Senior Project Proposal 2018-2019

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Modular Rocket

OTRA

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Overview

The purpose of this paper is to inform the reader of the progress made on the OTRA member's senior project. Since this project has no previous work done, the following sections will go into great detail over the various aspects of the rocket. To give the best description of the rocket, each section has been broken down into the design, analysis, manufacturing plans, and planned testing. At the end of the paper, the proposed budget as well as deadlines will be reviewed. Currently the rocket is on schedule to be completed late winter term or early spring term.

The members of this project aim to fly this rocket at the 2018 ESRA Spaceport America Cup. The Spaceport America Cup, hosted by the Experimental Sounding Rocket Association, began in 2017 and has grown to include over 70 schools and 1500 students from across the world. The goal of this project is to create a solid-fueled rocket that is capable of reaching 10,000ft apogee, but is also able to accept a liquid fueled engine and reach 30,000ft. To this extent, the design of the rocket must be modular. This means that the rocket will be able to be assembled and then fully disassembled with as few individual components irreversibly secured as possible. This will allow the rocket to interchangeably test different components, such as fins, nosecones, engines, etc. and be able to serve as a starting point for future years of OTRA.

Nose Cone

Design

When deciding the shape of the nose cone there are a several factors that need to be accounted for. These factors are the diameter of the rocket body and the maximum velocity of the rocket. The reason for the diameter is to calculate the total length of the nose cone, and the reason behind the speed is to determine the shape of the nose cone itself. According to the rocket designed by MIT [1], the length should be 1:3, but it can range up to 1:5.5 according to Madcow Rocketry [2]. The nose cone to rocket body length will be 1:5.5 which makes the nose cone 6 inches in diameter and 33 inches in length.

The next step is to determine a nose cone shape. According to aerospaceweb.org, the shape depends on the speed [3]. The faster the rocket travels, the more stable and less drag will be acquired by a more pointed design. Current simulations show the rocket going in the transonic region which is defined as 0.8 to 1.2 Mach. Due to the higher speed, the decision was made to use a Von Karman shaped nose cone. This decision was made using suggestions from a paper written at uakron.edu [4]. Their paper states that the Von Karman shape is ideal for speeds around Mach 1.2. Even though OTRA's rocket is planned to go near the bottom of the transonic region, Von Karman would be a good fit since this rocket will eventually flown to higher elevations in future missions. In those missions, it is probable that future rocket operators are going to reach higher speeds which would require the Von Karman nose cone.

Analysis

The main analysis that needs to be done is the amount of heating generated on the nose cone to ensure the fiberglass will not fail in flight. There is a rough estimate of the amount of temperature increase that will occur, but the estimate will be refined in the future. Using equations depicted in an article by Ben Brockert [5], current temperature increase is estimated at 86.4°F at the tip. Assuming the nose cone will initial temperature will be about 85°F due to the desert heat, means that the nose cone will be achieving temperatures of around 171.4°F. This was done as an estimate to ensure that our fiberglass nose cone would not fail. Once the durability of the nose cone has been analysed, it can be determined whether insulation will be needed to protect the electronic components located in the nose cone. If foam is needed, it will also have to be determined what type of foam should be used. There are two potential, insulating foam choices. The higher temperature foam needs to be shaped, while the lower temperature foam can be poured into the nose cone and then trimmed if needed.

Manufacturing

Due to the complexity of the shape, creating a mold of the nose cone that is very accurate would be very time consuming and expensive. Due to these restrictions,it has been decided to purchase a pre-manufactured piece. This will reduce manufacturing time and produce a more accurate shape. A purchased nose cone will also be a cheaper alternative since the tooling would be relatively expensive and multiple nose cones would be needed to perfect the process. This manufacturing process was then compared to the cost of the premade nose cone at $150. The nose cone has a built in metal tip, therefore the heat resistance of the nose cone will be dramatically improved. All these reasons led to make the choice that it would be a more efficient use of resources use the premade piece rather than attempting to manufacture a nose cone on campus. Even so, there will be the option to make a nose cone as a contingency plan.

Testing (plan)

Due to the fact that the nose cone will be purchased, there will not be much testing to be done when it comes to shape and aerodynamics. What will need to be done will be testing for recovery. The recovery will have to jettison the nose cone to deploy the parachute. There will need to be testing done to confirm that the nose cone will get out of the way in time and that the jettison system is powerful enough for the weight of the nose cone.

Recovery

Design

The design of the recovery system is broken into three parts Parachute,and Separation. Parachute section details the selection of a main parachute and a drogue chute. When the rocket arrives at apogee, the drogue parachute is deployed. Once deployed, it will need to support the mass of 60 lb. When the rocket reaches 1,000-1,200 ft, it will deploy the main chute and slow down the rocket to a safe landing speed to prevent damage to the frame or fins. Not damaging the fins will help the team score better at Spaceport America since one of the scoring criteria is damage on recovery.

Sub-section 1: Parachute

The selection started began with the size of parachutes needed for the main chute. The first parachute choice was a round hemispherical parachute. The reason being that the functions of a round hemispherical parachute better met the needs of the rocket. The idea of a round parachute is that it is connected around its circumference to the payload and collects air as it is driven up into it by the descent. This keeps the parachute rigid and inflated, allowing the payload to fly safely down to earth. "The round hemispherical parachute design was very reliable. It was rare for anything to go wrong with a round parachute and consequently, it was used for many years."(R1) The downside to the round design was a lack of maneuverability. The round parachute could only pivot on its center point - meaning it could only change the direction to a very small extent which is what is needed to reduce the drift of the rocket.

The second major design decision was if we would have a drogue chute for a dual-deployment or not. In simple terms, dual-deployment really means: two recovery devices in the rocket that are ejected at different times during the flight. The reason why we decided for a drogue chute is to reduce the drift distance of the rocket especially important when recovering from high altitudes. Since we plan for the rocket to be able to go higher in the future. This system will reduce the amount of drift the rocket has as it falls by allowing the descent rate to remain higher the drogue system reduces the amount of drift the rocket will experience by reducing the time the wind has to blow the rocket downrange.

Sub-section 2: Ejection

Making decisions about the ejection system starts with a basic question, where do you want the recovery system to eject. Based on the overall size and weight of the rocket it was evident that a robust recovery system would be used thus ejection would need adequate space for deployment, the easiest place for this to happen was determined to be the connection between the nose cone and body tube. The basis of the ejection will be done between two bulkhead attached to the two respective tubes with a chamber on the body tube and an insert on the nose cone. Within the chamber will be a small amount of black powder that will supply pressure to shear the pins used to hold the bulk heads together during flight. The main requirement was the force required to eject the entire nose cone. The design approach was to determine the ejection method first and then design the connections to the tubes.

Analysis

Sub-section 1: Parachute

After we decided on what we wanted to use for the shape of the parachute and if we should include a drogue chute. We started to calculate the sizes we would need for the parachutes. As a general rule of thumb when designing a parachute “the descent velocity of your rocket should be between is 3.5 to 4.5 meters per second (11.5 to 14.8 feet per second)”. [8] You can determine the area of the parachute from the following equation:

$$S = \left(\frac{2 \times g \times m}{\rho \times C_d \times V^2} \right)$$

Where S is the area of the parachute, g is the acceleration due to gravity; which has a value of 9.81 m/s2 at sea level, m is the mass of the rocket (with empty engine) as measured in grams, r is the density of air (1225g/m3) at sea level, Cd is the coefficient of drag; estimated at 0.75 for a round canopy, and V is the descent velocity we choose. Since we decided on a round canopy, the diameter is found by the formula:

$$D = \sqrt{\frac{4 \times S}{\pi}}$$

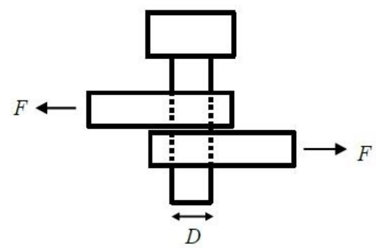
For Drogue Chute selection we used the same calculations as the main chute, but “adjusted the descent velocity to 50mph which is a general rule of thumb of drogue chutes”[8]

Sub-section 2: Ejection

In addressing the first question of the ejection charge or method the decision was between black powder and other non-pyrokinetic methods. The two reasons to investigate these other non-explosive releasing actuators is the potential shock and the safety concerns of explosives. Non-explosive methods of separation produce less of a shock on the surrounding panels [9], these shocks are negligible for our systems due to the relative size of our rocket and the distance between the shock and electronics. The safety of black powder is also still a concern with any amount in possession, however the amount we would be using would be on the order of five grams [9] for each ejection test and the release mechanisms in the parachute lines.

With black powder selected as the ejection method and the bulkheads on the nose cone and body tube designed we now look towards holding the tubes together with shear pins. With shear pins selected the calculations are statically based on the max shear force that the bulkheads will exert. In the equation below the Area (A) is the pitch diameter of the pins selected, tau is the shear strength of the material for the pins and the force is an estimate for the force required to perform full shear.

$$\tau = \frac{F}{A} \qquad \tau = \frac{F}{\pi(r)^2} \qquad \tau = \frac{4F}{\pi(D)^2}$$



Manufacturing

Once our main parachute size and drogue chute has been selected much of the parachutes will be bought from trusted distributors. Building our own parachutes, while possible leads to many unknown factors of there construction. We decided to save time and doubt with pre-bought parachutes allowing us to put more time towards testing. For the manufacturing of the ejection system bought shear pins will be used as to maintain a more precise measure of their shear strength, while the bulkheads and structure will be made in the campus machine labs. The only manufacturing difficulties that should present themselves for ejection is the style wanted for the chamber and pin, using a large cylinder of aluminum for this would lead to excess waste of metal while Tig welding aluminum blocks together saves much more. Welding blocks together requires us gaining more experience with this type of welding till proficient enough to feel safe in it construction. Between the universities facilities and the tools that the on campus rocket club has tooling and manufacturing should be relatively simple processes.

Testing (plan)

For recovery testing there are multiple levels of tests that will be performed, a basic static loading test, static ejection testing, and dynamic chute deployment, and hopefully a fully launch at Brother Oregon. The static loading tests will be the chutes and cords with the full connections between the cords and the appropriate bulkhead to test the connections, tender descenders, and forces that will be exerted during descent. The static ejection test will be the the nose cone and main body tubes fully connected as they would be in flight and the system on a slightly raised ramp to allow for movement in the free air. Once set-up the system would then test the ejection portion to see the force exerted and allow a determination on whether the force is sufficient to perform ejection once in flight. The dynamic chute deployment will likely be done of a structure attached to the rocket test stand to allow the nose cone to be pulled off during travel by a motorized vehicle and then at a sufficient speed deploy the drogue chute and then later test the cord connections by releasing the main parachute. The main test of the entire system at altitude would hopefully be in the spring at Brothers Oregon with a local rocketry club there to test up to 8000 feet, and allow the entire recovery system to be tested together during actual flight.

Body Tubes

Design

When considering designs for the main body material, carbon fiber and fiberglass were the final two choices. Both composite materials follow a similar manufacturing process. The process is taking fibrous material or mesh and creating layers from the mesh. The layers are bonded together using resin. By orienting the mesh differently, different properties are improved or diminished. To reduce the risk of creating out of tolerance parts, the body of the rocket will be bought from off the shelf parts. Buying pre-made parts also has the added benefits of a consistent surface finish, known material values, and creates a more predictable manufacturing timeline.

The body tubes chosen are .083" thick with an ID of 6" and manufactured by Dragon Plate. This size of ID was chosen because it was adequately sized to house a liquid engine as well as the current solid fuel engine. Two sections of 45" inches will make up the body of the rocket. The two sections will be joined with an aluminum coupler. In following Spaceport regulations, the length of the body coupler must be equal to the diameter of the rocket. The current coupler is therefore designed with a length of 6" with 8 holes on each end of the coupler for the body tubes to mount onto to ensure the body tubes do not twist and no bending occurs to ensure that the rocket maintains a straight flight path.

The strength to weight ratio of carbon fiber will allow for a monocoque design that minimizes internal support structures and allows for components to be attached directly to the body tubes. This allows the support structures to be less than 20%, down to 10%, of the overall rocket weight. The body tubes themselves will be approximately 11.4 lbs, also around 20% of the overall rocket weight, and can save around 5 lbs in support structures.

Analysis

While the strength of carbon fiber can be approximated using aluminum, it is difficult to obtain accurate results without intimately knowing the process used to create the carbon fiber. This is due to the many different types of weaves, layup patterns, and resin compositions that can exist, which changes the properties of the final product. Knowing the weave type, layup schedule, percentage of the weight that is resin, as well as the carbon's thermal properties, will then allow for applying classical laminate theory to determine the properties of our final body tubes, only after which accurate analysis can be run.

A monocoque design also helps the overall analysis of the rocket by reducing the number of overall components that can share or contribute to a load. For example, the thrust from the motor will be able to act almost directly on the body tubes, and the axial loading acting on the nosecone will also be directed on the body tubes instead of structural recovery components. Having a minimal number of forces act on each component of the rocket allows us to assume our FS are accurate as few other forces will act on that component and therefore allow us to further reduce the weight of structural components in the rocket in order to be as light as possible.

For now, the body tubes have been modeled to be under drag forces and thrust from the rocket motor and strength was approximated using aluminum. Stresses on the body tube were found to be slightly under a FS of l0. This supports a monocoque design without critical failure in the body tubes.

According to Box, Bishop and Hunt [22], drag forces on the body tubes are able to be approximated as the sum of two forces, the body drag and base drag. The drag forces are based off of the characteristic length (ltr) which is the total length of the rocket body, the length of a boat tail (lc, 0 in our design), the body diameter (db and dd), and the coefficient of Viscous friction (Cf(fb)).

Body Drag The drag on the rocket forebody is estimated using equation (41)

$$C_{D(fb)} = \left[1 + \frac{60}{(l_{TR}/d_b)^3} + 0.0025\frac{l_b}{d_b}\right]\left[2.7\frac{l_n}{d_b} + 4\frac{l_b}{d_b} + 2\left(1 - \frac{d_d}{d_b}\right)\frac{l_c}{d_b}\right]C_{f(fb)}$$

Base Drag The base drag on the rocket is the drag due to the low pressure region at the base of the rocket that is caused by boundary layer separation. This drag is estimated using equation (42)

$$C_{D(b)} = 0.029\frac{\left(\frac{d_d}{d_b}\right)^3}{\sqrt{C_{D(fb)}}} \qquad (42)$$

Figure 1: Body Drag on a Rocket by Box, Bishop and Hunt [22]

The coefficient of viscous friction is dependent on Reynolds number and the critical Reynolds number (Rec), 5*10^5.

Viscous Friction As discussed in section 3.1 the viscous forces on the rocket are dependent on Reynolds number. The friction force coefficient is given by equation (45).

$$C_f = \begin{cases} \dfrac{1.328}{\sqrt{Re}} & \text{when } Re \leq Re_c \\[2ex] \dfrac{0.074}{Re^{1/5}} - \dfrac{B}{Re} & \text{when } Re \geq Re_c \end{cases} \tag{45}$$

where B is given by equation (46).

$$B = Re_c \left(\frac{0.074}{Re^{1/5}} - \frac{1.328}{\sqrt{Re}} \right) \tag{46}$$

Reynolds number is given by

$$Re = \frac{\rho V L}{\mu} \tag{47}$$

Figure 2: Viscous friction coefficients by Box, Bishop and Hunt [22]

Assuming max drag at Mach 1, the coefficient of drag must be corrected for compressible flow. Box, Bishop and Hunt offer the following correction for compressible flow.

At subsonic speeds ($Ma < 1$) the corrected aerodynamic coefficient is given by equation (55) [Cramer, 2002]

$$C_i' = \frac{C_i}{\sqrt{1 - Ma^2}} \tag{55}$$

where C_i is the aerodynamic coefficient in the incompressible regime and Ma is the free stream Mach number.

At supersonic speeds ($Ma > 1$) the corrected aerodynamic coefficient is given by equation (56).

$$C_i' = \frac{C_i}{\sqrt{Ma^2 - 1}} \tag{56}$$

The problem with this estimation method is that C_i' goes to infinity as Ma goes to 1, which no longer fits experimental data. It is suggested in Ketchledge [1993] that in order to avoid this situation, the following equation is used for $0.8 < Ma < 1.1$.

$$C_i' = \frac{C_i}{\sqrt{1 - (0.8)^2}} \tag{57}$$

Figure 3: Compressible Flow Correction by Box, Bishop and Hunt [22]

Using these values and assuming max drag at Mach 1, the drag on the length of the rocket body is estimated to be about 444 N.

Manufacturing

Because of carbon fiber's somewhat unique composition, research was performed into how best to machine carbon fiber. As mentioned earlier, carbon fiber is made of long, woven carbon fiber mesh and resin. The carbon fibers pose a challenge to machine because they do not break off easily and have a tendency to wrap around tooling. The wrapping phenomenon can dull and even break tooling prematurely.

To counter this affect, tool should be run at higher than normal speeds. This will cause the carbon fiber to break off in smaller sections preventing a long strand of carbon fiber to wrap around the tool. The type of tooling that works the best for carbon fiber are HSS (high speed steel) and carbon tipped tools. For drills, the carbon tipped ones will be used over HSS. For endmills, diamond pattern, HSS endmills will be used. The diamond pattern on the endmills also prevents wrapping. Neither of these options are expensive.

The resin is the last thing that needs to be considered. Heat will damage the resin bonding causing the carbon fiber layers to deform and seperate. Carbon fiber also retains heat. The resin composition also means that water and normal coolants cannot be used without damaging the resin. In order to reduce heat buildup within carbon fiber, slow feed rates will be used. Research has shown that for small production runs, machining without coolant can work at the cost of increased surface roughness and tool wear. The surface roughness can be accepted and decreased by hand after machining.

Testing

The tubes were modeled under the max theoretical stress in SolidWorks FEA to ensure the tube wall would not fail. The selected thickness performed well under this model, and will be subjected to further testing once the materials have been bought. Once the materials are acquired, testing will be done to ensure that any flex in the body tubes will not alter the angle of attack for the flight of the rocket. Natural frequency testing will also be conducted to ensure that the forces exerted on the tube and internal systems do not lead to natural excitation. Destructive testing may also be done to find the body tube's main points of failure and ensure they are not being placed under load.

Engine Mounting

Design

As OTRA is flying a solid fuel motor this year, the housing for a premade solid motor differs than that of a liquid engine. A premade solid motor is sold individually and requires a casing and end caps to be attached around the motor. The motor casing is usually held in place within the rocket body by centering rings that keep the motor concentric and parallel with the rocket body at all times so that the motor is not imparting an angle of attack to the flight of the rocket.

When first designing the engine mounting other engine mounting methods were looked at. As the motor casing is extremely thin, only fractions of an inch larger than the motor itself, a way of securing the canister to the centering rings and body tubes is needed. Many of the rockets in the competition class utilize epoxy and other resins to mount the motor canister directly to the body tube. This design is simple and cheap. However, it makes subsequent launches more difficult and leaves few options for adapting the rocket for other purposes. A modular approach that would allow the rocket's solid fuel motor to be substituted with a liquid fuel motor with minimal modifications to the rest of the rocket. The best way to maintain overall modularity is to use a fin canister with integrated internal centering rings for the reloadable motor canister. Using a fin canister allows for the whole motor mount and fin assembly to be assembled outside of the rocket, or for different designs to be interchanged into the rocket without affecting other structures. Once ready, the whole assembly can be inserted into the bottom of the rocket and bolted to the carbon fiber body tube. This design would also ensure the motor canister is held securely and with good alignment within the body tube. It also helps maintain consistency when mounting the fins, keeping everything vertically aligned and perpendicular to the body.

In order for the assembled motor casing to sit inside the engine mount, caps were designed around the casing's own caps that allow for the fuel's exit through the nozzle at the rear of the motor and extrusions in the front cap. The current iteration of the motor mounting assembly consists of an upper thrust-bearing ring/cap, a center non-load-bearing guide ring, a lower light-load-bearing guide ring with a retainer and four slotted rods. All eight parts are to be machined from aluminum. Aluminum 2024 will likely be the alloy used despite its significant cost. Figure X.0 below depicts the current motor mounting assembly. This is designed to accept a 3.970 inch diameter by 27.938 inch long AeroTech Solid Rocket motor casing [10].

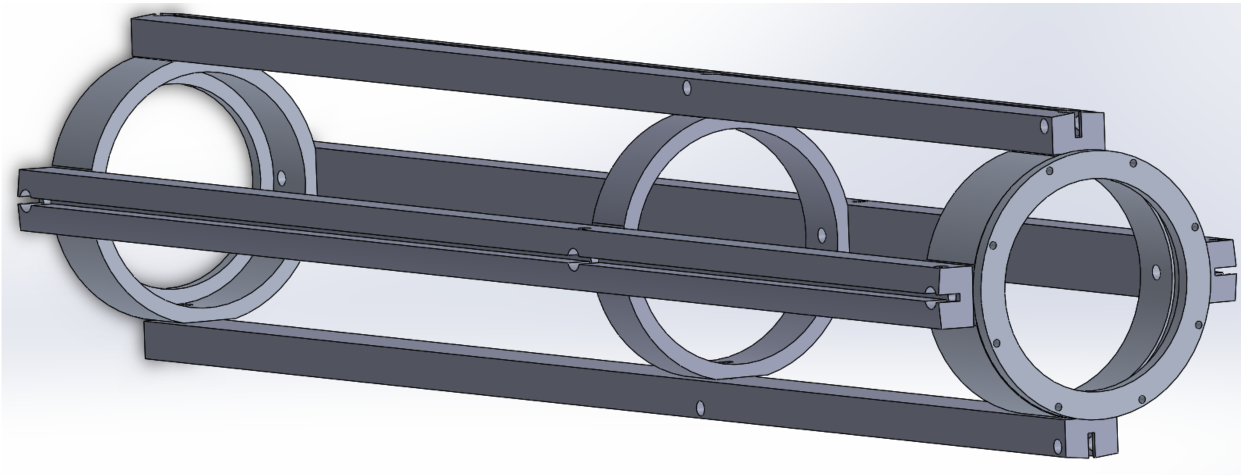


Figure 4: Motor Mount Assembly

The main downfall of this design is a substantial in-air weight and material costs. To counter this, a revision of this design that will more effectively utilize the body tube as a structure will be completed over winter break. This revision would remove a significant amount of material. The most significant material reduction would come from the thrust-ring (far left) being made independent from the rest of the assembly. Removing the thrust ring will reduce the weight of the slotted rods to almost a third of what they are now.

Analysis

Based on the Solidworks mass properties, the overall weight of the motor mount assembly is 7.99 Lbs. This assumes 1 Lb for steel fasteners and all of the machined components are made from 6061-T6 aluminum. The finite element analysis of the motor mount components are still a work in progress. However, the upper thrust bearing cap is showing a factor of safety of roughly 15. Since the needed factor of safety is 1.5-2.0 on most components, a significant amount of material will be removed to reduce weight while still maintaining structural integrity.

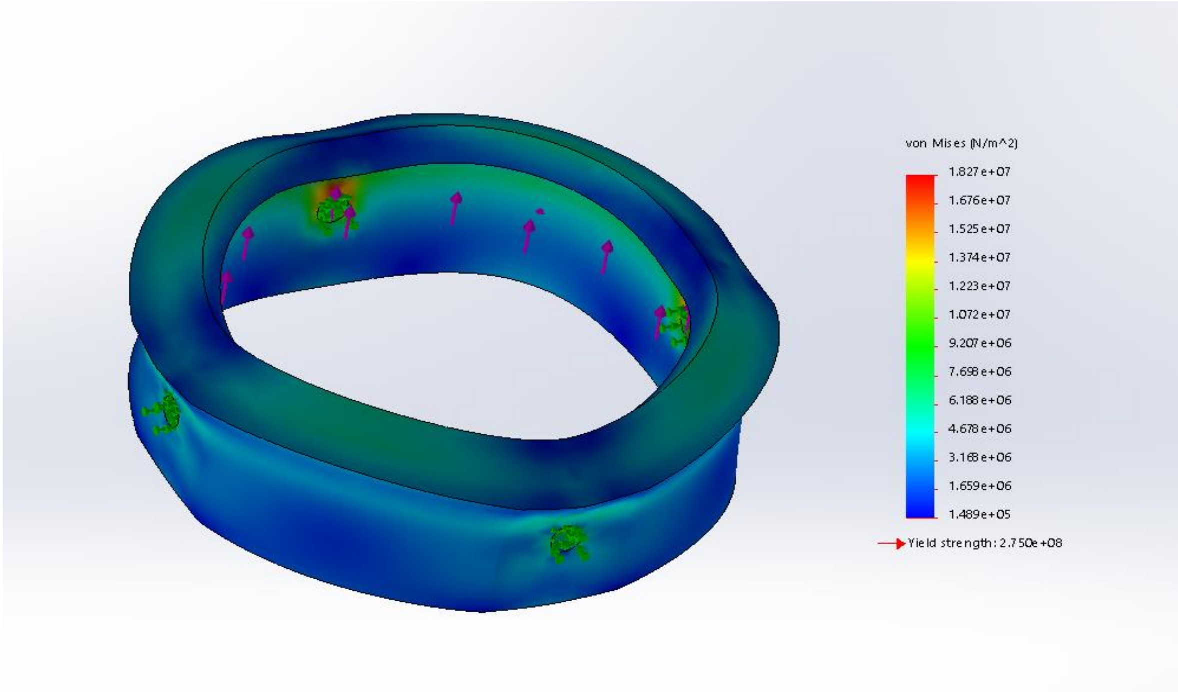


Figure 5: FEA on the upper thrust bearing cap with a safety factor of 15

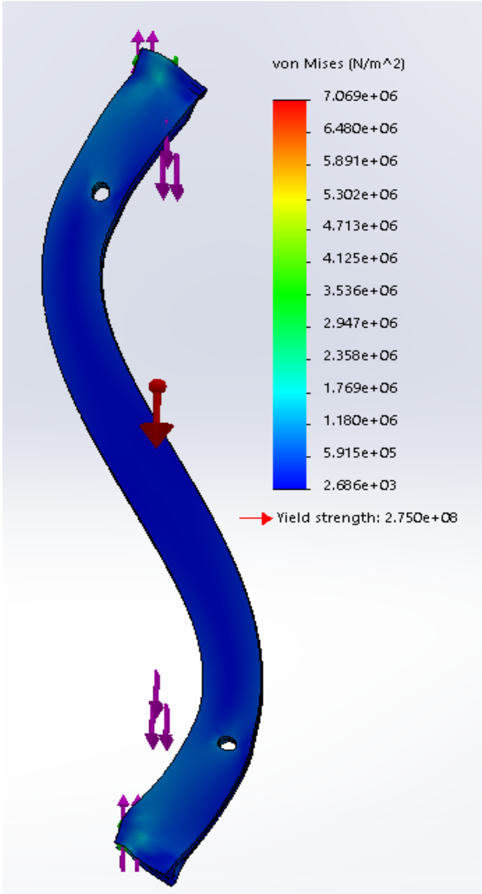


Figure 6: FEA on a fin slot where drag and thrust are applied with a large safety factor

FEA through Solidworks has shown that multiple components have FS of approximately 10 under load from drag forces and/or the thrust of the motor. This means that the structural components of the rocket have much more weight than necessary. Reducing the excess weight of the rocket to the absolute lightest weight possible will take quite a bit of fine tuning, but saving at least a bit of weight will allow the rocket to reach hundreds more feet in altitude.

Manufacturing

Manufacturing of the motor mount components is set to begin early winter term. To begin manufacturing at this date, the team will finalize the design by the end of winter break. Currently, all motor mounting components are designed to be machined from commonly available stock sizes. The components will be manchinable using the manual and CNC milling machines and lathes here at Oregon Tech. The slotted fin mounds will be machined from 1”x1” aluminum bar stock and the three rings will each be machined from separate 6”x6”x2” billet aluminum blocks.

Testing

Testing is expected to take place late winter term otherwise with early or mid spring term being the latest start dates. There are several testing options to choose from depending on budget and access to a motor testing facility. Option 1 is to test fire the motor to observe how the mounting handles the designed load. This would be the most accurate way to test the mounting. However, Option 1 only proves if the mounting will hold or not. It determine the operating factor of safety. Option 1 is also by far the most expensive option. Option 2 is to do a low height, weight drop to simulate the sudden and substantial thrust produced by the motor. This option is far cheaper than option 1, but gives less accurate data. Option 3 is to perform destructive testing on the motor mount assembly to find the locations and methods of failure along with the tested factor of safety. This would be ideal, but would require extra manufacturing time and material costs. Currently, a method of testing has not been selected, as the options will be dependant on several factors moving. Natural frequency testing may also be done to make sure the engine mount system is not prone to natural excitation that would cause it to move within the body tubes or tear itself loose.

Fins

Overview

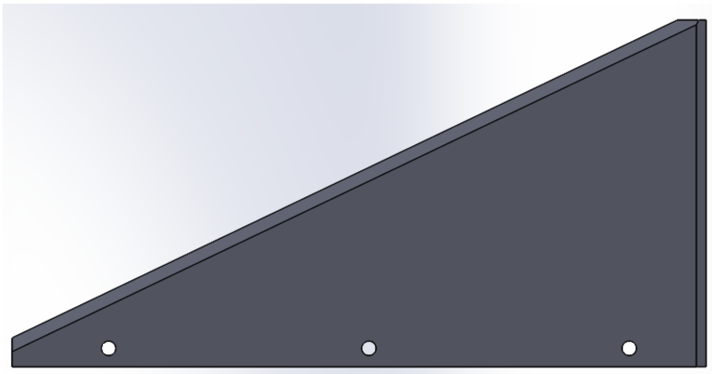


Figure 7: Front View of Completed Rocket Fin

In order to ensure the overall stability of the rocket throughout the flight, a set of four identical fins are installed towards the bottom of the rocket. These fins serve as minuerature wings, providing lift to compensate for the rocket tilting mid-flight and keeping the center of pressure below the center of gravity at all times. The most difficult problems with designing the fins for the rocket occurs when the rocket reaches speeds equal to and above mach 1. Attempts to use computational fluid dynamics to model the fin at these speeds is almost impossible and most design must be based off of previous work. For this reason, each design decision is made based on scholarly research and analyzed as much as possible using popular rocket modeling software.

Design Goals

Because rocket fins can not be designed using computational fluid dynamics to achieve an optimal geometry, a set of goals are chosen for the fins to achieve. Using previous research and test data, several different models of rocket fins can be created to achieve the desired goals. The goals of the rocket fins are to keep the center of pressure between 1.5 and 5 body calipers from the center of gravity, ensure the rocket meets the required stability and speed values when leaving the launch rod, and meet a factor of safety of 1.5. Meeting these goals while also minimizing drag and weight will create a nearly optimized fin for our rocket.

Fin Design

The following sections will lay out the reasoning behind each aspect of the rocket fin design, followed by the analytics from simulation software proving the design meets criteria. Fin shape, position, cross section, thickness, and fillets are explained with in depth reasoning

Fin Shape

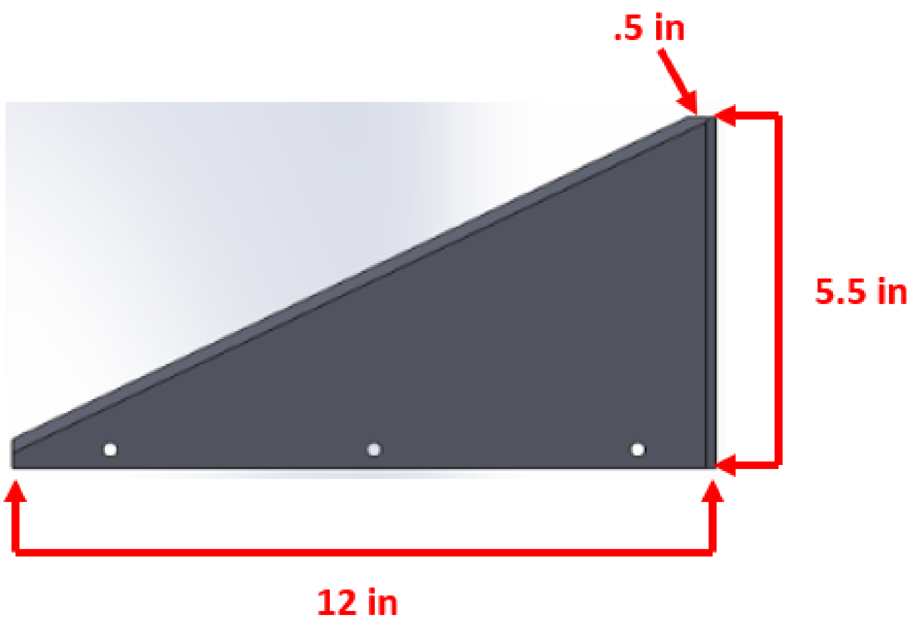


Figure 8: Front View of Fin With Dimensions

A slightly clipped delta shape is currently the choice for the general shape of the fin. This shape was chosen for its aerodynamic performance in the high transonic region and supersonic region. A fully clipped delta shape is best for supersonic speeds while the expected range of speeds for the OTRA rocket is just under supersonic [15]. While a normal clipped delta has much longer clipped edge, the lower speeds of the OTRA rocket mean less clipping is optimal.

Fin Cross Section

Currently, the fin thickness is set at .125” thick in order to create as little drag as possible. The fin thickness correlates with the drag of the fin directly and a thinner fin results in a lower drag coefficient [16]. The selected thickness is especially thin given the size of the fin, but maximum forces on the fins are expected to be low due to the lower elevation goal of 10,000 ft. The leading edge of the fin will be sanded to a point to create a sharp edge, while the trailing edge of the fin will be sanded to a flat surface of .06” in accordance with NASA recommendations [17].

Fin Fillets

At the base of the fin where the fin and rocket body come into contact a fillet should be utilized to reduce drag. This fillet aids in ensuring air travels smoothly around the base of the fin rather than creating extra turbulence. An especially large fin fillet at transonic speeds in detrimental to rocket drag and so a fillet size of ½” is selected [18]. In order to keep the rocket as modular as possible, the fillet material will be chosen according to the ability to easily scrape away the material after use. Current research is focusing on water soluble epoxy while materials such as silicon are also being considered, but no final material has been selected.

Fin Location

In order to keep the center of pressure within the acceptable range, the fins should be located close to the bottom of the rock as possible. Due to limitations of the motor mount, the fin must be located ¼” from the bottom of the rocket. Locating the fins at the bottom of the rocket keeps the center of pressure between 1.5 and 5 body calipers from the center of gravity.

Fin Material

The options for fin material are aluminum alloys, carbon fiber, or fiberglass. Aluminum is extremely strong and gives the fins an excessively high factor of safety, but the weight of the fins would be much higher. Fiberglass begins to experience problems above mach 1 and would not be viable for faster flight. Carbon fiber is extremely strong and stiff, but it is both difficult to work with and has varying material properties. In order to make a selection of fin material, more research into the strength of carbon fiber is necessary. In order to make a selection, team member will begin studying laminant stack theory to better understand how to manipulate the material properties of carbon fiber. Final selection of fin material will be based off of which materials weight the least while still meeting the minimum criteria for strength and stiffness.

Fin Analysis

An acceptable fin for the OTRA rocket needs to keep the rocket with a specified stability margin, avoid creating extra drag on the rocket, and meet material requirements to avoid breaking. Two programs are used to ensure the fins meet these criteria: Openrocket simulator and AeroFinSim. Openrocket is an open source rocket simulation program for simulation hobby rockets and is useful for rockets going up to mach 1. AeroFimSim simulates the stress the rocket fins will undergo due to the flutter phenomena.

Openrocket

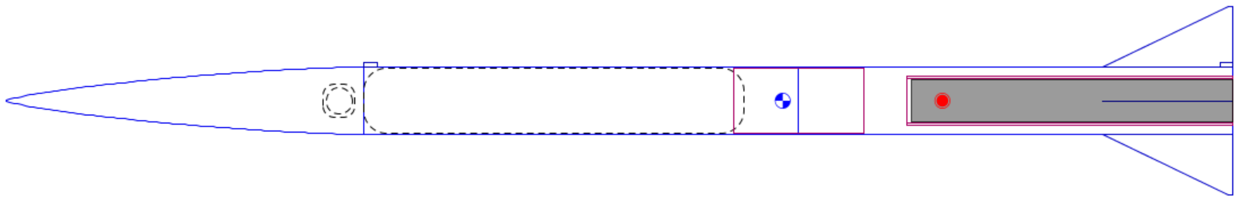


Figure 9: Openrocket Analysis Model (Openrocket)

Openrocket allows the user to test different rocket geometries to find a suitable rocket setup for the given requirements. Using the determined rocket properties along with test geometries of fins allows the user to see the effect of different fin shapes and thicknesses on the rocket. For the purpose of the OTRA rocket, Openrocket is used to ensure the rocket maintains a stability between 1.5 and 5 for the duration of the flight and leaves the launch rod at 100 ft/s. Figure 4 and Figure 5 both show that these conditions are met using the fin design described above.

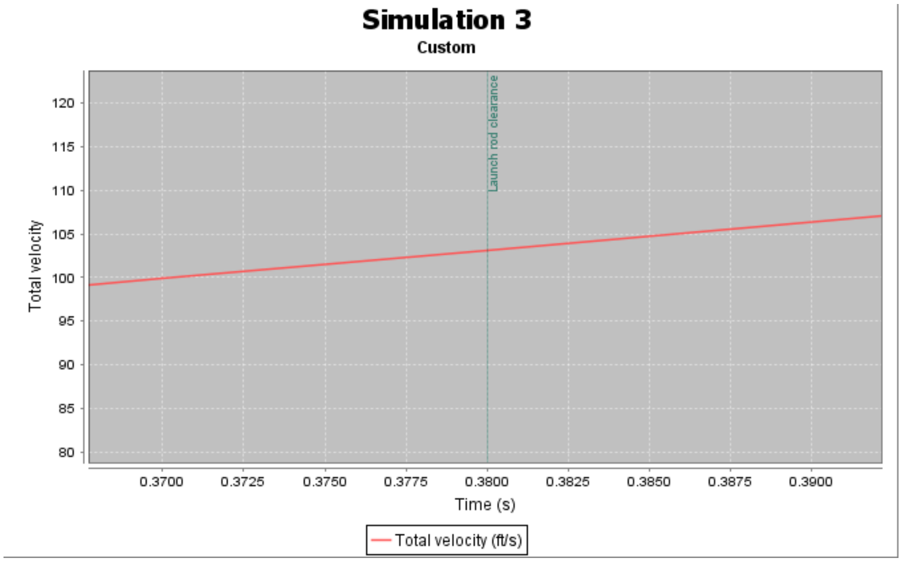


Figure 10: Velocity at Launch Rod Clearance (Openrocket)

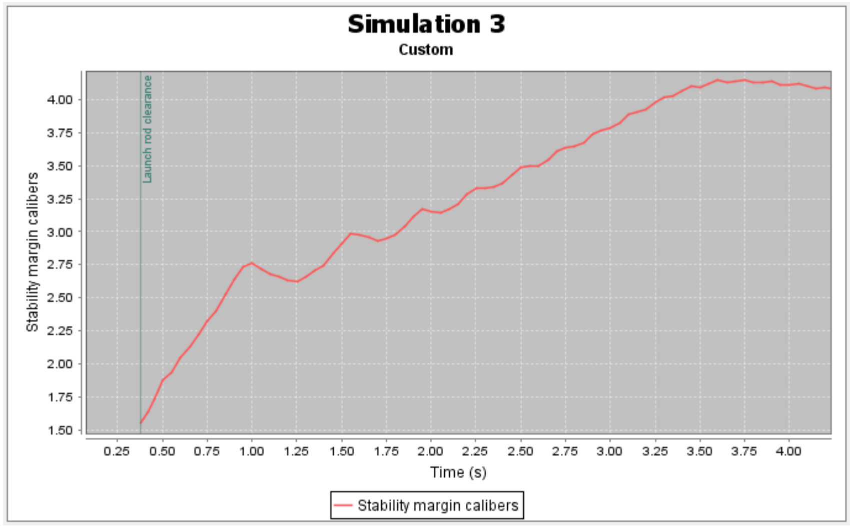


Figure 11: Stability Calibers Minimum and Maximum (Openrocket)

AeroFinSim

A primary concern when designing fins is a phenomena called fin flutter. This occurs when the fins vibrations continuously build on themselves due to the force of the air [19]. The analysis program AeroFinSim can give an approximation of the required velocity needed to cause catastrophic failure of the fin. In order to use this software the material properties of the fin are needed, meaning carbon fiber and fiberglass can not be analyzed until more research is done. Figure 6 depicts the program's estimate of maximum velocity for an aluminum fin with the geometry specified above.

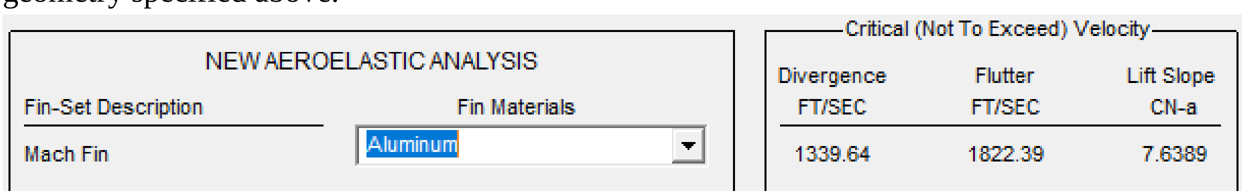


Figure 12: AeroFinSim showing critical velocity (AeroFinSim)

FEA

In addition to making sure the fin has proper stability, analysis was done to ensure that our chosen method of bolting the fins into slots on the engine mount would not cause the fin to fail. The main force that could lead to the shearing of the fins would be the drag force on the fins. The maximum drag force was estimated to occur during the rocket's movement in the transonic region, right before the rocket reaches speeds of Mach 1. The drag was also estimated when the rocket was traveling with zero angle of attack. According to Box, Bishop and Hunt [22], the drag on a trapezoidal fin at a zero degree angle of attack can be estimated as the sum of two forces, the fin drag and interference drag. The coefficients of drag are based off of the thickness of the fin (Tf), the characteristic length of the fin midcord (lm) the number of fins (n), the planform area of the fin (Afp), and the coefficient of viscous friction (Cf(f)). The planform area is equal to the area of the trapezoidal fin plus the radius of the rocket body times the fin height and represents the area of the fin as it extends to the centre line of the rocket body. The coefficient of viscous friction is dependent on Reynolds number and the critical Reynolds number (Rec), 5*10^5 (Figure 2).

Fin drag The fin drag on the rocket at zero angle of attack is given by equation (43).

$$C_{D(f)} = 2C_{f(f)}\left(1 + 2\frac{T_f}{l_m}\right)\frac{4nA_{fp}}{\pi d_f^2} \tag{43}$$

Interference Drag The drag due to interference effects between the fins and the body is given by equation (44)

$$C_{D(i)} = 2C_{f(f)}\left(1 + 2\frac{T_f}{l_m}\right)\frac{4n(A_{fp} - A_{fe})}{\pi d_f^2} \tag{44}$$

Figure 13: Equations for Drag Coefficients on Trapezoidal Fins by Box, Bishop and Hunt [22]

As with the drag forces on the body, the drag coefficient must be corrected for compressible flow (Figure 3).

While drag is usually calculated along the leading edge, the max drag can be calculated along the entire surface of a fin. Applying the max drag along one side of the fin will lead to maximum stress and displacement. The max drag along a set of 4 fins for an old iteration of the fin was found to be ~1206 N. While the maximum drag is now less for the newest iteration of the fin as its surface area is smaller, applying the larger force ensures an additional factor of safety.

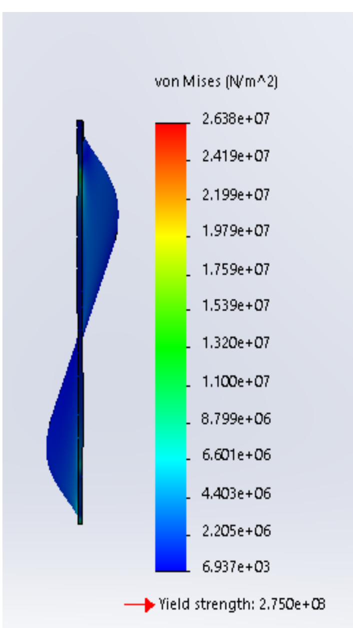


Figure 14: Max Stress from Drag Forces on a Fin

FEA analysis was also done with aluminum to approximate the strength of carbon fiber due to the complicated material properties of carbon fiber which are dependent on the layup pattern. FEA shows that the bolt holes and slot of the fin will not fail as there is a FS slightly over 10 on the fin.

The design of the fin also included choosing the location of the holes to bolt into the engine mount and rest of the rocket. FEA showed that the closer the hole was to the free edge of the fin, the smaller the max stress would be, but also showed that even placing the holes very close to the slotted edge of the fins would not significantly increase the max stress and displacement.

Manufacturing

Three methods of manufacturing fins are focused solely on manufacturing out of carbon fiber. Manufacturing aluminum fins would only require some machining work, but creating carbon fiber layups would require a special manufacturing process.

Female-Male Mold

By using both a female and male mold at the same time to perform carbon fiber layups, a smooth surface can be achieved on both sides of the layup. Normal carbon fiber layups with a vacuum bad have a smooth side and a rough side based on which side is in contact with a hard surface. Using both a female and male mold means both sides of the layup will be in contact with hard surfaces and have a smooth finish.

Aeropoxy of Two Sides

Two seperate sides of the fin could be manufactured independently then help together with extremely strong epoxy. This would reduce weight but require twice as many layups and the creation of perfectly symmetrical molds.

Brick Layups

A simple brick of carbon fiber could be manufactures, from which the shape of the fin could be cut. This method would be the most repeatable, but would require the use of tools and would destroy several tools in the process.

Testing

In order to ensure the fins will not break during the rocket launch, several tests should be run to determine the strength of the fins.

Load Bearing Capacity

Fins should be able to bear the launch weight of the rocket applied normal to the front face of the fin and two times the force due to max acceleration applied to the top edge of the fin (Newlands, Heywood & Lee, 2016). These two tests will ensure in-flight forces to not negatively affect the fin. In addition to the in flight forces, the fin must be able to withstand the force of the rocket landing after the flight, with the mass of the rocket traveling 15 ft/s. The fin must also be tested to withstand the recovery forces experienced.

Stiffness Testing

When performing load bearing tests, the fin should be checked to ensure application of the weight of the rocket onto the front face of the fin does not bend the fin more than 10 degrees (Newlands et al., 2016). This will ensure the fin is stiffness is enough to resist fluttering effects.

Drag Testing

Finally, if technology such as a wind tunnel becomes available, the fin should be tested for drag affects. Knowing the drag caused by the fins will help in approximations of maximum rocket apogee, especially when each fin will be slightly different due to manufacturing tolerances.

Air Brakes

Design

Part of the goal in the Spaceport America competition is to reach a certain altitude. There is a tolerance to surrounding this altitude and if the rocket falls out of this tolerance points will be deducted. To ensure the rocket reaches the designed altitude, it will be fitted with a slightly overpowered engine and air brakes. The larger engine will force the rocket slightly above the 10,000 foot goal. Deploying the air brakes at the right moment slow down the rocket so it will not go past the desired altitude.

The two main designs of air brakes were investigated, variable controlled system and a released and locked system. The variable controlled system would be more complicated both mechanically and in software. The variable control system involved having a stepper motor constantly adjusting the air brake's pitch based on sensor input. This system would also require a lot of power in order to run a high torque stepper motor for the estimated 15 seconds of air brake run time.

The current design is a release and locke system. With this system, drag profiles in subsonic flows for deployed and undeployed air brakes will be analysed using CFD software. Knowing the rocket's drag profile will allow for computing exact time to deploy the air brake flaps to achieve the 10,000 foot goal.

The air brake system is comprised of four hinged air brake flaps recessed flush to cutouts in the body tube between the engine and recovery system. The mechanical system is planned to utilize a pneumatic piston and linkages. This piston will be attached through linkages to the four flaps. A compressed CO_2 cylinder will be the operating gas and pressure will be released by an electronically controlled valve. Once deployed, the cylinder will lock into the extended position with the use of pins under spring tension.

Analysis

Further analysis of this system is postponed until the rest of the rocket design has been finalized. But the present condition of the air brake analysis has max drag force, which allowed for linkages to be designed and for an initial iteration of airbrake sizing. Over winter break and early next term, there will be CFD modeling performed to further refine the forces the system will experience. The modeling and testing of the system will allow for final components to be selected.

Manufacturing

The manufacturing plan is as follows. Due to the the air brake flaps unique shape, they will be manufactured onsite in the composites lab. The hinges will be commercially sourced as will the CO2 canister, hoses, and fittings. The pneumatic cylinder, locking system, and linkages will be manufactured by OTRA members in the OIT machine shop. The tentative plan for manufacturing the air brake system is winter term 2019. Final steps before building the air brake system is to work with the the college's safety department to prevent any potential safety hazards. If compressed gas design can not be used, one of the previous spring powered designs will be implemented.

Testing

Once the system is manufactured, testing of the air brake system components will begin. This will include pressurizing the cylinder and our valve release system to make sure it will not break. Using refined CFD analysis max loading on the brakes will be known. These max conditions can be applied in a static test to the air brake system. This will test the cylinder under load as well as make sure the locking mechanism is strong enough.

Budget

Engine Costs

Estimates for a Level 3, class M solid motor			
Supplies Description	Unit Cost	Qty	Total Item Cost
Class M Motor	$579.99	3	$1,739.97
motor adapter	$48.89	2	$97.78
motor retainer	$48.89	2	$97.78
Engine casing	$481.50	2	$963.00
forward engine closure	$145.00	2	$290.00
aft closure	$145.00	2	$290.00
forward engine seal disk	$37.45	2	$74.90
Engine Subtotal	$3,553.43		

Airframe Costs

Estimates for a cylindrical aluminum and carbon fiber body			
Nosecone	$149.95	2	$299.90
Aluminum sheet	$300.00	2	$600.00
Aluminum extrusion	$53.50	1	$53.50
resin	$309.95	1	$309.95
resin hardner	$57.95	2	$115.90
balsa wood	$5.00	15	$75.00
carbon fiber sheet	$249.95	2	$499.90
carbon fiber tubing	$150.00	3	$450.00
fiberglass	$49.45	1	$49.45
epoxy	$399.95	1	$399.95

modeling foam	$102.68	4	$410.72
sanding discs	$20.00	5	$100.00
tooling	$200.00	2	$400.00
flush rivets	$0.25	48	$12.00
fin bolts (1/4")	$2.00	48	$96.00
plate bolts (1/4")	$2.00	12	$24.00
nuts (1/4")	$1.18	$60.00	$70.80
Airframe Subtotal	$3,967.07		

Airbrake Parts

Estimates for deployable air brakes to reach precise apogee			
servo motor	$106.99	3	$320.97
servo brackets	$11.95	2	$23.90
microcontroller	$47.95	2	$95.90
Airbrake Subtotal	**$440.77**		

Recovery Mounting

Estimates for various subsystems that make up the recovery system: mounting, parachute, and various instruments			
Drogue Bulkhead	$20.00	2	$40
plexiglass sheet	$50.00	2	$100
Explosive plate	$350.00	1	$350
Main Bulkhead	$40.00	2	$80.00
Ejection Cylinder	$50.00	2	$100.00
Cradle Arms	$20.00	2	$40.00
Parachute Cradle Disc	$30.00	2	$60.00
Metal Framing	$150.00	1	$150
U-bolt	$10.00	4	$40

Quick links	$5.00	4	$20
Machining Tools	$250.00	1	$250
Recovery Mounting Subtotal	$1,230.00		

Recovery Flight

Igniter	$20.00	4	$80
Tender decender	$80.00	3	$240
Swivels	$6.00	3	$18
Rigging	$50.00	5	$250.00
Parachute(main)	$300.00	1	$300.00
Parachute Bag	$30.00	1	$30.00
Drogue	$100.00	1	$100.00
Drogue Bag	$20.00	1	$20.00
Kevlar ropes	$25/250ft	250 ft	$25.00
Recovery Flight Subtotal	$1,063.00		

Recovery Fasteners

3/14 M.D. Bolt	$2.40	30	$72.00
1/6 M.D. Bolt	$2.40	18	$43.00
3/14 Nut	$2.40	30	$72.00
1/6 Nut	$2.40	18	$43.00
3/14 Washer	$1.20	30	$36.00
1/6 Washer	$1.20	18	$21.00
Flair Sleeving	$5.18	12	$62.00

Flair Nut	$2.10	12	$25.20
Screws	$3.00	12	$36.14
Alignment Pins	$2.50	5	$12.50
Fasteners Subtotal	$422.84		

Recovery Electronics

Altimeter & accelerometer	$107.69	2	$215.38
GPS/Rocket locator	$346.15	2	$692.30
stage controler	$150.00	2	$300.00
Batteries	$50.00	2	$100.00
Electronics mounting	$100.00	2	$200.00
Electronics Bay sheilding	$400.00	1	$400.00
Electronics Subtotal	$1,907.68		

Spaceport America Travel Costs

Estimates to travel to ESRA Spaceport America			
Competition Deposit	$200	1	$200
Final Application Cost	$500	1	$500
Attendance Costs	$250	10	$2,500
Lodging Costs	$250	10	$2,500
van rental	$1,923	1	$1,923
truck rental	$1,923	1	$1,923
trailer rental	$1,923	1	$1,923
Spaceport Subtotal	$11,469		

Total Project Cost	$24,054

List of Decided Parts

DragonPlate Braided Carbon Fiber Round Tubing ~6" ID x 48" [11]
Fiberglass 6" Filament Wound Metal Tip 5.5:1 Von Karman Nosecone [2]
Aerotech RMS-98/10240 Casing [12]
Aerotech 98mm Forward Closure [13]
Aerotech 98mm Aft Closure [14]

Funding Sources

Klamath Falls Catalyze	$5,000
Peter Barrett	$500
NASA Oregon Spacegrant Committee	$9,300
Total Matching Funding	**$14,800**

*OTRA will apply to RBC to seek remaining funding, and will also look into receiving manufacturer discounts.

Timeline

Fall 2018	October	November	December
	·Airframe design iteration No. 1 ·Engine selection and engine mount design ·Apply to Oregon Space Grant Consortium	·Airframe design iteration No. 2 ·Research electronics ·Complete senior project reports	·Airframe design iteration No. 3 ·Finalize airframe & recovery design ·Complete manufacturing plans ·Finalize electronics setup ·Submit entry into Spaceport America (Dec 10)
Winter 2019	**January**	**February**	**March**
	·Purchase Materials for Rocket Construction ·Begin Manufacturing ·Apply to Oregon Tech RBC funding (Jan 17) ·Project Update 1 for Spaceport (Jan 25)	·Continue Purchasing Necessary Materials ·Materials Testing ·Continue Manufacturing Rocket Entry Deposit for Spaceport Due (Feb 15)	·Complete Rocket Manufacturing ·Prepare Rocket For Live Tests ·Project Update 2 for Spaceport (Mar 8) Deadline for Spaceport Fees (Mar 29)

Spring 2019	April	May	June
	·Test Completed Rocket at Brothers (April 19-21) ·Make Necessary Adjustments to Rocket	·Second Chance to Test at Brothers (May 17-19) ·Project Update 3, Report and Session Materials Due for Spaceport (May 17) ·Finalize Rocket for Competition	·Complete senior project ·Launch Rocket at Spaceport America Cup (June 17-22) ·Final Report for NASA OSGC (July 30) ·NASA OSGC Symposium (Nov 14-15)

Teammates and roles

Daniel Quon	Chief Engineer, Structures/Engine Mount Analytics
Jack Markee	Airframe Team Lead, Airbrake Design, Manufacturing Lead
William Thode	Recovery Team Lead, Recovery Design
Keaton Webb	Structures Lead and Design
Christopher Anderson	Fin Design and Analytics, point of contact with NAR and Tripoli Level 3 certification
Marco Belluta	Airframe Team, Nosecone design
Hunter Jones	Airframe Team, Airbrakes and Body Design
Anthony Ramos	Recovery Team, Safety Officer
Ethan Van Gent	Structures/Engine Mount Teammate

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Appendix

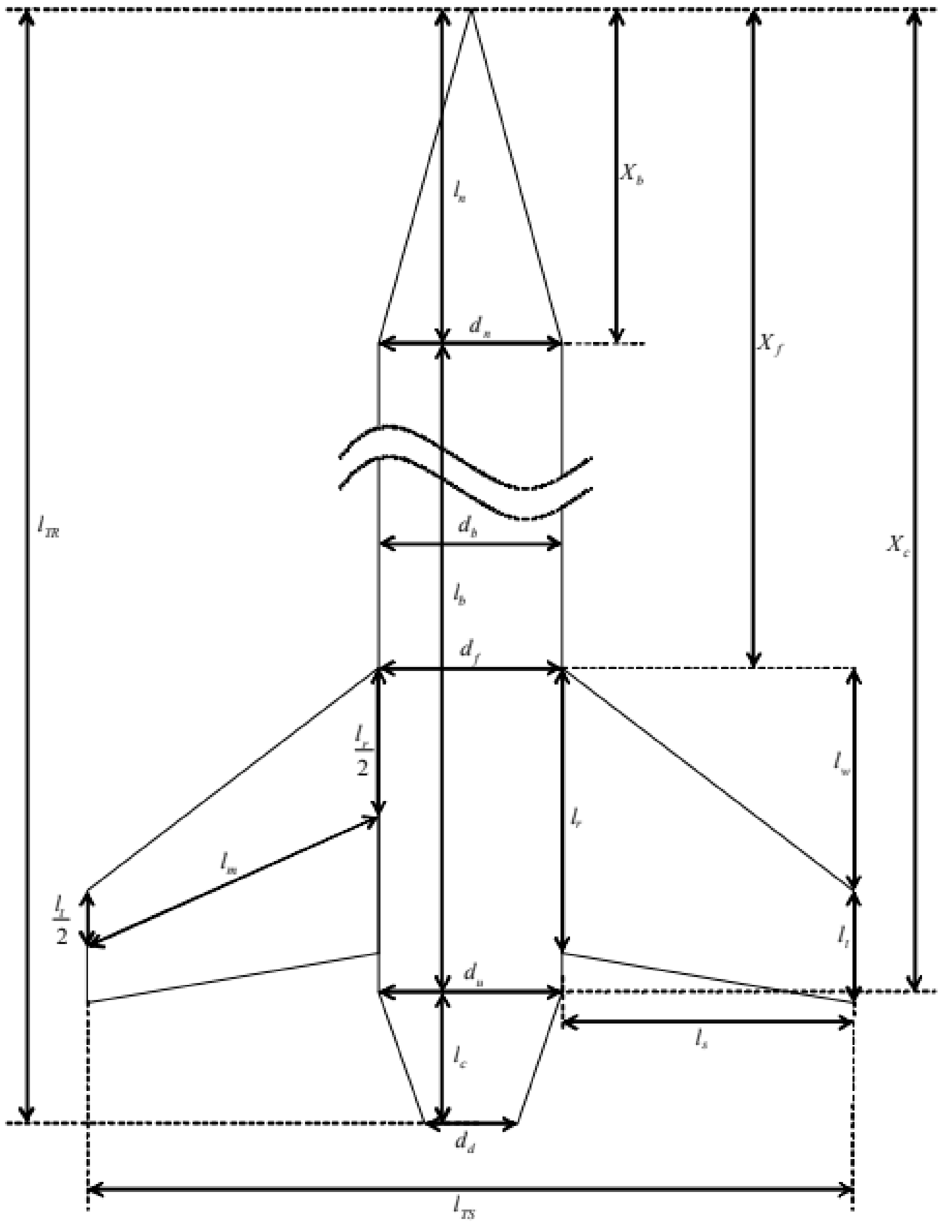
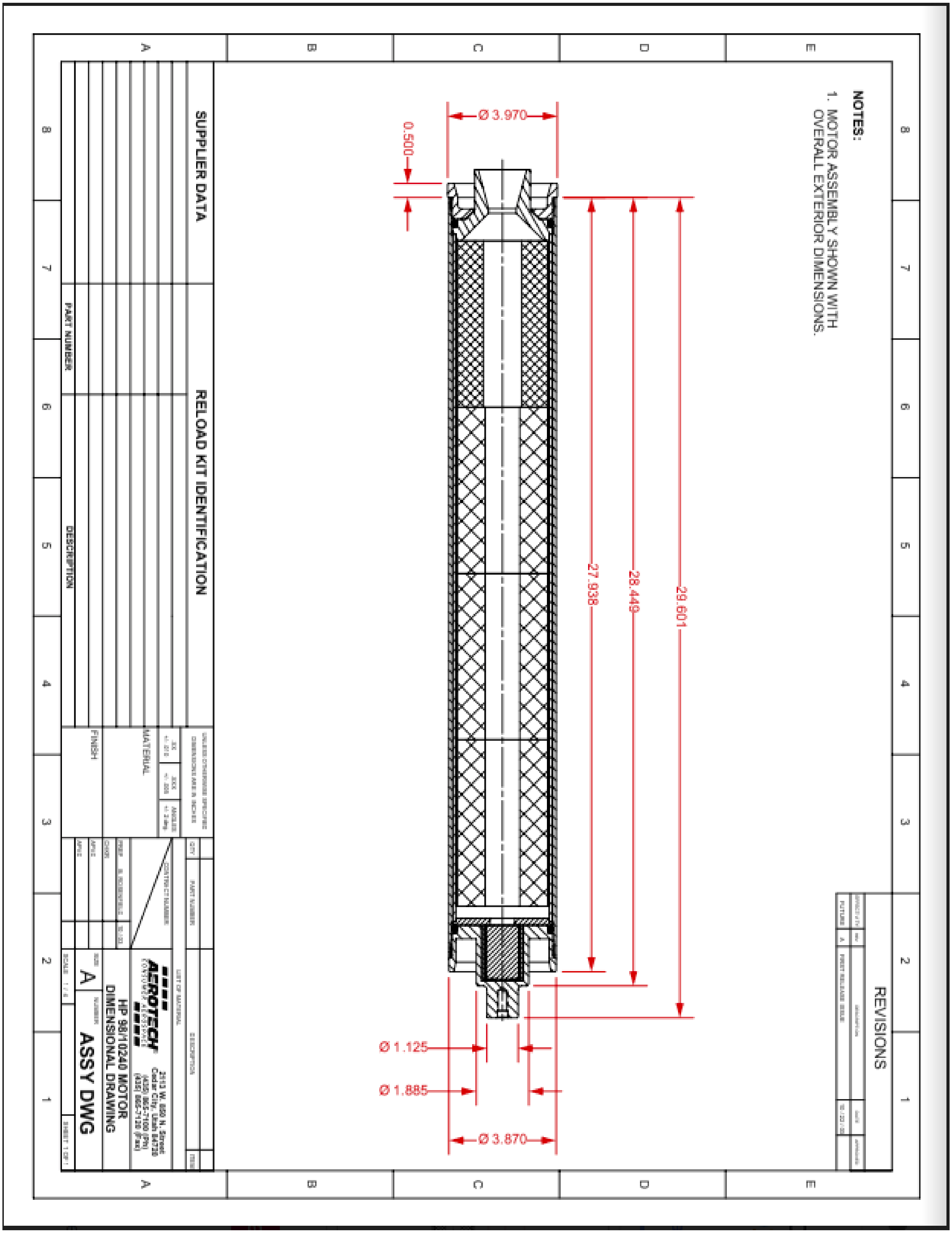


Figure 3: Schematic of a simple rocket with showing the principle dimensions


NOTES:
1. MOTOR ASSEMBLY SHOWN WITH OVERALL EXTERIOR DIMENSIONS.
REVISIONS
FIRST RELEASE ISSUE
Ø 3.970
0.500
27.938
28.449
29.601
Ø 1.125
Ø 1.885
Ø 3.870
SUPPLIER DATA
RELOAD KIT IDENTIFICATION
PART NUMBER
DESCRIPTION
MATERIAL
FINISH
AEROTECH
2513 W. 850 N. Street
Cedar City, Utah 84720
HP 98/10240 MOTOR
DIMENSIONAL DRAWING
A
ASSY DWG