Cowboy Rocketworks at 2018 Spaceport America Cup

Team 54 Project Technical Report

Oklahoma State Univeristy AIAA Rocketry Team[1]
Oklahoma State University, Stillwater, OK 74078

Oklahoma State University's AIAA Rocketry Team, Cowboy Rocketworks, is competing in the 2018 Spaceport America Cup in the 10k – COTS – All Propulsion Types category. The launch vehicle, *Results May Vary*, will fly to 10,000 feet AGL with an airbrake unit and camera payload that will be compiled into 360° video after flight. The airbrake is an improved design from the airbrake designed in 2017 with the ascent phase of the rocket monitored and controlled by the autonomous system the Controls Team developed. This system will utilize an array of sensors to provide acceleration, velocity, and altitude data to an Arduino which will actuate the fins accordingly to reach the 10,000ft goal. In order to do so, the projected altitude will be continuously calculated using equations derived from Newton's Second Law. The payload contains five cameras connected to an Arduino Nano that autonomously begin recording video prior to launch and stops recording after touchdown. These two subsystems are flying on a rocket made entirely of SRAD fiberglass airframes and CNC-cut fins and centering rings. This rocket is entering the competition having flown twice before and bolsters confidence in the rocket's design and hardware.

Nomenclature

COTS	=	commercial off-the-shelf
d	=	cylinder diameter
l	=	length
m	=	mass
PLA	=	polylactic acid
SRAD	=	student-researched and developed
UHMW	=	ultra-high wolecular weight polyethylene

I. Introduction

The Oklahoma State University AIAA Rocketry Team was founded in August 2016 with the intention of competing in the Spaceport America Cup and revitalizing the interest in rocketry at the university. The Spaceport America Cup served as the driving factor to certify the team's members with the Tripoli Rocketry Association, incrementally build larger and more complex rockets, and secure the support from the university and its faculty.

Following the entry in the 2017 Spaceport America Cup, and with the generous support of donors and sponsors, the team was able to design a larger rocket for the 2018 Spaceport America Cup. Upgrading from a 4" diameter to a 6" diameter airframe, this allowed for a better designed payload and improved airbrake with fewer constraints as dictated from a 4" diameter rocket. Multiple team members achieved Level 3 Certifications which helped the number of test flights accomplished for this project.

OpenRocket was used extensively as the primary modeling software of the rocket and its flight simulations. All performance metrics as stated in this paper are gathered from OpenRocket unless otherwise stated.

---

[1]Hunter Billen, Jordan Chancellor, Garett Foster, Nicholas Foster, Nicolas George, Cole Henderson, Kyle Hickman, Samantha Huckabay, Gerald McCullers, Katelyn Powell, Nicholas Rozell, Timothy Runnels, Austin Stottlemyre, Garrett Townsend, Lucas Utley, Andrew Walsh, & Garrett Wilkens.

The team's program name is Cowboy Rocketworks, and they are flying a 12.5'-tall rocket named *Results May Vary* in the 10k – COTS – All Propulsion Types category.

The Cowboy Rocketworks team was faced with a challenge: How to build a rocket that stops at 10,000 feet exactly? There are many different ways to approach this problem. Some teams build a rocket and try to get it to weigh exactly enough to hit the altitude mark. A major problem with this strategy is that it doesn't account for weather cocking of the rocket or variances in motor power or simulation accuracy. The next possible option is to build an airbrake that just simply deploys. This is an option for shaving off altitude and slowing down the rocket, but ultimately suffers the same shortfalls already discussed. That leaves one other scenario: create a smart altitude control device that knows when to decelerate the rocket and when to let it fly. Such an idea is easier said than done, and creating a device that is robust and sophisticated enough to handle the task can be quite difficult. To solve this problem, Cowboy Rocketworks decided to go all in and created a Controls Team for the Spaceport America Cup. This team was tasked with designing an airbrake system to control the ascent of the rocket intelligently. To do this, a series of prototype designs were created by the team. They were then evaluated for efficacy by a series of test and further refined until the best design emerged. From there, the airbrake was manufactured, tested, and programmed to perform optimally. This process is further explained in the System Architecture Overview.

This year's team consists of 14 members attending the Cup and 3 others who made valuable contributions to the team's progress, but who are unable to join at the competition. Austin Stottlemyre is the team's Director. Hunter Billen, Jordan Chancellor, Nicolas George, Cole Henderson, Kyle Hickman, Samantha Huckabay, Katelyn Powell, Nicholas Rozell, Timothy Runnels, Garrett Townsend, Lucas Utley, Andrew Walsh, and Garrett Wilkens are attending the Cup. Garett Foster, Nicholas Foster and Gerald McCullers also made significant contributions to ensuring the team's success in the competition.

Cowboy Rocketworks' sponsors include Spirit AeroSystems, OSU Student Government Association, OSU CEAT Student Council, and 100 friends and family members of the team who donated during our PhilanthroPete fundraiser with the OSU Foundation in fall 2017.

II. System Architecture Overview

Cowboy Rocketworks' launch vehicle, *Results May Vary,* consists of several subsystems which include Propulsion, Aero-Structures, Recovery, Payload, and Airbrake. The airbrake is a significant technological development that will ensure *Results May Vary* successfully reaches a precise target apogee of 10,000 feet AGL.

It is flying on an Aerotech M1939W motor, weighs 71 pounds on the pad, is 6" in diameter, and has a height of 12.5'. The minimum static margin is 2.62 as determined by OpenRocket.

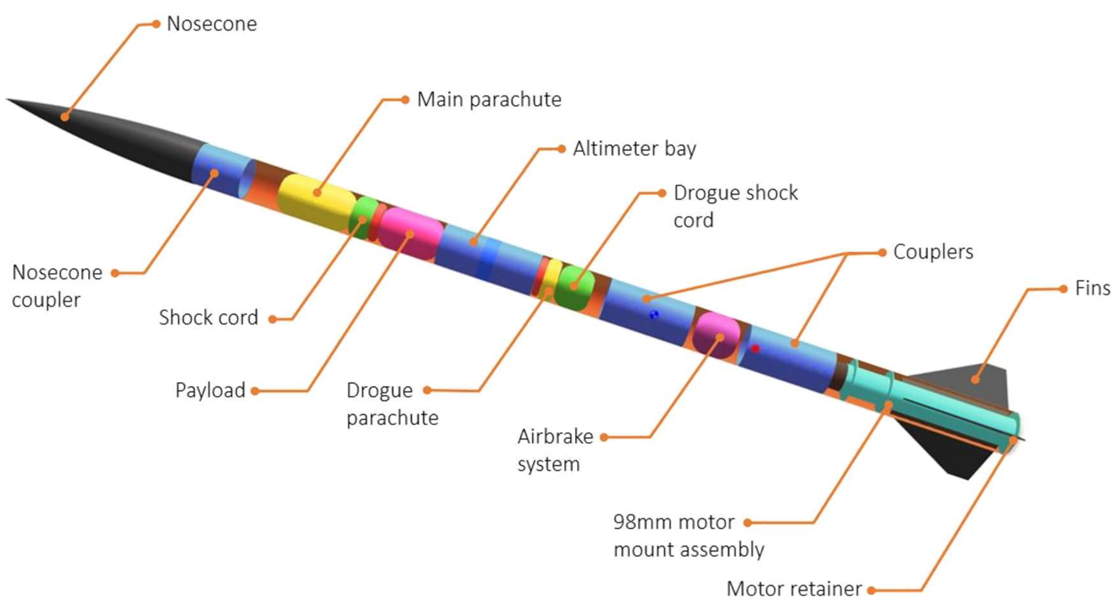


Figure 1. *Results May Vary* Cutaway View. Graphic illustrating internal components in relation to exterior airframe and structural components.

A. Propulsion Subsystem

The propulsion system for *Results May Vary* is an Aerotech M1939W composite solid-propellant rocket motor. The performance of this motor as specified by the manufacturer is shown in the figure below.

Total Impulse (N-s)	**10481.5**
Avg. Thrust (N)	**1939**
Peak Thrust (N)	**2429.7**
Burn Time (s)	**6.2**
Propellant Weight (g)	**5719**

Figure 2. Aerotech M1939 Performance Specs

This motor is in the form of multiple propellant grains and will use a reloadable Aerotech 98/10240 motor casing with a plugged forward closure. In total, the propulsion system will contribute approximately 19.82 pounds (8988 g) to the overall launch vehicle weight.

In order to maintain integrity and reliability with the propulsion system, no modifications to the motor will be made. Furthermore, the given manufacturer instructions will be closely followed for motor assembly.

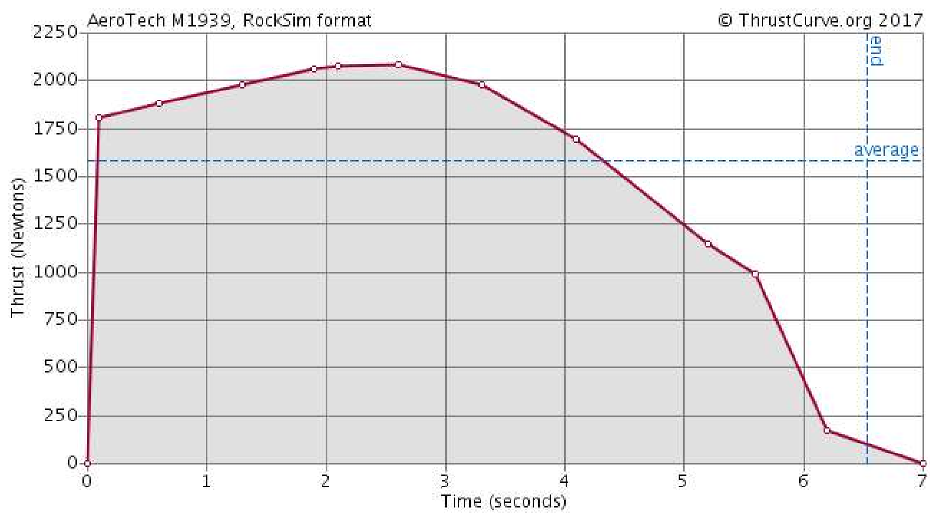


Figure 3. Aerotech M1939 Thrust Curve. *Thrustcurve.com*

B. Aero-Structures Subsystem

1) Fiberglass Tubes

This year, Cowboy Rocketworks began making SRAD rocket body tubes and sheets. The tube-making process involved wrapping fiberglass weave around a mandrel. For convenience and ease, the casting mandrel was an extra-long phenolic coupler section purchased from Public Missiles. This allowed for the purchase of commercial coupler sections for couplers and electronic bays. In the future as the manufacturing processes become better and tolerances become tighter, these couplers will be SRAD parts as well. The process that was used for *Results May Vary* is described below.

First the fiberglass cloth was cut to size to correspond to the width and number of wraps needed to achieve certain dimensions. 6 wraps were used, and this proved sufficient in strength as well as weight. The mandrel is prepared by cleaning it with mineral spirits and adding a layer of wax paper wrapped around the mandrel. Special care was taken to ensure there are no air bubbles, and the paper has the non-stick surface pointing outward. A generous layer of petroleum jelly is distributed along the length for proper lubrication. Another layer of wax paper was added to the outside of the mandrel with the non-stick surface facing inwards. Finally, the second wrap of wax paper is sprayed with a non-stick cooking spray. This ensures the paper will easily come off the inside of the tube.

Fiberglass resin is prepared simultaneously by another team member. A tube of 6” outer diameter with 6 wraps required 30 fluid oz of resin and a corresponding 300 drops of hardener. The resin is poured in two 12 oz containers such as a standard plastic party cup, and the hardener premeasured in a separate container, such as an epoxy mixing cup. When ready, the two constituents are mixed together at room temperature.

To begin wrapping the fiberglass cloth, some of the mixed resin is poured onto the top of the prepared mandrel. The leading edge of the fiberglass cloth is wrapped onto the mandrel and the resin gently rubbed into the cloth with a gloved hand until saturated. The mandrel is turned and fiberglass wrapped in slight tension while pouring resin intermittently between the wraps. A downward sweeping motion keeps air bubbles from forming. This process is continued until the last of the cloth is wrapped around the mandrel.

To finish the tube, it is set upright to harden. This takes anywhere from 20 minutes to an hour, depending on the temperature of the room, ventilation conditions, and lighting, as all these factors have been observed to affect the hardening time. Once the tube has cured, it is pulled off mandrel. The ragged ends are cut off with a table saw, and the whole tube sanded to ensure a smooth finish.

2) Fiberglass Sheets

Sheets were made using pre-existing commercial fiberglass sheet (G10 Garolite) to press layers together while curing. Sheets were made with 12 layers of fiberglass cloth for fins (yields 3/16” thick) and 8 layers (yields 1/8” thick) for centering rings and bulkplates.

The existing fiberglass commercial sheets were covered in wax paper with the shiny side up and sprayed with cooking oil. Next, the appropriate number of layers was cut out of fiberglass cloth with the layers oversized by about an inch in each direction. This insured that the entirety of the 12x12 section was usable. Next, 12 oz of resin was prepared. Then a small amount of resin was spread onto the bottom wax paper covered plate before the first layer was set on. Resin was added between each layer and smoothed with a plastic scraper. After the last layer, wax paper covering plate was placed on the layup and weights added to ensure an evenly packed layup.

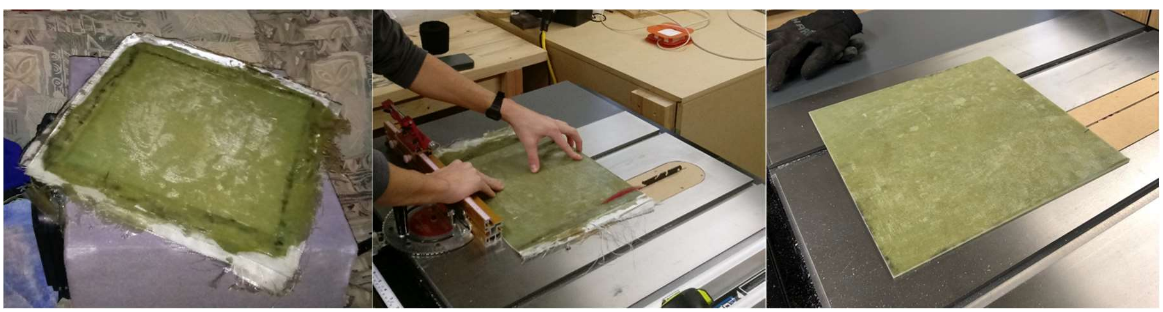


Figure 4. Stages of preparing a 12”x12” fiberglass sheet

A single 24”x24” fiberglass sheet 3/16” thick was made that became the rocket’s 3 fins and extra set of altimeter bay bulkplates. The 3 centering rings were cut from a 1/8” thick sheet. These parts were CNC cut with an Inventables X-Carve machine.

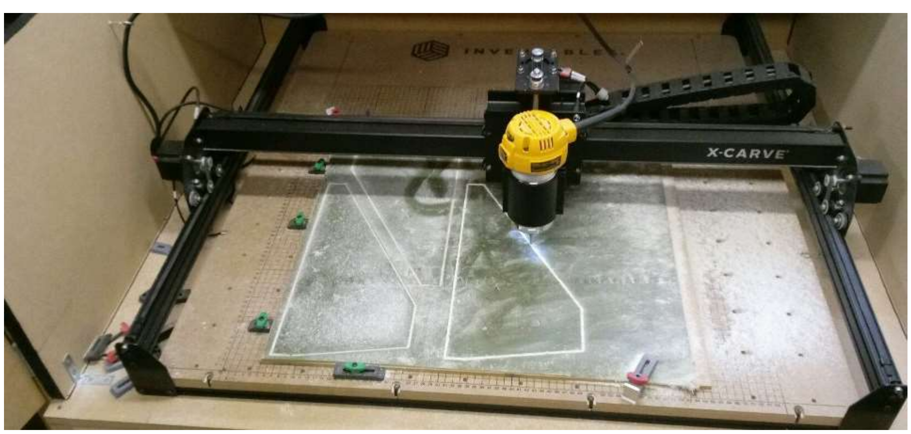


Figure 5. X-Carve CNC cutting fins from SRAD fiberglass.

3) Rocket Assembly

The assembly of the rocket began with sanding the inside of the aft, middle, and forward sections to allow the coupler sections, motor mount, and nose cone to fit. All epoxied surfaces were also sanded and washed to maximize surface area for epoxy adhesion. Next, fin slots were cut into the aft section by means of a routing jig designed and built by OSU students. The jig uses a Dremel tool and allows for perfectly straight slots to be cut in a variety of tube sizes.

To attach the aft 1515 rail button, a hole was drilled through the aft airframe section between two fins, and a wood screw placed through the rail button's hole and screwed into a small square of ¼" plywood on the inside of the aft section tube. Epoxy clay was spread over the wood block to reinforce the rail button. This process was used for both rail buttons which were designed and 3D printed from PLA plastic. They are airfoiled to reduce drag.

The 98mm motor mount tube is held in place by 3 fiberglass centering rings that were epoxied into the aft airframe with G5000 RocketPoxy. For motor retention, holes were tapped along the aft centering ring. An Aero Pack 98mm flanged retainer was then fastened onto the bottom centering ring and secured with the included screws.

The fins were sanded down to fit inside the slots and were held in place with G5000 RocketPoxy fillets, both inside the airframe and externally.

The altimeter bay is a 14" coupler with a 2" affixed slip band. The slip band had a 5/8" hole drilled into to it and a ½" hole in the coupler to countersink the rotary switches used for arming the altimeters. This helps reduce drag.

Results May Vary uses a metal-tipped 5:1 ogive filament-wound fiberglass nosecone from Madcow Rocketry. The included nose cone coupler and bulkplate are used. Commercial 6" couplers are also used throughout for joining the various sections.

To ensure that the sections stayed together during take-off, holes were drilled in all the sections attached to the coupler sections to allow aluminum rivets to be put in place. These rivets are threaded tube fasteners as manufactured by LumaDyne. They are used in the couplers attaching the aft and middle section, and in the coupler section attaching the middle to the forward section.

3 nylon shear pins (2-56) hold the forward section to the nosecone and at the bottom the electronics bay (middle coupler section) to the middle section. The holes for the plastic shear pins had to be tapped so the pins could screw in. The shear pins are designed to break off when the black powder charges ignite. When the black powder charge ignites, the rocket will break apart just below the electronics section and at the nose cone for the drogue and main deployment events, respectively.

5/16" forged eyebolts are used at the nosecone and altimeter bay which have a load capacity of 900 pounds. A 3/8" forged eyebolt is used as the aft-most attachment point on the airbrake (rather than attaching to the 98mm plugged motor closure). 1/8" vent holes in each compartment release internal air pressure.

Figure 6. *Results May Vary* following construction.

C. Recovery Subsystem

The recovery system is centered around a combination of three altimeters and four ejection charges to guarantee the deployment of both the drogue and main parachutes. In this system the charges are: The Primary Main, the Primary Drogue, the Backup Main and the Backup Drogue. The System as a whole is depicted below.

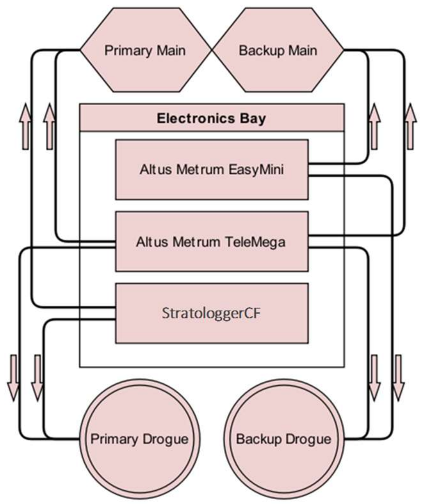


Figure 7. Altimeter wiring schematic.

The altimeters are an Altus Metrum TeleMega, an Altus Metrum EasyMini, and a PerfectFlite StratologgerCF. All three are attached by screws into the plywood sled of the electronics bay with rubber dampeners to mitigate vibrations.

The TeleMega is powered by a single cell Lithium Polymer (3.7 volt LiPo) battery capable of providing a minimum of 800mili-Amp hours (mAh). While the other two altimeters are each individually powered by nine-volt batteries secured in the electronics bay by zip ties, seated on the sled shelf, and snap connectors secured with electrical tape to maintain the circuit through the motor boost phase and for all the reactionary forces from the ejection charges.

Also, each altimeter connects to its own igniter for each of the drogue and main ejection charges to guarantee their ignition and deployment of a parachute. This built in redundancy ensures the recovery of the rocket as well as the payloads within.

The ejection charges contain a precisely measured amount of black powder as described in Eq. (1)[1] to adequately over-pressurize the body sections of the rocket to 15 pounds per square inch (psi) each for a successful deployment event.

$$m_{blackpowder} = \frac{3ld^2}{500} \quad (1)$$

In Eq. (1) $m_{black\ powder}$ is measured in grams, and l and d are measured in inches. An additional amount of black powder is added to top off the charge, equal to a quarter the original amount, in order to make sure the over pressurization does force the rocket apart. The primary charges are contained in 3D printed cylinders that add a directionality to the detonation of the charge. While skeptical at first the, the 3D printed pieces are entirely reusable and little to no damage with each burn.

The backup charges are two times as large as the main charges. This is primarily due to the issue that comes from an incomplete/inefficient burn of the black powder which has been experienced in a previous launch by the club, resulting in an unsuccessful recovery. The backup charges are contained within a piece of surgical tubing and zip tied closed on both ends upon the recommendation from the members of the Kloudbuster's Rocketry Club.

The rationale behind such a large amount of black powder is centered around the knowledge of how strong the fiberglass body tubes actually are. If the primary charges function perfectly, then with the body tubes open to the air, when the backup charges go off, they are immediately vented to the atmosphere and cause no harms to the rocket. If the Primary charges don't go off and the redundancy fails in that set of systems, the charges have to be sufficiently large enough to force the rocket apart when confronted with pressure induced by the rocket falling ballistically, which would hold all the sections together. Or if either of the main charges go off and they don't achieve what they were supposed to, the significantly larger charge is more likely to force out the parachute recovery systems.

The main charges are kept as close to the electronics bay as physically possible, allowing for the shortest amount of wire to be used in the connection and eliminate the chances of a disconnect from the altimeters. However, the drogue charges had to be moved to under the payload section due to design and mounting constraints.

A SkyAngle Cert-3 Drogue parachute, 22 inches in diameter, is used for the drogue deployment event at apogee. According to OpenRocket, to a terminal velocity of 94 ft/s from 10,000 feet AGL to 1,000 feet AGL. The use of a SkyAngle Cert-3 extra-Large main parachute 90 inches in diameter was chosen to support the fifty-one and a half pounds that the rocket weighs for the final descent following the main recovery deployment event. The primary altimeter will fire at 1,000 feet with the backup firing at 800 feet. If all goes as planned, the backup will fire, but the charge will have been used several seconds before as fired by the primary altimeter. This final event ensures a controlled touchdown at 26 ft/s according to OpenRocket simulations.

All separable portions of the rocket are joined together by coupler sections with a six-inch minimum shoulder (to match or exceed the six-inch body diameter) and secured by simple nylon shear pins. These shear pins provide the support to remain intact during boost and prevent drag separation, but cannot hold against the black powder ejection charge at which point they shear apart and allow recovery systems to deploy. Other sections that are joined also by couplers but do not separate (such as the airbrake to the aft airframe and the electronics bay to the forward airframe) are secured by aluminum 4-40 tube fasteners and rivets.

Following ejection charge-induced separation, the sections of the rocket are tethered together by lengths of 1" nylon shock cord. These segments of shock cord are 40' long to allow the force of black powder ejection to dissipate somewhat before the cord is pulled taught in tension. Longer shock cord reduces the energy of the system (lost by drag) and minimizes axial loading on the shock cord, eyebolts, epoxy connections, and airframe components. The cord is connected by ¼" stainless steel quick links and affixed to 5/16" forged steel eyebolts secured to the fiberglass bulkheads and all centrally connected at the electronics bay where ejection charges are located.

D. Payload Subsystem

Our payload is a system of five independent cameras that record video out the sides of the rocket and can be stitched together to create a single 360-degree video. The system is designed to begin recording once powered on. An accelerometer on board is capable of detecting launch which then begins a 20-minute timer. Once 20 minutes have passed, a mechanical relay will flip therefore cutting power to all five cameras. This is necessary so that the cameras do not continue to record and write over the footage from the launch. This design and development of this payload has enhanced the team's ability to manufacture aluminum and steel parts as well as work with electronic parts not directly associated with the rocket itself.

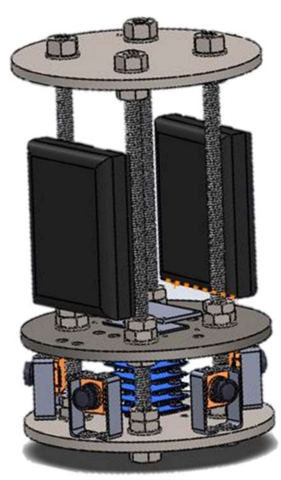


Figure 8. CAD model of payload

1) Payload Structure

The payload team chose to use three steel plates and four aluminum 10” rods as the main body of the system. Working with a local steel supply company, Stillwater Steel and Welding Supply, who was able to cut us three 6” diameter circular plates that were 0.25” thick, we chose 0.375” diameter aluminum rods in order to prevent buckling of the rods during high G environments throughout flight. From there the necessary holes on each plate were laid out in order to mount the four rods and all the components to the plates. Though it would have been easy to simplify the design down to only two plates instead of three plates, it was decided not to mount components from the bottom of a plate. During ascent of the rocket it was preferred that mounted components be pushed towards the plate and rather than pulled away from it. Using a print out of the CAD layout, the paper was placed on top of each plate and a drill press was used to customize each plate as needed.

Two types of nuts were used for accessibility and strength purposes. Underneath each plate are four nylon lock nuts followed by a washer that prevents vibrations from shaking those nuts loose throughout flight. On the top of each plate are two standard nuts followed by a washer. Having two nuts greatly decreases the chance of them vibrating and coming loose. However, all nuts also had thread locker applied in order to ensure a rigid structure during flight.

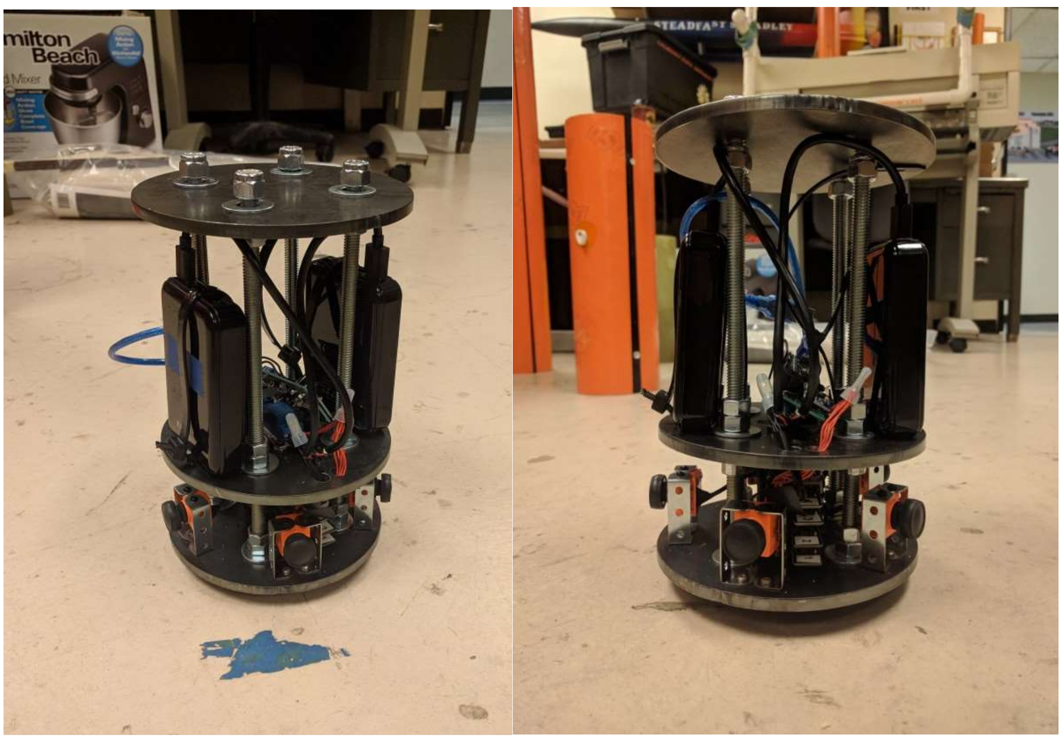


Figure 9. Payload assembly and structural design

The structure is mounted directly on top of the electronics bay, so that a sturdy and rigid location for the payload to be mounted to the rocket is achieved. This is important for the cameras, so that they will experience minimum vibrations throughout flight. The upper body tube where the payload will actually occupy will then have five holes for the camera lenses to protrude from and be able to record video properly. As the structure of the payload was finalized and all the parts were assembled a final weight of 9.02 lbs was reached which is extremely close to our targeted 9.00 lbs for the system.

2) Cameras

A number of cameras were considered for this payload. The original idea was to take advantage of the simple and light weight cameras that could be used in conjunction with a RaspberryPi. However, after much research these cameras would not provide a high enough quality or rigidity to justify their use. Next, GoPros were examined and other similar action cameras. For the allotted budget cheaper options were sought out that had the same functionality as that of these cameras. The RunCam Split cameras were selected. They are capable of recording in 1080p 60fps and can utilize a 64GB SD card as well as record in five-minute segments. This ensures that even if something goes wrong at some point during flight the entire video will not be lost. Another benefit to these cameras is that power loss to the camera does not corrupt the current file and therefore produces only minimal losses of video. These cameras price fall within the budget and are notorious for being durable since their original purpose is to be used on racing drones that are prone to many crashes. Each camera comes with a removable Wi-Fi dongle so that settings can be modified through a mobile app and files can be pulled from the cameras without having to remove each SD card.

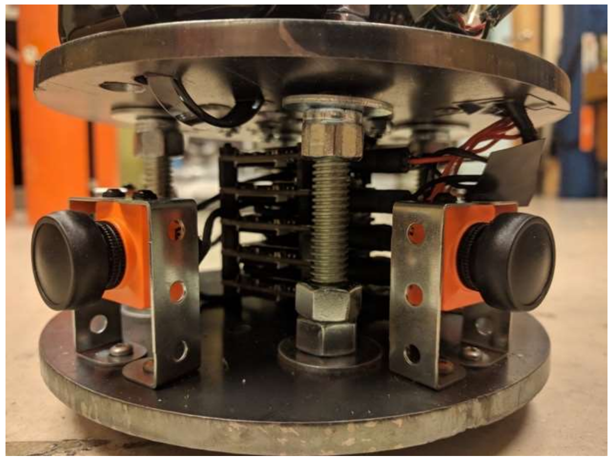


Figure 10. Camera assembly

Another major component to the choice of cameras was the angle of the camera lens. GoPros are notorious for their wide fish eye lens and make them a good fit for a situation like this. Fortunately, the RunCam Splits also are equipped with wide angle lenses that even allow for them to be turned vertically so that each camera still has overlapping video, but a much wider range of view from top to bottom is achieved. An early issue in design was the requirement to be able to easily remove the payload from the rocket. This was difficult since the camera lens needed to be as flush with the outside wall of the rocket as possible to get the best video, but this would inherently prohibit the removal of the payload. The solution to this is using the RunCam Split camera system to our advantage and unscrewing each lens prior to installation and then re-inserting the lens once the payload is successfully installed within the rocket. This allows for optimum camera placement.

3) Initiation Trigger

With the initial concept of using RaspberryPi's for the camera system, an accelerometer would be able to sense lift off and save the previous ten seconds and the following 20 minutes so that the footage would be of just the launch. However, with the RunCam Splits recording on the pad can begin and then using a similar accelerometer system with an Arduino Nano to cut power to the cameras 20 minutes after launch, so that unnecessary footage isn't recorded and the camera does not accidentally write over the launch footage.

Two power bank batteries are wired in parallel so that the output amperage is upped to 4.2A, which is necessary for all the cameras to work properly. One power bank will also power the Arduino Nano independently with 1A. The power banks connect to the cameras through a mechanical relay that is used to turn off the cameras after launch. The two power banks are designed so that when a device is plugged in the battery recognizes the device and automatically turns on to begin providing power. However, when wiring the two batteries in parallel this proves to be a problem since turning one battery off will inherently turn the other battery back on since it recognizes it as a connected device. To mitigate this issue, a 3A diode was connected to each positive end of the battery. This therefore prevents current flowing back into the battery and turning the battery on. From the relay, all five cameras are connected via micro USB cables to their respective port on the device.

When power is turned on, all five cameras immediately begin recording. This should make syncing the cameras when stitching them into a single 360 degrees video easier however, the Arduino Nano system also includes a buzzer that will beep prior to launch and then sustain one long tone when ignition is detected from the accelerometer. This will give the team a reliable auditory signal to sync the videos appropriately.

4) Testing

Testing has been completed on the payload and all the cameras function as intended along with the Arduino Nano and relay system that shuts off power once the flight is completed. Currently, the team is working on stitching together initial video recordings to practice for the final editing of the video. After the final launch prior to the SA Cup, the team will review video footage and ensure all systems worked properly throughout launch without major issues or vibrations during recording.

Figure 11. Battery endurance testing setup

E. Airbrake Subsystem

When designing the airbrake, there were a lot of aspects that had to be considered. Seeing as how the purpose of the airbrake was to manipulate the airflow around the rocket, aerodynamics were a chief concern of the Controls Team. One of the biggest choices was how many control surface fins to put on the airbrake. The Controls Team didn't want to compromise the structure by cutting away too much of the body tube, so the size of the fins became limited. It was decided that somewhere around 50% of the structure should remain at any point in the cross section where the holes would be cut. This also limited how many fins there could be. Since the rocket itself was designed to have 3 aft stability fins, it was only natural to have the airbrake have 3 fins as well. A 3 control surface fin design would also make downstream air flow effects symmetric over the aft stability fins which was another big concern. That's why it was decided to place the control surface airbrake fins “in-between” the aft stability fins. This greatly reduced changes in the flow over those aft fins in CFD simulations which it was felt would keep the rocket more stable.

On the note of stability, it was also important to be able to show that the airbrake wouldn't change the location of the center of pressure in such a way that the rocket became unstable upon deployment. For initial testing, the center of pressure was assumed to be essentially wherever the airbrake fins deployed. This was because the surface area of the fins would be larger than any other item extruding from the rocket causing pressure buildup at that location to dominate any other pressure contributions. This was tested further using CFD testing for each design using the methodology described in the next section.

Outside of aerodynamics, there were many mechanical considerations that had to be accounted for. Most importantly, complexity played a big role in what design choices were made. It wouldn't matter how good of an airbrake was designed if it was so complex that it wasn't realistic to build with the resources provided to the team. Additionally, more complexity also leads to problems with reparability. Since the competition takes place in the middle of the desert, the airbrake needed to be designed in such a way that it could easily be worked on with tools that are easy to transport to such a locale. Another benefit to simplicity is a simple matter of being less likely to malfunction. A more basic mechanism has less moving parts and less things that can go wrong. This also played into the weight of the airbrake system because the less components inside the airbrake, the less it weighs. Having less weight is important because it allows the rocket to reach a higher altitude with less propellant.

The final big consideration was which design would allow the control surface airbrake fins to deploy the quickest. This is important because the airbrake is going to reactively deploy. This means it needs time to react to changes in velocity and acceleration on the fly in order for the rocket to hit its target altitude. Simulations estimated that the entire coast phase would last about 18 minutes, with only 5 seconds of that occurring at high enough speeds for the airbrake to make a significant drag contribution to slow the rocket. If the deployment mechanism is too slow, this 5 second window of significant drag opportunity will be missed making the airbrake’s control algorithm dramatically less effective.

1) Hardware Design and Testing Methodology

The design process for the airbrake was largely iterative, following the same general pattern of steps over a series of rough designs until the best final design emerged. First, a rough design was created on paper. This includes general shapes of control surface fins, deployment mechanisms, and a rough internal layout.

Next, a Solidworks model was created of just the control surface fins and body tube. This model was then placed into a Solidworks assembly of the team's rocket so that CFD testing could be done. A series of test were conducted at different Mach numbers, densities, and temperatures to simulate different heights and stages of the flights. A control test with no control surface fins deployed was also conducted at the same test points. These results were then compared to an OpenRocket simulation with a plain body tube in the spot of the airbrake which simulates a no control surface deployed configuration. The drag results from the CFD control simulation and the OpenRocket Simulation were within 10% of one another which often equated to 0.5 lbf or less. This was determined to be close enough, because CFD in general isn't the most accurate. Once the mesh and settings were validated by the control case, the same settings were used with the airbrake control surface fins fully deployed. Drag produced and general airflow patterns were monitored during these tests. This was used to both see which designs produced the most drag, and what the effect of that drag disturbance was on downstream air. The best design was a combination of enough drag to effectively slow the rocket, but not so much so that it significantly disrupted flow over the aft stability fins. These results were used to show what size of control surface fin was needed for a design to be worth pursuing, and that information was used in the next step

Once a design was considered aerodynamically possible, the information on minimum control surface size was then plugged back into the rough design. At this point, the mechanism for deployment was evaluated to see if it could still work with the new sizing. If a mechanism wouldn't work, possible alternatives or modifications to the design were explored. If it still wasn't possible, the design was discarded at this point. Of the 6 proposed designs, 3 of them were stopped at this point. The designs that were left moved on to the next stage for even more computer aided testing.

The next round of CFD was done to gather more data on the designs integrated into the rocket body. Primarily, this was done to monitor the stability of the rocket so the Controls Team could see how the airbrake impacted the center of pressure location. As discussed earlier, the initial thought was to put the airbrake control surfaces directly on top of the non-airbrake center of pressure location in its farthest forward point. The integrated airbrake and rocket were evaluated over a range of Mach numbers to see how the center of pressure changed. The airbrake was evaluated at 25%, 50%, 75%, and 100% deployment of control fins. Of course, the settings from the verified control mentioned earlier were still used in an attempt to reduce error and increase accuracy of the simulations. At each test point, the torque in each axis was divided by the force normal to it relative to an axis at the tip of the nose cone as seen in the equations below. Of course, the rocket is asymmetric so calculating the CoP about only 2 axis did not provide an accurate representation of what was really happening aerodynamically. To combat this, a series of axis were set up at the tip of the nose cone, each offset by 22.5 degrees from the last. This allowed for the center of pressure to be calculated about 6 independent axis, and for the values to be averaged together to create one more realistic number.

$$CoPx = \frac{Ty}{Fx} \qquad\qquad CoPy = \frac{Tx}{Fy}$$

The second purpose for the additional CFD was to create a CD vs Mach curve for the airbrake. This information was needed to accurately model how effective the airbrake would be at reducing altitude. Initially, the Controls Team attempted to use OpenRocket for this task. There is a plugin for using a custom CD vs Mach curve for a rocket, but there was no way to be able to switch between the different curves for different levels of airbrake deployment. To get around this hurdle, the Controls Team went through the source code of the OpenRocket program and used the same methodology to create a custom launch simulation in MATLAB. The program takes initial time, position, velocity, and acceleration data generated by OpenRocket from the second that the boost phase stops and iterates through at a defined time step to calculate a final altitude. Once again, using a control case of no control surface fin deployment the simulation estimated within 2 meters of what OpenRocket did which was deemed an acceptable level of error. The reasoning for choosing MATLAB to do this was because initially the Controls Team planned to use a PID algorithm which MATLAB would more easily be able to tune.

At this point, the remaining airbrake designs could truly be compared to one another. Simulations were run using the MATLAB code with the airbrake fully deployed to see exactly how much altitude it would shave off. The design that performed best was then selected as the final choice. A parts list was put together and the needed materials for the design were ordered. At this point, the airbrake was assembled and the MATLAB code was used to test different algorithms for control surface fin deployment and find the optimal way to slow down the rocket in flight with the chosen design.

2) Design Iterations – Design 1

Figure 12. Design 1 in the fully deployed state.

The Controls Team's first design started with a linear actuator place at the center of the airbrake system. A center ring was used to support the airbrake system. There was also a plus-shaped component placed on top of the actuator. The component is tied, by wire, to a corresponding rod below it, at the aft end of the airbrake system. For each fin, there are four total rods. One rod attached to the wire, another attached to a bar on the back side of the fin, and the last two attached to a bar that is connected to the ring. These rods had holes at both ends that connected to a center rod connecting the four different rods to allow for rotation. Each fin was slightly curved to stay streamline with the rest of the body of the system and is connected to the body using a hinge. When the linear actuator activates it would push the plus-shaped component upwards, pulling the wire as well as the hinge upward. This would swing the fins upward to a location almost perpendicular to the airbrake system.

What made this design likable was that was designed to be completely modular. It also allowed for a large amount of fin surface area to create a significant amount of induced drag. However, due to the amount of drag that was created a powerful actuator was required. The Controls Team had trouble finding a linear actuator that reached the parameters that were needed and that was within the team's budget. Another restraint with this design is that it was not able to deploy quickly.

In the end, the Controls Team decided not to use this design and look into other viable options for an airbrake system for our 2018 Spaceport America Cup entry.

3) Design Iterations – Design 2

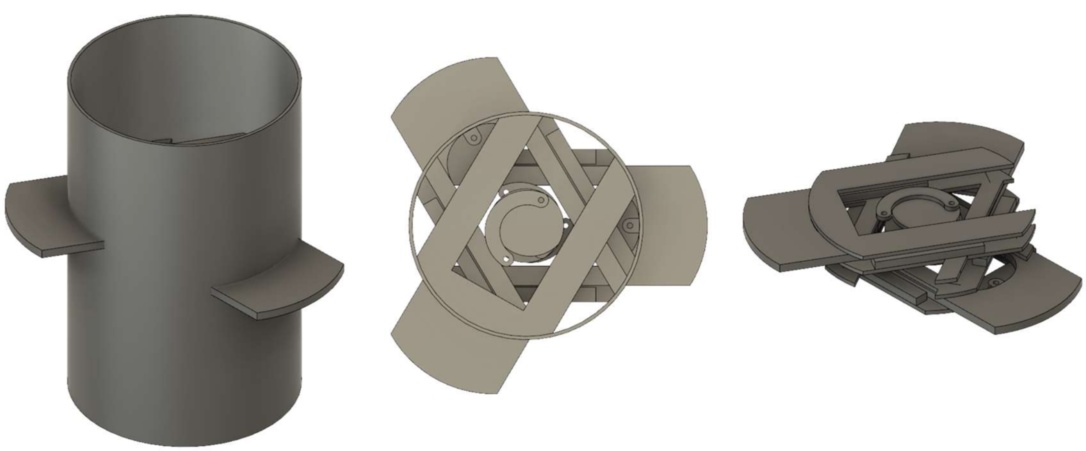


Figure 13. Design 2 in the fully deployed state

This design focused on maximizing surface area that could be used for induced drag of the rocket via the airbrake while allowing for a rotational stepper motor to be the means of actuation. This resulted in a design that was made up of three “fins” that would slide out of the airframe, perpendicular to the airframe, in a linear fashion. The motion and amount of deployment was to be controlled by the rotation of a cylindrical, geared “hub” that would serve as the interface between the drive motor and the fins. The fins also would be stacked on top of each other, with some spacing in between each fin to allow for support “tracks” that the fins would ride along and in turn creating fairly tight tolerances that the assembly would need to conform to. The components were intended to be manufactured out of 6061-T6 aluminum and assembled using off-the-shelf hardware.

This design seemed very feasible due to the availability of parts and similarities between various parts that would needed to be manufactured. However, upon completing the 3D/CAD model of the hardware, looking at the manufacturing equipment available and determining how the hardware would be assembled, the team came to the conclusion that this specific design would be very difficult to complete and implement with the available time and resources while also creating a piece of hardware that could be easily serviceable, should parts need to be altered or if parts were to break.

Although this design was not chosen to be a part of our Spaceport America Cup entry for the 2018 competition, the controls team intends to refine the design and explore alternative manufacturing techniques so that the design has the possibility of becoming actual hardware on future rockets.

4) Design Iterations – Design 3

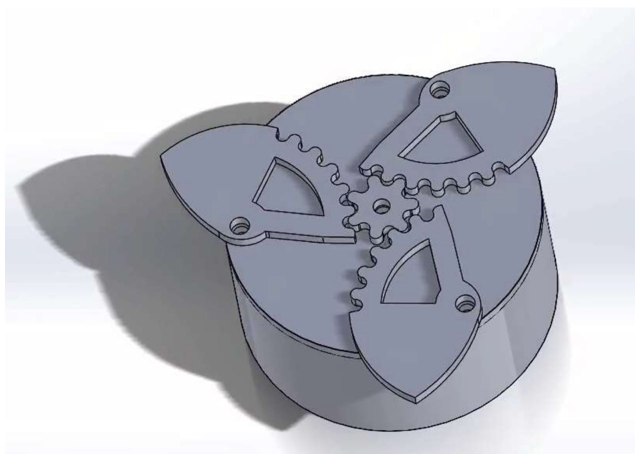


Figure 14. Cutaway capture of Design 3

This design was chosen as the hardware that would be manufactured, assembled, and installed onto the Cowboy Rocketry entry for the 2018 Spaceport America Cup competition.

This particular design was originally destined to be “thrown out” as a design option for the Spaceport America Cup rocket that our team would be putting together. This was because the amount of surface area that would be available for use in creating induced drag on the rocket was much lower that the amount of surface area that was expected to be obtained on alternate designs. However, this design was kept as a possibility and ultimately selected as the final design due to the simplicity of the design, compared to other options that were explored.

The final design consists of three fins that rotate out of the airframe in a radial fashion, perpendicular to the airframe. The actuation will come from a central stepper motor that interfaces with the fins by a central gear and matching gear teeth on each of the fins. The fins and central gear will be assembled between two discs and everything will be fastened together with off-the-shelf hardware. The fins, central gear, top and bottom discs will be machined out of ¼ inch 6061-T6 aluminum plate, by a three-axis CNC machine. The stepper motor will be attached to and be supported by the top disc in the assembly.

Another integral component that will be cut to size and epoxied to both the top and bottom discs, allowing for interfacing with the fins, will be a 1/16 inch layer of Ultra-High Molecular Weight Polyethylene sheet (UHMW). The UHMW sheet will serve as a glide surface for the fins to move along, with very little friction. The UHMW sheet is also a durable material and will be able to stand up to heat of the New Mexico desert during competition.

This “sandwich” of components (bottom disc, fins, UHMW sheets, and top disc) will be affixed into the rocket with the help of repurposed bulkhead plates and segments of 1x1 inch t-slot framing. The bulkhead plates will be epoxied into the coupler section using high strength rocketpoxy, directly below the airbrake's section of airframe and directly above the motor tube. The t-slot sections will then be fastened to the bulkhead plates providing somewhat of a frame for the airbrake. The bottom discs of the airbrake "sandwich" will then be fastened to the ends of the t-slot framing sections, effectively securing the airbrake hardware. This method was chosen for mounting due to the fact that the coupler, that the bulkhead plates will be attached to, can be separated from the rest of the airframe. This will allow for easier access to the airbrake hardware for any maintenance or adjustments that might be necessary by essentially being able to pull the entire airbrake assembly outside of the airframe.

While this had not been the intended final design from the beginning due to the lower surface area, it was the design that was feasible for the team to manufacture and assemble with the resources and time available. This design will also serve as a stepping stone for the team to create more advanced airbrake systems in the future.

5) Avionics Hardware Considerations

The avionics hardware is probably the area of the airbrake that seemed like it would be the easiest, but ended up being one of the hardest. One of the biggest challenges facing the Controls Team was putting together a good enough avionics that would do the job without spending a ton of money. It's easy to get carried away and spend thousands of dollars on sensors that can detect the pressure change from an insect flying by at 1 MHz, but that amount of data would almost be too much. It was also important to not get carried away getting a ton of fancy electronics that also weigh a bunch for obvious reasons. Along with weight, it was imperative to get sensors that aren't bulky. The airbrake on the teams rocket was only budgeted 20" worth of tube and that's a lot less than it sounds. That also plays into the fact that the sensors needed to be low power. There wasn't much space available for large batteries, and with how hot the inside of the tube may get in the desert, large batteries could pose an overheating problem inside the rocket.

A challenge to finding cheap and lightweight sensors was making sure they were good enough to accomplish the goal of providing good information quickly to the Arduino. This meant finding sensors that had high enough accuracy and resolution to calculate what the projected altitude is on the fly, and when motor burnout occurs. On the flip side, sensors that read too quickly and produce noise are a bad thing in this case. The Controls Team strived to strike a balance between the two areas. It was also very important to get sensors that could easily communicate to the Arduino without significant post processing. This allowed for more simplistic coding and less potential for misreading or errors.

The last problem faced by the Controls Team was finding sensors that could withstand a rocket launch. The fact is most products available for the Arduino were not designed with 20g's of acceleration in mind. This was a problem experienced first-hand by the OSU Senior Design team when launching their quadcopter. To solve this, an effort was made to ensure the data sheets of every sensor used was checked to ensure failure would not happen from launching alone. Additionally, every component or wire that could possibly vibrate loose is hot glued down to ensure it stays put.

6) Software Layout Considerations

The software was really the heart of the whole airbrake. It harmonized the airbrake hardware and electronics together into one functional unit. One of the biggest challenges that the Controls Team focused most on was optimizing the software. Since the airbrake needed to react to what was happening in real time, every clock cycle of the Arduino was important. The Arduino's 16 MHz may sound like a lot, but anything outside of the simplest calculations can take up a bunch of cycles. For example, the SD card logging software initially opened and closed the log file between every data point it was writing, but after changing that to writing a whole line of data points at once the cycle time for polling and writing the sensor data reduced by 3/10ths of a second. That change allowed the software to go from polling sensors at 3 Hz to around 12 Hz.

Repeatability is another big factor with the code. Great effort was taken to ensure it was as simplistic as possible to ensure it didn't do anything unexpected. This means more than just simply using the least amount of lines and letters possible in the code, because when it comes down to it the Arduino probably won't get confused. The code was kept simple for the benefit of those working on it. Especially with multiple people editing code, it's important that variables are intelligently named, the code flows in a logical manner, and functions are used to reduce redundancy in the code. This also made the code easier tune for the airbrake which once again leads to more predictable results.

Focus on simplicity doesn't mean that the code is too bare bones, however. A buzzer was implemented which will sound unique tones for normal operation, malfunctioning sensors, abnormal readings, or low batteries. Such redundancies allow the airbrake to check itself in the case of human error. This adds a second layer of security into the airbrake operations and make it less likely to malfunction. Of course, the buzzer isn't the only diagnostic tool. An SD card was also implemented which allows for the logging of all data that the airbrake gathers from sensors. It also records what position the airbrake is in during flight. This is the "black box" of the airbrake ensuring that if something does go wrong, it can be more easily diagnosed after the event. The electronics are set up in such a way that anything short of the SD card physically breaking wont corrupt the log files on board ensuring flight data will always be available.

7) Final Avionics Layout

The Controls Team decided to base the avionics around an Arduino platform. A full list of parts can be seen below. The Arduino Uno R3 was chosen due to its wide range of support, shields, and libraries available making it the easiest platform to work with. Powering the Arduino is a 2000mah 7.3Wh lithium ion battery that is regulated through an EnergyShield 2 Basic. Initial testing has shown that this battery should provide power for at least 7 hours which should be more than enough. Connected to the Arduino is a series of sensors. The first is an Adafruit BMP280 Sensor. It ranges from -500m to +9000m above sea level. Its accuracy is +/- 1m which should be more than sufficient for what's needed for the code. The next sensor is the Sparkfun ADXL377 accelerometer which ranges from -200g to +200g's. This is an analogue sensor, and initially the Controls Team ran into issues with the Arduino because it only had a 10bit ADC which did not provide sufficient resolution. To counteract this, the ADS1115 Board which provides 16bit resolution was used in conjunction with the accelerometer. In order to create logs of all the data being collected, the Adafruit SD Breakout Board was used which provides a quick means for storing data. This board is particularly nice because the SD card is able to be clicked into place instead of just resting in a slot. Power was routed to all these sensors from a distribution board made from a simple perf board. This allowed one power port on the Arduino to be distributed to 8 different wires. A Piezo Buzzer was also used to play noises for both normal operation and if there is an error detected in the sensors on startup.

The airbrake itself is actuated by a NEMA 17 Stepper Motor that has 0.6N*m of holding torque. Simulations run by the Controls Team show this is more than enough to actuate the airbrake, even at the highest force loading. The motor is powered by a 3.7V lithium ion battery that plugs into a barrel jack connector. There is a 100 μF capacitor in between the battery and the motor to handle any voltage spikes that may occur to protect the motor. A DRV 8825 stepper motor driver is used to interface between the motor and the Arduino allowing for precise control over the airbrake's movement. A full parts list can be seen below.

The entire airbrake was wired using standard electronic jumper cables. The diagram for this wiring can be seen in the picture below along with a flowchart for the code running on the Arduino.

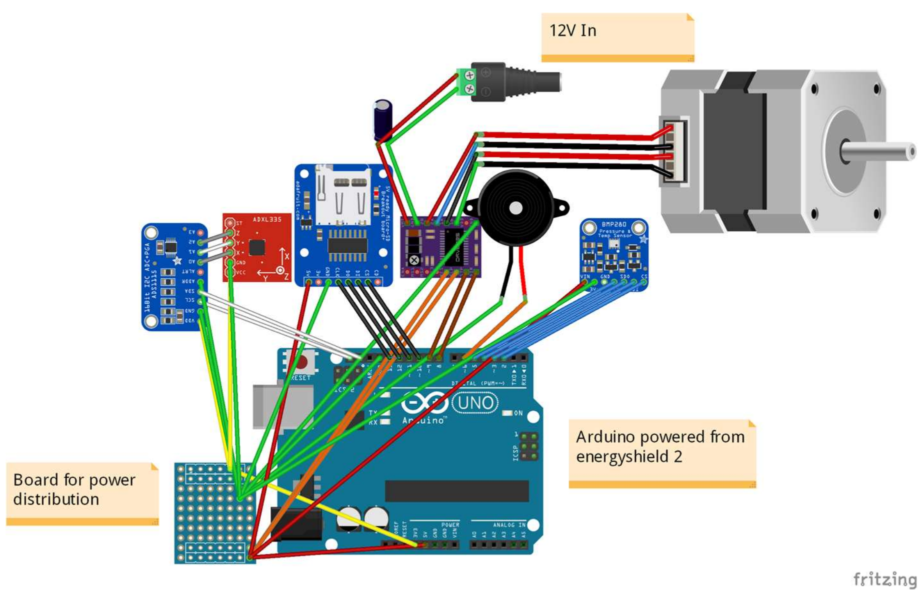


Figure 15. Final avionics wiring schematic.

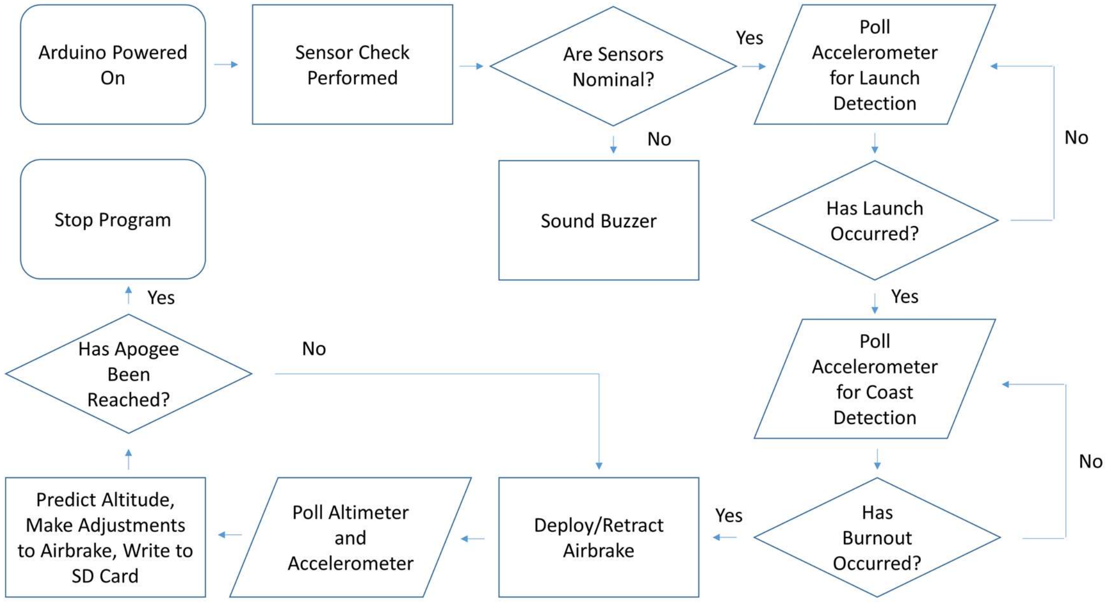


Figure 16. Software Flow Chart

8) Results of Avionics Testing

The first test of the avionics hardware was performed in March. It consisted of launching the Arduino, SD Board, Accelerometer, and an altimeter on a rocket to make sure they could all handle the forces of a launch. For this test, a SL100 was being used as the altimeter, but that has since changed. The reason for this was problems with the altimeter being difficult to interface with the Arduino. All electronics did successfully held up and recorded data as expected for this test.

Next, the Avionics package did an endurance test to make sure the code performed as expected and to check how big the log files can get. The Arduino was plugged into a power outlet and run for 3 days collected data the entire time. Throughout the test, sensor data read remained constant and the log file stayed at a reasonable size meaning the code was good and the test was successful.

As of writing this, the final test performed was to see how long the Arduino lasts under the battery power pack powering it. The Arduino ran for 7.3 hours before the battery pack was switched off due to concerns of the battery level getting too low. This constituted a successful test due to demonstrating the ability to run all day without being recharged.

9) Final Airbrake Configuration

The final full airbrake configuration can be seen below. The fiberglass plate on the bottom screws into the motor, and then the 80/20 rods are connected by bolt to the plate. The reason for these rods is to space the airbrake up above the coupler tube connecting the airbrake tube to the aft sections. Threaded rods are then screwed into the 80/20 rods and go through the entirety of the airbrake. A forged eye bolt is screwed into the top plate which is held on by bolts. This design provides a means for the parachute to connect to the motor without sacrificing structural strength.

Figure 17. Final airbrake

III. Mission Concept of Operations Overview (CONOPS)

During flight at the 2018 Spaceport America Cup, Cowboy Rocketworks' launch vehicle, *Results May Vary,* will experience various stages of performance and functionality throughout flight.

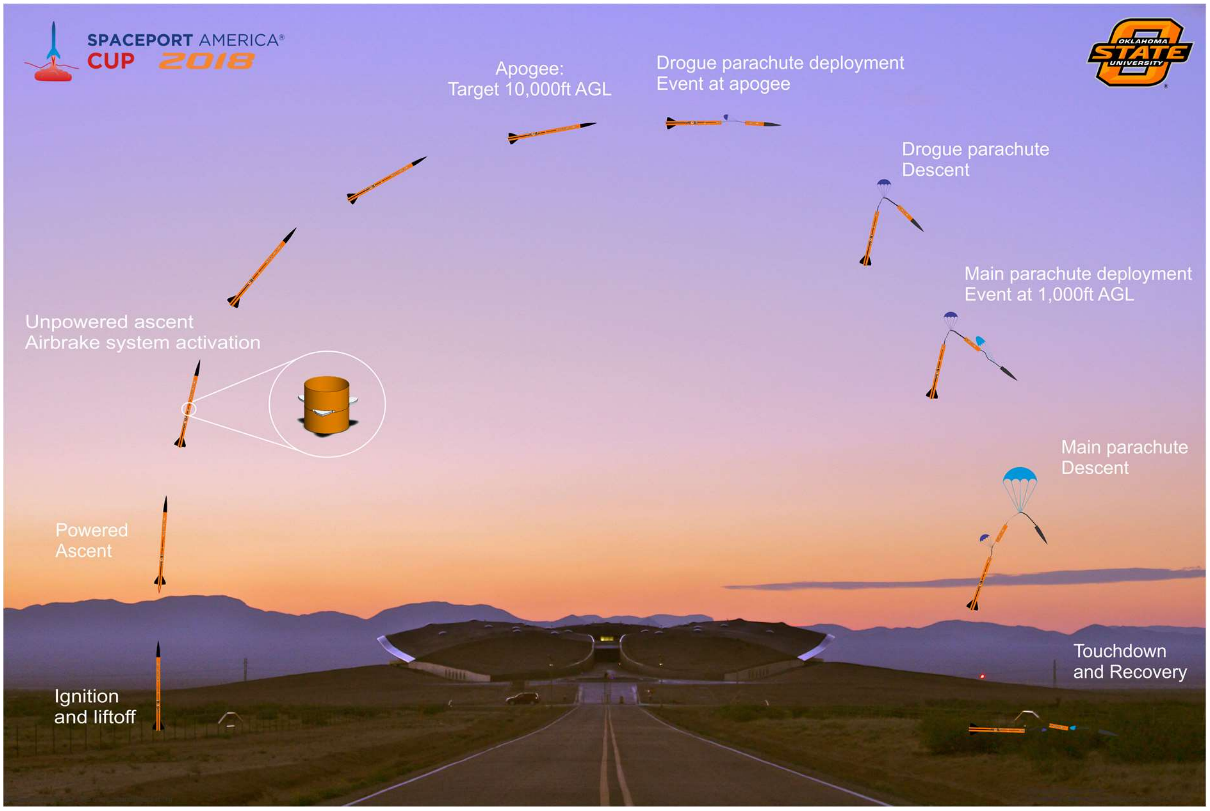


Figure 18. Cowboy Rocketworks *Results May Vary* Concept of Operations Overview.

The flight trajectory of *Results May Vary* begins with motor ignition which is achieved by electrical arming and launch at the ESRA-provided launch control system. The student-prepared electronic match burns briefly, igniting the forward-most end of the propellant grain. As the Aerotech M1939W composite motor comes up to pressure, and the liftoff sequence is initiated. As thrust builds, the trust to weight ratio exceeds one, and the rocket begins ascent up the ESRA-provided launch rail. The 3D-printed airfoiled rail buttons ensure direct vertical ascent as the rocket clears the 17-foot tall rail. Once the aft-most rail button is cleared, the rocket is free of all ground support equipment and begins the powered ascent phase of flight.

During ignition and liftoff, the airbrake as developed by Cowboy Rocketworks, remains disengaged as the system registers the current altitude remains below the expected altitude at motor burnout. Upon clearing the launch rail, the rocket has achieved the necessary velocity for the fins to provide aerodynamic stability. This aerodynamic stability is confirmed by a thrust to weight ratio at liftoff greater than 5:1. With *Results May Vary* launching under a 6:1 ratio, the fins will provide the necessary stability for powered ascent. The rail departure velocity is 62 ft/s according to the model's OpenRocket simulation.

Powered ascent under motor boost lasts 6.2 seconds during which the airbrake is still mechanically disengaged, and the actively operational subsystems are propulsion, payload, and recovery (altimeter recordings). Upon motor burnout, *Results May Vary* is simulated to be moving at 518 miles per hour, having passed maximum velocity just a half second beforehand at 561 miles per hour and an altitude of 3700 feet AGL.

Following motor burnout, the unpowered ascent phase of flight begins during which the majority of its altitude will be reached. Propulsion systems are now inactive and reload hardware becomes unused weight. Presently the airbrake will engage and become mechanically operable, taking altimeter input, running the software program, and automatically extruding the fins to gradually induce drag and reduce the expected apogee to precisely 10,000 feet AGL.

After successful airbrake operation, apogee is expected to be 10,000 feet at which point the redundant altimeters register maximum altitude. The primary altimeter, an Altus Metrum TeleMega will fire the drogue charge to separate the rocket into two halves and deploy the 22-inch SkyAngle Cert-3 drogue parachute. The secondary altimeter, a StratologgerCF, will also fire at apogee. As the drogue parachute unfurls, downward velocity will increase to terminal velocity of 141 ft/s. Here the airbrake will return to gridfin zero angle of attack (flush with airframe) and become mechanically inactive for the remainder of the flight.

Results May Vary will fall from 10,000 feet to 1,000 feet under the drogue parachute with the redundant altimeters monitoring descent, anticipating the altitude for main event ejection. At 1,000 feet AGL, the primary altimeter will fire the main parachute ejection charge. The redundant altimeter will fire at 800 feet and separate the rocket should the primary altimeter fail.

The main ejection charge pushes all components inside the forward airframe out of the rocket. This includes two sets of shock cord, the SkyAngle Cert-3 XL main parachute, but not the payload. The main parachute will unfurl and reduce the descent rate of the entire rocket to 14.5 ft/s at which point the segments of *Results May Vary* will touch down gently near the launch site.

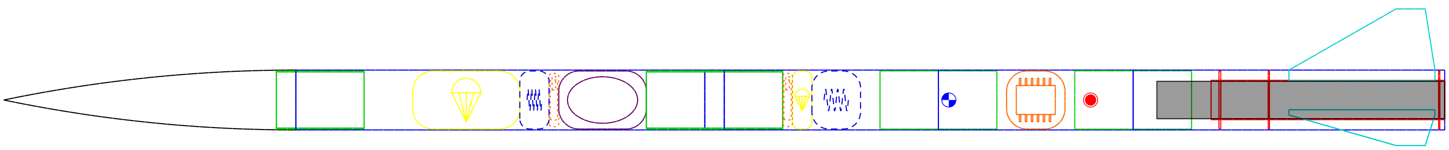
Mission success is characterized primarily by two recovery deployment events, touchdown and recovery without damage to any components of the rocket including aero-structures, recovery components, and payload. Apogee close to 10,000 feet is also important but only significant following a safe return to the ground.

These collective mission phases contribute to a successful flight at the 2018 Spaceport America Cup.

IV. Conclusions and Lessons Learned

Cowboy Rocketworks has come a long way in two years. The team is tremendously excited to be competing in the largest collegiate rocketry competition in the world. Its members look forward to building more of the rockets from scratch, especially now that they are making their SRAD fiberglass airframes and sheets. Regardless of the outcome at the 2018 Spaceport America Cup, the team has achieved so much, and the road here has shaped the student's lives during their time in college and will affect their professional careers for years to come.

Rocket Design



Rocket

Stages: 1

Mass (with motor): 63.2 lb

Stability: 2.36 cal

CG: 97.065 in

CP: 112 in

M1939W-P

Altitude	10857 ft
Flight Time	181 s
Time to Apogee	26.1 s
Optimum Delay	19.2 s
Velocity off Pad	45.2 mph
Max Velocity	627 mph
Velocity at Deployment	84.4 mph
Landing Velocity	9.07 mph

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
M1939 W	1582 N	6.52 s	2084 N	10340 Ns	5.62:1	11.7 lb	3.86/29.6 in

M1500G-0

Altitude	5061 ft
Flight Time	129 s
Time to Apogee	18.5 s
Optimum Delay	15 s
Velocity off Pad	52.3 mph
Max Velocity	400 mph
Velocity at Deployment	86.3 mph
Landing Velocity	9.4 mph

Motor	Avg Thrust	Burn Time	Max Thrust	Total Impulse	Thrust to Wt	Propellant Wt	Size
M1500 G	1491 N	3.5 s	1717 N	5217 Ns	6.14:1	5.8 lb	2.95/26.2 in

Parts Detail

Sustainer

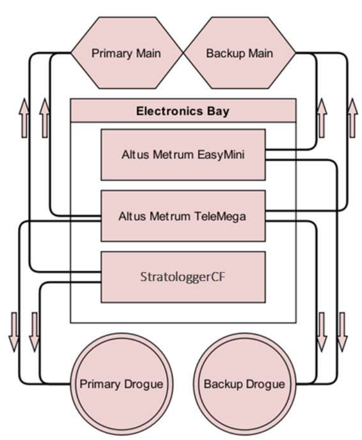
Mad Cow 6" Nosecone	Fiberglass (1.07 oz/in^3)	Ogive	Len: 30 in	Mass: 3.42 lb
Nose Cone Coupler	NEW FIBERGLASS (1.2 oz/in^3)	Dia_{in} 5.775 in Dia_{out} 5.998 in	Len: 9 in	Mass: 1.15 lb
Body tube	Fiberglass (1.07 oz/in^3)	Dia_{in} 6.01 in Dia_{out} 6.17 in	Len: 42 in	Mass: 4.45 lb
SkyAngle Cert-3 XLarge	Ripstop nylon (0.22 oz/ft^2)	Dia_{out} 126 in	Len: 11 in	Mass: 2.81 lb
Shroud Lines	Tubular nylon (25 mm, 1 in) (0.312 oz/ft)	Lines: 3	Len: 100 in	
24" Parachute Protector		Dia_{out} 5.5 in		Mass: 0.201 lb
Shock Cord	1" Blue Nylon Wildman Shock Cord (0.44 oz/ft)		Len: 480 in	Mass: 1.1 lb
Payload		Dia_{out} 5.984 in		Mass: 9 lb
Slip Band	Blue tube (0.751 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 2 in	Mass: 0.212 lb
Electronics Bay	Blue tube (0.751 oz/in^3)	Dia_{in} 5.775 in Dia_{out} 5.998 in	Len: 14 in	Mass: 1.14 lb
Drogue Compartment	Fiberglass (1.07 oz/in^3)	Dia_{in} 6 in Dia_{out} 6.17 in	Len: 22 in	Mass: 0.146 lb
SkyAngle Cert-3 Drogue	Ripstop nylon (0.22 oz/ft^2)	Dia_{out} 22 in	Len: 2 in	Mass: 0.375 lb
Shroud Lines	Tubular nylon (25 mm, 1 in) (0.312 oz/ft)	Lines: 3	Len: 24 in	
Drogue Shock Cord	1" Blue Nylon Wildman Shock Cord (0.44 oz/ft)		Len: 480 in	Mass: 1.1 lb
Tube coupler	Cardboard (0.393 oz/in^3)	Dia_{in} 6 in Dia_{out} 6 in	Len: 12 in	Mass: 1 lb
24" Parachute Protector		Dia_{out} 5.5 in		Mass: 0.201 lb
Air Brake	Fiberglass (1.07 oz/in^3)	Dia_{in} 6.013 in Dia_{out} 6.17 in	Len: 20 in	Mass: 2.12 lb
Tube coupler	Fiberglass (1.07 oz/in^3)	Dia_{in} 6.013 in Dia_{out} 6.013 in	Len: 12 in	Mass: 1 lb
Air Brake Components		Dia_{out} 5.984 in		Mass: 6 lb
Aft Section	Fiberglass (1.07 oz/in^3)	Dia_{in} 5.99 in Dia_{out} 6.17 in	Len: 32 in	Mass: 3.39 lb

Motor Mount Tube	Blue tube (0.751 oz/in³)	Dia$_{in}$ 3.88 in Dia$_{out}$ 4.06 in	Len: 24 in	Mass: 1.64 lb
Forward Centering Ring	Fiberglass - Wildman (1.21 oz/in³)	Dia$_{in}$ 3.858 in Dia$_{out}$ 5.99 in	Len: 0.187 in	Mass: 0.234 lb
Mid Centering Ring	Fiberglass - Wildman (1.21 oz/in³)	Dia$_{in}$ 3.858 in Dia$_{out}$ 5.99 in	Len: 0.125 in	Mass: 0.156 lb
Aft Centering Ring	Fiberglass - Wildman (1.21 oz/in³)	Dia$_{in}$ 3.858 in Dia$_{out}$ 5.99 in	Len: 0.125 in	Mass: 0.156 lb
Fins (3)	Fiberglass (1.07 oz/in³)	Thick: 0.187 in		Mass: 2.74 lb

Appendix B: Project Test Reports

Tests for Cowboy Rocketworks in preparation for the 2018 Spaceport America Cup

Date	Type	Description	Status	Comments
1/15/18	Other	Begin CFD optimization of fins	Successful	Based optimization off current research papers
1/19/18	Other	First iteration of SRAD fiberglass tube	Successful	Smaller diameter for first iteration
2/5/18	Other	Begin CFD validation of CP locations with fins	Successful	Rocket shouldn't destabilize when airbrake deploys
2/16/18	Ground	Ejection charge test	Successful	For internal pressure validity
2/17/18	In-Flight	First flight test using SRAD tubes	Successful	Small scale test flight only
3/11/18	In-Flight	High-G test of SRAD tubes	Successful	15G simulated, good recovery
4/6/18	Ground	Large-scale ejection charge test	Successful	Took 2 attempts
4/8/18	In-Flight	First large-scale test flight on M1500G	Successful	Deploy of main at 1200m not 1200ft
4/16/18	Ground	Validate airbrake and code work on ground	Successful	Airbrake actuates successfully, Code ran for 2 days
4/16/18	Ground	Check Battery life of avionics	Successful	Battery lasted over 7 hours
5/3/18	Ground	Endurance test for camera batteries	Successful	Batteries allow 5 cameras to record for aproximately 3 hours
5/30/18	Ground	Full-scale ejection charge test	TBD	With airbrake and payload hardware
6/1/18	In-Flight	Full-scale flight test	TBD	Full motor, payload and airbrake functionality
6/2/18	Ground	Verify video stitching techniques	TBD	Video stitching using commercial software



Altimeter Bay wiring schematic

Appendix C: Hazard Analysis

Team	**Rocket/Project Name**	**Date**		
Cowboy Rocketworks	Results May Vary	5/25/2018		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation approach**	**Risk of injury after mitigation**
Motor ignites early on launch rail	Short in electrical ignition system	Low; Most of launch system will be set up by Spaceport America Cup personnel and launch control is overseen and operated by Spaceport America Cup personnel.	Arm recovery energetics before inserting igniter. Should the rocket launch early it will not endanger spectators by falling in an uncontrolled manner	Low
	Accidental launch ignition by launch control crew		Have only one crew member at launch rail during and after insertion of igniter.	
			Touch ends of igniter wire together during insertion to reduce chance of accidental ignition of igniter.	
Fuel grains ignite during flight preparation or transportation	Flames or sparks impinging on fuel grains	Low; No preparation activities for Results May Vary require open flames and few have the potentiality of creating sparks	Store fuel grains in a flame-resistant case until motor is loaded.	Low
Black powder ignites during flight preparation or transportation	Flames or sparks impinging on black powder	Medium; Active altimeters can sometimes falsely ignite attached charges	Store black powder in flame resistant case until flight preparation	
	Electronics unintentionally ignite black powder		Completely disengage all power sources from electronics during loading of black powder charges	
			Only arm altimeters when rocket is in launch position	
Electrocution by electronic systems during flight preparation	Short created by accidentally touching exposed metal of electrical systems	Low; power sources are all low voltage (9V or less) and wires being used are insulated	Completely disengage all power sources while working on electrical systems	Low

Appendix D: Risk Assessment

Team	**Rocket/Project Name**	**Date**		
Cowboy Rocketworks	Results May Vary	5/25/2018		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation approach**	**Risk of injury after mitigation**
Explosion of solid-propellant rocket motor during launch with blast or flying debris causing injury	Cracks in Propellant grain	Medium-Low; Motor in use is a large motor but is a COTS motor. Motor will be reloaded by experienced team members	Visually inspect grain during reload	Low
	Debonding of propellant from wall		Inspect motor casing for damage and cleanliness	
	Gaps between propellant sections and/ or nozzle		No non-essential personnel in launch crew	
	Chunk of propellant breaking off and plugging nozzle		Launch crew farther than 200 feet from rocket at launch	
	Motor case unable to maintain operating pressure		Follow reload procedures outlined in instruction manual	
	Motor end closures fail to hold			
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Rocket does not achieve proper lift off speed	Low; Fins are secure, and flight proven. TWR is in excess of 6.8	Firmly attach fins with high grade epoxy and sand fiberglass at epoxy joints to ensure proper bonding	Low
	Failure of rocket fins		Ensure Proper lift-off weight	
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Altimeter fails	Medium; many timing critical events lead to several chances for failure	Use redundant recovery systems with multiple	Moderate
	Deploy charges are not properly prepared		Test samples from deployment charges	
	Drogue deploys too early/too late		Perform static ejection charge tests with parachutes in flight configuration	
			Perform flight tests of rocket in competition configuration	
			Visually track all rockets in flight until ground contact	
Recovery system partially deploys and comes in contact with personnel	Parachute is improperly folded/stored	Medium; an improperly folded parachute with almost certainly cause the recovery system to improperly deploy. Chutes packed into tube too tightly may possibly not deploy when rocket separates	Spend time practicing folding parachute and double check folding work in field.	Moderate
			Perform static ejection charge tests with parachutes in flight configuration	

Recovery system deploys detonates before launch and causes an injury	Improper handling of black powder Glitch in electronic deploy systems	Medium; Black powder is a volatile material that can be set off accidentally	Store Black powder charges in metal Keep minimal number of people near armed Wait until ready to launch to arm recovery system	Low
Main Parachute deploys at apogee and rocket drifts into an area where it could cause an injury	High winds cause rocket to drift	High; any amount of wind can cause a rocket with a high-altitude apogee deploy to drift a long distance	Use dual deploy with a small drogue at apogee and main chute at lower altitude. Launch far from any populated areas and Ensure winds are not above safe speeds prior to launch	Low
Rocket motor does not ignite when command is given but does ignite when team approaches	Poor propellant consistency Damp propellant Improperly installed igniter	Low; commercial motor and igniter are being used	Wait until range safety officer gives go ahead to approach rocket Have team approach slowly and carefully and watch for signs of ignition	Low
Rocket falls from launch rail during preparation	Rail buttons are not properly secured to hold weight of rocket Rocket slips from the hands of the team while putting it on the rail	Medium; a heavy rocket is prone to slippage and puts more stress on rail buttons	Use proper construction techniques and materials for rail buttons Load rocket slowly and ensure that load crew has control of rocket at all times	Low

Cowboy Rocketworks

Materials Checklist

All materials should carry duplicates when possible

- ☐ *Results May Vary*
- ☐ 98/10240 Motor casing
- ☐ 98mm forward closure
- ☐ 98mm aft closure
- ☐ 98mm forward seal disk
- ☐ Motor igniters
- ☐ Masking tape
- ☐ Electrical tape
- ☐ Zip ties
- ☐ Cordless drill
- ☐ Cordless drill bits and attachments
- ☐ 9V batteries
- ☐ Wire strippers
- ☐ Pliers
- ☐ Table scale
- ☐ Hanging scale
- ☐ Measuring tape
- ☐ Black powder
- ☐ Electronic matches
- ☐ Black powder canisters
- ☐ Model rocket wadding
- ☐ Precision screwdrivers
- ☐ Arming screwdrivers
- ☐ Grease
- ☐ Vinyl gloves
- ☐ Epoxy
- ☐ Mixing cups for epoxy
- ☐ Mixing sticks for epoxy
- ☐ First aid kit
- ☐ Sandpaper
- ☐ Shop towels
- ☐ Cleaning supplies
- ☐ Knife
- ☐ Personal Identification
- ☐ Pen
- ☐ Clipboard

Cowboy Rocketworks

Assembly Checklist

- ☐ Ejection charges wired into altimeters
- ☐ Fresh battery connected properly
- ☐ Fresh battery secured properly inside altimeter bay
- ☐ Fresh battery with **taped** snap connector
- ☐ Altimeter bay sealed and secured with switch OFF
- ☐ Altimeter bay is screwed together and secure
- ☐ Black powder charges are secure on either end of altimeter bay
- ☐ Ensure static ports on altimeter bay are free and open to air
- ☐ Attach payload to the electronics bay
- ☐ Attach lenses to cameras
- ☐ Install airbrake
- ☐ Confirm that screws are tightened
- ☐ Recovery devices connected via quick links to (6) eyebolts
- ☐ Parachutes and shock cord packed on correct side of parachute protectors
- ☐ Vent holes free of paint, gunk, dirt, and fuzz
- ☐ Shear pins installed through nose cone and forward airframe
- ☐ Shear pins installed through airbrake airframe and ebay
- ☐ Fasteners installed through altimeter bay and forward airframe
- ☐ Fasteners installed through airbrake and aft airframe
- ☐ Insert motor
- ☐ Secure motor retention

Cowboy Rocketworks

Pre-Flight Checklist

- ☐ Motor installed
- ☐ Motor retention good
- ☐ Ensure static ports on altimeter bay are free and open to air
- ☐ Confirm all shear pins are in place
- ☐ Confirm all tube fasteners are in place
- ☐ Rail buttons secure
- ☐ Tracking on
- ☐ Flight card completed

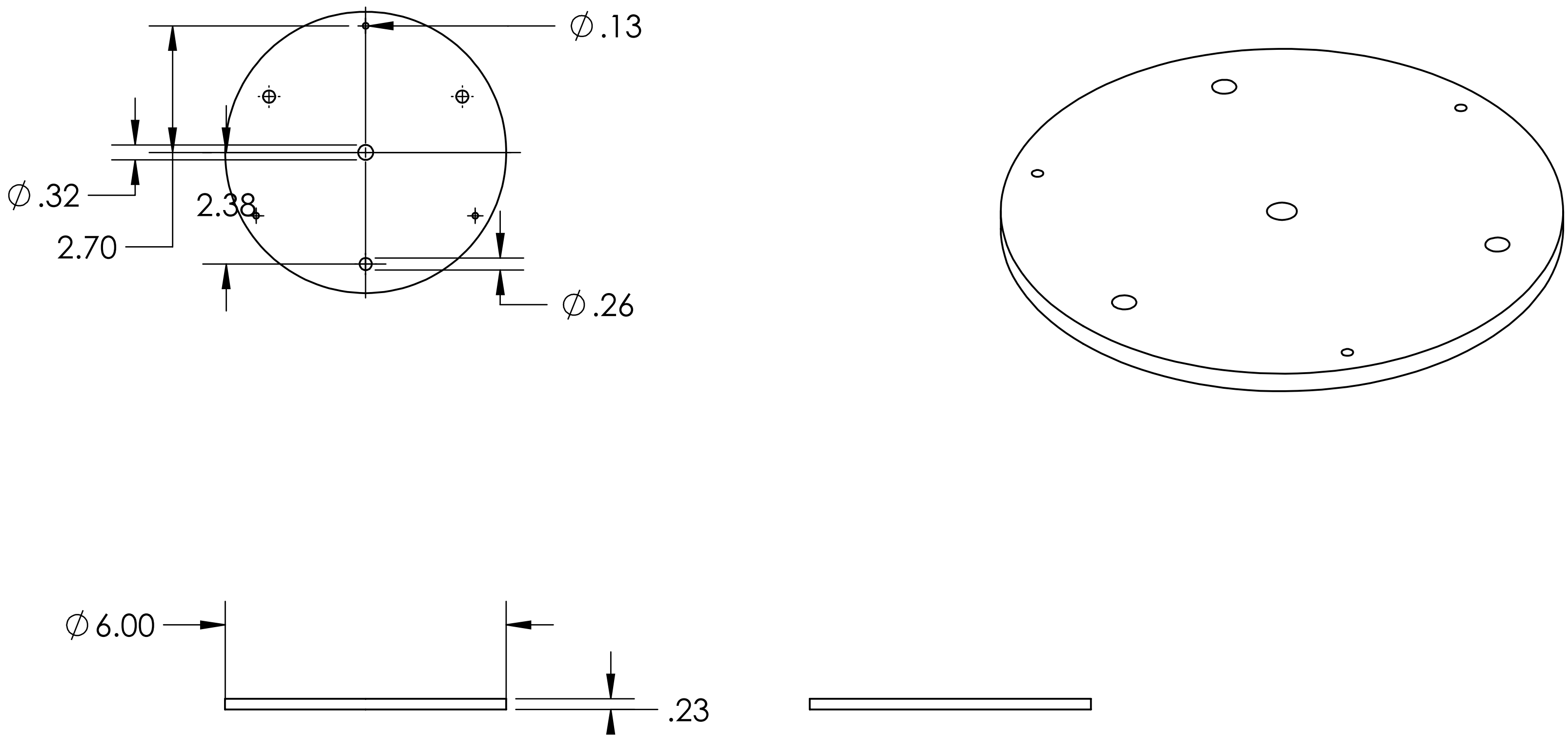
Cowboy Rocketworks

Launch Checklist

- ☐ Strip igniter wire leads
- ☐ Igniter on hand for installation once on the pad
- ☐ Confirm tracking on
- ☐ Slide rocket onto launch rail
- ☐ Arm electronics via external switches
    - altimeters
    - airbrake
    - payload
- ☐ Install igniter in motor
- ☐ Connect igniter leads to power
- ☐ Good luck wraps
- ☐ Confirm continuity

Appendix F: Engineering Drawings

(THIS PAGE BLANK, CONTINUED ON NEXT PAGE)



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

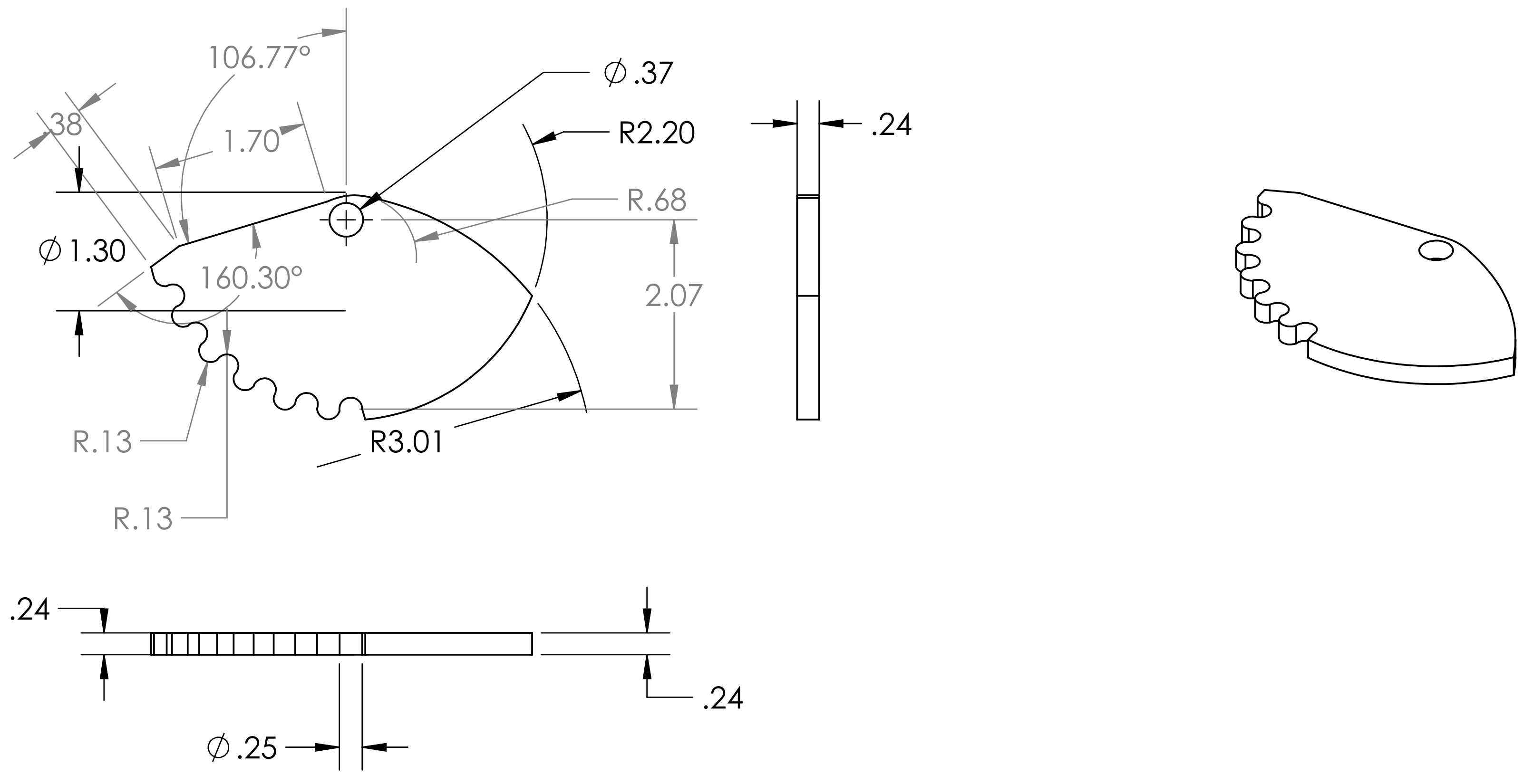
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	base Rev A	

SCALE: 1:4 WEIGHT: SHEET 1 OF 1



2 1 B A

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

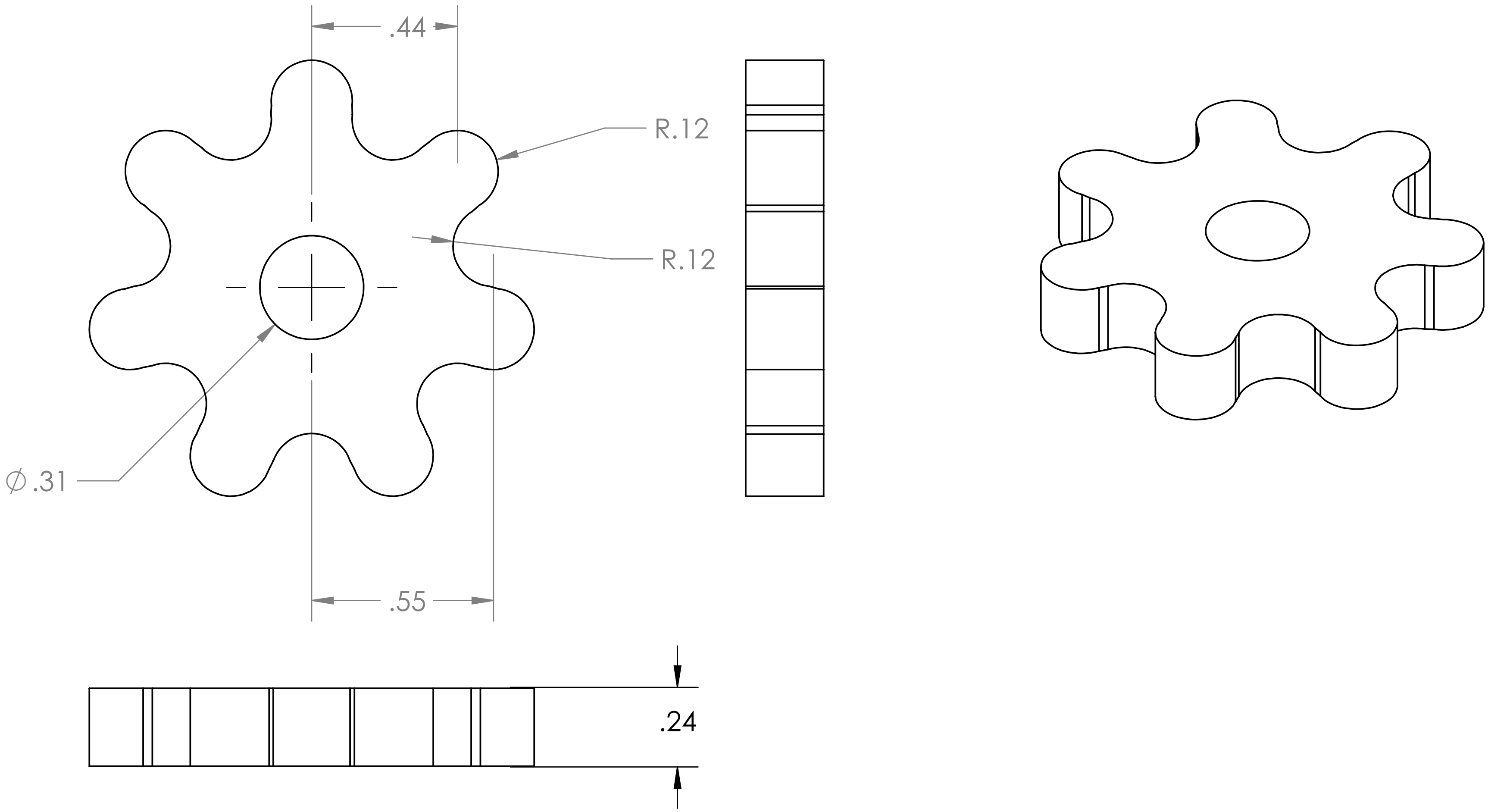
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Fin Rev A	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

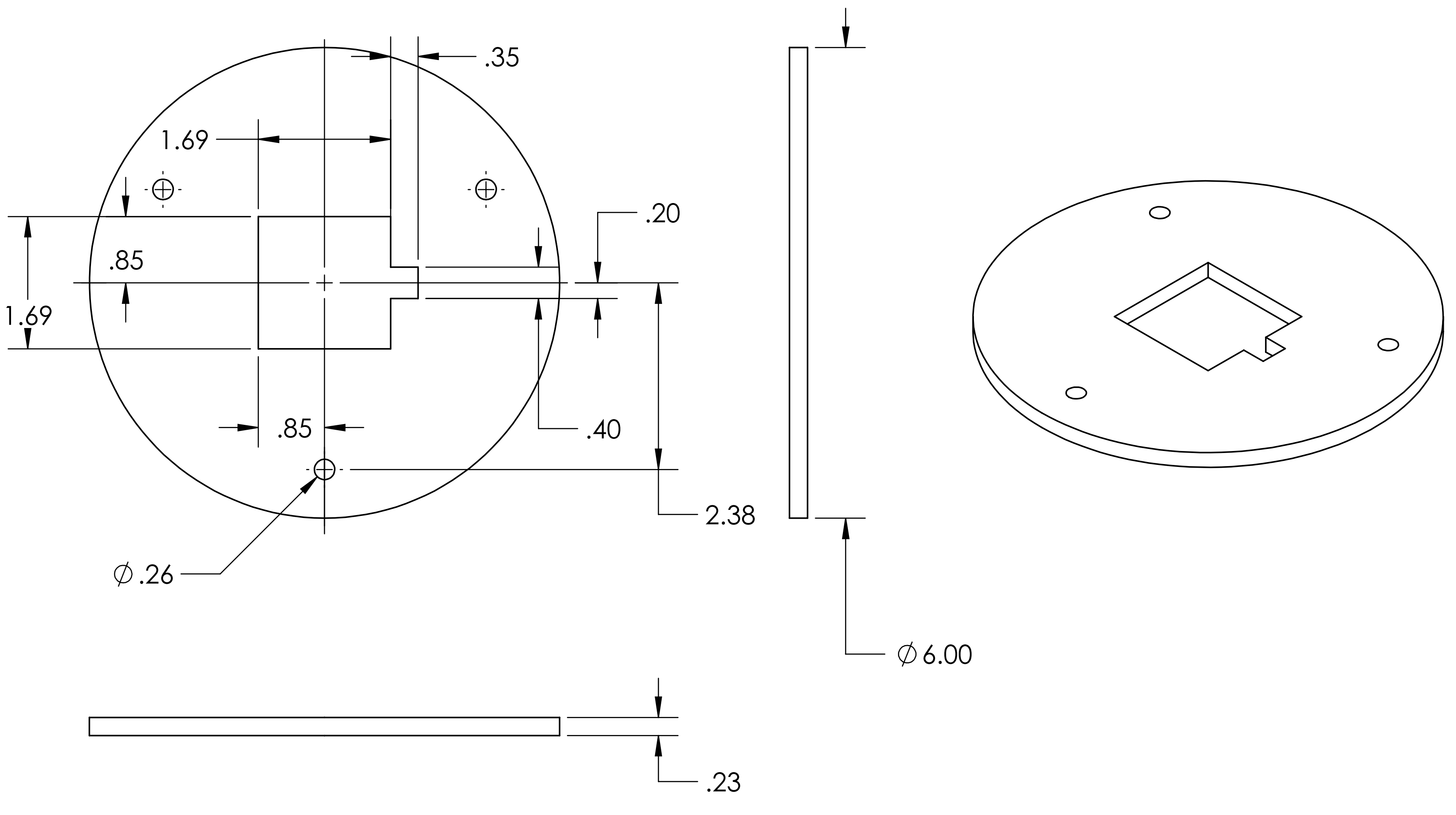
PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

TITLE:

SIZE	DWG. NO.	REV
A	gear small Rev A	A

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

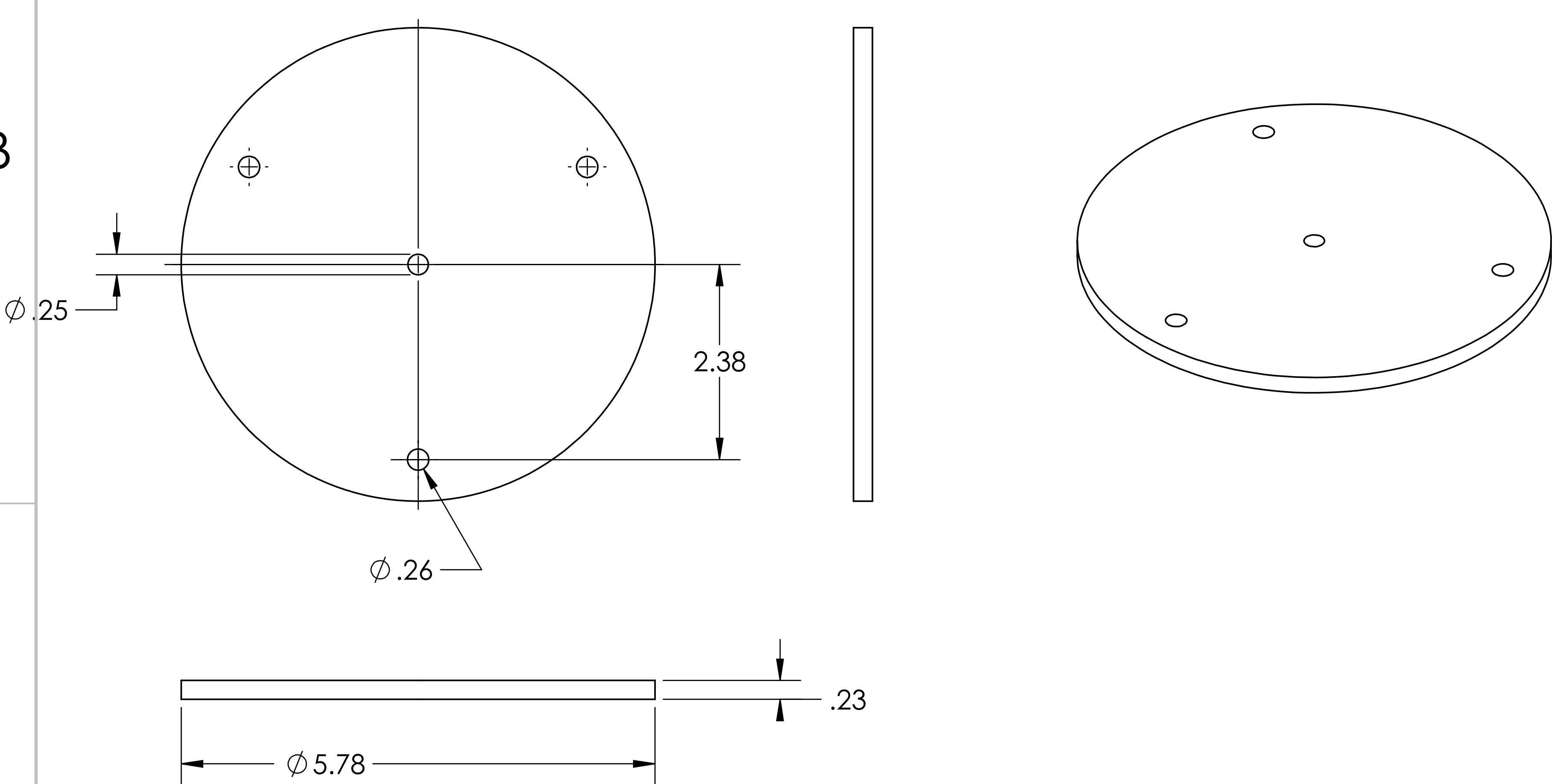
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A DWG. NO. Sensor base Rev A REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

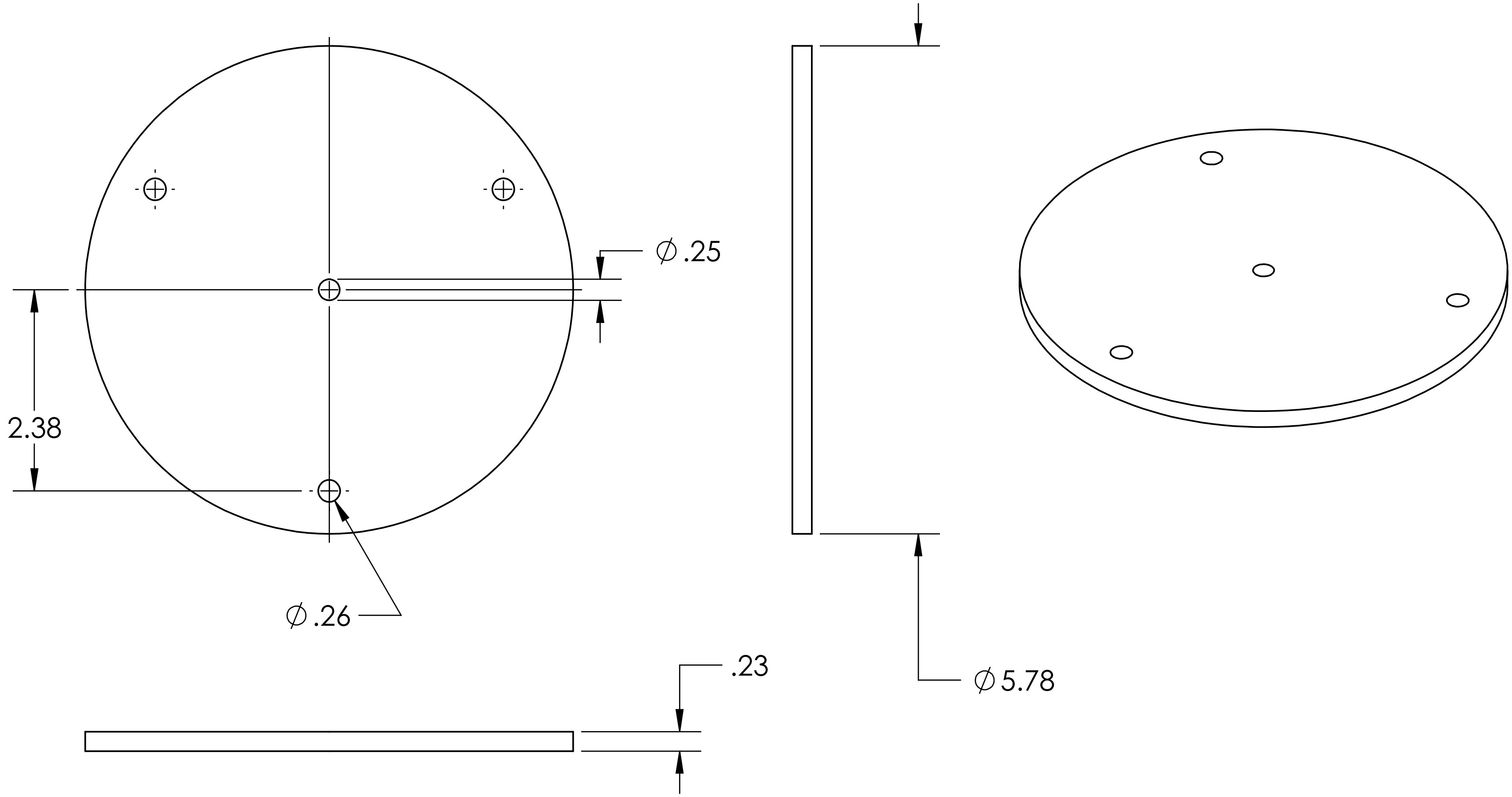
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A | DWG. NO. Top and Bottom Plate | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

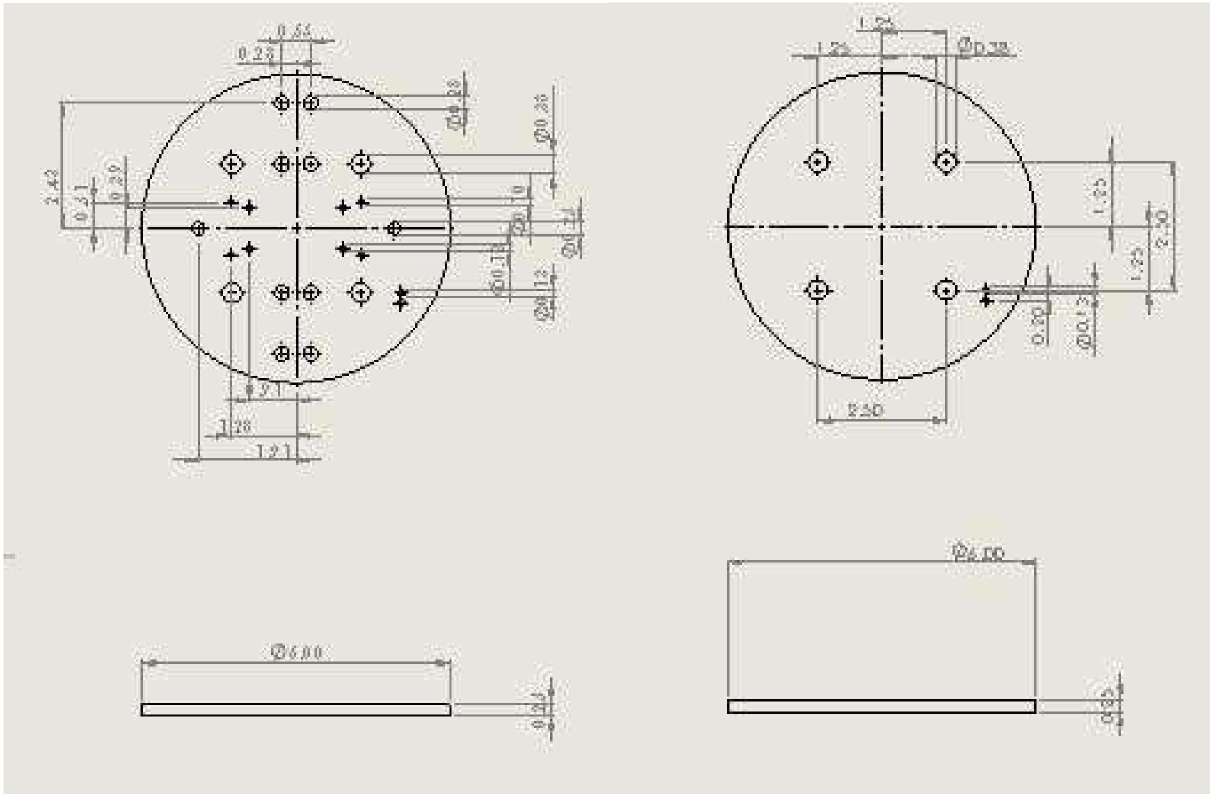
COMMENTS:

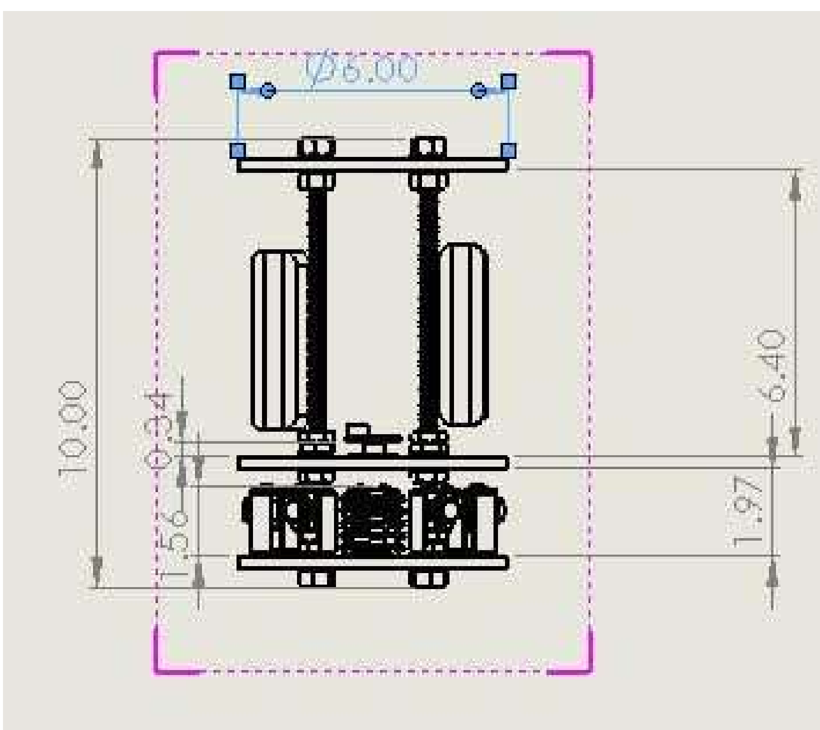
TITLE:

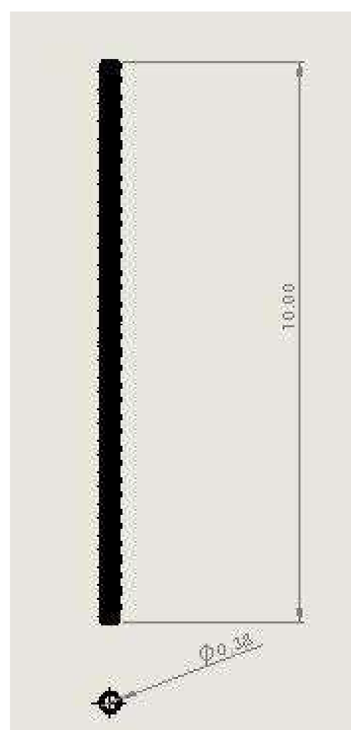
SIZE	DWG. NO.	REV
A	Top base Rev A	A

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

Payload Drawings







Appendix G: Airbrake

Airbrake Hardware Bill of Materials

Item	Quantity
1' long 1" 80/20 pole	3
1' x 2' 1/4" plywood sheet	2
1' long 1/4" threaded rod	3
1" long 1/4" bolt	3
Shoulder Screw 1/8" diameter 7/8" long	3
1/8" nylon nut	3
1/8" washer	12
1/4" diameter 1/4" long nylon spacer	6
1/4" lock nut	3
9" long jumper wires	42
1'x1' 1/4" fiberglass sheet	1
1" long 1/4" diameter nylon spacers	18
1/8" bearing	6
3/8" forged eye bolt	1
3/8" lock nut	1
1" long 3/8" bolt	1
3/8" fender washer	6

Timeline of Flight Events

Time	Event
T+0	Launch
T+~7	Burnout Occurs
T+7.1	Airbreak Initializes
T+7.1-24	Airbreak Auto Adjusts to Changing Conditions

Acknowledgments

The Cowboy Rocketworks team would like to thank its sponsors: Spirit AeroSystems, OSU Student Government Association, and OSU CEAT Student Council. Without their financial support and advising, this program wouldn't have grown, let alone afford the resources to compete in the 2018 Spaceport America Cup.

An enormous thank you as well to our 100+ donors who contributed to our PhilanthroPete fundraiser with the OSU Foundation in fall 2017. They helped the team raise $8255, even more than our $8000 goal. Their generosity has made our participation in the Cup a reality.

The team would also like to thank the technical expertise, advisement, and support of Jamey Jacob, Andy Arena, Bob Brown, Mark Logan, Alex Cooper, and those at Oklahoma State University who have helped the team achieve reach this competition.

Finally, the team would like to extend their gratitude and appreciation to ESRA and the Spaceport America for administering and hosting such an incredible event.

References

[1]Canepa, Mark, *Modern High-Power Rocketry 2*, Trafford Publishing, Victoria, BC, Canada, 2005, pp. 108.

[2]OpenRocket, Software Package, Ver. 15.03, Sampo Nickanen, Open Source Software, 2012.

[3]SolidWorks Student Edition, Software Package, Dassault Systemes, Velizy,-Villacoublay, France, 2016.