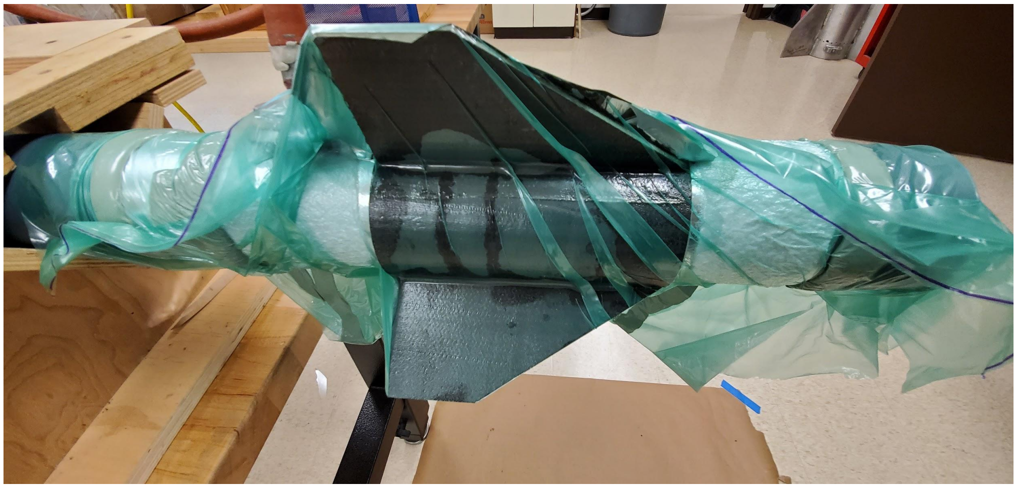
Timeline

- After finishing our flight review in November, we researched whether we should buy premade launch lugs or 3D print original ones that are designed to minimize base drag, as well as the optimal location for each launch guide based on the separation points in our rocket; also, we compared heat resistance and tensile strengths of different filament materials, and, after finding out our maximum dynamic pressure (Max Q, maximum amount of force on the front of the rocket), we chose materials Materials were then selected based on what we needed to design our rocket around.
- January-April was used for building our rocket and testing components that we would use.

Components

- Blue Tube
  - 3” diameter flexible phenolic from Always Ready Rocketry
- Coupler
  - Made of Blue Tube with an outer diameter of 2.9”
  - Cut to length and used to house our Avionics’ Electronics bay.
- Nose Cone
  - 3” diameter fiberglass
  - Found in storage and used in a previous Transonic mission.
- Fincan
  - We made our fin can out of carbon fiber by first wrapping mylar around our 3” body tube then carbon fiber 6 times to build thickness. We then

wrapped 3 layers of carbon fiber around the mylar, applying laminate epoxy to each layer. We then slowly wrapped the can with heat shrink tape and used a heat gun to constrict the epoxy while it cured. After this, we made the fins themselves by placing two layers of carbon fiber on either side of the 0.125" thick foam core. We then added epoxy to each layer, with peel ply and mylar on either side to get a rough finish while protecting the two aluminum plates that would clamp down on the whole assembly while the mess dried. After the epoxy had cured, we cut the block into a square shape with a bandsaw and then water jet the shape of the fins on the square. This made a total of 4 fins, giving us an extra one in case one of the fins began to delaminate. We then epoxied these fins to the fin can with one line of laminate epoxy each, making sure to align the fins with a jig that could constrain the fins and fin can on an axis. After all three were epoxied on, we worked on adding strength to the fins with a method called tip-to-tip. This method works by laying sheets of carbon fiber from each tip of the fin, adding epoxy, and sheets of mylar and bleeder fabric to protect the can, and then compressing the assembly with a vacuum system. After this vacuum was lifted, the next step was to decrease drag by sanding the rough parts where epoxy cured in lumps. This was effective and we continued to do so until all three fins had a matt finish. Then we added another layer of laminate epoxy to the fins to gloss up the surface and



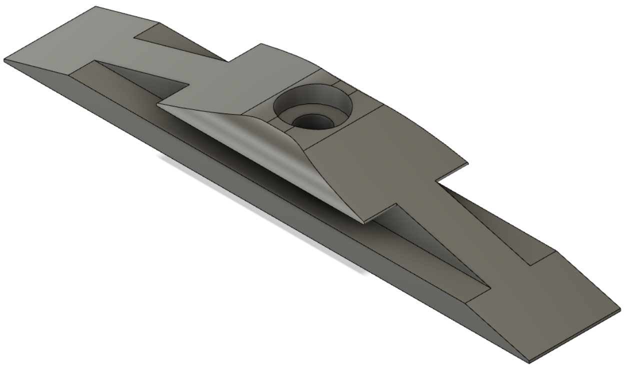
reduce the drag as much as possible.

Picture of tip-to-tip vacuum bagging process (epoxy bubbles can be seen, so we had to sand those down)

- If future teams are looking into fin cans, one thing we would advise while epoxying the fins to the can itself is to create a rigid jig that ensures each fin is equidistant from the others (3 fins, so centers of fins are 120 degrees apart), as well as level and in the middle of the fin can's surface. We didn't have a proper jig for alignment, so 1 of our fins was off centered when looking from below

- Rail guides
    - Originally designed and printed in Carbon Fiber PEEK and tested to withstand the force of the rocket at takeoff. However, after our failed launch attempt they slightly melted, due to the heat of the rail and the friction, so plastic rail buttons were used instead.

Testing of PEEK Carbon Fiber Rail Guides



- Launch guides resisted 50 lbs in a static suspension test

Extra Information

- We used paint that provided a gloss finish over our rocket; we avoided going over the $900 budget limit by having Damian's Paint and Body shop paint our rockets for free

- The failed attempt involved the launch team mistaking the small 3" vehicle for a K240 motor instead of an L550; as a result, the zip ties that were being used were not strong enough to withstand the large amount of pressure inside the Ox tank. This led to the zip ties breaking too early and the rocket propelling itself off of the rail without igniting. The rocket then landed hard on the ground, making a hole in the tube and a crack in the nose cone. On-site engineering tactics were used to repair the rocket, such as using kevlar mixed epoxy to strengthen the hole as well as adding epoxy to the nose cone to smooth out the crack. The next problem was strengthening the integrity of the broken section, so a Pringles can and multiple layers of painter's tape were installed between the fuel grain and body tube to prevent buckling. Then, we replaced our launch guides that had melted from the heat generated from the launch rail with plastic pre-bought launch lugs. Although these were less aerodynamic, they were significantly sturdier and heat resistant than our launch guides. We were able to redo the black powder charges for Stage 3 and launch the rocket for the second time.

Airframe Team Conclusion

- Because the parachute didn't open on recovery, one of our carbon fiber fins broke on impact with the ground.
- Data for the mission was recovered; however, we believe that that data is inaccurate. We suspect that we didn't properly seal the E-bay chamber with the gasket maker lead; as a result, not all holes were covered and hot gasses could have potentially leaked into the E-bay, so the altimeter read the data produced by the hot gasses and caused an incorrect reading.
- Some things we could have better prepared for was the communication from Stage 3 to the launch team to prevent misinterpretation, as well as testing the launch rails on a piece of the body tube, rather than on a large strong block of wood, as there is less strength on a piece of blue tube.
- Some final suggestions to future teams: avoid shear pins as they complicate the calculation of black powder, make sure to test your launch lugs as they will appear on the rail, and don't forget to verify all masses and positions of materials with the people in charge of keeping the most updated files of Rocksim and RASAero.

Recovery

Recovery Team Object

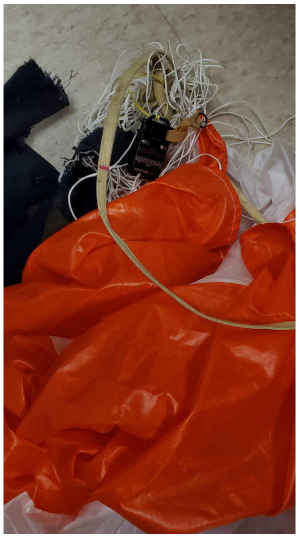
- Allow the rocket to achieve Mach 1 by minimizing mass and occupied space, and safely recover the rocket by deploying a parachute at apogee to reduce opening forces and reducing drift by expanding the parachute at a predetermined lower altitude.

Timeline

- Begin with research in January while looking into methods that would decrease mass.
    - Options found: streamer, reefing, not so much dual deployment because it would increase mass and increase the amount of space needed.
- Found the best parachute for reefing in late January: Apollo chute.
- The idea to reef a parachute with rings was discouraged by complexity and radial forces, so then replaced the idea with wrapping Jolly Logic around the base of the chute so that it would act as a streamer. This idea was put into all of our models in March, but only small inaccurate tests could be done about the mechanism itself because the parachute had not come in yet.
- Worked with avionics through April to determine charge redundancy and found shock cord length.
- Practice folding parachute 1 week before launch.
- Cut Nomex sheets right before launch.

Components

Apollo chute on right, Jolly Logic device (black), nomex sheet (blue), kevlar shock cord (yellow small)



Shock cord and Jolly Logic elastic band mechanism

- Apollo Chute - 14 gores
  - Initially chosen because of reefing capabilities: multiple gores that would allow the Jolly Logic mechanism to wrap around the bottom of the parachute.
  - To calculate the opening force that would be experienced, we used the Knacke parachute manual equation:
    Opening Force = Area*Dynamic pressure*Geometry based coefficient*Force reduction factor
  - The found value was then used with a safety factor of 2 because of the variability of the force reduction factor and geometry-based calculations. This force was then actually reduced because the parachute was not opening from a completely constrained position. Instead, it was already partially open, reducing the force further.
  - The exact calculations gave us a force of 242 lbf. This number was then doubled to 484lbf as a safety factor and the rest of the hardware was chosen to withstand this value.
- Jolly Logic - Used to "reef" our parachute
  - The streamer was the alternative but still required a Jolly Logic to release the parachute to full capacity.
  - We debated whether we should use a case; however, this would have complicated the release mechanism, make it harder to turn on and off and take up more packing volume. This device was modeled in Fusion 360 along with the parachute in order to estimate a packing volume needed, as this would determine the forward body tube length.

    - The use of this device meant that we could constrain the bottom of the parachute — close to the shroud lines — and the “reefed” chute would act as a streamer until the altimeter inside the device detected a preset altitude of 500ft to release a pin and loosen the parachute from the elastic band.
- Kevlar Shock Cord
    - Availability, budget, and known strength and heat resistance.
    - The length was recommended to be 2-3 times as long as the rocket so that the nose cone would not ram back into the body tube and to reduce the effects of tangling.
        - Also, having the shock cord substantially longer than the rocket body avoids the forebody wake effect phenomenon.
            - If the parachute is too close to the rocket body, the wake/turbulence caused by the rocket body interrupts the airflow going to the parachute. As a result, there’s insufficient airflow in the parachute and a subpar recovery.
- Nomex Sheets
    - Heat resistant material protecting the parachute from the black powder charge. This was a predetermined material that we chose because of availability and known heat resistance.
- Swivel
    - Attached from the parachute to the shock cord in order to mitigate tangling of shock cord with shroud lines

Extra Information

- Jolly Logic needed to be turned on at Stage 3 after the black powder was in place: we had to confirm with mission control that it was ok to undo the parachute, turn on the device, roll the parachute back up, and place it back into the rocket.
- The parachute was packed too tightly into the nose cone (reason of failure).
    - As the rocket reached apogee, the black powder popped as planned. However, because of the placement of the parachute in the nose cone, the parachute was only forced more into the nose cone and the weight of the rocket, combined with insufficient shock cord length, made it impossible for the “snatch” to pull the parachute out of the nose cone. This meant our descent rate is estimated to be around 130 ft/s, too fast for a safe recovery and causing considerable damage to the airframe.
- The Jolly Logic worked as planned because, once we recovered the rocket, we observed that the Jolly Logic mechanism did in fact release, even inside the nose

cone. This suggests that the only reason for failure was the improper packing and placement of the parachute.

- In the future, teams should meticulously pack, place, and test their recovery systems to ensure success. We conclude that parachutes work better when placed in the body tube further aft than the release point caused by the black powder (shoulder of nose cone). This prevents the black powder from further stuffing the parachute and allows the nose cone to shoot off first and pull the parachute out with it, rather than relying on the backward force of the weight of the rocket to pull the parachute from the nose cone.

Recovery Team Conclusion

- Since the beginning of the new semester, ideas on how to recover the rocket were scarce, little complexity could be added, and only a single deployment bay could be used in order to reduce mass and length. The final solution was discovered and put into practice immediately, our calculations following suit. At the launch pad, only one method of failure was discovered which caused a faster than expected descent rate. This, however, gave us a clearer understanding of how parachutes should be packed in the future.

Avionics

Avionics Team Object

- The Avionics team will create a functioning Electronics Bay and electrical system of the rocket to collect data and work with recovery to deploy a parachute at apogee.

Timeline

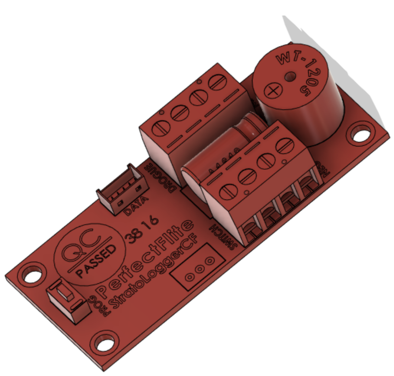
- January/February
    - We spent these two months in the planning and designing phase and that was when we completed all of our CAD models.
- March
    - During this month we started buying or manufacturing the parts needed for the E-bay.

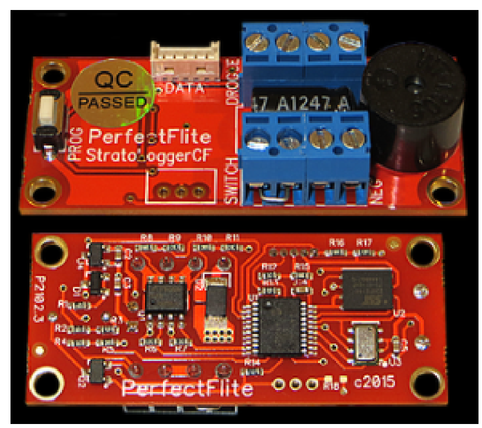
- We also started working on the Eggfinder, learning how it works and getting ready to assemble it.
- We also turned on our Altimeter and vacuum tested it to make sure it works properly

- April
  - There were a few last-minute changes during this month so we did go back to the planning phase for a few days and designed new 3D printed pieces
  - The last week of April, 26-30, was when we finished all of our parts and did our first final assembly
- May
  - Because everything else for our E-Bay was done we spent our final week before launch, 3-6, working on the Eggfinder and doing what we could to make it work.

Components

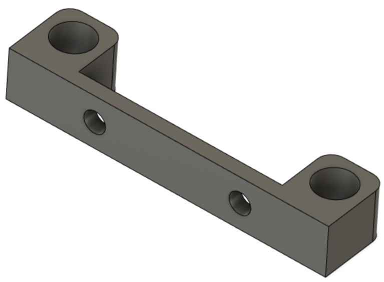
- Stratologger CF
  - Possible dual deployment, which allows us to have a redundancy charge
  - Small profile making it easier to use in a sub-diameter vehicle
  - Everything we need to access the external program is in-house



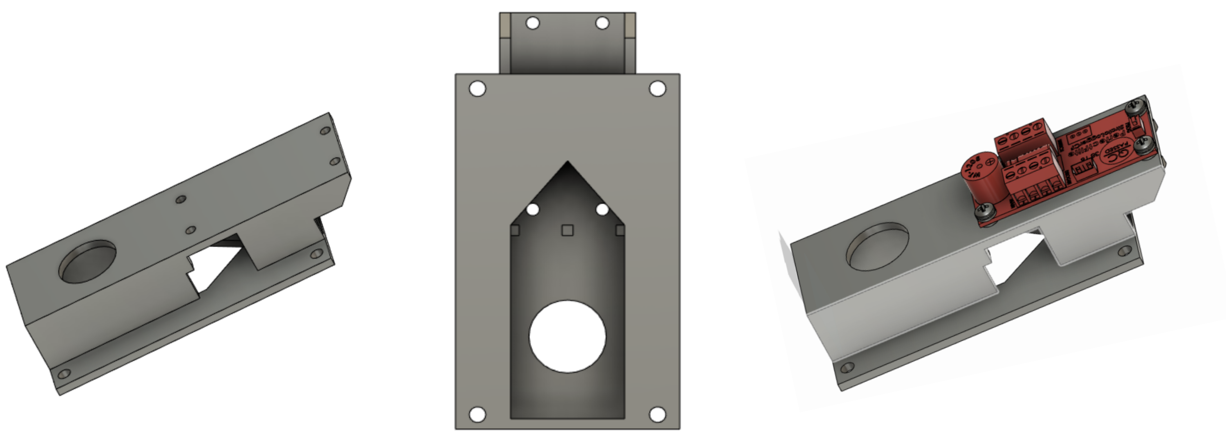


- Wires - 18" wires to connect pyro charges, wires to connect switch and battery to the altimeter
  - The yellow casing on the wires used for the switch and battery was completely stripped off to allow a greater amount of maneuverability
- Battery - 9 Volt Duracell Battery
  - Known to work and stand up during the forces of flight

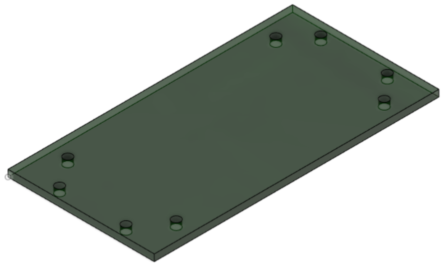
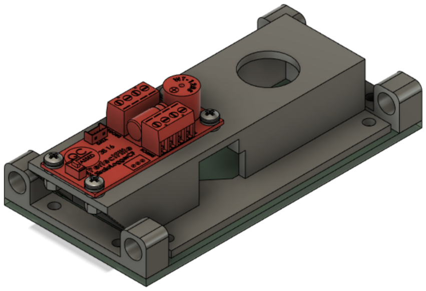
- Switch - Rotary
  - Switch band was not used to save space
  - Wires are connected on the switch using heat shrink and then the switch was screwed into the body tube, more information below
- Sled Holders - 3D printed using PETG, mounts the sled to the allthreads
  - These pieces allow us to have more options when deciding the material and the mounting procedure of the sled



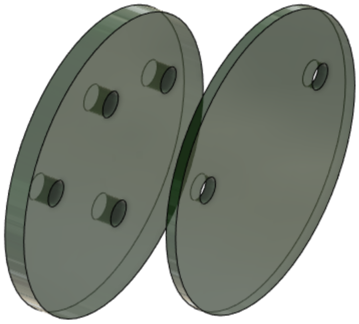
- Altimeter Mount - 3D printed using PETG, mounts the battery and altimeter
  - Allows us to use a sub-diameter vehicle



- Fiberglass Sled - 0.1" thick

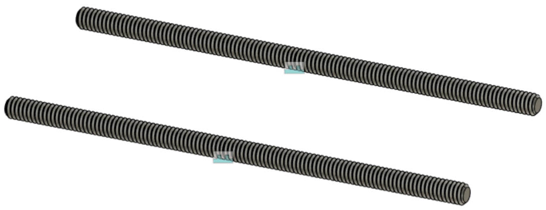
 

- Fiberglass Bulkheads - 0.2” and 0.1" thick
  - Two different thicknesses were used because one will be connected to the U-Bolt and will be subjected to the majority of the force during deployment.

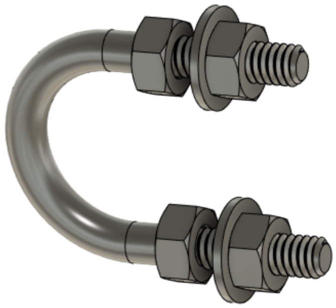


- Blue Tube Coupler - 5” in length
  - Due to the 3D-printed altimeter mount, we were able to shorten the length of the E-Bay. 5” in length gave us enough space to fit everything while also saving us weight.
- U-Bolt - Steel, rated for 420 pounds
  - All aluminum U-Bolts found were not rated high enough for our safety factor or were too large for our E-Bay
    - McMasterCarr part number 2936T34

- Allthreads - Aluminum, 5 ½" in length
    - In-house
        - McMasterCarr part number 94435A313

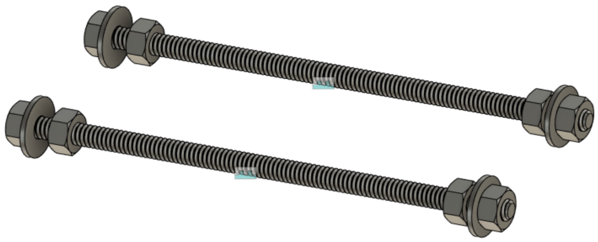


- Steel Hardware - 4 nuts and 2 washers used to connect U-Bolt to the bulkhead
    - Steel was chosen for the U-Bolt so we wouldn't have any different material connected to one another
        - Nuts, McMasterCarr part number 92141A029
        - Washers, McMasterCarr part number 92141A029

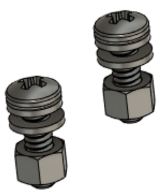
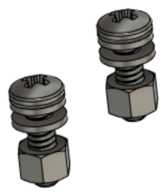
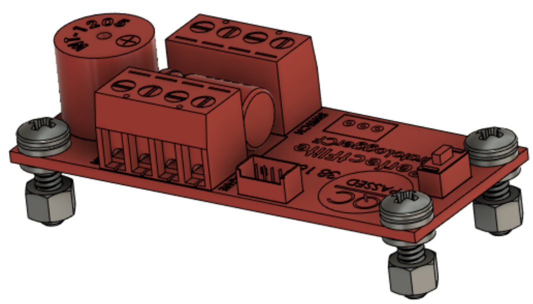


- Aluminum Hardware - 8 nuts and 4 washers used to hold the sled and allthreads in place

- Aluminum hardware was chosen for the allthreads so we wouldn't have any different material connected to one another
  - Nuts, McMasterCarr part number [90670A029]
  - Washers, McMasterCarr part number [93286A013]

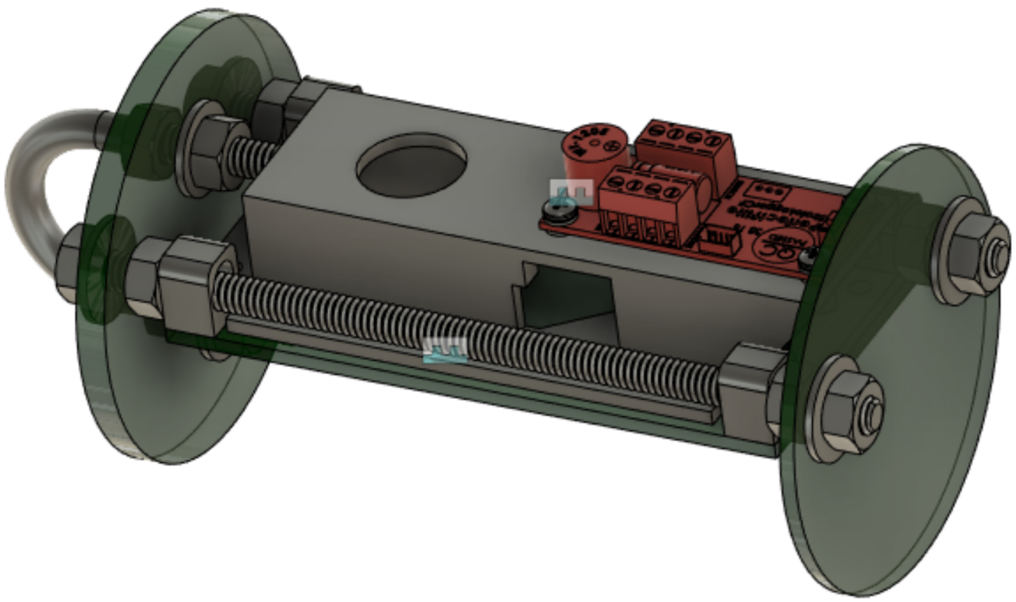


- Mounting Hardware - 4 bolts, 4 nuts, and 4 washers used to mount the altimeter
  - Bought specifically to mount the altimeter because we needed hardware that was small enough for the Stratologger CF
    - Bolts, McMasterCarr part number [98019A237]
    - Nuts, McMasterCarr part number [91735A104]
    - Washers, McMasterCarr part number [98019A237]

- Plastic Hardware - 8 bolts, 8 nuts, and 8 washers used to mount the sled to the sled holders and the altimeter mount to the sled
  - Plastic was chosen because at first we were trying to have a GPS module in our E-Bay, and they stayed when the GPS idea was scraped
  - In-house

Full E-Bay



Extra Information

- E-Bay Design Breakdown
  - Bulkheads
    - We epoxied the 0.2" thick bulkhead into our coupler tube because it was also the bulkhead that the U-Bolt is attached to.
    - Once the bulkhead was in place, we pre-placed the U-Bolt and Allthreads and then used Loctite Threadlocker (Blue) to keep from loosening caused by vibrations.
  - Sled
    - The sled will be fully assembled — all printed pieces, altimeter, and wires — before sliding along the allthreads into the E-Bay
  - Final Parts
    - Once the sled is in, two aluminum nuts will be put on the allthreads to hold it in place, the switch will be installed — the installation procedure is detailed below — and then the 0.1" thick bulkhead will be placed on top.
- Switch Assembly
  - Because we decided to make our Transonic rocket be a 3" vehicle instead of a 4" vehicle, there were very few options for the position of the switch

and switch band. Due to this, we decided to not use a switch band which in return will give us more flexibility in the placement of the switch; however, we had to resolve a few problems first before we could implement the design into our rocket.

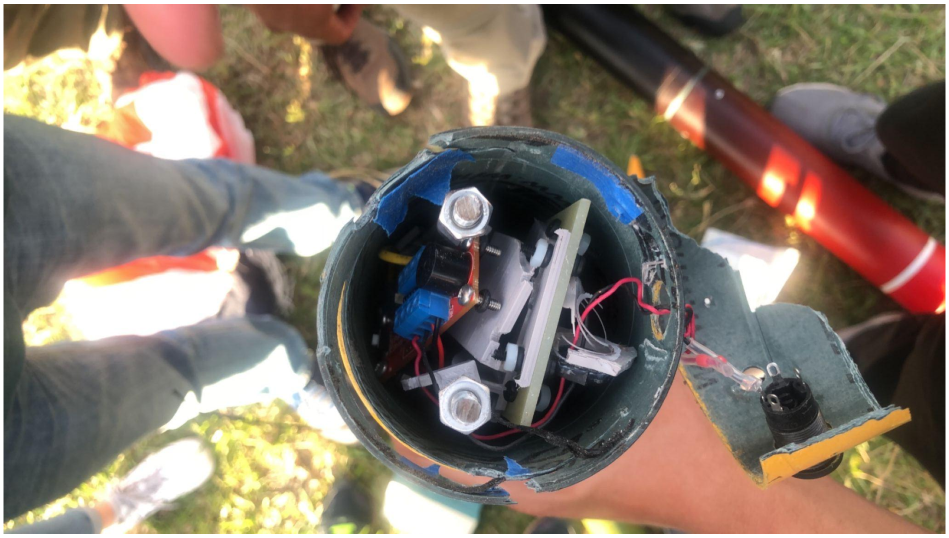
- <u>How will the switch be installed?</u> We found the best way to install the switch is to simultaneously drill through both the body tube and the avionics bay coupler and have a piece on the inside for the switch to screw into.
    - Along the same plane of the switch, we would also drill holes for the Lumedyne nuts and vent holes so everything would be together and it makes putting it together/lining up holes easier
    - Another thing to account for are the wires twisting when installing the switch, so make sure to pre-twist the wires in the opposite direction
- <u>Because the switch has to be removable how will the wires be installed?</u> Because our switch is screwed into the rocket we can not solder the wires to the switch making it non-removable. So to get past this we would expose more wire than would originally be needed and wrap it around the connection points. We would then place a piece of heat shrink around the wire and connection piece to solidify it.
- <u>Will the connection hold up to our projected force?</u> For our Transonic rocket we were projected to hit 13 G's of force off the rail, so minimizing the moveability and exposed sections of the wires is crucial. The heat shrink connection removes the chances of exposed wires touching and it can always be tested by pulling on the connection.
    - Because of the force experienced during flight, the wires, if not secure, will be moving around all over the place. This could allow two pieces of exposed wire to touch which could then short circuit the system, causing your data to be lost and even damage the parts.
    - After the heat shrink connection has had time to cool, we would proceed with the pull test, and if there was any moveability we would redo the connection.

- <u>GPS and EggFinder Information</u>
    - <u>Why it was not included in the final Rocket</u>
        - A week before launch we had finished everything for avionics except for the Transmitter, and there was still lots of work to do for it. But unfortunately for every problem we solved, another would come up in its place and we ran out of time to fix them. Below you will find resources, ideas we had, and problems we encountered — some with solutions — while working with the Eggfinder Transmitter TX Rev4 Board.
    - <u>Assembling the EggFinder</u>
        - There are lots of sources found online detailing assembly. I have included a video and the manual explaining it below
            - <u>Video:</u> https://www.youtube.com/watch?v=EnXyD1dyZbo
            - <u>Manual:</u> file:///home/chronos/u-924a63058cf8d65259b9a7fe8df4d611b2c4d9a9/MyFiles/Downloads/7374995.pdf
    - <u>Battery type</u>
        - The Eggfinder was not designed for a regular 9V battery as it takes in too much power and it cannot keep up. It is recommended to use a 7.4V LiPo battery instead
            - The Eggfinder TX Rev4 board draws a current of 70mA; when choosing a battery, make sure to check how many mAh hours it has: for mine, I hooked a 1000mAh battery to it. 1000mAh will last at most 14.3 hours without accounting for heat.
    - <u>3D Printed Mount</u>
        - Just like the Altimeter mount we designed, we also created one to hold the transmitter and the LiPo battery. It was printed with PETG, 100% infill, and a layer height of 0.2. We also lined up the holes that will mount the Transmitter mount to the sled with the corresponding holes on the Altimeter mount for convenience. This way they will interlock with each other, saving space on the sled and making the connection better.
    - <u>Problems Encountered</u>
        - When working with the Eggfinder or anything similar, check all solder connections after you do them. This way you won't have to go back later and have to work around many parts.

            - Check for solder bridges — when two separate connections have solder in between them — and for holes that aren't completely filled.
        - Towards the last few days of working with the Eggfinder, whenever the battery was plugged in the capacitor in the upper right hand corner, oriented with the battery on the left, would begin to heat up. I suspect that it's either a connection with a resistor is missing or something with the battery
        - During the last week before launch, we changed how the switch was being installed. This change made it that the sled won't be able to slide in as expected because the Eggfinder would hit the new piece. This can be fixed by printing a new mount for the Eggfinder.
- Tips for Avionics in Sub-Diameter Vehicle
    - Plan out the placement of the switch and wires during the CAD phase
        - The switch placement caused us problems later on because we didn't account for the amount of space it takes up when installed. How we fixed this problem is detailed above.
        - Modeling wires not only helps with space management but you can tell how long and where they need to be.

Avionics Team Conclusion

- Overall
    - Our Avionics was a success. The E-Bay protected the altimeter and we were able to get some data even though it wasn't complete. Then for the Eggfinder, even though we weren't able to incorporate it in our rocket, we still made lots of progress that can be used later on.
- E-Bay Performance
    - Our E-bay was almost completely destroyed after launch because our parachute didn't fully deploy. All the printed parts were broken, wires were thrown around, the switch was falling out, allthreads were bent, but, despite all this, the Altimeter survived. It only tilted slightly but was still beeping normally, and the data could be read off of a computer.



Propulsion

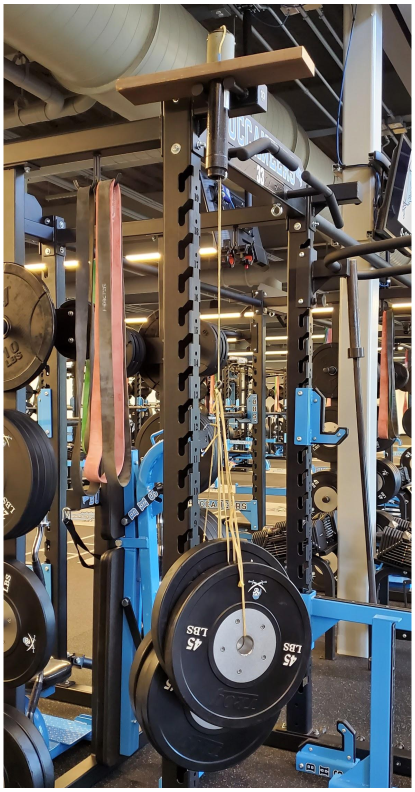
Propulsion Team Object

- The Propulsion team will choose a motor that provides enough thrust for *Exodus* to reach Mach 1, and we will design a retention system that will retain our chosen motor.

Timeline

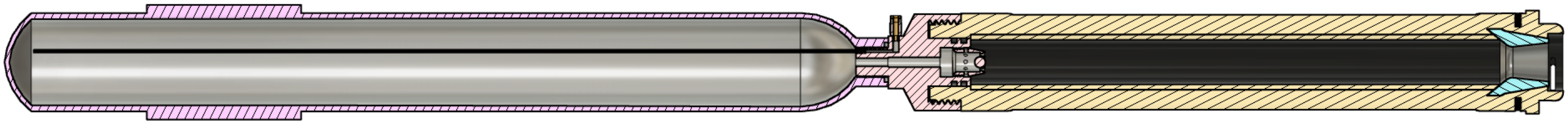
- August/September
  - While working on our Math Models, we used thrust data for the L550 engine.
    - Later, in an attempt to shorten the rocket and decrease mass, we tried redesigning the rocket to the dimensions of a K240, but we had problems with speed.
- September through December
  - Determined that Hypertek's motor adapter was the most efficient and compact retention system we could use.
  - Created CAD models of the ox tank, injector bell, fuel grain, and motor adapter to help visualize our design in PDR/CDR.

- January/February
  - Used Fusion CAD models to import bolts and determine which type we needed.
- March through May
  - Practiced drilling and tapping on a used fuel grain to develop a procedure that'll ensure we get an accurate bolt depth (procedure detailed later in *Components* section).
  - Created a mock version of our retention system using a PLA adapter and spent fuel grain, and tested how much it could hold (only held 225 lbs because the suspension line we hung the weights on was wrapped around the zip tie holes, which aren't meant to withstand tensile stress).
  - After testing, we followed our tapping procedure and began modifying the aluminum motor adapter and actual fuel grain for final construction.



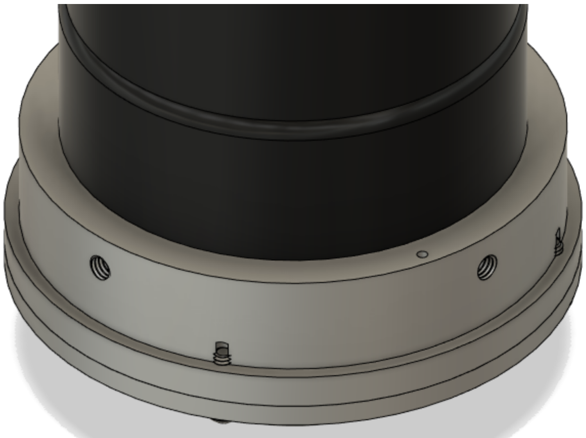
Components

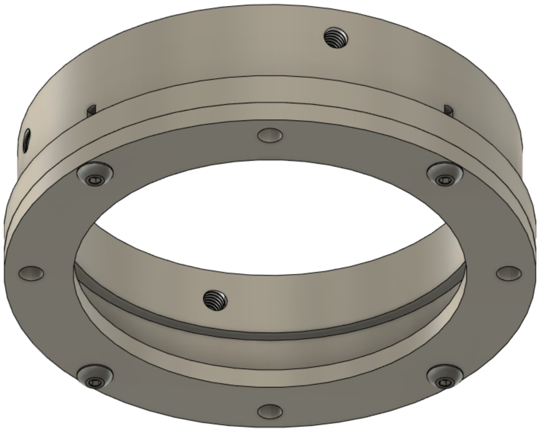
- Hypertek L550 Hybrid engine -
  - Initially simulated rocket using a K240, but we weren't reaching Mach 1. Since the K240 is the most powerful motor in its class, we had to move to the next tier: the L-class. The L550 engine was available in storage and has already been flight-proven by previous Transonic teams as an effective motor.
  - Fully CAD modeled a complete L550 motor to help visualize and design our retention system, including a nozzle (Blue piece) created using real measurements (shown below)



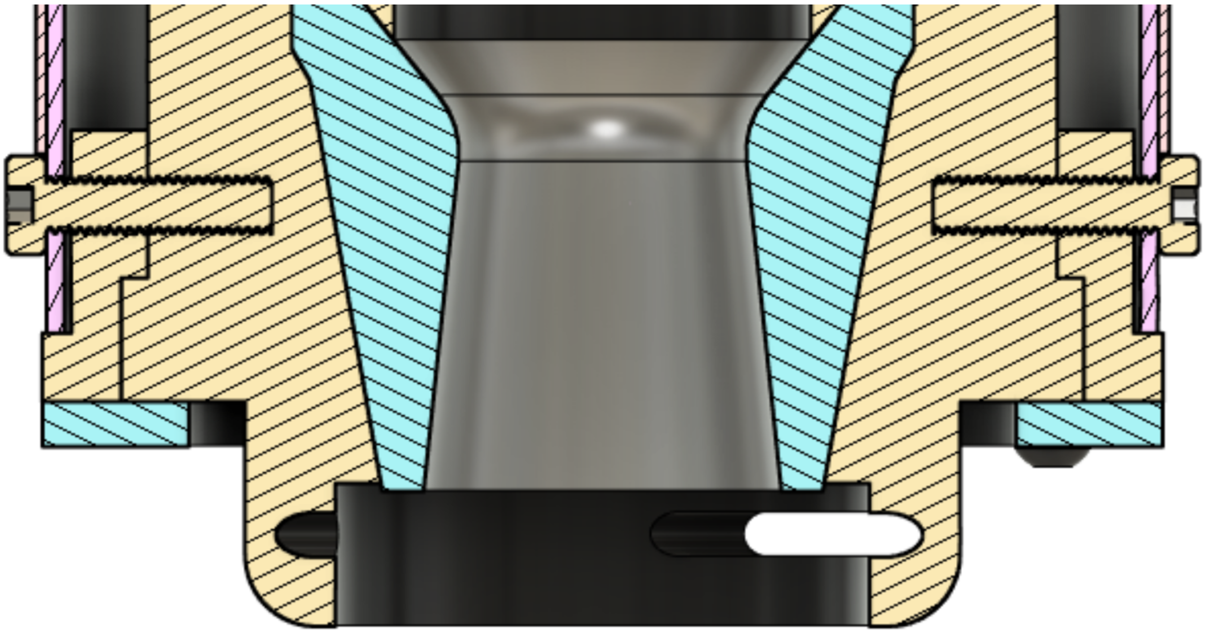
- Analyzing the motor for modeling also increased our understanding of how the injector worked and how the ox tank is filled.

- Hypertek Rear Motor Adapter -
    - Manufactured to fit around the bottom lip of an L-motor
    - L-motor is minimum diameter in a 3" body tube, so the rear motor adapter was the only design we could think of to retain the motor
    - 4 bolts connecting upper and lower components of adapter (shown in right picture)
        - 98164A063

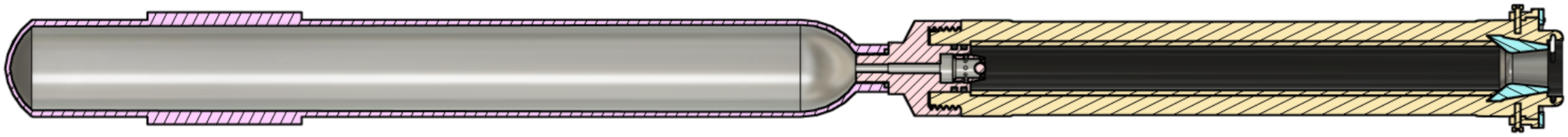




- Retention Hardware -
    - 4 bolts connecting the adapter to the body tube
        - 92855A416
    - Considerations when choosing bolts:
        - Head height - didn't want a bolt that had a tall head because it would create a lot of base drag.
        - Quantity and cost of bolts - wanted excess bolts for testing at a lower price.
        - Length of threads - only a certain length that we could drill into the fuel grain before we hit the nozzle, so we had to choose bolts that didn't go too far into the grain while still maintaining significant thread engagement.



Full Assembly

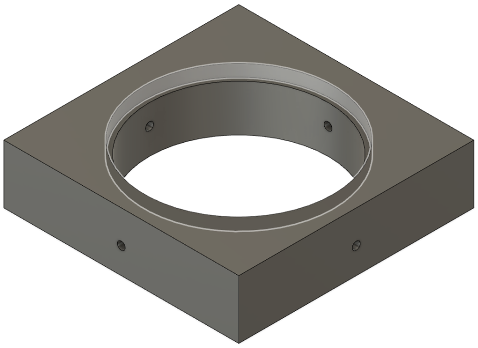


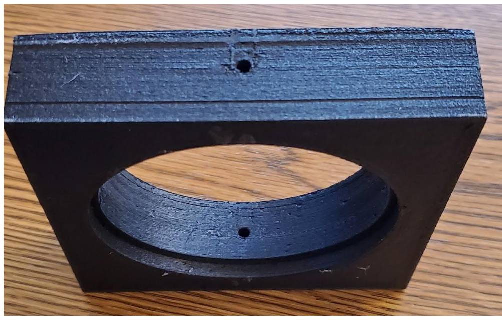
Extra Information

- Development Process for our Retention System
    - Initially, we designed our retention system to also include a 3D printed sleeve that fitted around the front end of the ox tank so that the ox tank shoulder would transfer thrust to the sleeve (sort of like an engine block); however, it was emphasized during PDR that the sleeve was made redundant by our motor adapter system, and we decided to eliminate the sleeve as it would also further complicate construction (installation, tolerances, time management).
    - We determined that we needed to simultaneously bolt both our motor adapter and fuel grain to the body tube; however, we needed to model the inside of the fuel grain to see how much material we can drill into before we hit propellant and cause a critical failure. Then, we practiced tapping a

spent fuel grain to see how composite threads hold up (they will hold, but it's very easy to cross thread and destroy the hole).

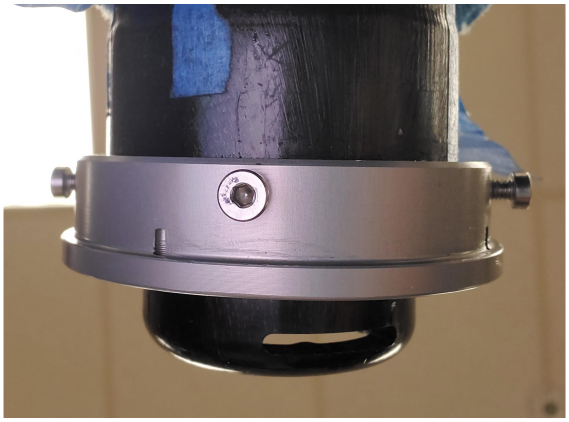
  - For the actual system, we 3D printed a drill jig that aligned the fuel grain and motor adapter (used clamps to keep components rigid) while we drilled through both components.

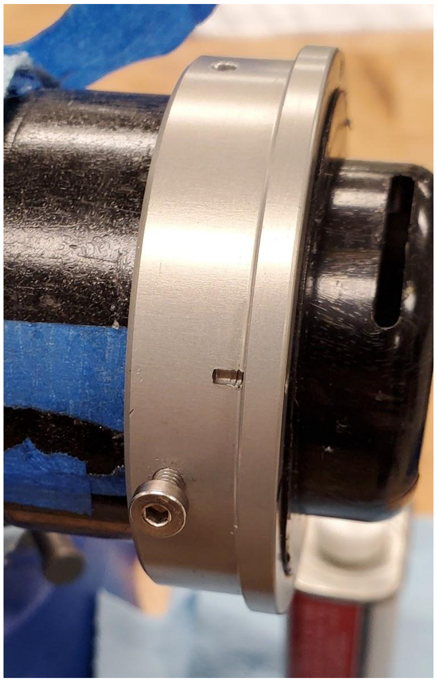




- Procedure for Bolt Depth
  - We used the drill jig to bore holes in the motor adapter first.
  - For the fuel grain, we lowered the platform until we were able to achieve full lockout on the drill (turned handle all the way until it stopped). In the locked position, we raised the platform until the drill bit barely touched the surface of the fuel grain. Without moving the platform, we shifted the component and used the laser function on the drill press to align the drill bit with the hole in the jig. Then, we calibrated a caliper to the bolt depth that we measured in Fusion, making sure to calibrate the length slightly lower than the actual to approximate for setup errors. We used the depth measure feature on the caliper (the little rod sticking out at the end) to see how much we had to shift the platform vertically. So, we aligned the caliper with the threads that raise the platform and raised the platform by how long the little rod was.
    - The drill bit has a tapered end, so we used an end mill to square the bottoms of the holes and make sure we're able to thread the whole length of the hole.
- Tapping Through Motor Adapter and Fuel Grain
  - After drilling all holes in both components, we tapped the aluminum motor adapter first. When tapping, we made sure that the fuel grain and tap wrench were level and, when looking at eye level, that the hole was in the middle. To make sure we didn't break a tap, we started with a tapered tap and threaded the whole hole, and we made sure to partially thread the hole in the fuel grain below to prevent clocking problems. Then, we followed the initial threads in the fuel grain with a plug tap and bottom tap to thread along the whole length.

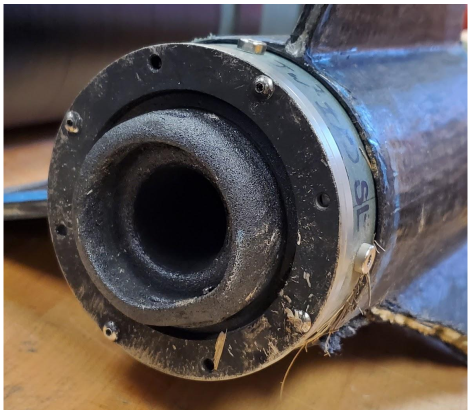
- We put a bolt in each completed hole to keep the components aligned while tapping the other holes.



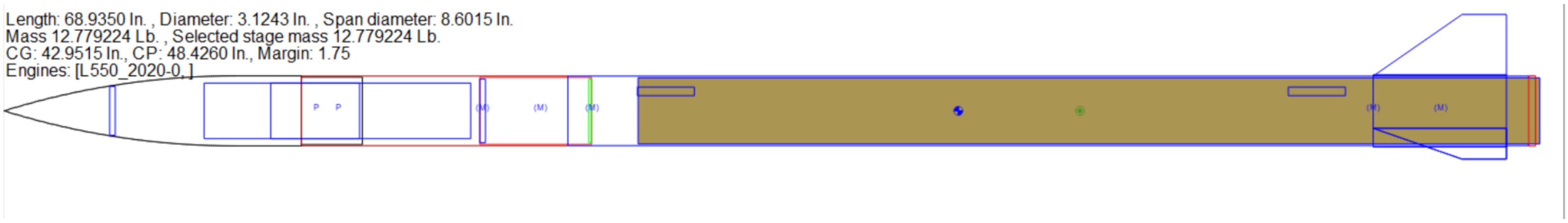


<u>Propulsion Team Conclusion</u>

- Similar to our 1lb/1mile rocket, we found that our engine did not perform at 100% efficiency. After weighing each Transonic team's fuel grain and comparing masses, we found that we burned 150-200g less than the 5th/6th Transonic's engine. However, when inspecting the flight video, we found that our engine burned for 5-6 seconds. So, there were most likely problems with nitrous filling or not reaching a high enough temperature for combustion.
- After recovering our rocket and inspecting the damage dealt, we found that our retention system was perfectly intact; however, the impact of landing seriously bent our ox tank, and it took quite a bit of force and "finagling" to remove the ox tank out of the broken body tube.



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; RASAero can more accurately model our launch lug design and give us better drag data than RockSim (a description of launch guides can be found on pages 19-22 of the RASAero User Manual).

- Problems Occurred on RockSim Pro
    - CP calculations -
        - When analyzing the Center of Pressure, we saw a significant discrepancy between RockSim's calculations and that of RASAero. We found out that RockSim had been using its way of calculating CP all year, while RASAero uses Barrowman's method of calculating CP: our margin jumps from 3.33 (RockSim) to 1.75 (Barrowman). We changed to the Barrowman equations in RockSim because the Barrowman method has been proven to be reliable over the last 30 years.
    - CG comparisons -
        - When comparing our rocket's CM to RockSim's CG, we found that the discrepancy originated from RockSim's placement of the motor's CG. RockSim places the CG of the motor in the middle, but the actual CG of the motor that we measured was further forward than RockSim's. This matched our problem where our actual CM was further forward than RockSim's predicted CG.
        - To fix the CG of the engine in RockSim, we edited the motor file in EngEdit and made the mass of the motor equal zero. Then, we

placed a mass object that is equal to the motor mass (3878g) approximately where we measured the CG of the actual motor. This made our actual CM and RockSim CG match perfectly and fixed our discrepancy.

Launch Day Stage 1/2

- Shear pins were discouraged from use because calculating the force required for them to be effectively utilized was much more difficult than just relying on a friction fit nose cone feature.
- Launch angle had to be discussed with RSO. This is because we wanted to launch into the wind, which was described as a (+) launch angle by the RSOs, but in RockSim a (+) launch angle is simulated as with the wind. So, we had to clarify that we used a (-) angle in RockSim to launch into the wind, but in reality we are using a (+) angle on the FRR.

Launch Day Stage 3

- At this time, one of the few adjustments needed was to turn on the Jolly Logic mechanism. This required the careful communication of exactly what was needed to be done to make sure the device was prepared to release the pin at the predetermined altitude and was placed back into the rocket in the correct way.

Conclusion

- Flight Analysis:
    - With the added weight on the back from fixing the body tube and the Pringles can, our margin decreased, but we still had a very stable flight.
    - After recovering the rocket, the altimeter read back to us an apogee of 10590 feet. However when we plugged our altimeter into a computer we were given an apogee of 2300 feet. We do believe that 10590 feet is the

true value as from watching the flight it looks like it went well above 2300 feet. Another thing validating it is that both our deployment charges went off and one was set to 9,999 feet.

  - When we plugged our altimeter into the computer we were given a speed of mach .3. This didn't comply with our apogee though, so we ran a frame analysis. We only had good videos of the beginning of our burn so we only found our speed during the first second of our flight. This speed was found to be mach .3 which matches up with our math model. This also proved that we went faster as we were projected to hit mach one 3.55 seconds into flight.

- Expected vs Outcome:
  - We were expecting to smoothly go through all 3 Stages and easily reach the launch rail. However, we weren't expecting the zip ties to fail
- Changes for Repeated Mission:
  - Put the parachute in the body tube to ensure a successful parachute.
  - Better communicate the exact motor specifications with the Stage 3 team
  - Better test launch lugs for expected flight conditions and temperature
  - Finish model comparison with the actual vehicle earlier so that you don't have to scramble to make your vehicle stable.