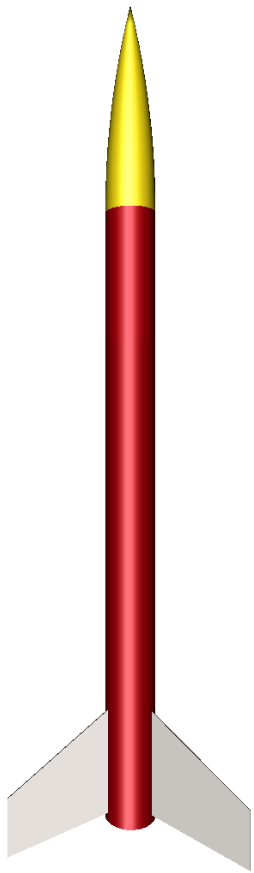
Wisconsin Space Grant Consortium Regional Competition:



Ad Astra
(To the Stars)

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Introduction:

In early February 2013, a meeting was held at the University of Minnesota for all who were interested in joining a team that would be competing in a regional competition hosted by Wisconsin Space Grant Consortium at the end of April. The meeting was hosted by the Associate Director of the Minnesota Space Grant Consortium, Dr. James Flaten, and the details of the regional competition were thoroughly discussed. The competition goal was to build and fly a rocket that had a maximum body diameter of 4”, a maximum length of 72” and a maximum weight of 120 ounces. The rocket was to use a Cesaroni I540 motor with the motor eject in place. Following that meeting, the people that wanted to join the team began discussing a design. For the next month, there was serious focus on the design, and after that several weeks were spent procuring parts and building the rocket. Now, in early April, construction is beginning to wrap up, and the team, now called Ad Astra, is preparing for the competition.

Rocket Design:

From early February, the design was focused in three major efforts. First, a drag team worked to design and build a drag device that would be able to slow the rocket and shave several hundred feet off of the projected apogee. They spent several weeks debating how to best do this, and in the end settled on a design that would use airbrakes that would deploy and remain open for the remainder of the flight. An avionics team then worked to coordinate the proper sensors and computers to deploy the airbrakes at the correct time, as well as to ensure proper deployment of a parachute for recovery of the rocket. Finally, an airframe team worked to design the rocket itself, which serves as a housing for all of the other subsystems. From the beginning, it was clear that the rocket would need to be quite large in order to contain all of the other parts, and as such a 4” diameter rocket was quickly settled upon. From there, several other design constraints were taken into consideration.

Work centered on the use of RockSim to design the rocket and simulate rocket flights. First, the fact that the motor eject could not be removed from the rocket meant that it had to be used, or at least vented, into the central area of the rocket containing the parachute and other ejection charges. As a result, a decision was made to split the rocket into two lower sections, with one housing the motor mount tube, fins, and eyebolt for the end of the shock cord. The second part of the bottom, which will be riveted on for the flight, contains the airbrakes. The airbrakes are designed to fit and work around the motor mount tube, which although anchored in the very bottom part of the rocket, goes past the airbrakes as a way of venting the motor eject into the cavity above. This upper area of the middle section, which is sealed off from the airbrakes by a centering ring, has the parachute and other ejection charges. The avionics bay serves as a coupler between this middle section and the top of the rocket, which contains the altimeters, flight computers, sensors, and a GPS dog-collar. Once all of these items could be accommodated, the length of the rocket was set, and from here other design items, such as fin size, were taken into consideration in order to establish a safe static margin. In addition, the length of the rocket and size of the fins were adjusted so that the rocket would easily clear 3000 feet, thus ensuring that deployment of the airbrakes would be necessary.

Several other things were taken into consideration early. First off, 1010 rail buttons were chosen as the rail guide. Members of the team had worked with these before, and as such they were a known commodity. Things were slightly complicated by the fact that they needed to be mounted off of the rocket body in order to accommodate the airbrakes, but this was not a difficult process. The screws were replaced by longer screws that went through the stand-off blocks and into blocks on the inside of the rocket. It was also decided that rivets would be used to secure the middle and bottom sections, as well as the avionics bay and the top body section. In all of these cases, three rivets were used. In addition, the avionics bay was secured to the middle of the airframe by three number two shear pins. This will prevent drag separation, which is critical, since the use of airbrakes will highly increase the odds of a drag separation if the parts are not joined using shear pins. Static vent hole sizes were then discussed. It was decided to vent all of the sections of the rocket, and as such a venting hole that was 0.25” in diameter was drilled in the lower body, the upper body tube, and into the avionics bay. As a final step, it was decided to use a HAMR mount as a motor retention device.

From here, the design process moved into materials. Due to the fact that time was a primary concern, manufactured materials were chosen for use whenever possible. This led to the fins, body tube, nose cone, centering rings, avionics bay, and numerous other parts being ordered off the shelf and then slightly modified if necessary. For other parts, most notably the airbrake system, there were no commercial options available, and as such the airbrakes and much of the internal parts supporting them were 3D printed using printers owned by the University of Minnesota. Once these decisions had been made, the design was effectively complete, however certain factors, such as the length of the central body tube, were left vague enough that they could be changed if necessary to accommodate alterations to the recovery system or the airbrakes. However, this did not prove to be a problem, and as such, the construction has proceeded identical to the design.

Aerodynamics:

The rocket was designed from the start to exceed 3000 feet in almost any flight condition. As such, the nosecone is a PML-3.9” Ogive plastic nose cone. The rocket uses a 48” Quantum Tube body as the airframe. This is cut into three sections, with the top section, acting as a coupler between the nose cone and avionics bay, being 10.5” long. The avionics bay which attaches the two sections is 7.5” long, and the middle section of the rocket is 24” long. The lower section of the rocket is 13.5” long, and it houses three identical PML Fin-D-08 Prism Fins, a precut fin design that is 0.093” wide and features a square edge. The rocket will be finished with a single coat of primer and then a coat of spray paint, which will give it a matte finish that is not extraordinarily smooth, but still known to fly well. Before painting, the rocket will be thoroughly sanded with 120 grit sandpaper to ensure the primer and paint adhere well.

Avionics:

We are using the Raven 3 altimeter by Featherweight to record the data for our flight. The Raven was chosen because it was a known factor that we had used in past projects and it was straightforward to use. In addition, we are also using the Featherweight Interface Program (FIP) to display all of the Raven’s recorded data, check the altimeter’s functions, and configure its outputs. This software is also readily available on Simon Shuster’s laptop, which will be brought to the launch site and will be used download the altimeter data after the flight.

The parachute will be deployed using ejection charges controlled by the Raven 3 altimeter. To sense when the rocket is at apogee, the raven considers multiple factors. One of the main factors is pressure. As altitude increases, pressure decreases. Thus, when the altimeter detects a pressure increase, one of the conditions for apogee is met. However, if the avionics bay is not vented correctly, this pressure increase may be detected when the rocket is not descending. To avoid this error, the altimeter also takes the rocket's velocity into consideration. When the velocity becomes negative (with respect to the rocket's initial velocity), the other essential condition for apogee is met.

While these techniques seem perfectly reliable, there is a slight possibility of a misaligned altimeter or a flight trajectory far from vertical. To account for these anomalies, a backup parachute deployment will be used that utilizes the altimeter's timer. Using the software package RockSim, simulations will be run to gauge at what time the rocket should be in the descent phase. Inserting this time into the altimeter provides one last backup measure if the other conditions regarding pressure and velocity are not met. When the altimeter's timer exceeds the preset time value, the parachute will finally be deployed.

To operate the airbrakes, an accelerometer (Sparkfun MPU6050) and microcontroller (Arduino Uno) will be used. The accelerometer was chosen based on its relative low cost and, more importantly, its adaptability to the Arduino interface. Arduino-ready functions were accessible through the Sparkfun website that helped avoid writing programs entirely from scratch. The Arduino Uno was chosen mainly because members of the avionics team had prior experience with it. This type of microcontroller is also one of the most user-friendly, with plenty of function libraries available online.

The MPU6050 sends 6-axis acceleration data to the microcontroller in real time throughout the rocket's flight. In turn, the data will be integrated to determine the velocity of the rocket. With the use of a barometric pressure sensor, there will be enough data to determine the precise velocity of the rocket at a given altitude. Separate sensors are being used for two reasons. Using the microcontroller to integrate velocity once more to calculate position not only bogs down speed necessary for serial transfer, but it also provides a less accurate reading than a barometer. However, in order for the barometer to work properly, the avionics bay needs to be properly vented. This is not an issue, as it is already going to be vented for the Raven. This will ensure that the pressure sensor works properly, and thus we will have two sources of velocity data. There is simply too much variance involved with multiple integrations and dependence on an internal timer for the accelerometer to work alone.

Using the velocity and altitude data, the rocket's apogee will be projected at intervals on the order of milliseconds. Flow control loops will be used to constantly check when the rocket may reach the desired altitude of 3000 feet. Once specific "if" statement will be implemented that calculates the projected apogee if the airbrakes were deployed at that instant. When this condition is calculated to be 3000 feet (within an allowable tolerance) a voltage will be sent by the Arduino to a servo motor that operates the airbrakes.

Airbrakes/Recovery System:

After serious initial thought, it was decided to use airbrakes to achieve the competition goal of 3000 feet of altitude. The airbrakes were designed for a single deployment, and they would then remain open for the remainder of the flight. Although the actual drag induced by the airbrakes is currently unknown, it will be found using wind tunnel tests in the near future. It is expected that the coefficient of drag with the airbrakes deployed will be high enough that the rocket will be able to get within 100 feet of the targeted altitude.

We considered using steel or aluminum for our airbrakes. We examined the densities of both to try to figure out how much our airbrake system would weigh. Then we realized that we would need to learn how to weld to build our brakes. So we then considered the material known as G10 and epoxy. Later we decided to 3D print the more complicated parts of our system. Eventually we decided to 3D print all of the parts and epoxy them together because it was simplest to build. To 3D print the airbrakes we went through an initial design first, and worked our way to a better final design. Our first design was created in SolidWorks, and we went so far as to have it printed. The design was essentially two vertical plates, one of them being curved to be flush against the body of the rocket and with a flat surface coming out at 45 degrees, and the other being flat, straight up and down. After seeing it printed we noticed several things we could improve upon. One problem was that the flat vertical surface didn't sit flush against the body of the rocket, and therefore wasn't very sturdy. The second problem was that the two vertical surfaces weren't long enough. This meant the surfaces didn't fully cover the slots cut into the rocket, and as a result increased drag. The two pieces were connected with CA, which was very weak.

To correct all this we made both of the vertical surface curved to fit the curvature of the rocket's body, with another half inch added onto the width, with a 45 degree plane extending out of each. The curvature of both vertical planes allowed the brakes to be sturdier. The added width covered the slot entirely. Additionally, we created a slot in the inner vertical surface for a magnet to be installed. The best improvement was the two 45 degree planes coming out of both vertical surfaces, because they offered a lot of surface area to be epoxied together. The construction of these two was done so the 45 degree plane coming out of the outer piece would be glued to the bottom of the inner's 45 degree plane. This is so there's no possibility of it catching upon deployment.

Once we came near a finalized product we had to consider what would be the method of deployment. We quickly realized that deploying the airbrakes would not be difficult; the challenge would lie in keeping them from deploying too early. This comes from the initial acceleration of the rocket wanted to push the brakes out, and also from the skin friction of the body. At first we considered magnets to keep them in place; however, we threw that idea out, since we would not be able to release them. Then we thought of using strings, and having them cut once we reached a certain altitude. We figured this was a simple and efficient way to keep the airbrakes up. Our final design consisted of all of our previous thoughts, plus a few more.

We decided to use a string to hold the airbrakes up until deployment. To help pull the airbrakes down we attached springs to the top of them and below the slots. To hold the brakes in place once deployed, we placed magnets on the inside body of the rocket and on the airbrakes. The brakes are designed so the majority of the deployment is cause by the wind resistance. Unlike our initial thoughts though, we decided against cutting the string. Our actuator is a small electric motor which causes the rotation of three arms. To best utilize this, we looped the string around one of the arms, and then down to the airbrakes. Once the actuator receives a signal, the arms will rotate and allow the string to become slack. After that, the springs pull the brakes downward with the help of the wind resistance. Finally, the brakes are locked into place by their design and the magnets.

The recovery system relies heavily on the avionics systems packaged above it. As mentioned before, the Raven 3 will be used to set off two different ejection charges, both of which will be placed at the bottom of the cavity containing the parachute. Each charge will be approximately 1.56 g of FFFF black powder. The first will be triggered when the altimeter detects that the rocket has reached apogee and has begun to fall. The second, as a failsafe, will be triggered a second after the rocket will have reached apogee, or about 15 seconds into the flight. In addition, the motor eject also vents into this cavity, and although the 1.3 g charge used for the motor eject appears insufficient to separate the rocket sections, it can definitely contribute to the other explosions if it goes off at the same time. Following the explosion, a parachute protector which covers the parachute will be forced up and into the avionics bay. The force of the explosion should be sufficient to then sever the shear pins holding the components together, and from this the rocket should separate and the 54" diameter parachute should deploy. This parachute is attached via a series of slipknots to a 30' tubular nylon shock cord, which should be long enough that zippering should not be a problem. Furthermore, the shock chord will be secured to a U-Bolt in the avionics bay and a forged eyebolt at the middle centering ring using a quick link, so it is more likely that the cord will snap before the connections do. Once the parachute has been deployed, the rocket should descend at a speed of around 21.5 ft/s, which is somewhat fast, but should still be safe. Once the rocket has landed, it will be located using a Garmin GPS dog collar system.

Construction:

The construction process initially proceeded relatively slowly, as parts did not begin arriving until mid-to late March. However, once it began, things progressed rapidly, and the rocket has come together in the course of a little more than two weeks. The main project was divided on lines similar to the teams, with the airframe team doing most of the airframe construction, the avionics team focusing on wiring and electronics, and the drag team working to build and install the airbrakes and its internal systems. For the majority of airframe construction, three types of epoxy were used. The first was DB 420 NS, which is made by 3M. It was primarily used on the fins, as the tips could be used to apply the epoxy quite accurately, and it fillets well. It was also used on other exterior parts, including the rail button extenders. DP 100, another 3M epoxy was used for the airbrake assembly, as it was ideal for quickly securing the two halves of each airbrake together. These parts could not be easily clamped, so the five minute set time worked well. Everything else was secured using West System epoxy, where 105 resin was mixed with equal parts 205 hardener and 406 filler to provide an epoxy that dried slowly but proves to be extremely strong. In terms of hardware, parts were chosen that would be as strong as possible. In the lower body, a forged eyebolt serves as the connection point for the bottom of the shock cord, and it attaches to a U-Bolt which is screwed into the avionics bay. Most of the internal parts are prefabricated wood or 3D printed, and these were all epoxied into place using West System epoxy or DB 420. Several parts, such as the actuator and GPS dog collar are intended to be removable post-flight, but these parts are then screwed into parts that are epoxied into the rocket. Once all exterior construction was complete, the body was sanded and prepared for painting, and the body will be primed and finally painted in a maroon and gold paint scheme.

Safety:

Considerations for safety were made throughout the design and construction process, and experts were consulted frequently for their advice. Our primary safety advice came from our team advisor, Dr. James Flaten, as well as Gary Stroick, who is the vice-president of the local Tripoli club and a certified Level III flyer. His experience was invaluable in all aspects of the design, and his frequent tips served to improve the rocket at all levels. His insistence on things like forged eyebolts, downward facing battery connectors, and redundant ejection charges helped to greatly increase redundancy and strength throughout the rocket. Construction proceeded in a lab with several other rocket teams, many of which had significantly more experience than this one. As such, consultations with them often proved valuable in solving minor problems and making good decisions about construction techniques. Throughout the construction progress, measures were taken to ensure everyone remained safe, this included the wearing of masks and gloves when mixing and using epoxy, the use of eye protection when things were being cut, and the use of facial protection when a dremel was used. The primary ground tests involve ejection charge size, and these were conducted in a sandy pit that was outside in order to prevent fires. Other tests, including wind tunnel testing and airbrake tests were straightforward and required little in the way of safety measures.

Once launch day arrives, a number of things will be done to ensure safety. First, a launch checklist, maintained by the team lead, will be used to ensure that everything is done in a proper order. Second, all electrical systems will be tested for continuity on the ground, but only armed after the rocket is sitting vertically on the launch pad. All quantities of explosives, including ejection charges and the motor, will be handled extremely carefully. There will be significant emphasis on proper packing of the parachute and shock cord as well, and this should ensure that the recovery system functions properly. The rocket will have a final inspection by Gary before we leave, and it will also be inspected a final time by the team before we present it to the RSO. By implementing all of these procedures, a safe launch should occur, and the rocket should also land safely.

Flight Characteristics:

Current flight characteristics are based entirely on RockSim predictions. Further information will be gathered through wind tunnel tests, but the RockSim values should be extremely close to the actual ones. The only major difference between the RockSim file and the actual rocket is the presence of the airbrakes in terms of drag, but this should not be a major factor when it comes to initial launch conditions. Without a motor or airbrakes, the static margin of the rocket is 3.74, which is overstable. When the rocket is sitting on the pad, the center of pressure is expected to be 54.7” from the tip of the nose, and the center of gravity will be at 43.1” from the nose. This gives a static margin of 2.9, which is extremely stable. Once the motor is lit, the rocket will accelerate around 20 gs and reach a velocity of 59.95 ft/s at the end of a 36” launch rail. It should clear this rail within 0.116 seconds. Without airbrake deployment, the total time to an apogee around 3250 feet is 13.2 seconds in ideal weather conditions. This means that the Cesaroni I540 motor will burn for 1.18 seconds, so the rocket would coast for about 12 seconds. After the parachute deploys, the rocket will drift for nearly 13 minutes. How far it lands will depend on the wind conditions, but in a light 5 mile/hour wind, the rocket is predicted to drift around 200 feet. This distance will increase greatly as wind speeds increase, but a GPS tracker on the rocket will assist in locating it after it lands.

Simulations:

Simulations were conducted using RockSim. As such, the effect of the airbrakes on drag could not be accurately simulated, but flights without the airbrakes could be accurately simulated. In the next week the team will be able to get into the University of Minnesota wind tunnels to do some quantitative testing, and after this accurate coefficients of drag will be known for the rocket with the airbrakes retracted and deployed. This should greatly increase simulation accuracy and also assist in the programming of the flight computers. Solid Works was used to design all of the 3D printed parts, including the airbrakes.

Launch Check-Off List:

The following is the launch check off list. It will be used on launch day to ensure the rocket is properly prepared for launch and that all systems are safe.

1. Prepare Airbrake System:
    a. Run a final test of the airbrakes and reset system
    b. Tighten string/motor assembly
    c. Check continuity in the motor
    d. Assemble bottom and middle sections. Rivet both parts together.
2. Prepare electronics:
    a. Check each battery for proper voltage
    b. Install batteries in battery clips
    c. Install sled in avionics bay
    d. Connect all wires
    e. Install avionics bay in the rocket. Rivet to upper body
3. Prepare recovery systems
    a. Measure out 2 ejection charges
    b. Wire up E-match to ejection charges
    c. Place charges in the airframe
    d. Attach E-match leads to wires from the avionics bay
4. Prepare the parachute/shock cord
    a. Untangle and straighten the shock cord
    b. Attach quick-link to the bottom
    c. Attach bottom quick-link to eyebolt in the bottom of the rocket
    d. Run shock cord up motor mount tube. Attach zip-ties around the cord and motor
    e. Feed shock cord through top centering ring
    f. Attach upper quick-link
    g. Attach upper part of the shock cord to the avionics bay
    h. Fold the parachute
    i. Attach parachute and parachute protector to slipknot in the shock cord
    j. Coil up excess shock cord. Wrap in painter’s tape
    k. Pack parachute, parachute protector, and shock cord into the rocket.
5. Motor assembly.
    a. Install motor reload into the motor casing
    b. Install motor casing into the motor mount tube
    c. Tighten HAMR mount
6. Final Assembly
    a. Attach the avionics bay to the middle section of the rocket using three shear pins
    b. Double check everything

   c. Report to RSO to fly.
7. At the pad:
   a. Set rocket on the rail
   b. Install the igniter in the rocket
   c. Arm the electronics
   d. Wait to ensure electronics are armed
   e. Clear the range
   f. Launch

Diagrams:

Figure 1: Team Organization

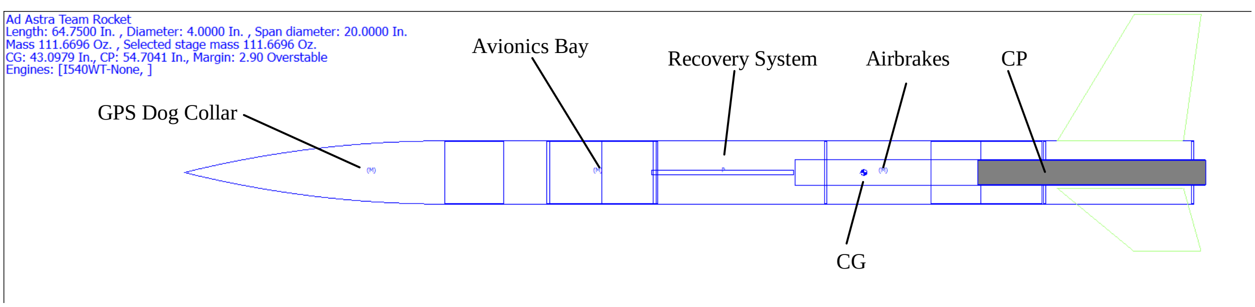

Figure 2: Rocket design with a loaded motor. Various parts are labeled.

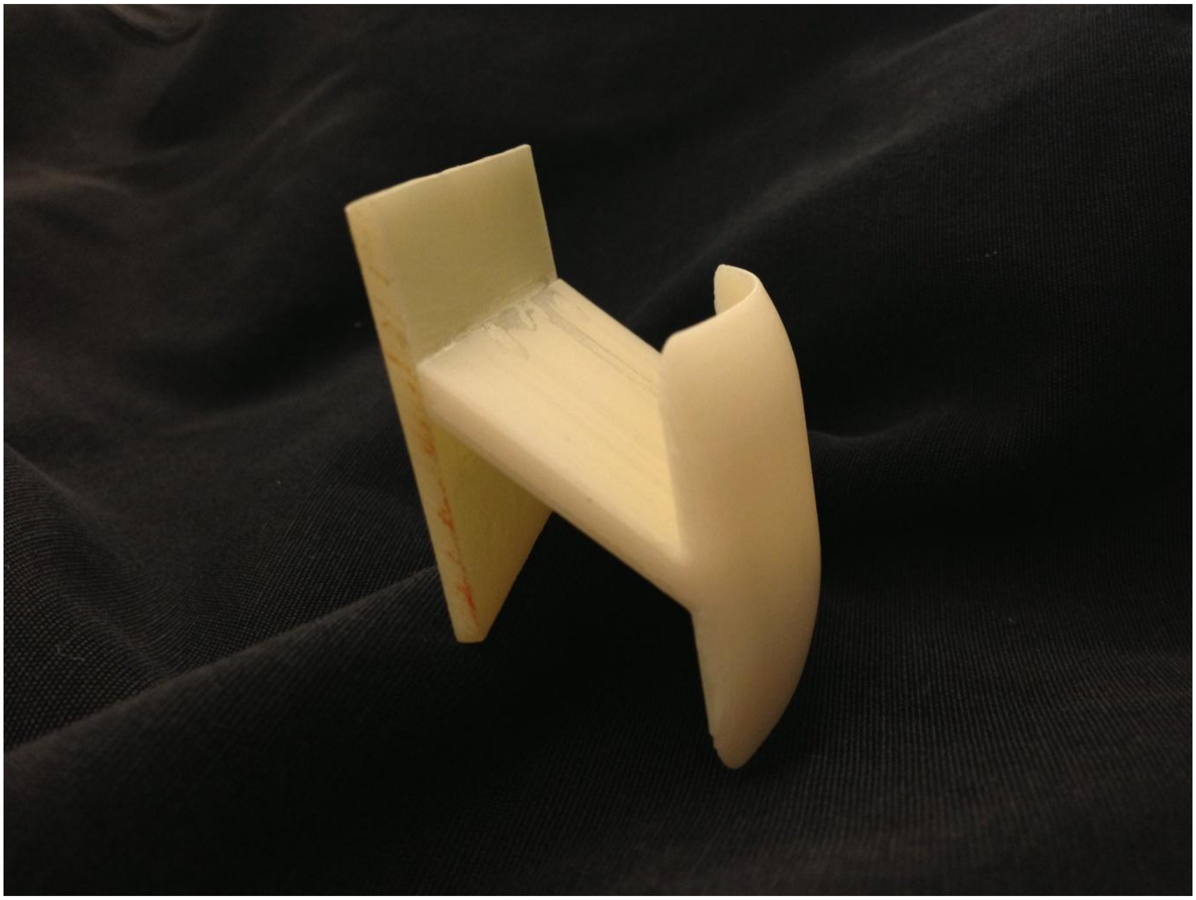

Figure 3: The first airbrake attempt, consisting of a 3D printed front and a G-10 back. After building these, it was realized that the entire airbrake needed to be 3D printed to maximize the amount of the airbrake sticking out of the rocket and also allow for easier assembly in the rocket.

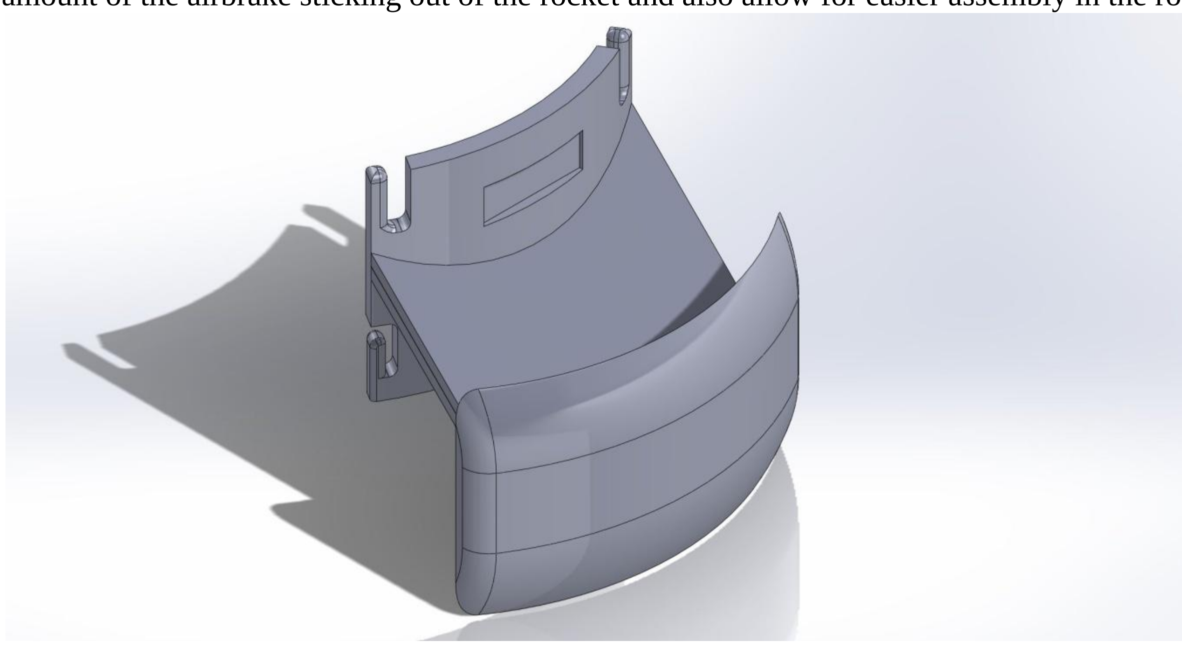

Figure 4: Solid Works CAD drawing of a completed individual airbrake. Note the slots for magnets and knobs on the edge for spring attachment.

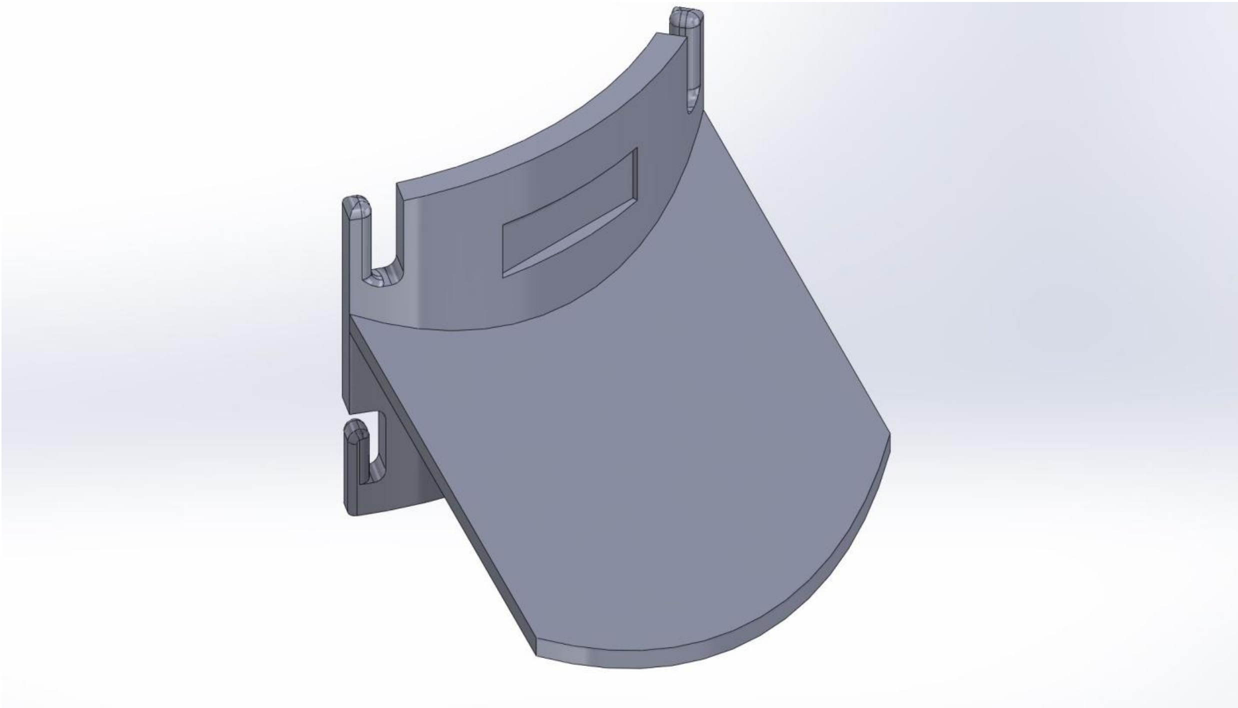

Figure 5: The back half of an airbrake. The main part fits directly into the front part of the airbrake. This makes assembling the airbrakes in the rocket extremely simple.

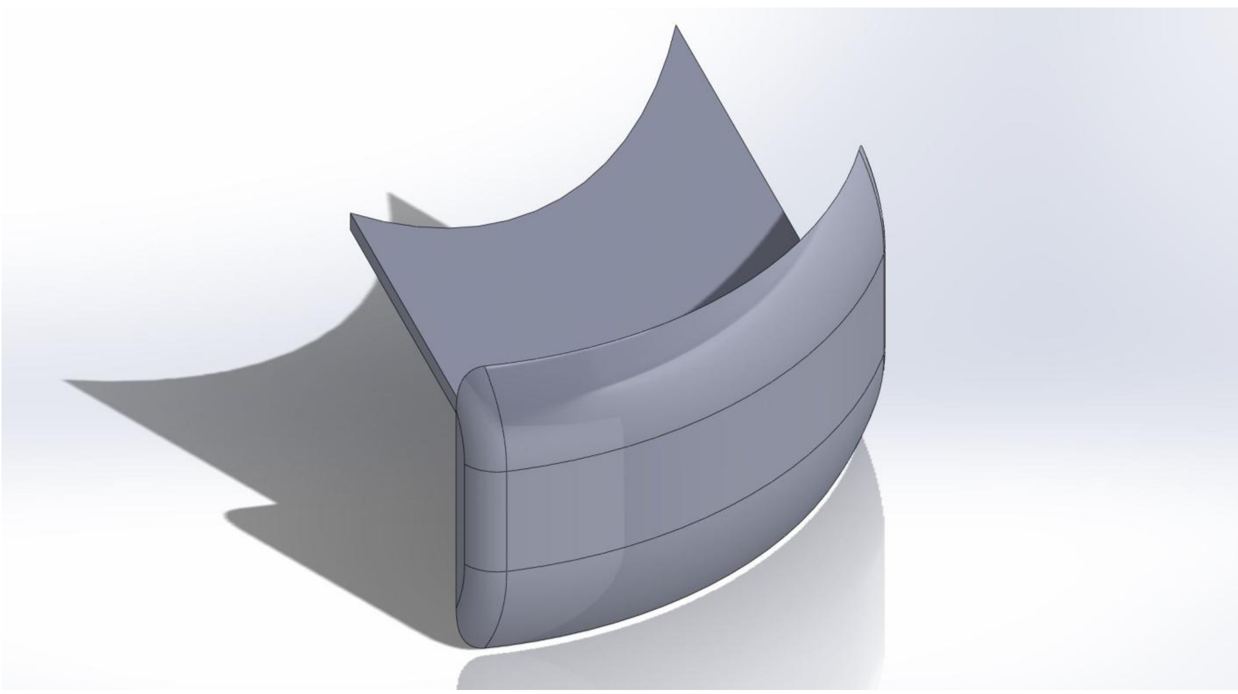

Figure 6: The front part of an airbrake. This fits directly onto the back half of the airbrake, with the main fin surfaces overlapping for gluing.

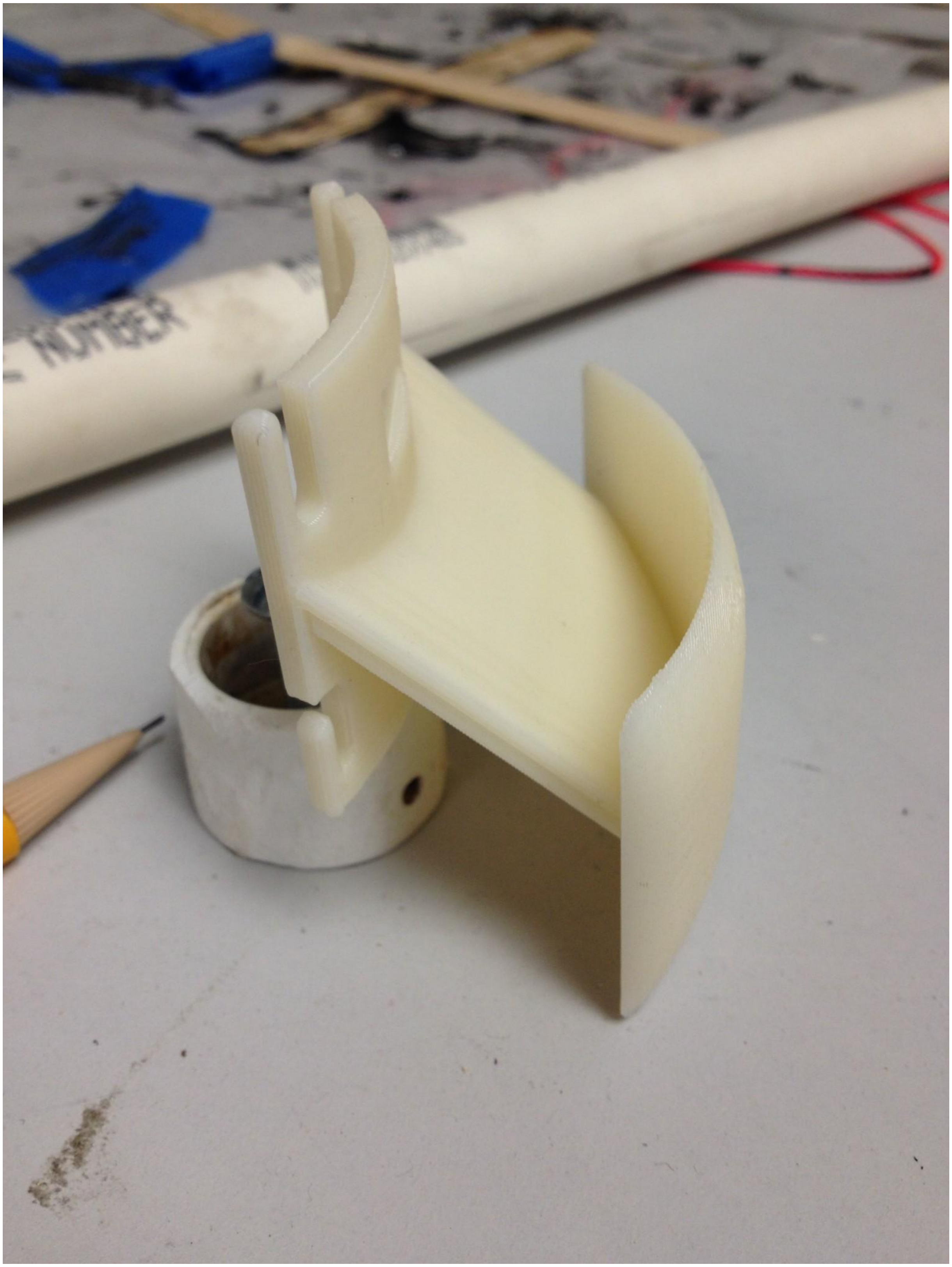

Figure 7: The two halves of the airbrake joined together. This shows what the final 3D printed part looked like and also illustrates how the two halves will fit together.

Figure 8: The completed (but unpainted) rocket body. Note the prism fins, which are reflective, as well as the airbrakes. This picture illustrates the airbrakes as if they are deployed.

Figure 9: The inside of the body tube with fin fillets. This picture clearly shows how we filleted the fins on the inside of the body using DB 420. It is somewhat rough, but it will be strong. The fillets on the outside were sanded significantly to make them smoother and more aerodynamic.

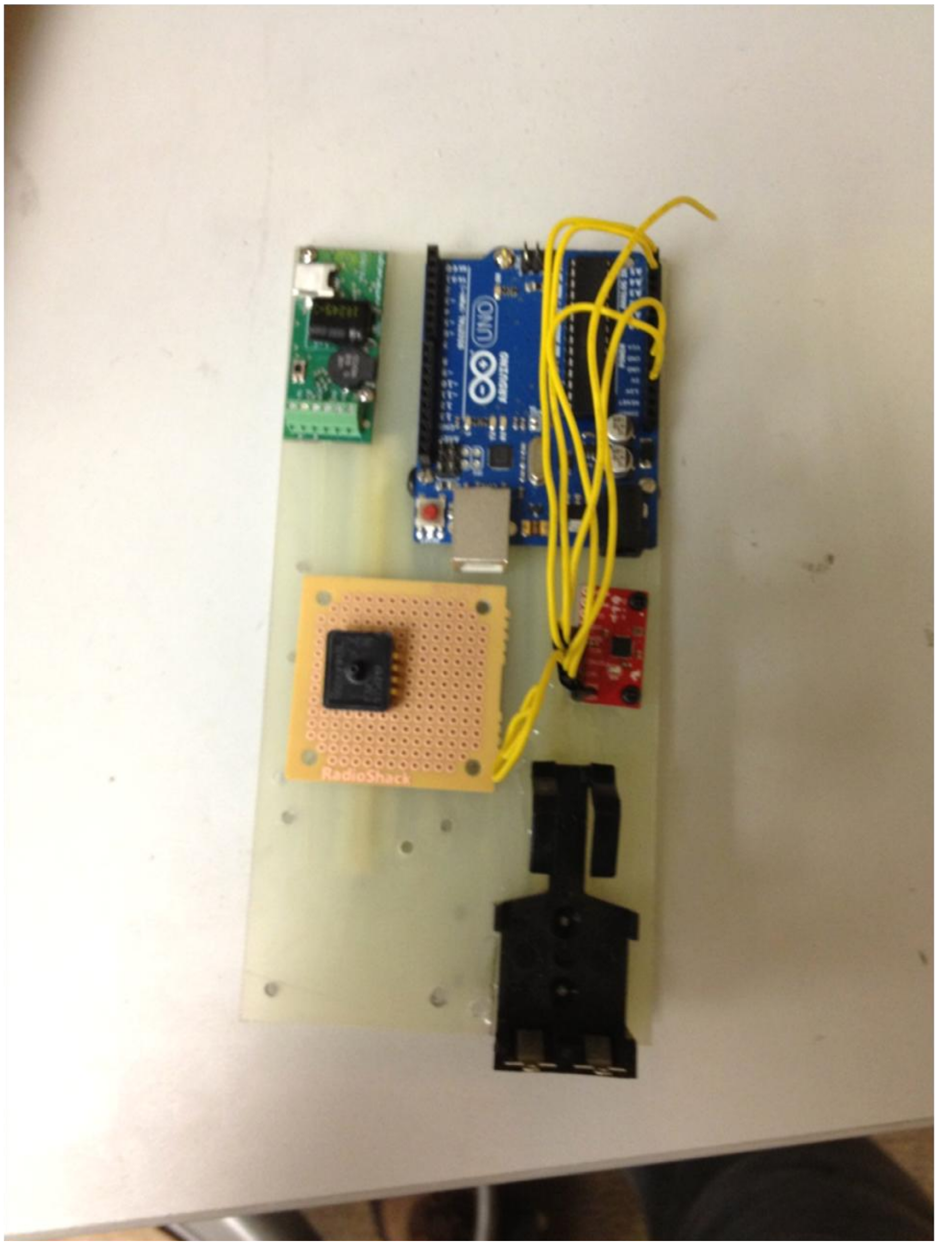

Figure 10: The sled from the avionics bay. This sled shows how our Arduino microprocessor, Raven 3 altimeter, accelerometer, and pressure sensor are mounted. There is additional room at the bottom left to mount a second altimeter for the competition. The sled also had one battery clip on this side, and two others are mounted on the back. All of these systems will control deployment of the airbrakes and the ejection charges in the lower part of the rocket.