Design of Rocket Glider Eyjafjallajökull

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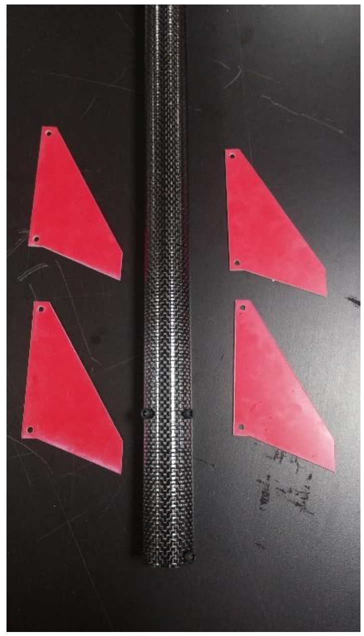
Eyjafjallajökull refers to the name of an Icelandic volcano that erupted spectacularly in 2010, grounding flights across Europe for several days. We thought a volcanic name was proper for our rocket glider because a rocket, after all, is just a volcano turned upside down.

We began the design of our rocket glider by selecting the critical component, the rocket engine. Given that the design guidelines specified we must have a 4 ounce payload, and knowing that the weight of the rocket itself would be around another 4 ounces, we decided to select the engine with the greatest payload capacity. We went with a single engine because it can be difficult to ensure that multiple engines all fire at the same time or when desired, and a single engine is the simplest and most efficient design given the constraints of the project. Therefore, we choose an Estes C11-3 model rocket engine that gave us a 6 ounce total payload. This was below the expected total weight of the rocket and payload, but we had to stay within the restrictions given, and we had to accept that the rocket would be slightly underpowered. The other benefit of the C11-3 is that is has a relatively short delay between the end of the thrust stage and the ejection charge. With a longer delay, there would be the chance that the engine charge would fire after the aircraft was already on a downward trajectory which would not lend itself well to the gliding portion of the flight. We want our transition to take place while the aircraft is either still traveling upwards, or peaking in altitude to allow for the longest possible gliding portion of the flight.

After we had decided upon the engine, we could begin to build the rocket glider. The outside diameter of the engine was 0.95 inches which dictated that we select a body tube with an inner diameter of 1 inch. The discrepancy between the outer diameter of the engine and the inner diameter of the tube was remedied by wrapping the rocket engine with masking tape until it fit snuggly inside the tube. Although cardboard is a popular choice for body tubes in amateur rocketry, we decided that cardboard was not rigid enough for rocket and lacked the aesthetic properties we envisioned for our rocket glider. Therefore, Tyler decided to purchase a 1 inch inner diameter carbon fiber tube to use as the body of our rocket.

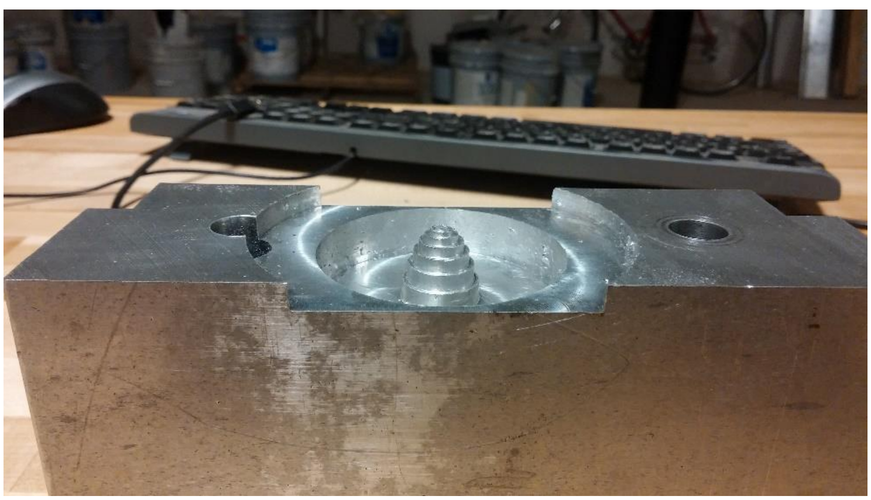
Figure 1: Body Tube (pictured with fins version 2)



Carbon fiber offered several structural advantages over cardboard in addition to the improved aesthetics. Carbon fiber boasts a Young's Modulus of 70 GPa and a shear modulus of 5 GPa. In contrast, cardboard has a Young's Modulus of around 0.6 GPa and a shear modulus of 0.2 GPa. Carbon fiber has a greater flexural rigidity and will be able to withstand any shear forces and bending moments that it is subjected to on the flight. The shear and normal stresses that our rocket glider experiences will be withstood without any issue by the carbon fiber. We expected the greatest stresses to occur during the transition from a rocket to a glider when the engine performs its second charge. This secondary charge could present problems for a cardboard tube, but we do not foresee it being an issue with carbon fiber. Additionally, carbon fiber can be drilled, and therefore, multiple anchor points for the engine, fins, or wings can be inserted into the body. Rather than having to attach components with gule which could fail due to the stresses of flight, we were able to anchor all of our parts with screws that were threaded into the tube itself. The durability of our rocket glider is therefore increased substantially, and even though carbon fiber was partially a visual choice, it is not without its practical benefits.

After the carbon fiber body tube had been selected and cut to a length of 13 inches, we needed to decide how to approach the nose cone. Several ideas were put forth, and Tyler decided to try and make a nose cone out of aluminum. Tyler thought that an aluminum nose cone would make a statement and it really had no practical purpose besides being durable. The plan involved milling a piece of aluminum fixtured to a rotary table and removing material in accordance with a parabolic equation that had been generated based on a trial and error approach. The plan called for also milling out the inside of the nosecone to make it hollow and light enough for flight.

Figure 2: Abandoned Nose Cone Version 1



However, after several hours spent milling the aluminum, it was determined that this approach was taking far too long and the aluminum nose cone was abandoned. The next version of the nose cone was made out of foam. The benefits of a foam nose cone are a quick construction time, a light weight (especially compared to aluminum), and durability. The foam does have poor aerodynamic properties as it is difficult to achieve a smooth surface finish, and the shape was not entirely uniform because the nose cone was constructed by hand. We decided that at the speeds our rocket would be traveling, the aerodynamic drawbacks of the foam would not be significant, and the quick manufacturing time was a benefit. However, after the nose cone had been completed, Tyler wanted it painted white. What we did not foresee was that the paint used chemically reacted with the foam and ate away at it, leaving the nose cone unusable. Consequently, we had to make another iteration of the nose cone. This time plastic (acetal a type of polycrstalline plastic) was the material of choice, and it was milled by hand to produce an acceptable shape. The plastic, when hollowed out, has a similar weight to the foam, and is much more streamlined because of its uniform shape and smooth surface finish. Additionally, the plastic is also durable and basically combines the positive characteristics of the aluminum and foam into a single material. The nose cone was machined to a wall thickness of ⅛" to allow for maxmium weight reduction will retaining rigidity and structural rigidity. The ending nosecone fit smoothly into the body tube and should demonstrate uniform flight characteristics.

Figure 3: Nose Cone Version 2

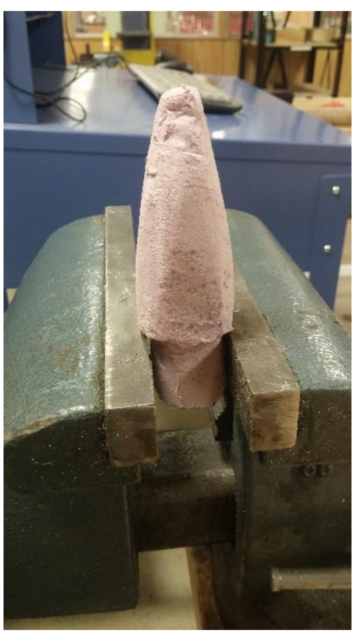


Figure 4: Nose Cone Version 4

The next phase of the build was fins. We determined early on in the design process that we wanted to make our fins out of a material that could be laser cut. Acrylic is rigid and durable, and relatively light so we choose to make the fins out of a sheet of acrylic. The basic shape of the fins was created in CorelDraw based mostly on existing fin designs. However, much like the nosecone, the first iteration of the fins was a failure. The holes we had drilled in the body tube of the rocket did not match up with the holes in the fins and the four fins total weighed 2.4 ounces. Adding this weight to the required payload already put us over the maximum lifting weight of the rocket engine. Therefore, a second version of the fins was needed. This time, a thinner acrylic was chosen, and the fins were made slightly smaller to reduce weight. We ensured that the holes in the fins were correctly spaced, and cut them out of a sheet of acrylic on the laser printer. Our fins were designed to be attached to the body tube by screws and thus were tangent to the body of the rocket glider. While this may seem unusual, and is not seen in any real-world rockets, this design should be acceptable and should allow for the stability that is necessary for a quality flight. Fins on a rocket mean that the center of pressure is lower than the center of mass, which reduces the pitch and the yaw of the rocket. The center of pressure is important because that is the point through which the lift and drag forces act. If the rocket begins to pitch or yaw, this will affect the maximum altitude the rocket can reach and will not result in the best performance. Having the center of pressure and center of mass as low as possible was our goal with the design of the fins and the payload.

Figure 5: Fins Version 1 (with Rocket Body)

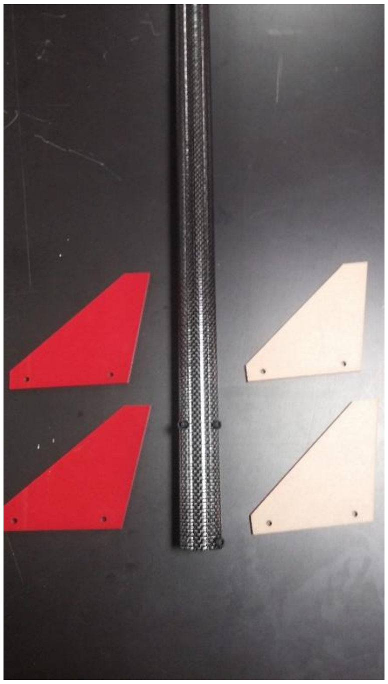
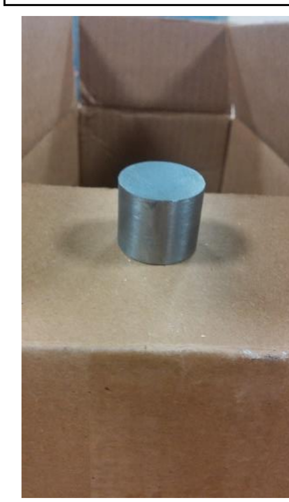


Figure 6: Fins Version 2

The payload itself was a piece of 1” diameter steel machined to the correct length and therefore mass. We decided to place our payload directly above the rocket engine to ensure that the center of mass was as low as possible. We choose this location to give the rocket the greatest stability in flight meaning that it would have a smaller tendency to pitch and yaw as it ascended.

Figure 7: Payload



Once the payload had been machined to size, we needed to decide on a wing design. The wing needed to be a balance of a large surface area, to give us a greater lifting force, and as light as possible. We decided to manufacture our wing out of the same material, acrylic, as the wings. This material is somewhat denser, and therefore heavier for the same area, as balsa, but it is more rigid, which was slowly coming to be the theme of our rocket. Initially, we had planned to screw the wings onto the body, much as we had with the fins, but Will decided that a better approach was to have a single wing. Tyler had the idea to cut a slot through the carbon fiber on the mill so that the wing could be a single piece and would be held in place by the body of the rocket itself. The wing was laser cut on the laser printer, slotted through the body tube, and secured in place with a plastic zip tie. We think that our wing size should offer a solid combination of light weight, rigidity, and surface area to allow for a sustained gliding flight. It was placed a little more than halfway up the body of the rocket glider to allow for the best flight characteristics.

Figure 8: Wing

Once the wing had been completed, we now had all the parts of the rocket glider necessary for construction. However, we still needed to decide on a configuration change. We knew that we wanted the center of mass to move forward (towards the nose) of the aircraft to allow for a better gliding portion of the journey. If the center of mass remained in the rear of the aircraft, the rocket would have a tendency to fall bottom first on the descent rather than glide. By moving the center of mass forward during the configuration change, the nose of the rocket glider should shift forward and the wing will be able to produce lift and keep the glider aloft rather than merely fall to the ground. In order to move the center of mass forward, we thought that we should eject the rocket out of the rear of the rocket. This would be accomplished by the ejection charge. If the rocket is secured on the top end by a solid body and the back end is free, the ejection charge should push it out of the rocket. However, engine removal would not be enough to move the center of mass forward significantly because the mass of the empty rocket casing is only 0.7 ounces, which is small compared to the overall mass of the flight vehicle (at 9.6 ounces). To move the center of mass further forward, we allowed the payload to also move forward within the rocket and compress a spring. This should allow the rocket engine to leave the rocket while the payload will slide forward. The configuration change is essentially a change in the mass distribution of the rocket glider and should allow for better gliding. The goal was to have the center of mass as low as possible during the ascent and rocket portion of the flight and have the center of mass transition as far forward as possible during the descent and glider portion of the trip.

Construction of the rocket glider itself was fairly straightforward once all of the components had been completed. The nose cone simply slotted into the top and was not glued in place because we did not foresee the ejection charge being powerful enough to move the payload forward and blow the nose out of the top of the rocket. The wing was then slotted through the body and secured in place with a zip tie. The portion of the wing passing through the body served to hold the spring in place. The spring was inserted from the bottom, and then the payload was inserted after the spring. The spring had to be compressed a small amount against the wing in order to ensure the proper location for the payload. The engine, wrapped in masking tape to create a tight fit against the body tube, (but not too tight to prevent ejection) was then placed inside the body through the bottom of the tube. The rocket engine was prevented from moving forward both by the combination of the spring and the payload and by the upper screws used to hold the fins in place. The fins were screwed at both the top and bottom with the screws threaded into the body tube. We made sure to select shorter screws for the bottom end of the fins so that they would not protrude through the body tube and block the exit of the engine from the tube when it came time for the change in configuration. The picture below shows the components of the rocket and their relative placement within or on the body tube.

Figure 9: Rocket Stack

After the fins had been screwed in place and spring, payload, and rocket engine had been added into the tube, it was time to add the last necessary element for launch, the guide tube. Although the launch platform boasted two guide rods, we decided to have our rocket rely on a single guide tube. This would reduce the friction between the guide tube and the guide rods and would mean that we did not have to worry about precisely placing two guide tubes on the body. This choice simplified the design and should also allow for better performance during the initial moments after ignition. The guide tube was chosen to be a plastic straw because it was light and yet rigid enough to guide the rocket off the launch pad.

When our rocket had been completely assembled, we weighed it because we were curious to see how far overboard we had gone. The final weight of the rocket was 9.6 ounces, 160% of the max lifting weight of the rocket engine. Even if we did not have a payload, we still would be right on the boundary of an acceptable weight. We expect that our rocket glider will leave the ground, but it will not ascend to impressive heights. Part of the problem was that we overengineered the entire project. Will's approach was to use the quickest and lightest method available, but Tyler insisted on going beyond what was required in terms of strength, and that ultimately meant that the weight reached an undesirable number. We could have gotten away with using lighter components that would probably have withstood the stresses associated with a C class rocket launch, but we went beyond the necessary minimums and created a rocket glider that has a high factor of safety, but not a high maximum altitude. Over the course of this project, we read several NASA documents on the design of rockets and were surprised to read that the ideal ratio of propellant to the total mass of a rocket is 0.91. The payload to total mass ratio is 0.06 meaning that the last 0.03 or 3% of the total weight of the flight vehicle is the actual components of the rocket (such as fins, body, and capsule). While this may be for vehicles intending to reach orbit, it is clear the weak point in our rocket glider is the meager amount of propellant in the rocket engine. Our rocket glider does not approach these ideal ratios, but, this is only the beginning of our aerostructures-driven passion for aircraft design.

Figure 10: Eyjafjallajökull