Oregon State University 30K Rocketry team 2019–2020 Technical Report

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This document details the overall design, systems integration, and concept of operations for the Oregon State University 2019–2020 30K rocketry team. The OSU ESRA project is student led, researched, and developed with the goal to reach a target altitude of 30,000 feet above ground level with a scientific payload.

Nomenclature

C_g = Center of Gravity
CNC = Computer Numerical Control
C_p = Pressure coefficient
C_D = Drag coefficient
$\bar{V}$ = Packing volume
D = Parachute diameter
BP = Black Powder
ECE = Electrical Engineering
ESRA = Experimental Sounding Rocket Association
MIME = Mechanical, Industrial, and Manufacturing Engineering
ME = Mechanical Engineering
OROC = Oregon Rocketry
OSU = Oregon State University
RF = Radio Frequency
SA = Spaceport America

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I. Introduction

The Oregon State University AIAA branch was founded in 2012 and holds a total of eleven student-led capstone design projects including rotor vehicle, air vehicle, and rocketry design disciplines. The Experimental Sounding Rocket Association (ESRA) 30K rocketry team is among the original teams of the AIAA chapter at OSU and is responsible for designing, manufacturing, and testing a solid motor level 3 rocket capable of reaching a target altitude of 30,000 feet with a scientific payload. The OSU ESRA 30k Rocketry team prioritizes an opportunity for students of any discipline interested in pursuing a career in the aerospace industry. This project is reliant upon individuals demonstrating exceptional skills in project management, budgeting, team collaboration, and fundamental engineering practices. The 2019-2020 OSU 30K rocketry team is driven by nineteen ME and four ECE undergraduate students with several involved non-capstone members. The team will compete in the Spaceport America Cup hosted by the ESRA and governed by the Intercollegiate Rocket Engineering Competition rules and regulations.

In efforts to effectively develop the design and fabrication of the rocket, the team is divided into the following six sub-teams: Avionics, Aerodynamics and Recovery, Payload, Propulsion Chemical Formulation, Propulsion Hardware, and Structures and Integration. Each sub-team has its own project goals, design concepts, and performance characteristics that are influenced by its project scope. Each sub-team manages their own technical portfolio that includes crucial documents such as a team Charter, house of quality, work breakdown structure, gantt chart, engineering drawings, test results, standard operating procedures, safety procedures, bill of material, and technical analysis. Further, the team has a leadership board including the team lead, operations lead, safety lead, weight and status lead, configurations lead, and sub-team leads. Each lead is responsible for developing project task-lists, demonstrating a high level of communication, ensuring safety, and reaching mission success.

ESRA's primary stakeholder is our team advisor, Dr. Nancy Squires. As a professor of the Mechanical, Industrial, and Manufacturing Engineering department, Dr. Squires has overseen the American Institute of Aeronautics and Astronautics chapter at OSU since its inception. Furthermore, John Lyngdal, Jim Baker, and Joe Bevier are key stakeholders and have contributed their knowledge and expertise, as Oregon Rocketry (OROC) mentors, to the success of the project. Lastly, all members of the ESRA team are stakeholders. Each member is dedicated to reach the common goal of placing first in the Spaceport America Cup.

II. System Architecture Overview

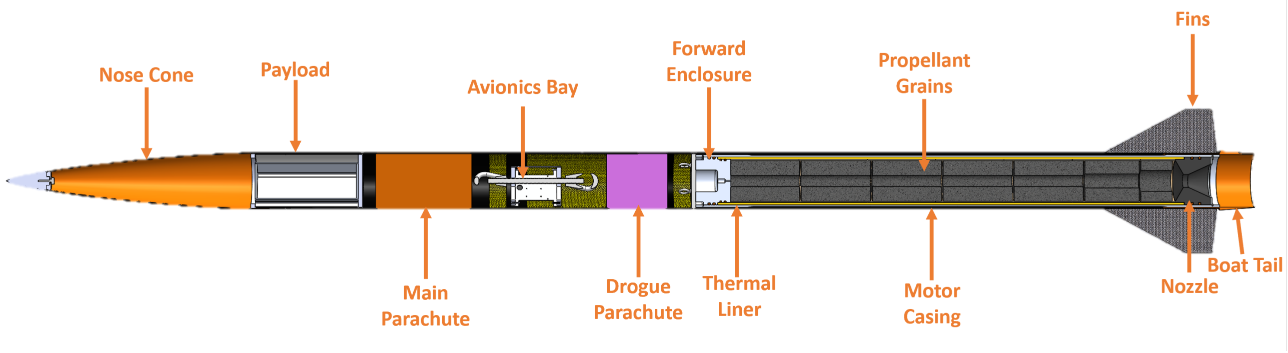


Fig. 1 Full-Scale Launch Vehicle Design - Cross-sectional Views

Figure 1 represents a cross sectional view of the Full-scale Launch Vehicle design. The launch vehicle is composed of three major sections: the nosecone, forward airframe, and aft airframe. Each major sections houses it's own critical subsystems and components. The nose cone is composed of fiberglass with an aluminum tip and houses the payload design. The forward airframe is composed of fiberglass and houses the main parachute and avionics bay. The drogue parachute is between the forward and aft airframe connected together by a mid bay coupler. The aft airframe is composed of fiberglass with nomex honeycomb core and G10 fiberglass fins. The aft airframe houses the solid propellant rocket motor and connects to a fiberglass boat tail aimed to reduce drag.

Once A and n are calculated, the propellant is characterized and these values can be used into BurnSim.

Richard Nakka's method is more complicated and involves calculating a burn rate for each pressure data point within the steady-state region of the pressure curve. This is a complex, iterative method that relates the geometry of the propellant grains, the instantaneous chamber pressure, the density and volume of propellant, and the geometry of the nozzle. Due to the complexity of this method, it will not be covered in detail here. For specifics, reference the ESRA Characterization Guide where all relevant equations are supplied. Like Jim Baker's method, Nakka's method results in a line of best fit from burn rate vs. pressure data points. See Figure 11. A and n values are ultimately determined using the same line of best fit method as Jim Baker's method. However there are two major differences. First, there are significantly more data points in Richard Nakka's method. Second, the data points in Nakka's method are instantaneous, not broad averages.

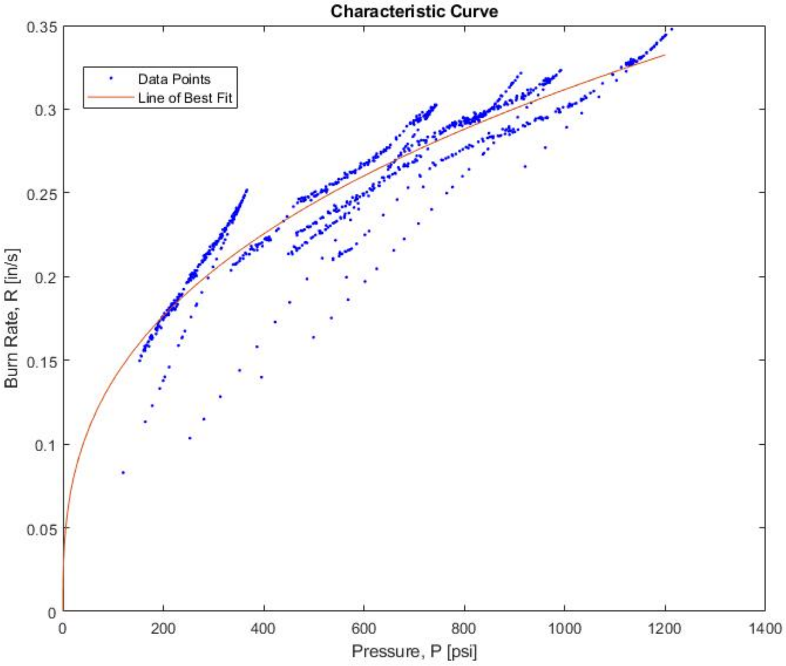


Fig. 11 Richard Nakka's Characterization Method

Both methods return reasonable values when used in BurnSim. Due to COVID-19, the team was unable to test which method was more accurate. That may be a good starting place for future propulsion teams.

B. Structures Subsystem

1. Nosecone

The main body of the nosecone will follow the Von Karman shape, to minimize drag as much as possible during flight. The current maximum velocity of the rocket is 2015 ft/s, which means the rocket will be travelling up to Mach 1.79 [2]. This indicates the rocket will travel at transonic and supersonic speeds, which are defined by a Mach number of 0.72 - 1.0 and 1 - 3 respectively [3]. This nosecone profile was selected, as it has optimal flight characteristics at transonic and supersonic speeds, when compared to the other available nosecone profiles [4].

The body of the nosecone will be made from fiberglass and aramid composites and will be manufactured using a female mold. The body of the nosecone will be 28 in. long with an inner diameter of 6.25 in. at one end and 1.95 in. at the other. There will be a 4 in. shoulder at the larger opening of the body to easily attach the joint tube. The joint tube will have an outer diameter of 6.25 in. so it is critical for these components to be made to specification.

The main body of the nosecone will be manufactured using a female mold that is machined with a Computer Numerical Control (CNC) mill. This allows the layup to follow the Von Karman profile and reduces the amount of processing required after the initial layup process. Using a female mold allows the outside of the nosecone body to have a smoother finish and requires less sanding than the male mold equivalent. Previous years have created both male and female molds with success, so both are viable options for the rocket this year [5]. However, although male molds are easier to manufacture and layup onto, they require much more post layup processing [6].

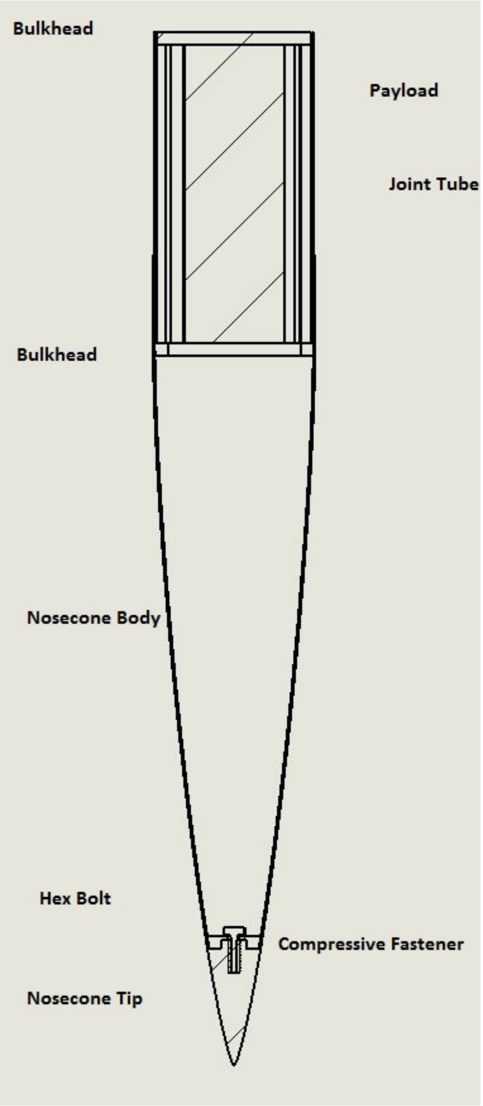


Fig. 12 Cross-Section of Nosecone Sub-Assembly

The nosecone tip will be machined out of aluminum, due to heat transfer during flight. The nosecone tip will be 4.6 in. long with an outer diameter of 2.1 in. on one end and a point on the other. The tip will be manufactured with a CNC lathe, to follow the previously discussed Von Karman profile. Machining this will give it a better point than if the nosecone was entirely manufactured out of composites. The sharp point of the nosecone tip is critical to the overall flight of the rocket, as it will help to reduce drag during launch and flight. One end of the nosecone tip will be machined to have a threaded hole to allow for attachment to the nosecone body. It will also have a step in it so that the tip can easily be centered for a flush and seamless transition from nosecone tip to the main body. The tip will be attached to the main body using a compressive fastener made of G-10 fiberglass laminate. The fastener will be machined to match the inner profile of the nosecone body and will be secured to the nosecone tip with a hex bolt.

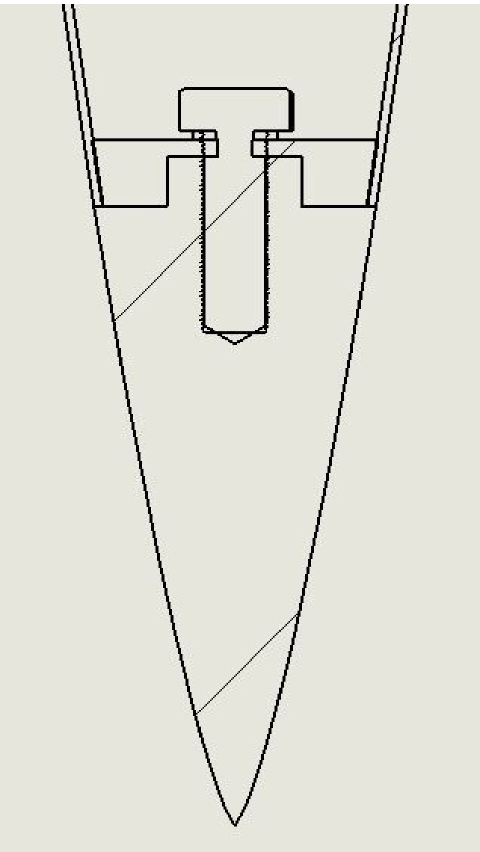


Fig. 13 Magnified Image of Nosecone Tip Sub-Assembly

2. Fore Aft Airframes

The rocket consists of two airframes: one upper and one lower. The airframes are the main structural components of the rocket and hold the interior components together. The design of the airframes were based heavily on previous years so that the same inner diameter could be used. This simplified many manufacturing processes and allowed for old molds and tools to be used, saving a lot of time. The lay out of the rocket and how the airframes are connected together can be seen in Figure 14. This shows the rocket during ejection, but also gives a good visual representation of how the main structural rocket components are connected throughout the interior.

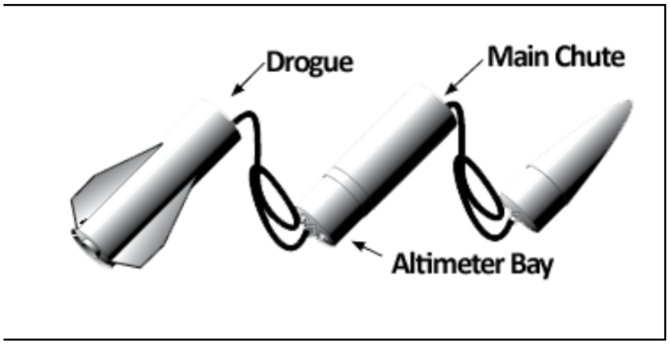
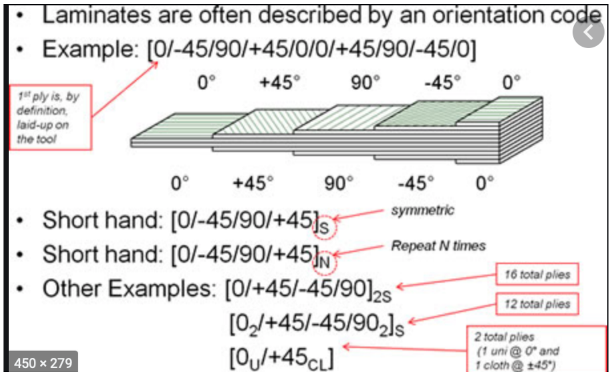


Fig. 14 Parachute ejection scheme composed of lower body,upper body, and nose cone

Both the upper and the lower airframes were manufactured and donated by Innovative Composites Engineering (I.C.E). The manufacturing process involves a multi level composite lay up of impregnated (epoxy is already applied) fiberglass sheets. The plies of fiberglass are layered with different orientations so that the fibers are woven and increase the strength in all directions. The layup used for the body tubes was [0/45/0/-45/0]. This means that each layer has 5 plies at three different angles. This ensures that the tubes are uniform and capable of handling stress in many directions. The general idea of a composite layout schedule can be seen in figure 15. Once the layers of fiberglass are applied and reach the desired thickness of the tube, the airframes are put into an oven to cure and harden. The airframes were received in this state from ICE and processes further to meet the requirements of our design. Processing done by the structures and integration team includes: cutting the tubes to length, sanding rough spots, and drilling holes for pressure, electronic activation, and shear pins (to hold the rocket together during flight).



- Laminates are often described by an orientation code
- Example: [0/-45/90/+45/0/0/+45/90/-45/0]
- Short hand: $[0/-45/90/+45]_S$
- Short hand: $[0/-45/90/+45]_N$
- Other Examples: $[0/+45/-45/90]_{2S}$

$[0_2/+45/-45/90_2]_S$

$[0_U/+45_{CL}]$

Fig. 15 Overview of composite layup schedules [9]

Originally the lower body was to be composed mainly of carbon fiber, as opposed to fiberglass. Carbon fiber has a higher strength and safety factor than fiberglass. However, due to issues with the supplier of the tubes, both the upper and lower airframes were composed of fiberglass. This still gave the necessary safety factor for the components, and also allowed for RF transparency throughout the entire rocket.

Both of the upper and lower airframes have an inner diameter of 6.25" and an outer diameter of 6.35". There is extra fiberglass on both forward ends of the tube to provide additional thickness for anti-zippering. This stops the parachute from ripping through the body of the tube in the case of deployment at higher than expected speeds. The upper body of the airframe is 34 inches and is being reused from last year. The upper body connects the nose cone and lower body together and houses the main parachute and electronic equipment for various functions such as GPS tracking of the rocket. The lower body is 73 inches in length and houses the motor, drogue parachute, and boat tail.

Testing on the airframes received from ICE provided reassurance that the tubes would be able to withstand flight conditions. The testing method for the airframes comprised of a compression test on a section of the tube and the data can be seen in figure 16. The tubes that were received were longer than the length of the rocket, allowing for parts to be cut off for purposes such as testing. The compression test was chosen because this is the primary loading condition on the tubes during flight. This loading comes from the thrust of the motor and the ejection of the parachutes. The compression test showed that the fiberglass tube could handle a max load of about 65kN. From calculations using a free body diagram of the rocket, it was found that during flight there would be a maximum compression force of 10.9kN. When comparing this to the test data the safety factor calculated is 6.5, showing that the structure of the rocket is well equipped to handle flight conditions.

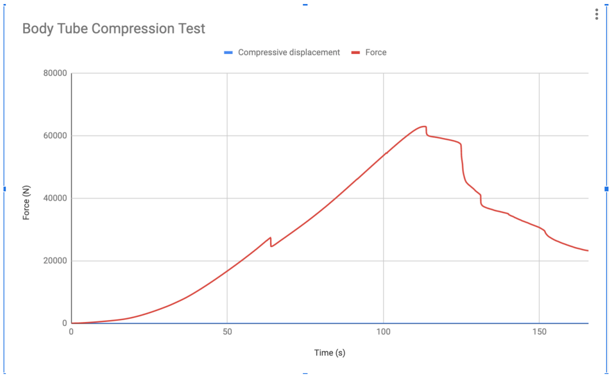


Fig. 16 Compression test data for airframes

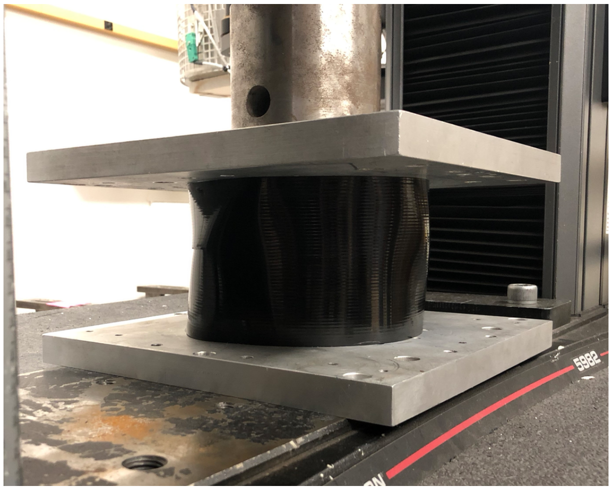


Fig. 17 Compressed Airframe Section

Figure 17 shows the section of body tube after compression testing. It can be seen that the tube is noticeably deformed, however still remains its general shape and form. There are some cracks inside of the tube section, but the fiber holds together well and does not fail in a brittle manner.

The sections of the rocket that separate during ejection to allow the parachutes to deploy are held together with shear pins. These shear pins stop the rocket from separating too early due to pressure differences that are caused as the rocket ascends to its max altitude. Testing was done on the shear pins to ensure that the forces they can resist are greater than the forces caused by the pressure differences due to the altitude change. Testing was done on the Instron machine and used to compress the pins. From the test it was found that 6 shear pins could withstand about 1kN. From this it was calculated that each shear pin could resist about 36 pounds of force. With 6 shear pins it was determined that this was enough strength to stop the rocket from separating earlier at higher altitudes.

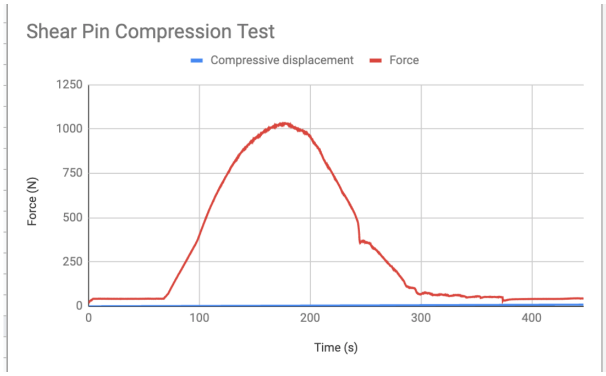


Fig. 18 Shear pins compression testing data

Figure 18 shows the shear pin testing results under compression loading. The maximum load occurs when the pins are just about to shear. Once the pins shear they are still able to hold a load since they are very ductile.

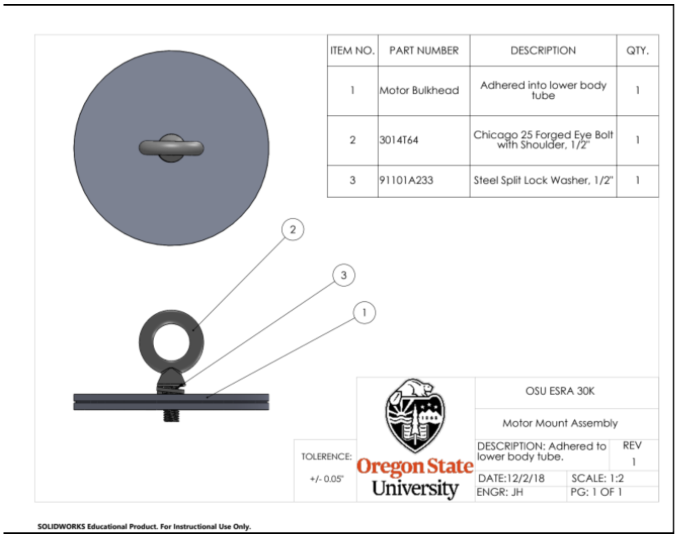
3. Bulkheads

There are a total of four disk shaped bulkheads inside the rocket. These bulkheads are manufactured out of .5" thick G10 fiberglass and designed as partitions throughout the airframes. They help to provide structure as well as stop debris and pressure forces from entering certain areas. Bulkheads also act as high strength connection areas to connect the separable components of the rocket to the parachutes, seen in figure 14. G10 fiberglass was chosen at the material for its strong and lightweight characteristics compared to alternatives such as aluminum. The first bulkhead, shown in Figure 19, is secured with radial bolts inside of the nose cone and is used to enclose the payload inside. Since the payload must able to be taken in and out of the nose cone for various reasons, this bulkhead is removable. Therefore, the bulkhead is installed with radial bolts, which are harder to install and manufacture, but provides a stronger method of joining than the typical method, epoxy resin.

Fig. 19 Nosecone Bulkhead

The next two bulkheads, general design shown in Figure 20 , are used to form the avionics (AV) bay and are connected with a threaded rod. The two disks form the top and bottom of the avionics bay, one of which will also be removable from the rocket for access to the electronics inside the AV bay. The bottom bulkhead is permanently secured inside the rocket through a new method. A section of a coupler was cut and pushed up against the bulkhead.

The coupler gives more surface area for epoxy to adhere to, which increases the compression strength greatly. The removable bulkhead has a threaded rod attached that screws into the bottom permanent bulkhead locking the avionics bay into the rocket, while still allowing it to be removed and worked on if needed. The top of the bulkhead is attached to the drogue (secondary) parachute that connects the nose cone and upper body after deployment with the eye bolt method mentioned earlier.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor Bulkhead	Adhered into lower body tube	1
2	3014T64	Chicago 25 Forged Eye Bolt with Shoulder, 1/2"	1
3	91101A233	Steel Split Lock Washer, 1/2"	1

Fig. 20 Avionics Bay Bulkhead Design

Fig. 21 Removable AV Bulkhead

Figure 21 shows the removable bulkhead that the AV bay attaches to. This set up allows the bulkhead to be easily pulled out to access the electronics of the rocket. This bulkhead locks the AV bay in place during flight by screwing into the permanently secured bulkhead already inside the rocket. The radial bolt, shown sticking out of the bulkhead in Figure 21, are used to secure the bulkhead to the rocket during flight.

The last bulkhead, shown in Figure 22, is inside the lower body tube of the rocket. This bulkhead's main function is to connect the lower body tube and motor to the drogue parachute so that after deployment the upper and lower body tubes are still connected. The bulkhead is disk shaped and is made out of the same material as the other three bulkheads; however, it has three holes drilled in the middle instead of one. The reason for this is to give the bulkhead a very solid attachment to the forward enclosure. The three holes are used to attach the two components with a threaded rod. Two of those threaded rods have eye bolts at the ends that attach the entire system to the drogue parachute in Figure 14. The bolts used to secure the forward enclosure to the motor tube can be seen in Figure 23.

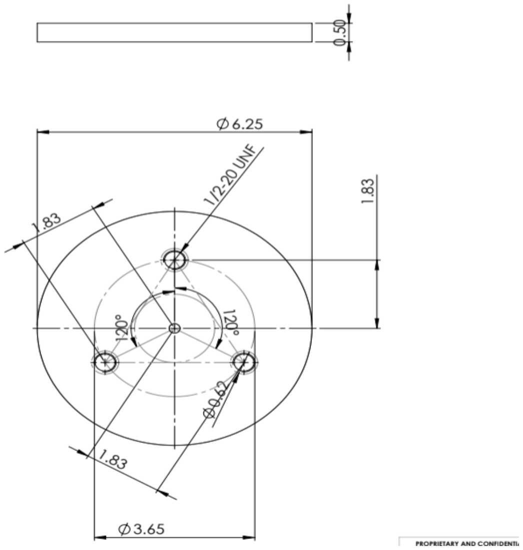


Fig. 22 Forward Enclosure Bulkhead

Fig. 23 Bolts for forward enclosure bulkhead

Fig. 24 Forward enclosure bulkhead inside the lower body tube.

Figure 24 shows the forward enclosure bulkhead attached to the lower body tube of the rocket. Similarly to the permanent AV bay bulkhead, the forward enclosure bulkhead has a section of a coupler epoxied behind it to give it additional security and support.

All of the bulkheads were cut using a waterjet. This machine combines high pressure water with sand abrasive to cut through high strength materials. Once the bulkheads were cut they were secured into the rocket. The bulkheads that were permanent (one of the AV bay bulkheads and the forward enclosure bulkhead) were secured with epoxy. The removable bulkheads were drilled and tapped around the circumference to secure the radial bolts to.

The bulkheads were tested in compression on an Instron machine. The new method of adding a coupler behind the bulkhead showed a large increase in strength. From previous year's data, it was seen that without a coupler behind the bulkhead the maximum compression strength the bulkhead with epoxy could endure was about 60kN. Data from the new design with a coupler and bulkhead system maxed out the Instron machine at 90kN. This gave a safety factor of 3.3 taking G-force into account. The set up of the bulkhead testing can be seen in Figure 25.

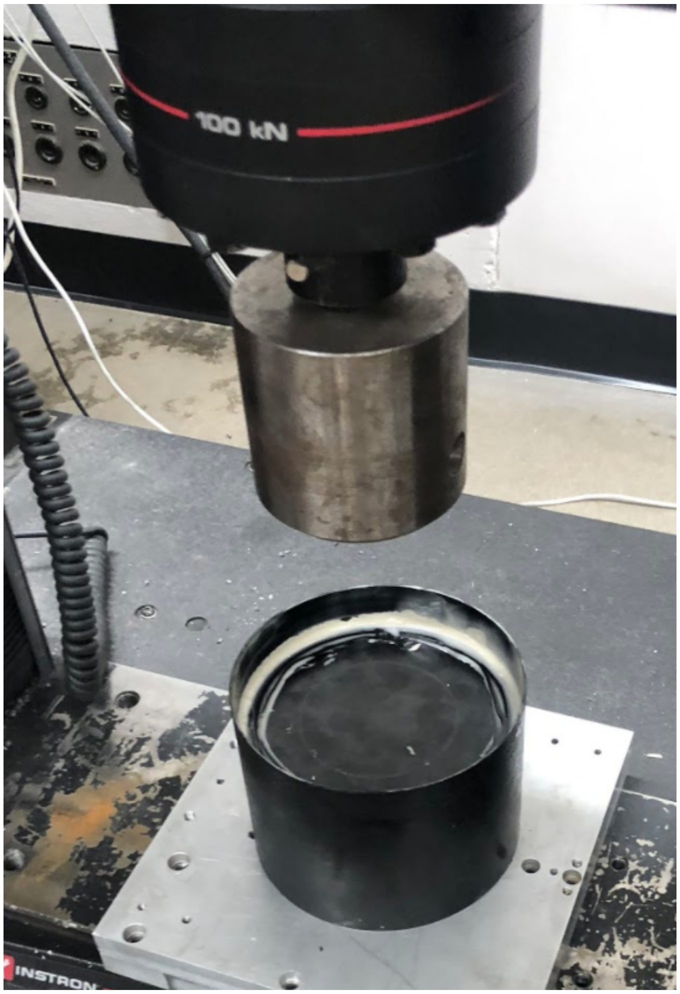


Fig. 25 Testing of Bulkhead w/ Coupler

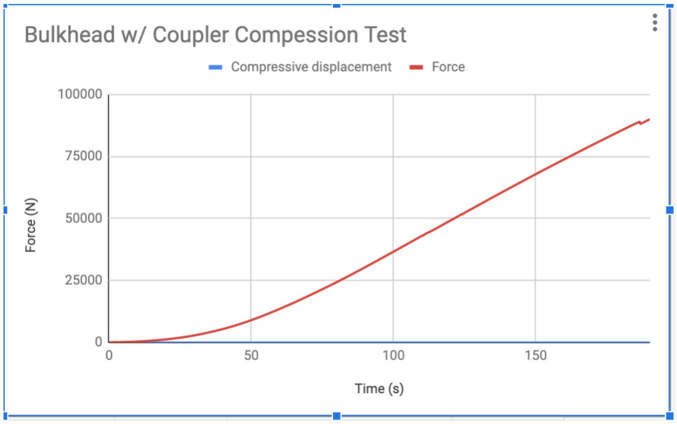


Fig. 26 Test results of Bulkhead with Coupler

Figure 26 shows the testing result of the bulkhead design with the coupler secured behind it. This set up maxed out the Instron machine and provided more than enough support to withstand the forces of the rocket during flight.

4. Mid -Body Coupler and Joint Tubes

The mid-body coupler connects the upper and lower airframe sections while keeping them rigidly aligned and allowing for separation during the ejection of the recovery system. The coupler was deigned following industry standard to have an OD that matched the ID of the air frame of 6.25 inches. This method is used by other rocket teams because of its weight efficiency, manufacturability and ability to maintain the desired connection [7]. This important component was made from Fiberglass because its RF transparency, light weight, strength, rigidity and easy machinability [7]. The coupler was laid up inside a scrap piece of body tube with the correct diameter using a layup schedule of $[0/45/\bar{0}]_{3F}$ for a thickness of about 0.1 inches. A compression test was conducted to verify its ability to withstand flight conditions as seen in figure 24, where it achieved a maximum force of 51 kN. The Mid-body coupler is just under three calibers at 16 inches long, which meets the IREC and ESRA requirements of at least 2 calibers, where a caliber is one diameter of the body tube [8]. The lengths of all joint tubes are shown in table 1. Half of the coupler is permanently fixed in the upper body tube with epoxy while the other half slips into the lower body and connected with shear pins.

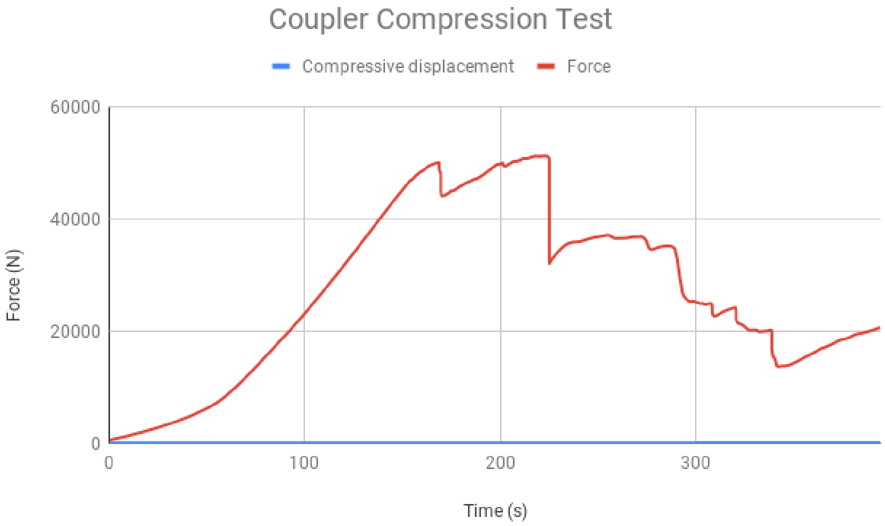


Fig. 27 Test results of Coupler Compression Test

Component	Length [in]
Mid-Body Coupler	16
Nosecone Joint Tube	12.3
Boat Tail Joint Tube	4.6

Table 1 Lengths of joint tubes in the airframe

5. Avionics Bay

Located in the middle of the upper body, the avionics bay holds all the electrical components, including systems used for communication and arming. The avionics sled is made up of three I shaped boards that form a triangular prism, shown in figure 25. The I shape allows for easier connection of the avionic system and reduces weight. These boards are mounted to a triangular shaped wedge frame with 10-32 screws on the top and bottom. Both the boards and wedges are made of 1/8 inch and ½ inch G10 respectively and manufactured using a Waterjet Cutter. The G10 was chosen because of its easy machinability, strength and appropriate thickness for each use.

The Telemegas and custom avionics components are attached on the outside of the three boards and the batteries stacked mounted to the back of one of the boards with aluminum brackets. The arming switches are held in place with aluminum brackets attached to the top of all three boards. For more information on the avionics components, see section E.

The avionics sled is held in place with two bulkheads and a threaded rod that runs through the prism and bulkheads, with eye bolts at the end of the rod. The bulkheads are used to mount ejection charges and the eye bolts become connection points for the main and drogue parachutes. The top bulkhead is permanently fixed with epoxy and, coupler ring, while the bottom is fastened with 4-40 radial bolts. Three flat head screws are glued on both bulkheads that match up with three holes in the wedge of the sled to help align the avionics bay during integration. Ejection and integration tests were used to validate this design.

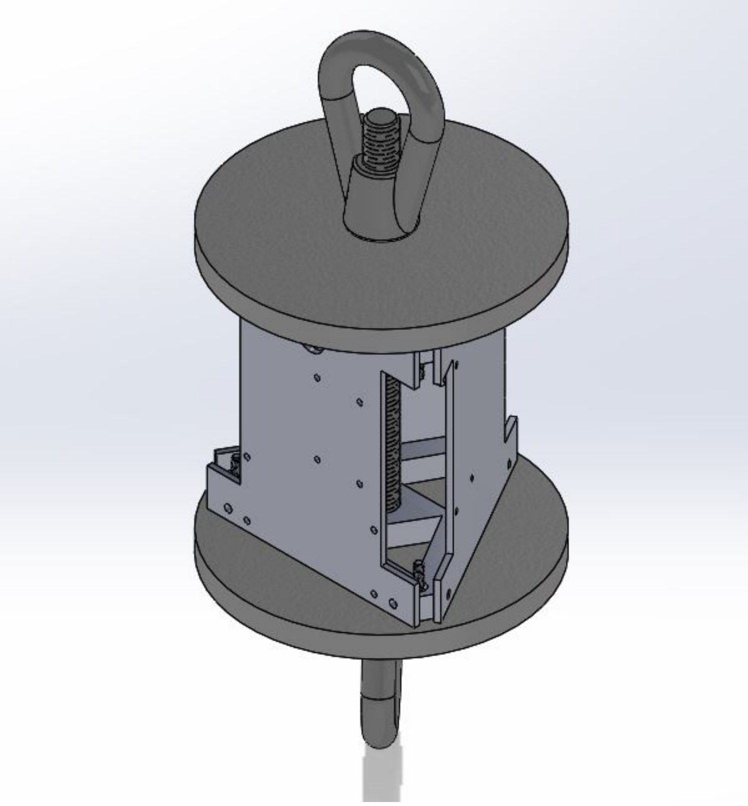


Fig. 28 Structure of avionics bay architecture without components

6. Motor Integration

The motor is integrated into the to the aft body tube through the forward enclosure with a bulkhead, two ½-20 eye bolts and a ½ -20 hex bolt. The bulkhead is permanently fixed to the inside of the body tube using Rocket epoxy 12.5 inches from the top of the tube. This bulkhead is then reinforced by a two-inch fiberglass coupler ring that is epoxied to the inside of the body tube by the rings outer edge to increase the amount of surface area glued to the body tube, providing additional strength. The motor itself is attached by the two eye bolts and one hex bolt to the bulkhead and into the forward enclosure. The eye bolts become the lower attachment points for the drogue parachute, which is housed above. Due to the size of the motor, there was only 0.2-inches space between the edge of the air frame and the motor tube, therefore centering rings were not used. Instead, on the lower end, the motor is attached to the boat tail and body tube with four screws, helping keep the motor aligned. For more information on the boat tail see section 9.

7. Fins

The fin manufacturing process consists of two separate but equally important steps. This section will cover the first, fin manufacturing and testing. The current fins are constructed from carbon fiber, a Nomex honeycomb core, and G10 high strength fiberglass creating a fin composite sandwich. The core and frame are shown in Figure 29.

Fig. 29 Fin Nomex honeycomb core and G10 fiberglass frame assembly.

This manufacturing setup is a lightweight, yet structurally sound layup consisting of 0°, 45°, and 90° plies of T700 unidirectional carbon fiber. The full layup schedule for the fins is [0/45/-45/90/c/90/-45/45/0], a symmetric, quasi-isotropic layup.

The Nomex honeycomb core, G10 frame, and carbon fiber plies were modeled according to the dimensions given by the Aerodynamics and Recovery subteam. The procedure outlined in this section was used to manufacture two test fins followed by five fins once finalized dimensions were received and the fin design was validated. The G10 frame was cut from a sheet of 1/8 in. fiberglass using the water jet at the Oregon State University machine shop located in Rogers hall. Next, the models of the honeycomb core and the carbon fiber plies were created and uploaded to the ply cutter software located in Graf hall. A 1/8 in. Nomex sheet was placed on the ply cutter table covered by a sheet of vacuum bag to allow proper suction to the table. The shape of the core was then cut on the machine. The carbon fiber was rolled onto the table and cut out using the same process as the honeycomb core but without the layer of vacuum bagging material on top. Finally, two pieces of film adhesive were cut for each fin to bond the first carbon fiber sheet to the core and frame assembly.

With the prepared fin materials cut, the layup began by applying a piece of film adhesive onto one side of the fin and core assembly. The use of a heat gun at this step increases the film tackiness allowing the film adhesive to stick to the frame and core. Next, four carbon fiber plies were placed one at a time on the side of the fin in which the adhesive is applied. Follow the given layup schedule above, starting with the 90° ply and ending with the 0° ply. Turn the fin over and repeat the film adhesive application and the layup on the other side. Next, vacuum bag the test fins and follow the cure cycle in Table 2.

Ramp Up to Gel Temp	180°F/hr
Gel Temp	180°F
Gel Time	1.5 hrs
Ramp Up to Cure Temp	180°F/hr
Cure Temp	270°F
Cure Time	2 hrs
Ramp Down	300°F/hr

Table 2 Fin Cure Cycle Information

To achieve a sufficient safety factor the test fins were tested using a mid span loading test according to following ASTM D7250. The goal if the load test was to derive the core shear modulus to input into the fin flutter velocity equation and verify that the fins would not flutter or shear off during flight. Although this testing method proved to provide a sufficient safety factor, more research should be on fin testing to improve confidence in the accuracy of the test results. The setup of the mid span load test is shown in Figure 30.

Fig. 30 Mid span load test performed on a test fin.

8. Fin Retainment

The second step in fin manufacturing consists of attaching the fins to the rocket through a tip-to-tip layup. Once the test fins had been manufactured, tested, and verified, five final fins were manufactured. An extra fin adds a small amount of manufacturing time but can significantly save rework time if one fin gets damaged or does not cure properly. The 2019-2020 Structures & Integration subteam had one fin that warped during cure due to an improperly placed ply and having four other fins in the same cure cycle allowed the team to continue without having to repeat the layup and manufacturing process for an additional fin. The final fins were then beveled along the outside edges as shown in Figure 31 using the bevel angle given from Aerodynamics and Recovery.

Fig. 31 Fin Bevel Jig for the Finalized Fins

The bevel is not done on the edge that attaches to the rocket body. The bevel jig was created from a scrap piece of wood and was cut to achieve the desired bevel angle. The jig was then clamped to the stand of the belt sander and used as a guide to obtain a consistent bevel between the fins.

The four finalized fins are next attached to the rocket using a tip-to-tip layup. First, the fins are attached to the rocket using a fin jig to align the fins to the rocket body and ensure 90° between all four fins. In Figure 32 the fins are attached to the rocket with an initial layer of RocketPoxy.

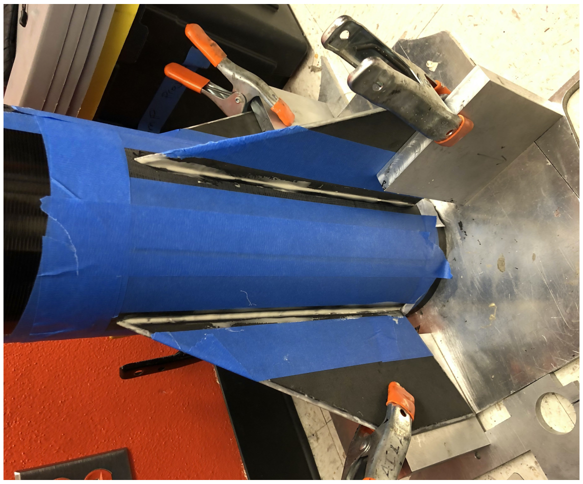


Fig. 32 Initial Fin Placement using the Fin Attachment Jig

This is allowed to cure fully before applying a filet on all fins between the rocket body and the now attached fin. A 1 in. PVC pipe and wax paper are used to create a consistent 0.5 in. filet on all fins [11]. Begin by placing a layer of RocketPoxy in the desired fillet area and place a layer of wax paper over the epoxy. Next, use the PVC pipe to press down on the wax paper and create a smooth even fillet. Clamp down the PVC pipe and let partially cure before removing the wax paper and PVC pipe to ensure the epoxy does not stick to the wax paper when removed. A proper filet as shown in Figure 33 is crucial before moving into the tip-to-tip layup.

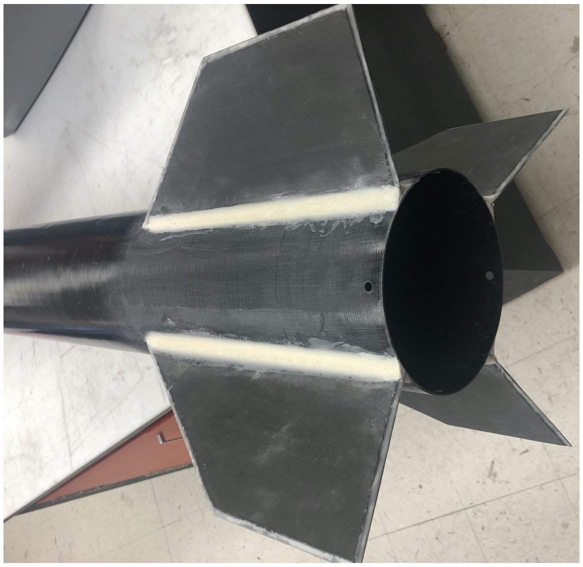


Fig. 33 Final RocketPoxy Fillets

Once the fins are adhered to the lower body tube with sanded, even RocketPoxy fillets, the composite used for the layup should be cut on the ply cutter as done previously for the initial fin manufacturing. This year's team used layers of T700 Unidirectional Carbon Fiber for the first four plies followed by a protective layer of impact resistant carbon fiber donated from Boeing. Each layer was tapered 0.5 in. from the previous ply to give a tapered effect. To begin, the smallest ply was laid up near the edge of one fin, over the body tube, and up the other side of the coincident fin to an equal distance from the edge of the fin. This layup was repeated for the increasing sized plies until the Boeing carbon fiber covered the entirety of one fin, the body tube, and the next fin face. The layup was done for all four sections of the fin. Once all plies were laid, the layup was vacuum bagged using the method outlined in Emma Fraley's thesis on fin design [11]. One modification to this method was to place a spare bulkhead in the lower body tube surrounded by sealant tape to prevent warping of the body tube during cure. Also, the entirety of the tube was not vacuum bagged but only covered the lower section of the lower body tube. The bagged tip-to-tip layup is shown if Figure 34.

Fig. 34 Bagged Tip-to-Tip Layup

The layup was then cured and the bagging material was removed revealing the final attached fins in Figure 35. Post processing should be done to remove sharp edges and reintroduce the tapered fin edge. RocketPoxy was added to fill voids and then sanded to achieve the desired look and function. A suggestion for future teams is to use black RocketPoxy for aesthetics. This can allow the fins to look uniform and sleek while filling voids before final painting.

Fig. 35 Cured Tip-to-Tip Layup

9. Boat Tail

The boat tail, shown in figure 36, is a component that goes behind the motor on the lower body tube, and although it does not provide much structure for the rocket, its main use is to decrease drag while the rocket is moving. Its tapered shape helps the aerodynamics of the rocket and it is also very light weight since it is composed of fiberglass and aramid. The boat tail also helps to provide a landing surface for the rocket. Since the bottom of the lower body is the first part of the rocket to hit the ground, the boat tail takes the brunt of the impact. This is why aramid is used for its high impact resistance properties. The boat tail is subject to large exhaust gas pressures from the motor and has been blown off of the rocket in the past.

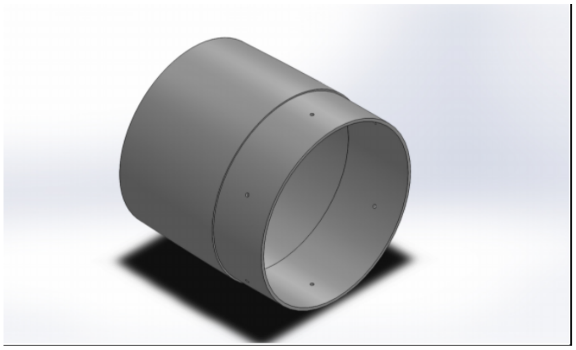


Fig. 36 Boat Tail Model

The design of the boat tail this year is very similar as the design from the previous year. The boat tail being used for the test launch is actually the same boat tail that was recovered from the previous year's rocket, shown in figure 37 . While a new boat tail was not ever manufactured, the plan was to use the same design and materials as last year.

Fig. 37 Boat Tail

With that being said, there are a few slight modifications to this year's boat tail. The hard point that attaches the rail pin to the rocket was changed to be drilled into the boat tail and then into the aft end of the motor tube. This provided the rocket with ideal rail button placement given the aspect ratio and center of gravity. This hard point along with 3 other radial bolts, secure the boat tail to the airframe at the aft end of the rocket. The hard point is the only bolt that screws into the motor tube. This decreases any stresses put into the motor tube and lowers potential failure areas of the motor. Since a new boat tail was not manufactured no testing was performed on the boat tail.

C. Aerodynamics and Recovery

1. Ejection System

The current ejection system for the rocket is a black powder system that requires the powder to be packed in surgical tubing and then taped to the bulkhead inside the rocket. The current amounts of black powder needed for the primary and redundant charges for both the main and drogue parachutes are listed in Table 3 and the lengths of surgical tubing required for each charge are listed in Table 4. Each charge has two rubber end stoppers on either end of the surgical in about one hour. A larger chamber would need to be built to cast full-scale ESRA sized grains. As of this letter, there has never been a student designed vacuum casted motor at spaceport. Doing so would certainly earn a lot of points at spaceport.

6) **Write up test report after every static fire:** It will be much easier to write reports after testing as opposed to later. It will also be very useful to you, as you now have all the information you need compiled in one place. It also makes it easier for future teams to learn from last year, if they don't need to go looking for any raw data. All the necessary information should all be in the report.
7) **Consider a phenolic Nozzle with a graphite insert:** Phenolic nozzles with graphite inserts have been used as an alternative to all graphite nozzles. They are cheaper, create less of a graphite mess on the lathe, weigh less, and have been tested by HART. Talk to HART if you are looking for more information on it.

C. Structures & Integration

The goal of Structures and Integration is to design, manufacture and test all structural components of the airframe and integrate all components into the final rocket. The biggest challenge was completing everything on schedule. The Structures and Integration team as a whole has a lot to accomplish and this year the team moved the first test launch up leaving us with less time to complete everything. This made setbacks with manufacture or material acquisition even more detrimental. With hard work, strategizing, prioritizing, and help from other team members, we were able to produce a testable design that would have been ready to launch by our intended first launch. One of the challenges with a mission like this is that many of the components are affected by another. This can tend to lead to going in circles with no progress if a decision is not made. Our team learned that it was often our team that had to be the one to make the decision and move forward, especially if it impacted our manufacturing schedule. Finally with so many parts made from composites, manufacturing flight worthy parts with our experience level made some components harder to make than others.

After the experience so far, many recommendations can be made. First and foremost, get certified on shop tools as soon as possible, including the ply cutter, waterjet, oven, CNC and respirator. Because there is such little time, having to wait to use a tool because of a certification can throw the schedule off. Secondly, take the Composites Manufacturing class if possible. So much of the rocket is manufactured with composites and being able to understand how to layup and work with composite materials will greatly help. As mentioned, this project is very time sensitive, so start manufacturing components as soon as possible. The sooner a component is manufactured the sooner it can be tested and redesigned if something does not work right. Collaborate with the other AIAA teams, even though they are all different projects, many are going through similar challenges with testing and manufacturing. Keep open communications between all sub-teams. Almost all the subteams are impacted by the other subteams and this is especially true of Structures and Integration. Keeping dialogue open between all groups will help everyone be successful. This is especially true with the Avionics team, who should be involved in the design for the avionics bay as early as possible. Finally, do not be afraid to ask for help. There are so many resources on campus between the mentors, grad students, previous team members, other teams, and professors, but they cannot help if not asked.

D. Aerodynamics & Recovery

The Aerodynamics and Recovery sub-team has several recommendations for the 2020-2021 ESRA Aerodynamics and Recovery sub-team. All of these recommendations come from the experience of previous years, research, guidance by mentors or GTAs, or trial and error by our sub-team. It is recommended that you look through our research, simulation, parachute, and Technical Revision 4 folders on Google Drive early on to get a starting point for this project. Other recommendations can be seen below.

1. Parachutes

Recommendations for the parachutes revolve around manufacturing. It is recommended to learn how to sew early and practice extensively. Ripstop nylon is a very challenging fabric to sew, so order extra materials to allow for practice. The parachute gores should be cut on the ply cutter and the seam allowance should be marked using the pen tool. This ensures all gores will be accurately cut and makes it easier to sew the gores together with a visible seam allowance line. Lastly, if the parachute needs to be patched, use ripstop nylon patching tape and adhere it to both the inside and outside of the parachute. This type of patch distributes the force along the entire patch and not just along the seam.

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