

2022-2023 MN Space Grant Consortium (MnSGC)

Midwest High-Power Rocketry Competition

Precision Landing Challenge

Preliminary Design Review

UMN MnSGC Rocket Team

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## **1.0 Executive Summary**

The ability to control where and how a descending rocket lands improve usability and decrease risk when flying rockets of any scale. High-powered rocketry is a good middle ground in terms of challenge and cost to test concepts such as vertical landing and guided descent on a rocket. Our team has taken on the challenge of designing and building a rocket that is capable of being steerable during its descent and landing its booster section upright on the ground.

Only one high-powered rocket will be built by the team. The rocket is a 4-inch diameter single-stage rocket with dual deploy capabilities. The rocket will fly on H225 and J293 motors. A parafoil will be ejected from the rocket at apogee and steered via remote control during its descent. A pyrotechnic shock cord separator, also controlled via remote control, will be used to disconnect the booster section when the rocket lands. Landing gear will be utilized to keep the booster section of the rocket upright upon landing.

Our team is made up of students from the University of Minnesota with a range of experience. All team members will participate in the building and launching of this rocket. Ethan Thompson-Jewell and Peyton Kramlich have obtained their level 1 certification.

The team completed the demonstration of rocketry knowledge requirements on February 19th, 2023. Where two model rockets were constructed, flown, and successfully recovered. Pictures can be found below in Photos 2.1& 2.2.

Construction of the rocket will take place during the last two weeks of march. Ethan and Peyton both have experience building high-power rockets and are Level 1 certified. With the additional help from our mentor Dr. Flatten, our team will build the rockets in an efficient manner taking safety into consideration when building and preparing for the flights. Our team plans on completing our test flight in April, date TBD.

## 2.0 Demonstration of Rocketry Knowledge

To demonstrate our knowledge of rocketry our team built and launched the Apogee Apprentice model rocket. Inside these rockets were altimeters to record all the data from their flights and they each flew around 100 ft. As shown in Photo 2.2 we had our entire team meet up for a build day and launched the rockets. We used a small launch pad as shown in orange in Photo 2.1.



**Photo 2.1** Introduction to Rocketry flight launch site before the model rocket launch.

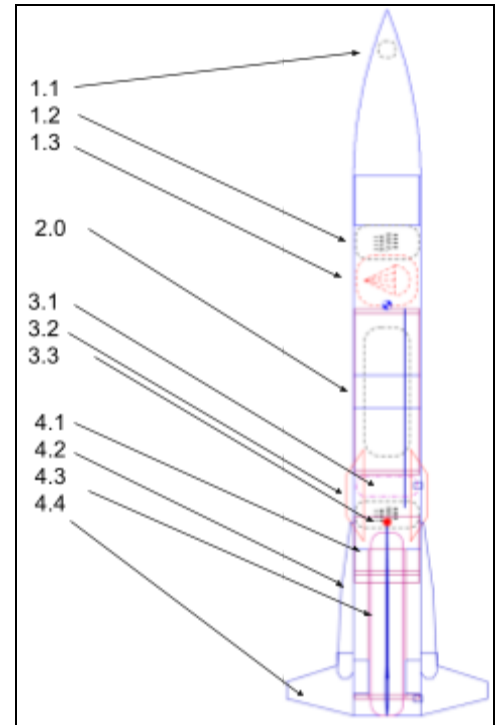


**Photo 2.2** Introduction to Rocketry flight, photo with the entire team post-launch at the launch site.



### 3.0 Rocket Design Overview

Upper Section	1.1	Nose Cone with Ballast
	1.2	Shock cord
	1.3	Parawing
Avionics Bay	2	Avionics (see section 7)
Lower section	3.1	Detachment mechanism (see section 9)
	3.2	Camera mount with Camera
	3.3	Shock cord
Booster section	4.1	separation point between lower section and booster section
	4.2	landing gear
	4.3	motor mount tube with motor mount adapter
	4.4	Fins



General information about the rocket can be found in this section. The following sections explain other subsystems in further detail. The rocket is a 4-inch diameter single-stage rocket with dual deploy capabilities. The mass and length of the rocket are as follows:

Total Mass with H-Motor- 83.6 oz

Total Mass with J-Motor- 103 oz

Length- 42.5 inches

Diameter- 4 inches

### 3.1 Upper Section

#### 3.1.1 Nose cone

The nose cone will be 10in long and made of PVC. Rivets will secure the nose cone to the upper section airframe.

#### 3.1.2 Airframe

The airframe will be 10in long and made of 4in bluetube. Shear pins will secure the upper section to the lower section.

### 3.2 Avionics Bay

Notes: The avionics bay (av. bay) will be 10in long and made of 4in blue tube coupler and will house the electronics within the rocket (see section 4). Self-centering bulk plates will seal the av. bay and is where forged eye bolts will be secured to mount the shock cord.

### 3.3 Lower Section:

An 8.5-inch blue tube lower section will be secured to the bottom of the av. bay with rivets. This section will house the decoupler mechanism and lower shock cord. A 4-inch coupler tube will be epoxied part way into the bottom of this section to connect it to the booster section, being careful to still allow the booster section to separate.

#### 3.3.1 Decoupler Mechanism

Two ends of the aft shock cord will be attached to the decoupler mechanism described in section 8.

### 3.4 Booster Section

#### 3.4.1 Airframe

The booster section airframe will be 10in long and made from bluetube. This section will be connected to the lower section via a 4in long coupler tube. This coupler tube will be epoxied to the lower section.

#### 3.4.2 Fin can

The fin can body will consist of a 10-inch long, 53mm diameter bluetube motor mount tube. The rocket will be compatible with both 53mm and 38mm motors. A motor adapter consisting of a 38mm phenolic tube and laser cut centering rings will allow for the use of 38mm motors in the larger 53mm tube. Laser-cut plywood centering rings at the top and bottom of the motor mount tube will straddle the fin tabs.

#### 3.4.4 Fins

The four rounded trapezoidal fins will be made of laser cut 1/4in plywood. Dimensions can be found in figure 6.1.

### 3.5 Motors and Motor Retention

The rocket will fly on a Cercaroni 273H225-14A H-Class motor, and a Cesaroni J293-13A J-class motor. T-nuts, machine screws, PVC standoffs, and washers will be used for backward motor retention. Forward motor retention will be accomplished by the motor casing used for each respective motor.

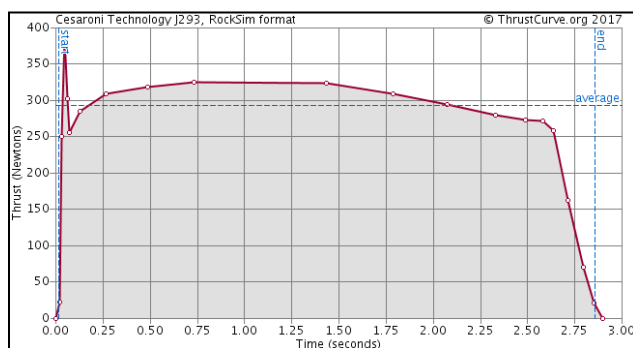


Figure 3.1 Thrust curve for J293-13A

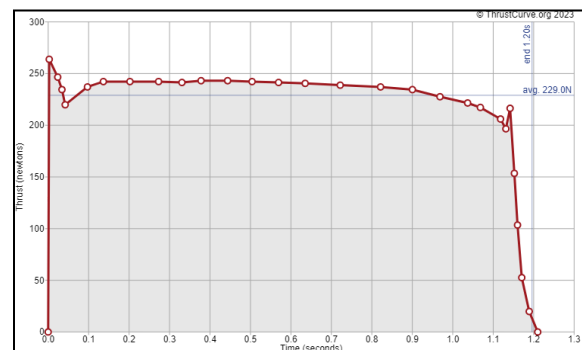


Figure 3.2 Thrust curve for 273H225-14A

### **3.5 Recovery devices**

#### **3.5.1 Parafoil**

Twin Keel rogallo Parafoil will slow the descent of the rocket and allow guided descent to be possible. See section 8.0 for more information.

#### **3.5.2 Altimeter**

An AIM USB altimeter will be used to control the ignition of ejection charges and have a secondary log of the rocket's performance including altitude, speed, and acceleration.

#### **3.5.3 Shock Cord**

The shock cord will be made of 1/2in tubular nylon. The shock cord will secure the upper section to the av. bay and the av. bay to the booster section. The shock cord will be tied to forged eye bolts secured to the respective sections.

### **3.6 Rail buttons**

Standard 1" rail buttons will be used to ensure the rocket flies straight on takeoff. The rail buttons will be positioned in between the fins, see simulation files.

### **3.7 Attachment materials**

#### **3.7.1 Epoxy**

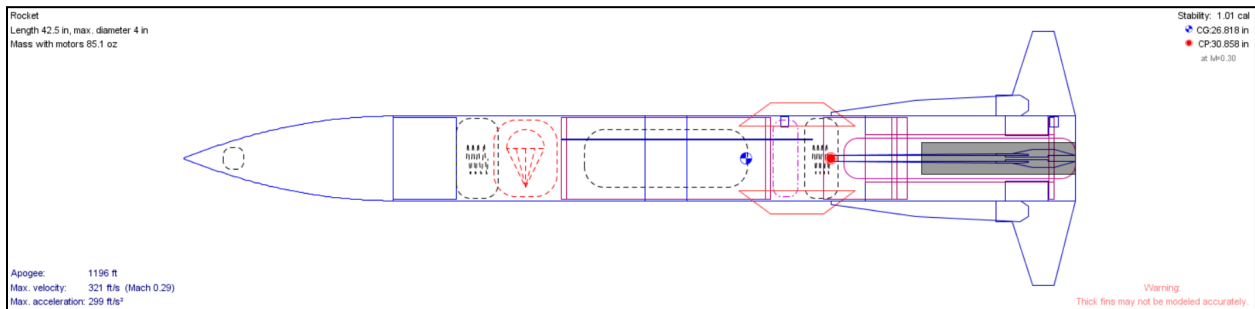
RocketPoxy will be used when permanently securing together such as fins to fin can, collars to couplers, camera mounts to the airframe, as well as, for applying fillets to fins.

#### **3.7.2 Rivets and Shearpins**

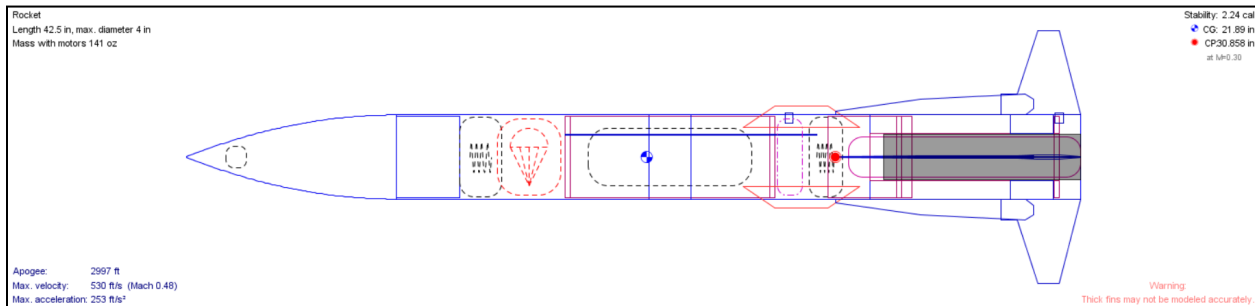
As mentioned prior, rivets will secure the nose cone to the upper airframe and shear pins will secure the upper airframe to the av. bay. This was chosen because the current setup will require the upper section to separate from av. bay, rather separate at the nose cone. Rivets will secure the lower section to the av. bay.

### 4.0 OpenRocket Simulations

As seen in Table 4.1, the OpenRocket simulations with the 273H225-14A H-Class motor are projected to fly upwards of 1000 ft with a stability of 1.01 cal. The apogee of our selected J293-13A motor brings us close but should not exceed the 3000 ft flight limit with a stability of 2.24 cal. In Figures 4.1 and 4.2 the OpenRocket simulations demonstrate the placement and mass of the camera mounts, indicating our intent to include such a feature in our competing rocket. Figure 4.3 shows the vertical velocity and acceleration of the H-Class motor over time and Figure 4.4 shows the same information for the J-Class motor. Both of these charts were obtained from an OpenRocket simulation.



**Figure 4.1** OpenRocket model with 273H225-14A motor. The warning applies to the camera mounts, and will not drastically change flight data acquired through simulations.



**Figure 4.2** OpenRocket model with J293-13A motor. The warning applies to the camera mounts, and will not drastically change flight data acquired through simulations.

Motor	Velocity off rod (ft/s)	Apogee (ft)	Velocity at deployment (ft/s)	Optimum delay (s)	Max. velocity (ft/s)	Max. acceleration ft/s <sup>2</sup>	Time to apogee (s)	Flight time (s)	Ground hit velocity (ft/s)
J293BS-3	60.5	2946	33.5	10.3	533	272	13.2	125	25.91
273H225-14A	71.6	1210	2.93	7.35	328	319	8.51	67.5	20.6

**Table 4.1** Flight data obtained from OpenRocket simulations of both motors to be used during the competition.

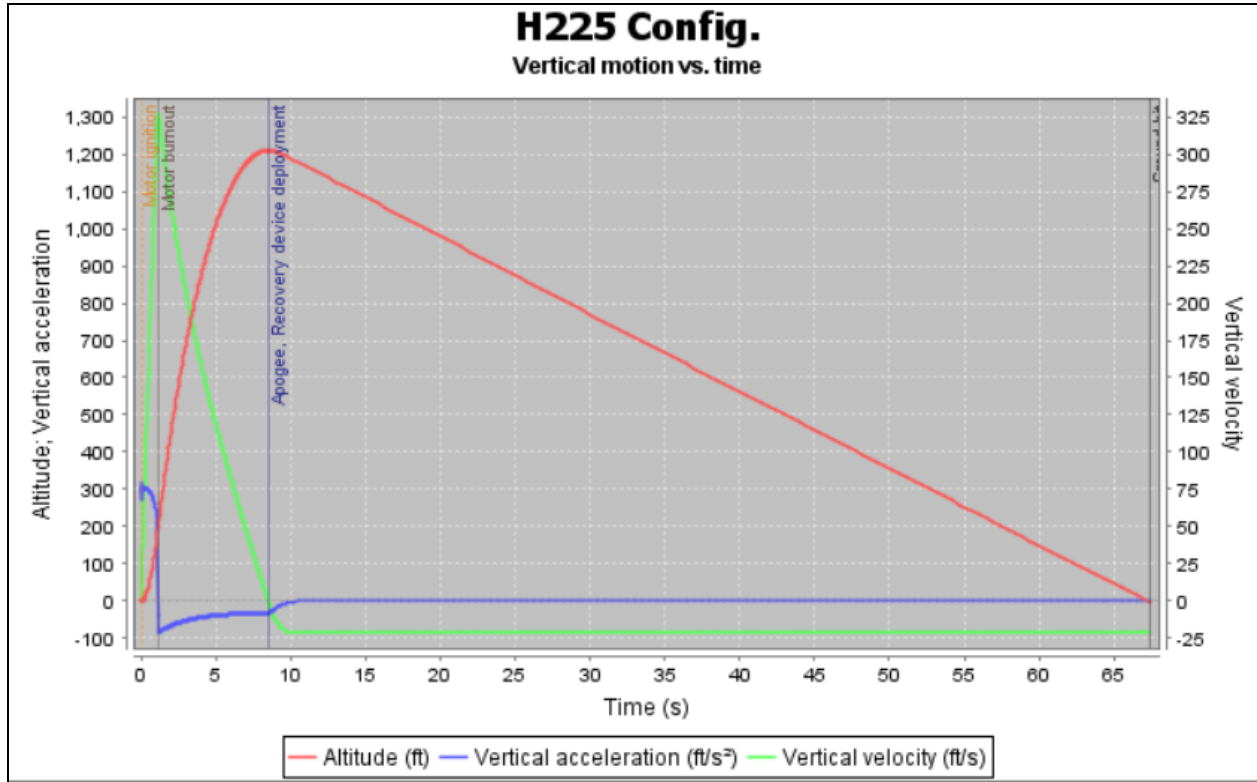


Figure 4.3 OpenRocket simulation using 273H225-14A H-Class motor.

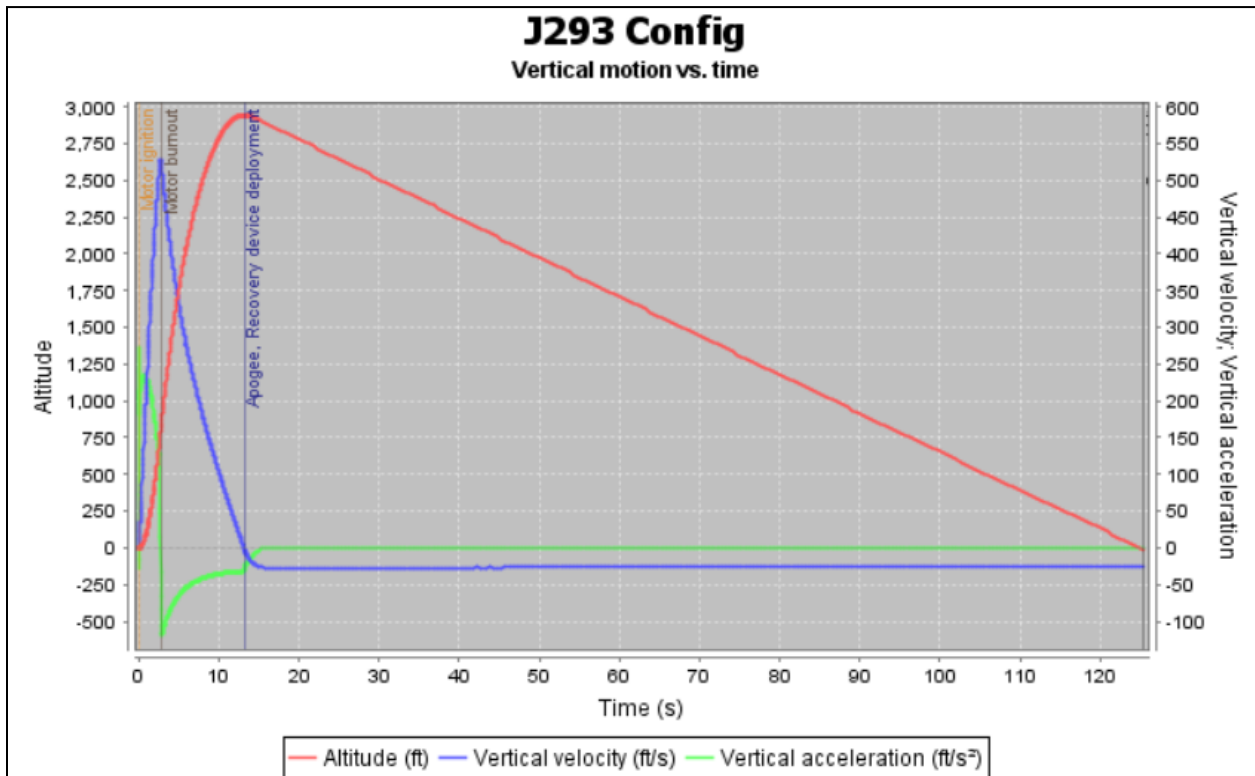


Figure 4.4 OpenRocket simulation using J293BS-3 J-Class motor.

## 5.0 Analysis of Anticipated Flight Performance

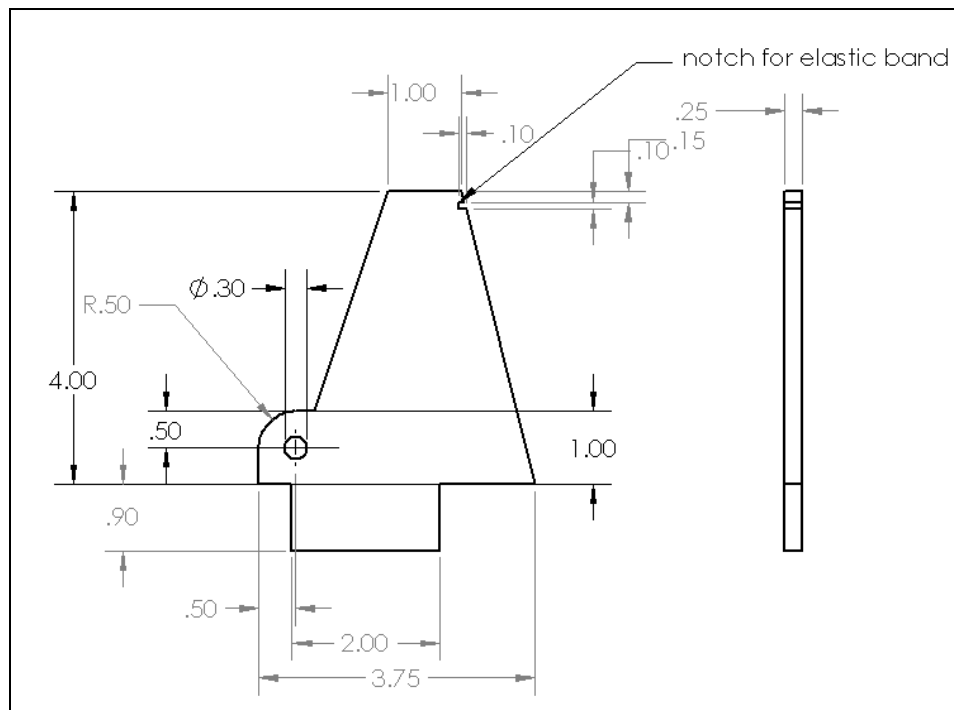
The open-source simulation software openRocket was used to make predictions about the rocket's flight performance. The simulation results found are shown in section 4. As noted the estimated max altitudes of the H225 and the J293 motor configurations are 1210 ft and 2946 ft respectively. Care was taken to attempt and make the simulations as accurate as possible to what the built rocket will look like. The simulation software tends to assume ideal flight conditions and it is for this reason that our team hypothesizes that the actual flights will perform slightly worse than simulated. Our team has left a ~200 ft buffer to account for sub-optimal flight conditions, and believes that this is a large enough safety factor to reach the flight requirement on the H225 motor configuration. Similarly, with the J293 configuration, our team expects that the rocket will actually reach a max altitude of closer to 2850-2900 ft. Similarly to max altitude, our team expects the peak velocity and peak acceleration to also be overestimated. However, we expect these final results to still be close to their predicted values. Our team believes that the decent speed estimated by the simulation software is an overestimate as well. From our research, other groups who have used a parafoil have found that it was more efficient at slowing a descending rocket down than a typical circular parachute. It is for this reason that we believe our rocket will be able to fall at a safe speed, despite the experimental parachute design.

Using a parafoil and servo we hope to change the direction of the rocket during descent. The servo will be controlled by a Teensy 4.1 microcontroller receiving commands from an XBee Pro SX. The commands will be servo angles sent from a controller with an onboard potentiometer. We are assuming that this change in angle on the servo will be enough to steer the parafoil by changing the geometry of the parafoil when pulled on either side. This device will be controllable from up to 1 mile away which we believe will give us enough distance to direct the parachuted rocket back to its landing zone.

The vertical landing system will deploy its legs during descent and the detachment mechanism, or tender descender, will release the booster section from the rocket body so that the still-aloft parafoil does not tip the booster section over. The Tender Descender will be controlled by the avionics package which will allow for remote control of when the booster section is released from the rocket. We expect the booster section to land from about 10 ft above the ground in free-fall after the tender descender is activated.

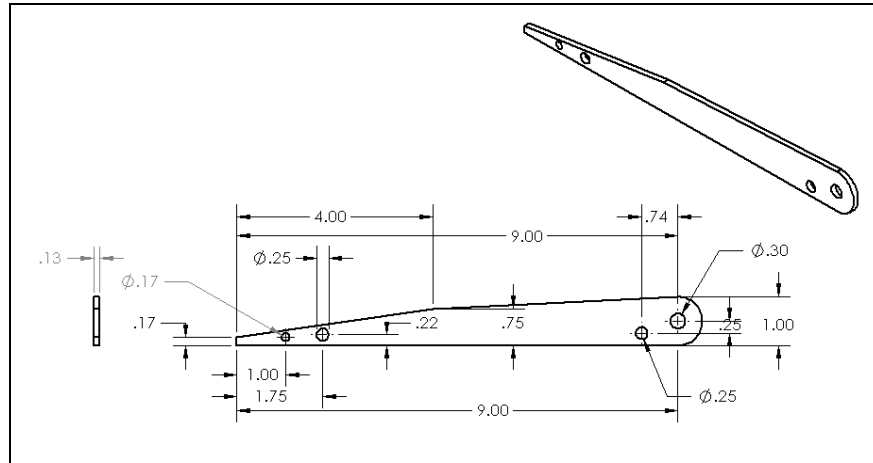
## 6.0 Vertical Landing Gear

The rocket booster section will be able to land vertically with the aid of landing gear. The landing gear consists of 5 parts. The fins, landing legs, tip inserts, elastic band, and dowels. The landing gear of the rocket is attached to each of the 4 fins and will pivot to deploy once the rocket is separated at apogee. During flight, the landing gear will remain “stowed”, i.e folded upwards against the body of the booster section as seen in Figure 6.3. The legs will be restrained in place by a rubber band wrapped around all 4 legs and slipped into a small notch cutout on the backside of each leg to prevent slipping. This rubber band will be fastened to a wire which itself will be permanently fixed to the lower section of the rocket. This means once the rocket reaches apogee, the rocket will separate into multiple pieces ripping away the restraining band holding all 4 legs in place. The fins will have a hole around which the landing legs will pivot. The landing legs will consist of two laser-cut pieces of 1/8in thick MDF spaced 1/4in apart joined together at the tip and their pivot. This will allow fins to slip in between the landing legs when being deployed. A dowel, seen in Figure 6.3, will prevent further rotation of the landing legs once in the deployed position. An elastic band will be secured to the bottom of the fins and at the dowel, locations noted in Figure 6.3. The elastic band will be tied around the dowel and stapled into the notch in the fins to ensure a secure connection. When released, the elastic band will cause a moment about the landing gear's pivot and move the landing legs into position after the rocket separates.

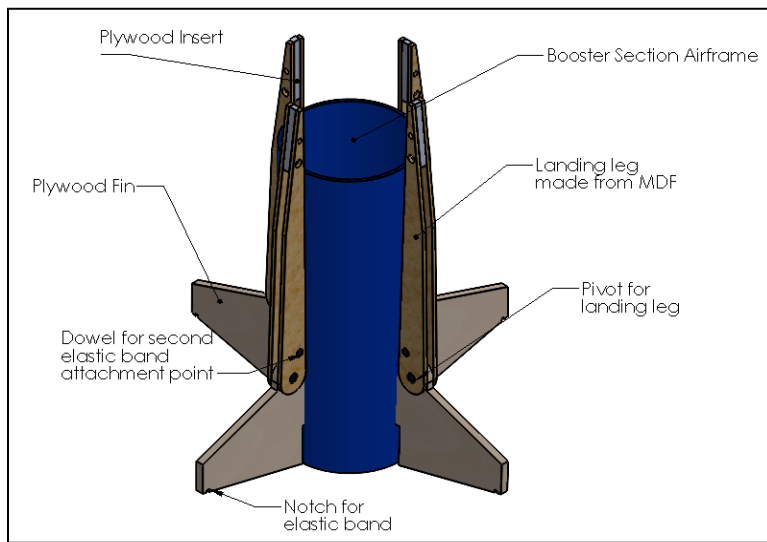


**Figure 6.1** Drawing of fins. Units in inches.

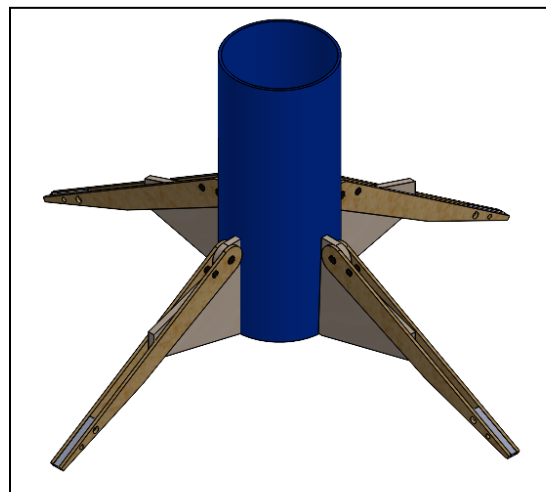




**Figure 6.2** Drawing of landing legs. Units in inches.



**Figure 6.3** Model of 'stowed' landing gear.



**Figure 6.4** Model of the 'deployed' landing gear.

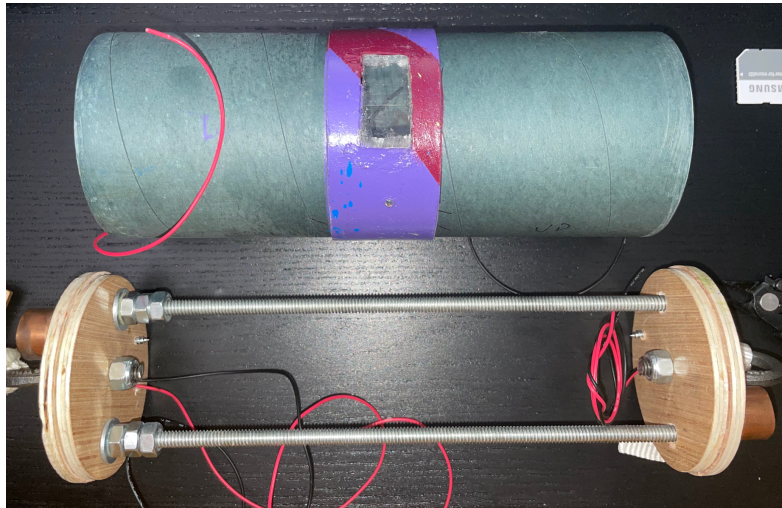
## 7.0 Rocket Avionics

Guiding the rocket to the ground requires a parafoil with adjustable geometry. By pulling on either side of the parafoil the direction of the gliding rocket will change. To accomplish this a servo with enough strength to pull either side of the parafoil will pull on one side of the parafoil and provide slack to the other. The angle of the servo will be defined by a 10 kOhm potentiometer on the controller PCB which will be sent by radio from an XBee Pro SX on the controller PCB which has an advertised range of 65 miles (105 km). The XBee Pro SX draws a lot of current which made it a struggle to integrate into our designs. We tried a 9v battery with a 5v regulating MOSFET and a custom 3.7v to 5v booster PCB with the PTN04050 but found that the 3.7v to 5v Power Boost 1000mAh from Adafruit was the only device capable of powering the avionics package with the XBee Pro SX. From our testing, we achieved a range of 0.8 miles without a clear line of sight and spotty connection. This will be sufficient range to communicate with our rocket during its descent on both the 1000-foot launch and the sub-3000-foot launch since the rocket will be guided at an altitude of 1000 ft. Since this test was conducted the XBee Pro SX configurations have been optimized so that it is able to achieve a much more stable connection. The bit transfer rate was lowered from 110 kb/s to 10kb/s which should allow a longer range as stated in the documentation for the XBee Pro SX, but another range test will have to be conducted. A larger omnidirectional 915 MHz antenna, as shown in Photo 7.3, was added to the ground station XBee Pro SX to improve range. In order to know if the XBee Pro SX is connected a response command was added so that every time the rocket avionics receive a potentiometer value, it will respond to the controller with an acknowledgment command. To display this connection, response delay in milliseconds, and potentiometer angle a Sparkfun OLED display was added to the controller PCB, as shown in Photo 7.7. Included are the electronics and PCB design for the controller in Figures 7.7 and 7.7.

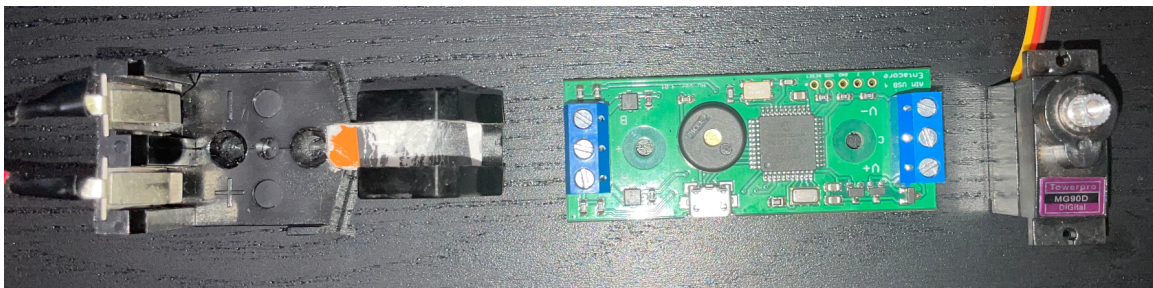
The avionics bay sensor array consists of an M9N Ublox GPS, LSM9DS1 IMU & MS5611 pressure sensor. Our goal is to allow this system to update as fast as possible in order to receive a command at any time but with our current GPS, the max polling rate to the GPS satellites is 5Hz. The GPS is capable of getting ECEF and NBME coordinates along with Lat Long. The GPS won't be used to accomplish a self-guided descent but the location data, and altitude data will be important post-flight. The LSM9DS1 will give us useful postflight data about the rocket's force vector, and Euler angles. The pressure sensor will be on board to get temperature and pressure data in order to make altitude calculations during the flight in case the GPS fails or is not able to update fast enough.

To keep the sensor devices, OLED, XBee Pro SX, and an antenna together with little movement a custom PCB was designed for the rocket's avionics bay. Included are the electronics design and PCB design in Figures 7.2 and 7.3. In order to hold the avionics devices a sled was modeled and 3D printed, as shown in Figure 7.1, with dimensions of 3.5 x 7 inches. This sled will be 3D printed using PLA+ material. The PCB will be screwed in at all four corners and a zip tie will be

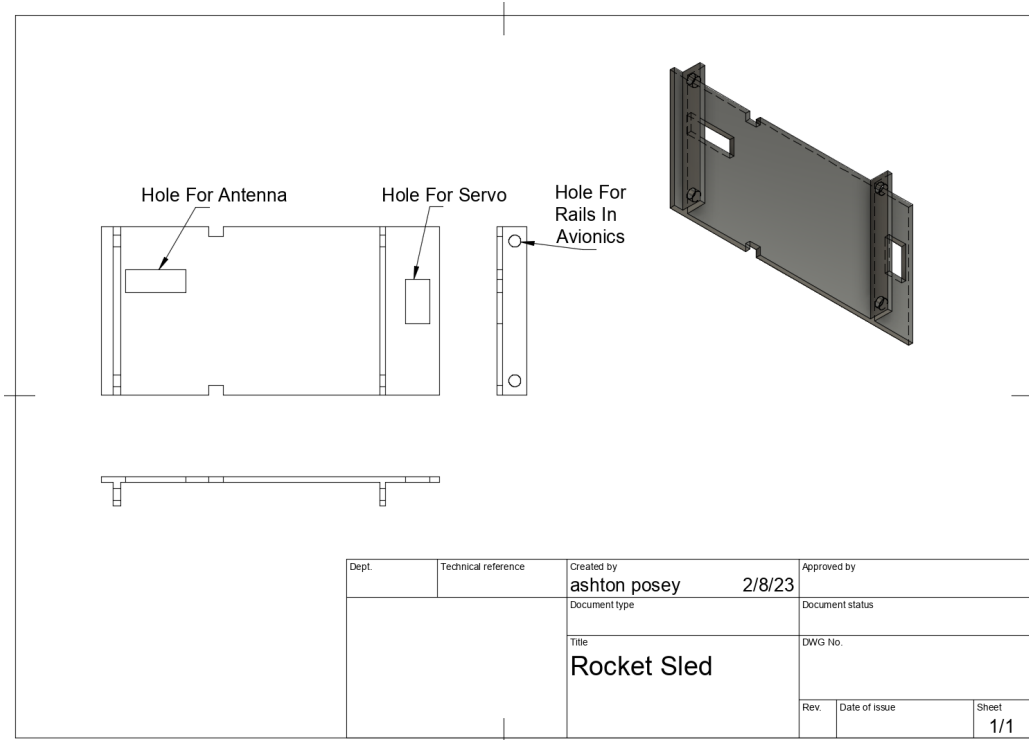
placed towards the center where lines across the PCB are marked as shown in Figure 7.2. This PCB will be placed on the side of the Rocket Sled with no protrusions and a rectangular cutout was added to the sled so that the antenna cable could pass through it as shown in Figure 7.1. The servo placement is shown in Figure 7.1, this spot was chosen since it is at the top of the Rocket Sled which will allow a line from the servo to the parachute to exit at the top of the avionics bay. As shown in Photo 7.2, we are using an MG90D servo with metal gears so that it will be as rigid as possible but we still have to test whether this servo will be strong enough to pull either side of the parachute. A similar design to the one shown in Photo 7.1 will be used for the avionics bay structure. Additions to this design are going to be two holes in the top of the bay so that plastic tubing can allow the chords from the parachute to reach the servo. On the side of the Rocket Sled that has protrusions an AIM USB altimeter and a 9v battery, to power the altimeter, is going to be screwed into the sled so that they can be placed in between the rails that will be holding the Rocket Sled. The AIM USB altimeter will be used to control the detonation of ejection charges during flight. The altimeter will separate the rocket at apogee which will deploy the parafoil.



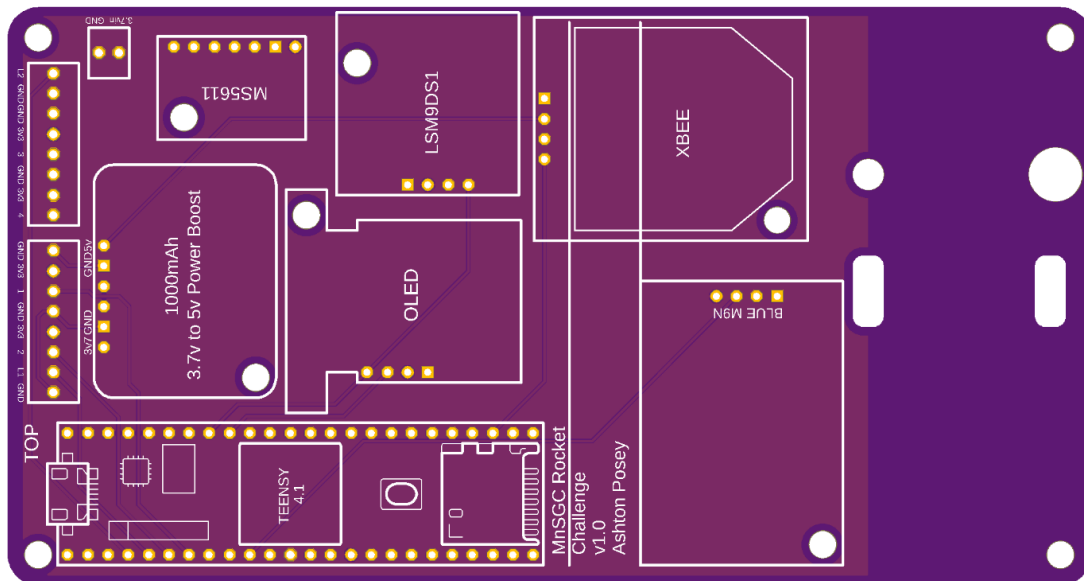
**Photo 7.1** Example avionics bay from previous rocket flight.



**Photo 7.2** 9v Battery Snap, AIM USB Altimeter, & Servo.

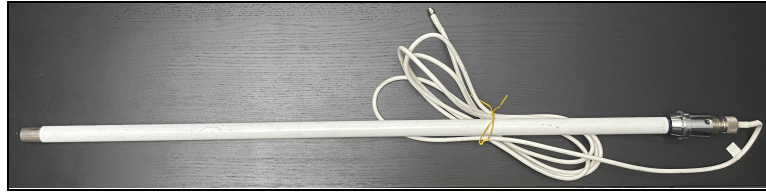


**Figure 7.1** Current design of the Rocket Sled to hold 9v battery snap, AIM USB altimeter, servo, and avionics PCB. Dimensions of the Rocket Sled are 3.5 x 7 inches.

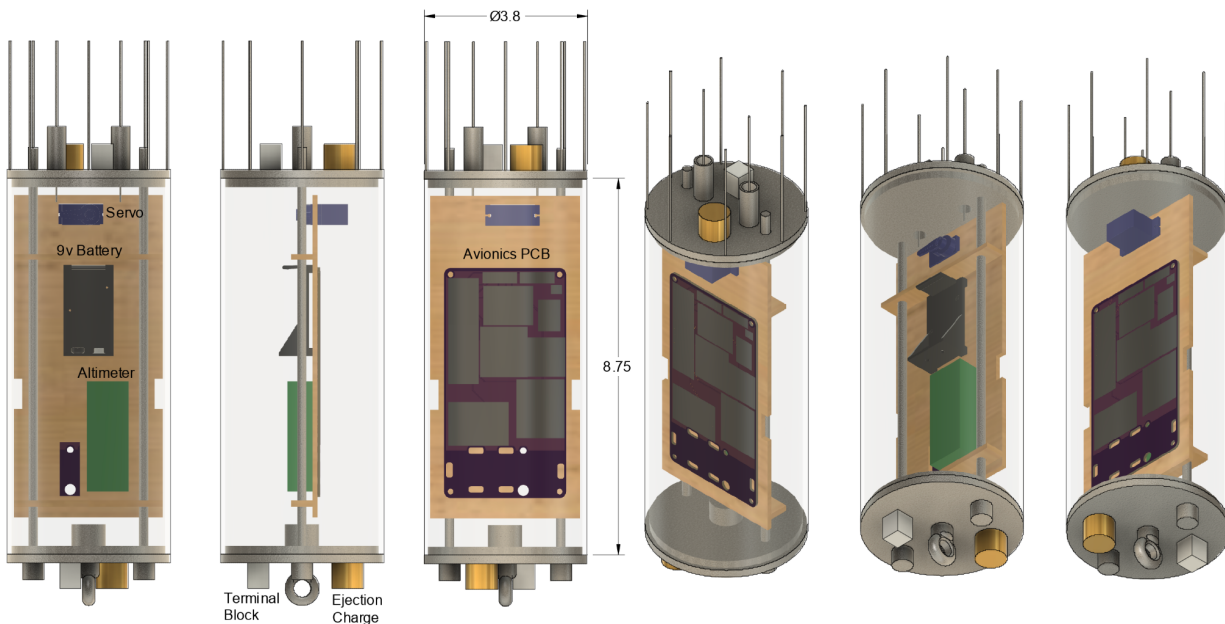


**Figure 7.2** Avionics PCB design.





**Photo 7.3** 868/915 MHz Omnidirectional LoRa antenna for the controller.



**Figure 7.6** 3D design of the avionics bay.

The fully assembled rocket avionics bay is shown in Figure 7.6. The brown plate is the Avionics Sled. In green, is the location of the AIM Altimeter. In blue is the location of the servo, it has direct access to the top of the avionics bay to move the parafoil strings that have direct passage through the top bulk plate. In gray above the Altimeter, is the 9v battery jack which will power the altimeter only. The Rocket PCB is in purple which will hold its own 3.7v battery. On the top of the bulk plates, there's a terminal block in white and an ejection charge in copper. The total weight for the sled, PCB, Altimeter, 9v battery, battery jack, and servo is 284.4g. The Blue Tube Coupler used to go around this avionics bay will be 8.75 in long and 3.8 in wide. The lines coming off the top of the avionics bay are the strings that will be attached to the parafoil.

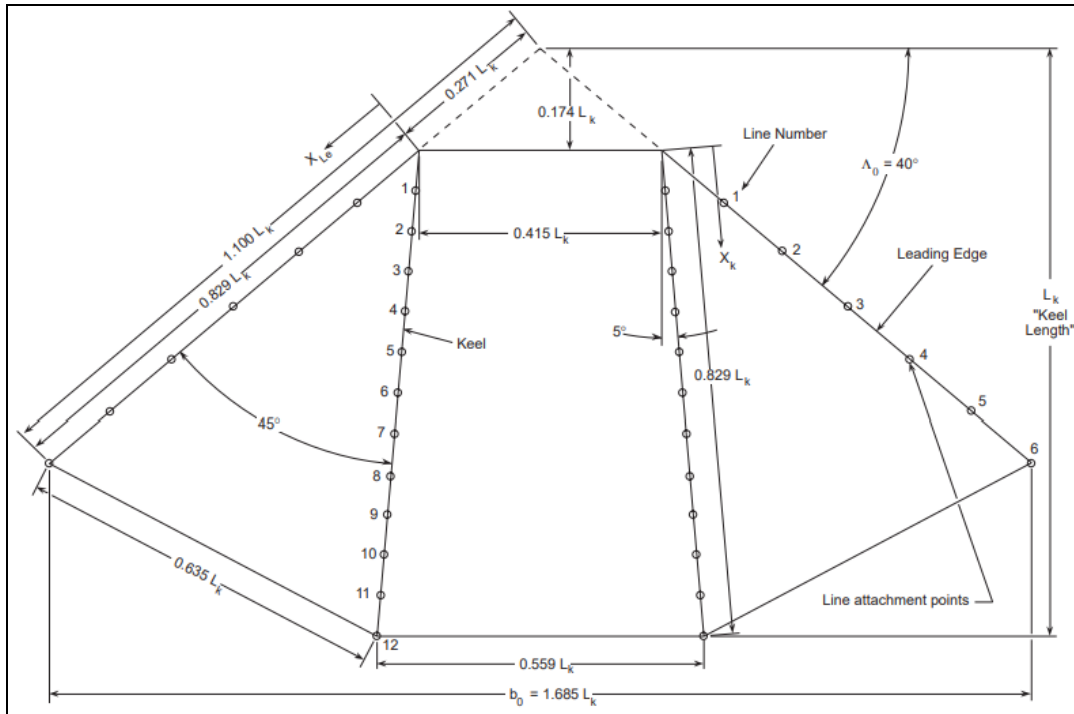
## 8.0 Guided Descent Components

Controlling the rocket's descent will be done, as mentioned previously, with a twin-keel rogallo parafoil. The template for the parafoil's design comes from Technical Publication #7 published by Apogee Rocketry. According to the documentation of this design, this parafoil is more efficient than a typical parachute and allows for a slower descent with the same planform area. With this in mind, our team has decided to use 44 inches as a keel length which will make the area of the parafoil similar to that of a 48-inch diameter circular parachute. Subsequent dimensions of the parafoil will be based on the 44-inch keel length according to Figure 8.1. In our simulations, we have used a 48-inch diameter circular parachute made of the same material to ensure we have a safe estimated landing speed, with a decent safety margin. The parafoil's body will be made from ripstop nylon, and the shroud lines will be made from kevlar string. Size #0 grommets will be used to reinforce the secure shroud line attachment points. In the event of high winds in an unfavorable wind direction on launch day, a jolly logic chute release will be used to deploy the parafoil closer to the ground.

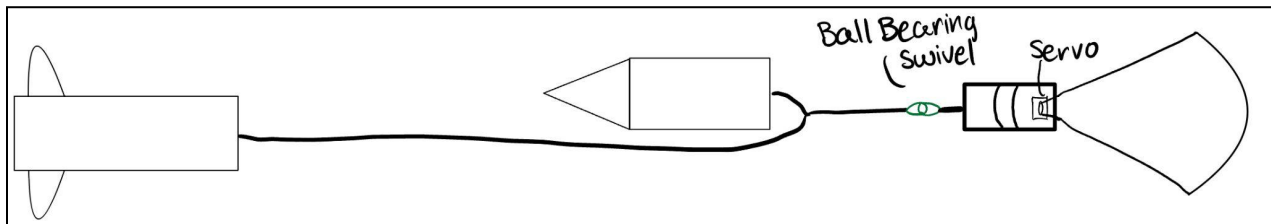
Charges will be placed on the top and bottom of the avionics bay in order to separate the rocket at apogee. The rocket will be fully separated with the upper and booster sections being separated at the avionics bay and lower sections. Once the rocket is in its descent stage of flight the components will be laid out as shown in Figure 8.2. An important note in Figure 8.2 is that the nose of the rocket will be placed above the tail of the rocket so they don't interact while rotating. A ball-bearing swivel was added to this design so that any rotation from the nose and tail of the rocket will not affect the rotation of the avionics bay and the parachute.

To change the geometry of the parafoil and allow for a change in direction we are planning on connecting the middle strings on the parafoil to a static metal ring on the top of the avionics bay with the outside strings attached to each end of the servo arm. This design is inspired largely by the Apogee Components lecture on a guided descent system where a servo changes the direction of the landing rocket, see Reference 4.





**Figure 8.1** Dimensioned drawing of Parafoil design to be used, Source 6.



**Figure 8.2** Decent stage of the rocket. The diagram from right to left includes the parafoil, avionics bay, ball bearing swivel, upper section of the rocket, tail of the rocket.

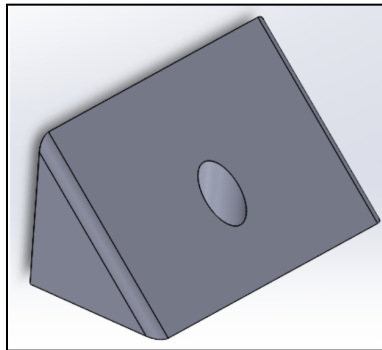


## 10.0 Camera System

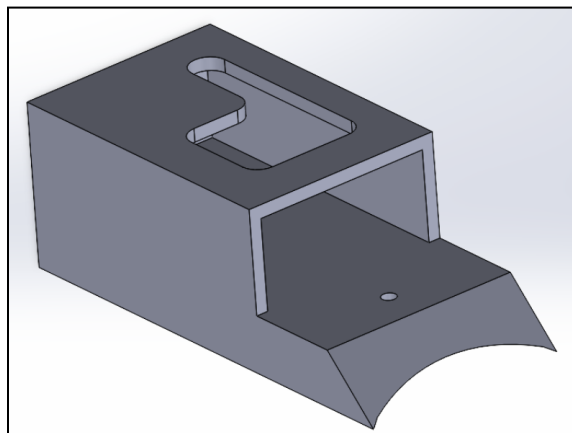
Two Mobius Pro Mini Action Cameras will be used to capture video during the rocket's flight. Cameras will be facing in the forward and aft directions and mounted to the airframe with 3d printed housing shown in Figure 7.1 and Figure 7.2.



**Photo 10.1** Mobius Pro Mini Action Camera.



**Figure 10.1** Camera Housing Cap with hole for rivet.



**Figure 10.2** Camera Housing with cutout on top for camera controls and rounded bottom to fit the shape of the rocket.

**11.0 Parts Lists**

<b>Rocket Avionics</b>		
Amount #	Part Name	Amount for one \$
2	<a href="#">Teensy 4.1</a>	26.25
2	<a href="#">8 Gig microSD card class 10 with SD adapter</a>	11.95
1	<a href="#">M9N GPS</a>	48.31
1	<a href="#">LSM9051 9DOF IMU (RETIRED PRODUCT)</a>	15.95
1	<a href="#">MS5611 Pressure Sensor (3-Pack)</a>	17.99
2	<a href="#">OLED Display</a>	18.50
2	<a href="#">XBee Pro SX</a>	134.87
2	<a href="#">Custom PCB (5-Pack)</a>	2.00
1	<a href="#">LED (with built-in resistors) (20 pack) (4 colors)</a>	9.95
2	<a href="#">PowerBoost 1000 Basic - 5V USB Boost @ 1000mA</a>	14.95
2	<a href="#">Slide Switch</a>	0.76
4	<a href="#">Momentary Switch</a>	0.13
5	<a href="#">male headers strips</a>	1.53
5	<a href="#">female header strips</a>	1.09
2	<a href="#">2-position terminal blocks</a>	1.78
2	<a href="#">8-position terminal blocks</a>	7.48
10	<a href="#">HEX STANDOFF M2.5X0.45 ALUM 11MM</a>	0.67
10	<a href="#">MACH SCREW PAN SLOTTED M2.5X0.45</a>	0.48
10	<a href="#">HEX NUT 0.197" STEEL M2.5</a>	0.18
1	<a href="#">MG90D Servo</a>	19.95
1	<a href="#">AIM USB Altimeter</a>	121.15
1	<a href="#">868/915 MHz 8 dBi gain Omni LoRa Antenna</a>	119.00
Total Amount \$		816.30

<b>Camera</b>		
Amount #	Part Name	Amount for one \$
2	<a href="#">Black Box Mobius Pro Mini Action Camera</a>	79.95
Total Amount \$		159.90

Parafoil		
Amount #	Part Name	Amount \$
3	<a href="#">Nylon</a>	7.99
1	<a href="#">Grommets &amp; Washers (1/4 in Hole) 144 sets</a>	15.23
1	<a href="#">100~1000Lb Braided Kevlar Line On Spool</a>	18.95
1	<a href="#">Chute Release</a>	139.95
1	<a href="#">Sewing Thread</a>	4.24
Total Amount \$		202.35

Landing Gear		
Amount #	Part Name	Amount \$
3	3d printed Modular Housing Sections & Modular Landing Struts	
3	3d printed Modular landing Legs	
6	<a href="#">Disc Magnet: Neodymium, Nickel Plating, 1.5lb Max. Pull.</a>	0.59
Total Amount \$		3.54

Auxiliary Items		
Amount #	Part Name	Amount \$
1	Registration Fee	400.00
2	<a href="#">Rocket Kits for Introduction to Rocketing</a>	12.50
2	<a href="#">Minivan Rental for Transportation to and from event</a>	61.00
Total Amount \$		547.00

<b>Basic Rocket Parts</b>		
Amount #	Part Name	Amount \$
1	<a href="#">4in x 48in Blue Tube Airframe</a>	43.95
2	<a href="#">4in x 8in Blue Tube Coupler</a>	12.31
2	<a href="#">1/4in x 2ft x 4ft Plywood</a>	14.94
1	<a href="#">1/8in x 4ft x 8ft Hardboard Tempered Panel</a>	12.98
1	<a href="#">Durable Plastic Nose Cone for High Power Rockets</a>	30.56
1	<a href="#">Quick Links</a>	3.51
1	<a href="#">Forged Eye Bolts</a>	5.91
1	<a href="#">Lock Nuts</a>	1.38
1	<a href="#">T Nuts</a>	1.38
2	<a href="#">Screws</a>	1.38
2	<a href="#">Washers</a>	1.25
1	<a href="#">53mm motor mount tube</a>	26.91
1	<a href="#">38mm adapter</a>	7.51
1	<a href="#">Rail Buttons</a>	4.46
10	<a href="#">Shock Cord</a>	0.68
1	<a href="#">RocketPoxy</a>	70.5
Total Amount \$		275.61

<b>Total Cost with a Budget of \$2500</b>	
Total Amount \$	2004.7

## 12.0 References

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