Project Heimdall

Preliminary Design Review Addendum

Cedar Falls High School

1015 Division Street, Cedar Falls, IA 50613

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1. Review of Major Changes

After thorough review, the Cedar Falls High School Rocket Club has decided to move forward with a modified version of Project Heimdall that does not include landing the booster section of the vehicle. While the team is confident in the current leg design, the amount of detailed work required to successfully complete this aspect of the mission exceeds what the team is capable of, especially while working on two other complex payloads

This decision has changed the overall vehicle design in several major ways.

The initial recovery system was originally designed to allow the payload section and booster section to completely separate at apogee so the booster could land independently. With this aspect of recovery no longer required, the recovery system has been changed to a much simpler and straightforward dual deploy design with two points of separation into 3 components. All components will stay tethered together.

With legs no longer in use, the team was able to nullify the derived requirement for minimum booster section length. Because no legs are being deployed on the booster, a 4 foot booster is no longer required to achieve an optimal landing leg radius. This allows for the team to shorten the booster section to 3.5 feet (42 inches).

Finally, the payload design has a few minor updates aside from dropping the landing payload. In the extra time the team has had since initial PDR submission, several tests were done on camera batteries. Initially, the team expected the internal camera batteries to be able to provide enough power to the cameras to film for over 2 hours, allowing for the vehicle to sit on the launch pad for the maximum amount of time and still be able to record launch. However, the tests proved this expected battery life to be insufficient. As a result, the team added two commercially available portable USB chargers to the design that can provide power to the GoPros for over 3 hours. These batteries will also power the data collection payload, allowing the team to limit excess mass from extra batteries. Payload retention design was also updated to accommodate these changes.

2. Updated Vehicle Design

2.1 Materials

- Airframe
  - For the vehicle airframe (body tube, nose cone, couplers) material the team selected fiberglass. Fiberglass is stronger than cardboard and cheaper than carbon fiber. The physical and chemical strength of fiberglass makes it an ideal material for vehicle construction. The only drawback of fiberglass is the possible safety hazard of cutting the material. Small particles can be irritating and harmful to the eyes and lungs. This can be mitigated, however, with proper personal protective equipment.
- Bulk Plates and Centering Rings
  - For all bulk plates and centering rings, the team selected fiberglass over plywood. While plywood is significantly cheaper and far easier to machine, modify, and reproduce, fiberglass is significantly stronger and can undergo greater stress before breaking. As the bulk plates and centering rings will be undergoing intense stresses during vehicle flight, the ability of the selected material to withstand these stresses is extremely important.
- Fins
  - Because the vehicle is projected to reach speeds of over 500 ft/s, having strong fins will be important to ensure fin flutter does not result in broken fins and subsequent catastrophic vehicle failure. Fiberglass has sufficient physical and chemical strength to withstand this stress during flight. It is cheaper than carbon fiber and stronger than plywood, making it the optimal material.

2.2 Design

The complete vehicle is 101.5 inches long and has a diameter of 6.17 inches (6.00” inner diameter). The vehicle will separate at 2 different locations into 3 different components during the recovery process. All of these components will remain tethered together during the recovery process (see section 3.2 for more details). The vehicle separates into the booster section (a), recovery section (b), and payload section (c), see Figure 2.2.1 below. The complete assembly of the vehicle is shown in Figure 2.2.2.

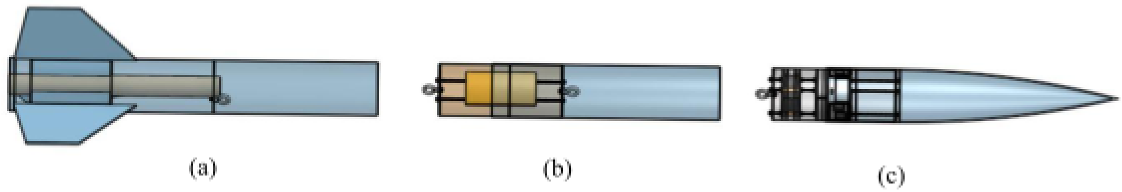

Figure 2.2.1

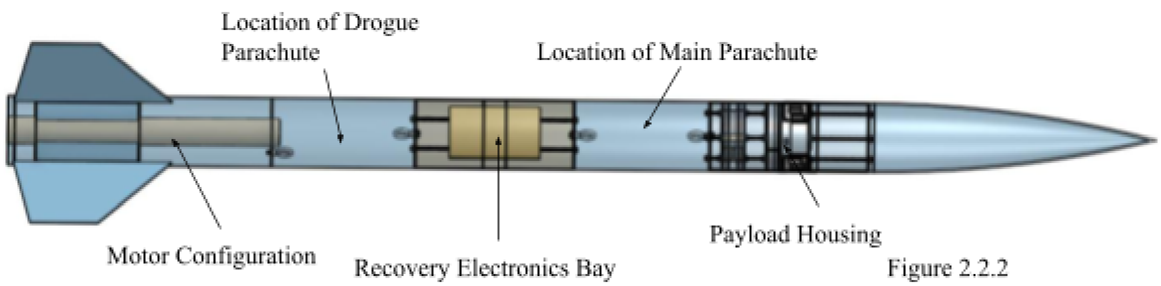

Figure 2.2.2

Payload Section

The payload section will include a 5:1 ogive nose cone because of the low drag provided by this shape. This helps the vehicle reach a higher projected altitude with such a heavy weight. It will also include a 14” fiberglass coupler (5.998” OD and 5.820” ID) with a 3.5” switch band. This coupler will house all of the payload and the switch band will provide area for the acrylic windows and vent holes. The coupler extends 6 inches below the switch band to provide enough contact area to hold the payload section (c) and the recovery section (b) together during flight. This coupler then also extends 4.5 inches above the switch band into the nose cone. This is the approximate maximum distance the coupler can slide into the nose cone before the cone begins to close. The nose cone will be held to the coupler with 4 two piece rivets. See Figure 2.2.3 below for a labeled diagram.

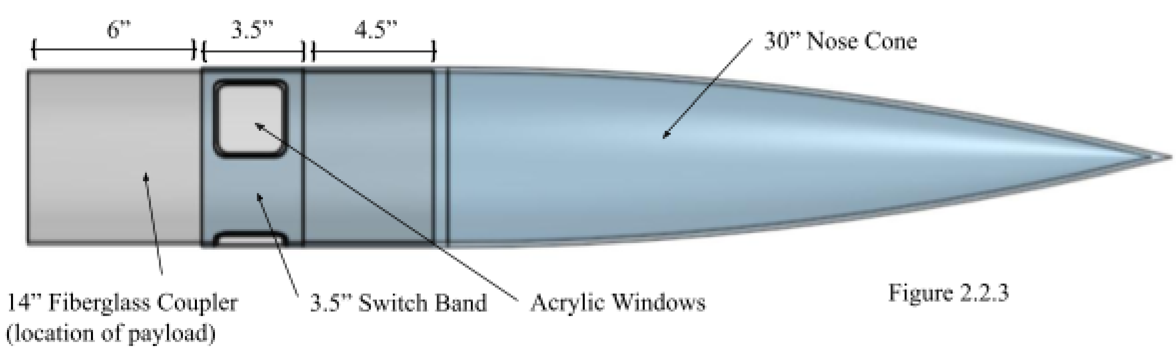

Figure 2.2.3

Additional information on payload retention in this component is detailed in section 4.

Recovery Section

The recovery section will be composed of 2 body tubes; one will be a 2” inch switch band, and the other a 24” tube that serves as the main parachute chamber. This section also consists of a 14” coupler (5.998” OD and 5.820” ID) that serves as the electronics bay. The 2” switch band will be located in the middle of this coupler, with 6” extending into the main parachute housing and the 6” on the other side extending into the booster section. The coupler that extended into the main parachute housing will be riveted to that 24” body tube using 4 two piece rivets to ensure these portions do not separate during flight. See Figure 2.2.4 below for a labeled diagram.

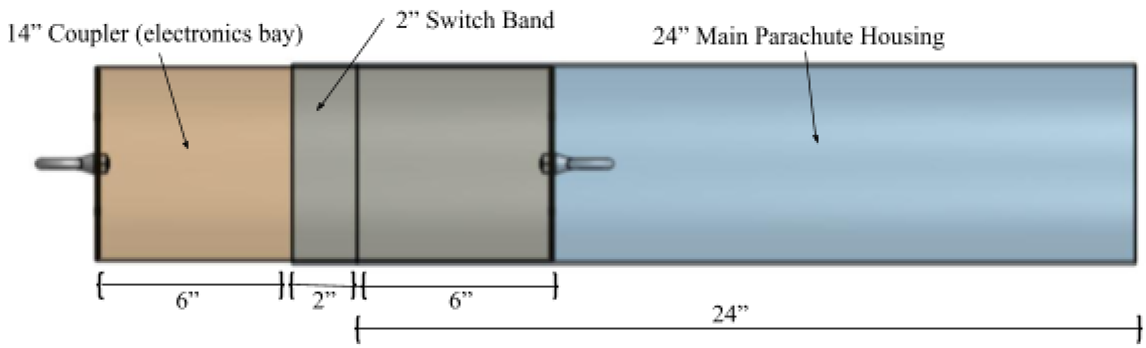

Figure 2.2.4

Details on electronics bay assembly are included in section 3

Booster Section

For the booster section, the team will use a 42” long fiberglass body tube. For the fins, three, 3/16” thick fiberglass, trapezoidal fins will be used. A 2.13” (54 mm) diameter, 24” long motor mount tube will be used along with 4 centering rings. The centering rings are placed on the top and bottom of fin tabs, and the top and bottom of the motor mount tube to maximize contact and strength. However, in order to minimize weight and cost, the very bottom centering ring will be made of plywood. This ring is mainly included so a large gap is not seen at the end of the vehicle. The area above the motor mount tube is designated as the drogue parachute chamber because it will be housing the drogue, protective wadding, and black powder charges. Refer to Figure 2.2.5 for a labeled diagram. Figure 2.2.6 details fin dimensions.

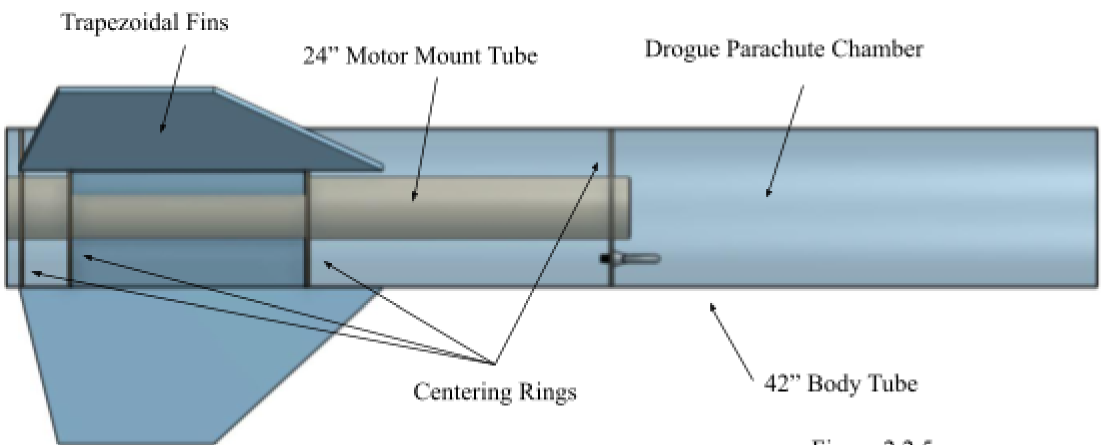

Figure 2.2.5

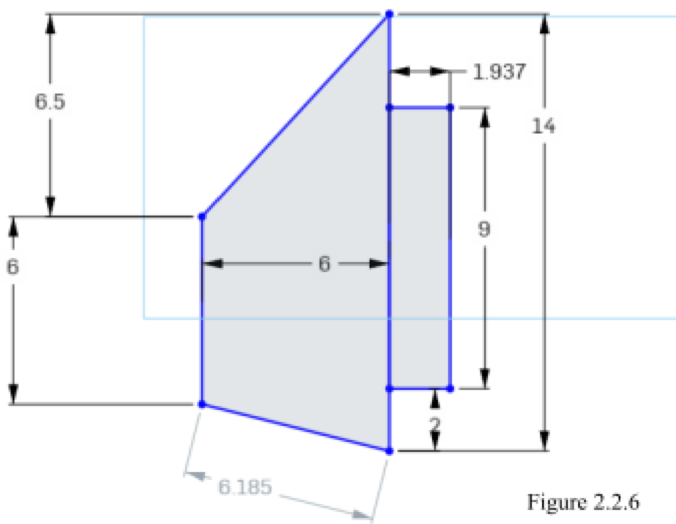

Figure 2.2.6

2.3 Weight and Center of Pressure

- Gross Lift Off Weight: 31.28 pounds
  - Booster: 12.93 pounds
  - Recovery Section: 7.66 pounds
  - Payload Section: 10.69 pounds
- Weight After Motor Burn Out: 28.79 pounds
  - Booster: 10.44 pounds
  - Recovery Section: 7.66 pounds
  - Payload Section: 10.69 pounds
- Center of Pressure (from tip of nose cone): 74.8745 inches
- Center of Gravity (from tip of nose cone, on launch pad): 60.77 inches
- Stability Margin

- On the Launch Pad: 2.29
    - At Rail Exit: 2.33
- Rock Sim Screenshot: Figure 2.3.1
- Stability Margin Analysis Screenshot: Figure 2.3.2

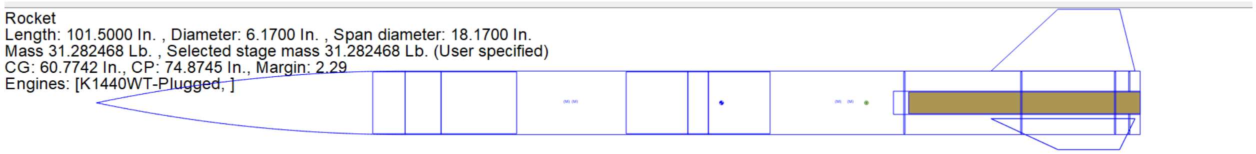

Figure 2.3.1

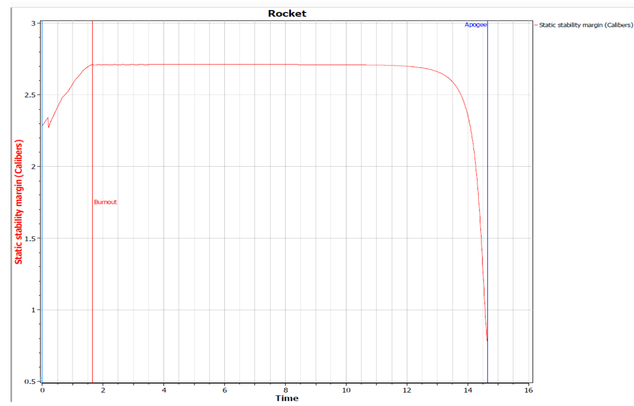

Figure 2.3.2

2.4 Expected Performance

- Maximum Velocity: 502.38 ft/s
- Maximum Acceleration: 469.42 ft/s^2
- Rail Exit Velocity: 78.11 ft/s
- Burn Time of Motor (K1440): 1.7 seconds
- Target Altitude: 3750 feet AGL
- Simulation Altitude: 3437 feet AGL
- Rock Sim Screenshot: Figure 2.4.1

Results	Engines loa	Max. altitud Feet	Max. velocit Miles / Hour	Optimal del	Max. accele Gees	Altitude at (Feet	Velocity at l Miles / Hour	Velocity at c Miles / Hour	WeatherCoc
	[K1440WT-Pl	3437.17	342.53	12.99	14.59	n/a	53.26	n/a	Safe

Figure 2.4.1

3. Updated Recovery Design

3.1 Components

- Main Parachute
    - Fruity Chutes 72” Iris Ultra
- Drogue Parachute
    - Fruity Chutes 24” Elliptical Drogue
- Shock Cords (1 for the main parachute and 1 for the drogue parachute)
    - 3/8" tubular kevlar (3600lb breaking strength)
        - 25 feet long
- Protective Wadding (for each of the two parachutes)

    - 18” Nomex Parachute Protector
    - Disposable Recovery Wadding (fireproof insulation)
- Ejection Charges (Primary and Secondary for both parachute deployments)
    - Black Powder Ejection Charges
        - Primary: 4 g
        - Secondary: 6 g
- GPS
    - AIM XTRA GPS
- Alitimiters (Primary and Secondary)
    - PerfectFlight StratologgerCF Altimeter

The 72” Iris Ultra parachute was chosen as the main parachute because it offers a higher coefficient of drag than other parachutes of the same size. This allows the vehicle to use a lighter parachute, limiting total lift off weight and still bringing the vehicle back to the ground within the kinetic energy requirements. The 24 inch elliptical parachute was chosen because it optimizes descent rate under the drogue parachute, bringing the vehicle down at a rate that is not too fast, yet fast enough to limit drift during recovery. For our shock cords we have chosen the ⅜” tubular kevlar cord due to its high strength and fire resistance. For the protective wadding we have chosen to use a combination of the 18 inch nomex parachute protector and disposable wadding. The parachute protector will be more effective at protecting the chute while the disposable wadding will provide extra protection and will fill volume in the booster section so not as much gas is needed to fill the chamber and cause ejection. This will aid in the deployment of the recovery system. For the ejection charges we have selected to use black powder ejection because of its low cost, simplicity, and reliability. GPS and Altimeters were selected due to familiarity and reliability. The team has used these products in the past, is familiar with them, and have never experienced a product performance failure.

3.2 Design and Diagrams

Deployment

At apogee, the main altimeter will trigger the primary ejection charge. This 4g black powder charge will separate the booster section (a) from the rest of the vehicle (b), deploying the 24” drogue parachute. In case of altimeter or charge failure, the secondary altimeter will activate a secondary 6g black powder charge to ensure the booster section separates from the rest of the vehicle and the drogue chute properly deploys. A tertiary charge, composed of the manufactured ejection charge on the CTI K-1440 will also be included to ensure deployment. This separation process is shown below in Figure 3.2.1.

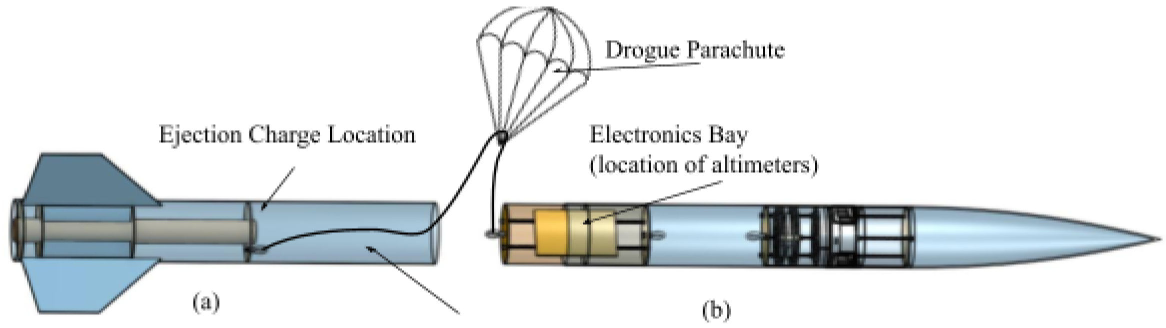

Figure 3.2.1

Note: the black powder ejection charges will rest at the bottom of the parachute chamber, against the top centering ring. Wires from the altimeters in the electronics bay will reach down through the deployment chamber to activate these charges. To avoid cluster, the parachute and kevlar cords are not shown in the above diagram. However, these components are located within the parachute chamber, above the ejection charges, meaning that as the gas expands during ejection, these components will be pushed out of the parachute chamber for deployment. Parachute and parachute harness are not to scale.

At 600 feet AGL, the primary altimeter will activate the primary charge for the main parachute deployment. This 4g black powder charge will separate the payload section (c) from the recovery section (b), deploying the main parachute. At 500 feet AGL, the secondary altimeter will activate the secondary 6g black powder ejection charge, ensuring the recovery and payload section separate. This process is shown below in Figure 3.2.2.

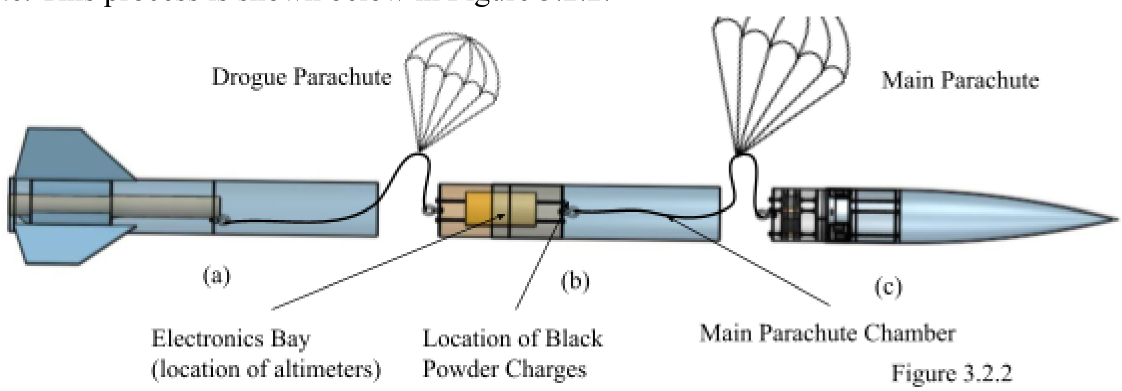

Figure 3.2.2

Note: the primary and secondary charges will be located within the parachute chamber, on the top bulk plate of the electronic bay. While the parachutes and kevlar cords are again not shown, they will be located above the black powder charges, ensuring deployment as the gas from the charges expands and pushes these components out of the vehicle. All components stay tethered together throughout the recovery process. Parachutes and parachute harnesses are not to scale/

The separation point of the booster section (a) from the rest of the vehicle will be reinforced with 2 shear pins to ensure separation does not occur prematurely. The separation point of the payload section (c) from the recovery section (b) will be reinforced with 3 shear pins for the same reason.

Electronics Bay

The design of the electronics bay accommodates both altimeters and the GPS device. In order to shield the altimeters from the GPS transmitter and to provide mounting area for altimeter switches, a circular bulk plate will be used perpendicular to a rectangular sled. The GPS will be mounted on one side, with the altimeters on the other. A metal grid pattern will be laid out along the bulk plate to create a Faraday cage to prevent GPS signals from interfering with the flight altimeters. Switches to activate the altimeters and GPS will be mounted on the other side of this bulk plate. Two Duracell 9-volt batteries will be secured on the opposite side of the sled to power each altimeter independently as well as a Lithium-ion Polymer battery to power the GPS. A labeled diagram is shown below (Figure 3.2.3).

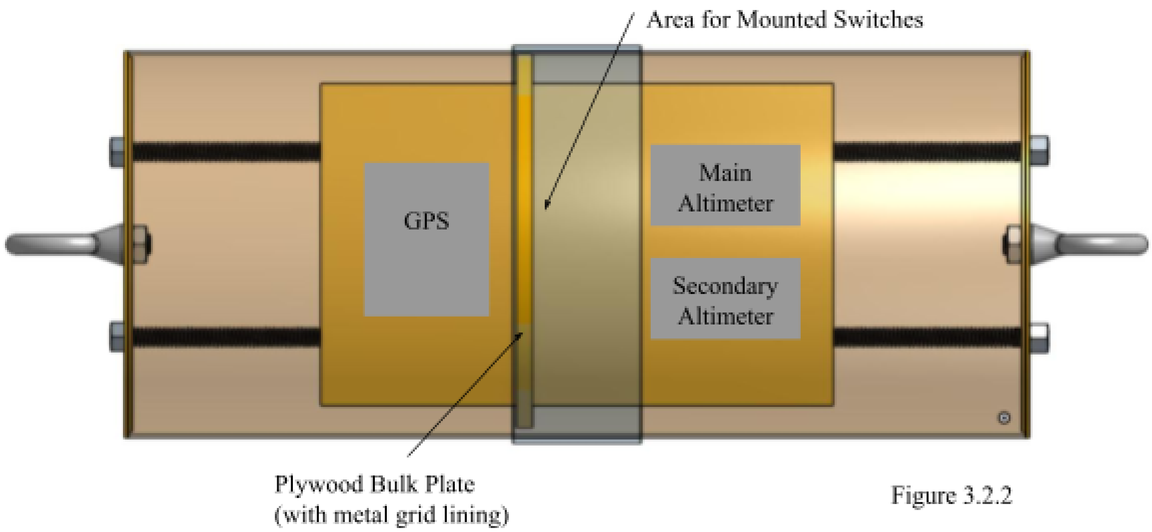

Figure 3.2.2

Note: The GPS will be located on the aft side of the electronics bay to keep it distant from the electronic matches that will be on the other side of the fore bulk plate (these matches ignite the black powder charges that deploy the main chute). Wires from the altimeters will run through bulk plates to the specified charge locations detailed above.

3.3 Expected Performance

Parachute Size Analysis

Because the payload section is the heaviest of all sections (see section 2.3), it will be used to set the descent rate limit in regards to kinetic energy.
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Maximum kinetic energy at landing is 75 ft-lbs. The payload section has an estimated mass of 10.69 pounds.

$10.69\ lbs \cdot \frac{1\ kg}{2.20462\ lbs} = 4.849\ kg$

75.00 ft-lbs $\cdot \frac{1J}{0.737562\ ft-lbs}$ =101.7 J

KE = $\frac{1}{2}mv^2$

101.7= $\frac{1}{2}(4.849)(v^2)$

v= $\sqrt{41.95}$

v = 6.477 m/s

$\frac{6.477\ m}{1s} \cdot \frac{3.28084\ ft}{1m}$ = 21.25 fps

21.25 fps will result in a kinetic energy of 75 ft-lbs of the 10.69 pound payload section upon landing. Therefore, the payload section shall not descend at a rate faster than 21.25 fps at landing.

Because the payload section is the most massive of all tethered components, and all of the components will be tethered together and descending at the same speed under the same parachute, the other components will not exceed a descent rate of 21.25 fps, regardless of their weight. If they did, the payload section would also descend faster, violating the kinetic energy at landing guideline.

Preliminary descent rate prediction from the Fruity Chutes Website for the 72” Iris Ultra Parachute with nylon lines shows the 28.79 pound vehicle descending at a rate of 20.03 fps. This ensures that the payload section, and therefore the other vehicle sections, will not violate the kinetic energy landing requirement. The graph below shows the prediction from Fruity Chutes (Figure 3.3.1).

Figure 3.3.1

Kinetic Energy of Each Section

Booster Section
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.3.1), the kinetic energy can be calculated using the estimated descent rate of 20.03 fps. $\frac{20.03\,ft}{1s} \cdot \frac{1m}{3.28084\,ft} = 6.105\,m/s$ $10.44\,lbs \cdot \frac{1\,kg}{2.20462\,lbs} = 4.736\,kg$ KE = $\frac{1}{2}mv^2$ KE = $\frac{1}{2}(4.736)(6.105^2)$ KE = 88.26 J $88.26\,J \cdot \frac{0.737562\,ft-lbs}{1J}$ =65.10 ft-lbs 65.10 < 75, therefore the booster meets the kinetic energy requirements.
Recovery Section
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.3.1), the kinetic energy can be calculated using the estimated descent rate of 20.03 fps. $\frac{20.03\,ft}{1s} \cdot \frac{1m}{3.28084\,ft} = 6.105\,m/s$ $7.66\,lbs \cdot \frac{1\,kg}{2.20462\,lbs} = 3.475\,kg$ KE = $\frac{1}{2}mv^2$ KE = $\frac{1}{2}(3.475)(6.105^2)$ KE = 64.76 J $64.76\,J \cdot \frac{0.737562\,ft-lbs}{1J}$ =47.76 ft-lbs 47.76 < 75, therefore the booster meets the kinetic energy requirements.
Payload Section
(1 J = 0.737562 ft-lb) (1 m = 3.28084 ft) (1 kg = 2.20462 lbs) Given the graphs provided by Fruity Chutes for descent rate (Graph 3.3.1), the kinetic energy can be calculated using the estimated descent rate of 20.03 fps. $\frac{20.03\,ft}{1s} \cdot \frac{1m}{3.28084\,ft} = 6.105\,m/s$

$10.69\ lbs \cdot \frac{1\ kg}{2.20462\ lbs} = 4.849\ kg$

KE = $\frac{1}{2}mv^2$

KE = $\frac{1}{2}(4.849)(6.105^2)$

KE = 90.36 J

$88.26\ J \cdot \frac{0.737562\ ft-lbs}{1J}$ =66.65 ft-lbs

66.65 < 75, therefore the booster meets the kinetic energy requirements.

Vehicle Descent Time

$t = \frac{x}{v}$,where x represents altitude in feet and v represents descent rate in feet per second.

The descent is divided into two stages, stage 1 (drogue chute) and stage 2 (main chute). Since the main chute opens at 600 ft. AGL, the descent covered by the drogue chute will be from 3437 ft - 600 ft = 2837 ft, and the main chute will cover the descent of the last 600 ft.

Descent rate under under the 24” drogue chute can be found using preliminary predictions on the Fruity Chute website (see Figure 3.3.2 below)

Descent Rate Under Drogue Chute: 73.13 fps

Figure 3.3.2

Time descending under drogue chute:

$t = \frac{2837}{73.13}$= 38.79 seconds

Time descending under main chute (using rate determined in Figure 3.3.1):

$t = \frac{600}{20.03}$= 29.96 seconds

Total descent time 38.79 + 29.96 = 68.75 seconds 68.75 < 90, meeting the descent time requirement

Vehicle Drift (using descent time calculated above)

1 mile = 5280 feet 1 hour = 3600 sec.	
Wind Speed	Vehicle Drift (in 68.75s descent)
0 mph	None
5 mph	$\frac{5\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile}$ = 7.33 fps $7.33\ fps \cdot 68.75\ s$ = 504 foot drift
10 mph	$\frac{10\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile}$ = 14.67 fps $14.67\ fps \cdot 68.75\ s$ = 1009 foot drift
15 mph	$\frac{15\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile}$ = 22.00 fps $22.00\ fps \cdot 68.75\ s$ = 1513 foot drift
20 mph	$\frac{20\ miles}{1\ hour} \cdot \frac{1\ hour}{3600\ s} \cdot \frac{5280\ ft}{1\ mile}$ = 29.33 fps $29.33\ fps \cdot 68.75\ s$ = 2016 foot drift
	All wind speeds up to at least 20 mph result in landing drift contained within the designated 2500 foot radius (assuming apogee occurs directly above launch pad).

Black Powder Charges

Because each separation point is reinforced with 2 or 3 shear pins, a pressure of at least 15 psi would produce a net force on the bulkhead of over 424 pounds, allowing for the shear pins to be broken and for ejection to happen properly. Both parachute ejections involve chambers with the same volume, so the calculations can be done together. The amount of black powder needed to achieve this can be calculated using the ideal gas law (PV=nRT). This equation can be rearranged to find n, the amount of black powder (n = $\frac{PV}{RT}$) The ideal gas constant, R, with these imperial units (Pounds force, pounds mass, inches and ^{o}R) is 266. The volume of the body tube is V = $\pi r^2 h$, where r = 3 inches, and h = 18 inches (even though each parachute chamber is only 12 inches long, the length of the 6 inch coupler is included because this volume will still need to be filled with gas for a complete ejection).

$V = \pi r^2 h = \pi(9)(18) = 508.94$ in^3

The absolute temperature of gas after combustion of black powder is T = 3307 ^{o}R.

Because charges are usually reported in grams, the results will be multiplied by the conversion factor 454 (there are 454 grams in a pound).

This leads to the final equation of:

$n = \frac{15(508.94)}{266(3307)} \cdot \frac{454}{1}$ = 3.94 grams

Online calculators from Rocketry Calculator and Hara Rocketry both verify these results.

To ensure that enough pressure is generated to cause a proper ejection, these results will be rounded up to 4 grams for the primary charge.

The secondary charge will need to be more powerful than the first to ensure separation if the first charge did not separate the vehicle completely. A charge that is composed of 6 grams of black powder would result in 22.84 psi, or 646 pounds of force on the bulkhead, a sufficient amount for backup.

4. Updated Payload Design

4.1 Camera Payload

In the time since the initial submission of the PDR Report, the team conducted several camera battery tests. Initially, based on GoPro website information, the expected battery life of each camera was 2+ hours. After using a GoPro Hero 9 and recording 4K video at 30 frames per second until the battery died, the team discovered the practical battery life of each camera is only about 1 hour and 17 minutes. This amount of battery life no longer allows for set up and activation of cameras before the vehicle is transported to and set up on the launch pad. The payload needs to be independent for a minimum of two hours before launch. This battery life inhibits that ability, and the cameras could possibly die before launch, a risk that can not be taken.

To address this issue, the internal camera batteries will be removed and the cameras will instead run off of two external batteries that can provide the necessary power for about 3.7 hours of filming. The batteries chosen are 2 x 10,000 mAh Charmast portable chargers. They are very small and carry a lot of energy for their size. Having 2 batteries with 2 outputs on each battery allows for one battery to supply energy to 2 GoPros and the other battery to supply energy to the third GoPro and the PCB (flight data collection computer). The total 10,000 mAh in each battery going to 2 outputs means each electronic device onboard the vehicle gets about 5,000mAh of usable power. The time of 3.7 hours was determined by using the GoPro's battery lifetime of 77 minutes for a battery size of 1720mAh and the external battery having a size of 5000mAh dedicated to each GoPro, resulting in 2.9 times higher capacity total. This means that each GoPro should last about 223 minutes, or 3.7 hours.

4.2 Data Collection Payload

Since the initial PDR Report, there have been no major changes in the design for the data collection payload. The only change is the power source. Because the cameras now run on external batteries and these batteries have extra available mAh, the data collection computer can also run off of these batteries, limiting excess weight added by an additional, separate battery.

4.3 Payload Retention Design

The Payload sled is comprised of the Inner frame, Outer frame, Electronics section, and Battery section.

The Outer frame is a 14 inch long fiberglass coupler with a 3.5 inch long switchband on it. The switch band has three 3"W x 2"H filleted rectangular holes cut into it by a CNC machine for precision while the inner coupler tube has three smaller 2.5"W x 1.5"H filleted rectangular holes cut into it. The larger outer openings are then filled with acrylic windows by epoxying the acrylic windows to the inner coupler tube since the inner coupler openings are smaller and leave a 0.25" border of fiberglass to secure the acrylic windows to. (see Figure 4.3.1)

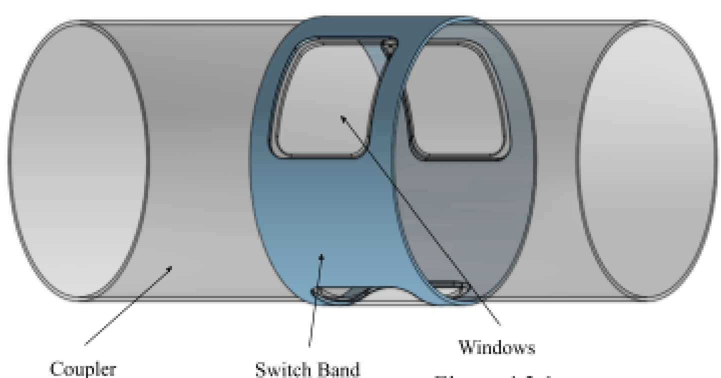

Figure 4.3.1

The Inner frame consists of two fiberglass bulk plates, one at the bottom and one at the top of the coupler, three ¼-20 aluminum threaded rods, 6 locking nuts for the threaded rods, and 1 steel forged eyebolt. This inner frame secures itself within the coupler, retains the electronics section and battery section, and offers an interface with the recovery system by providing a harness attachment point at the eyebolt. The inner frame is shown in Figure 4.3.2.

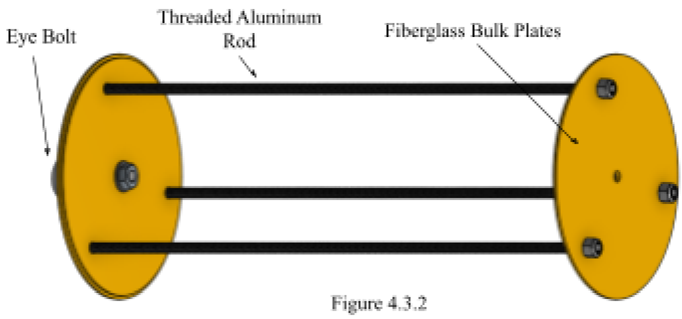

Figure 4.3.2

The Electronics section is made up of the PCB (data collection computer) section and GoPro section housed between two aluminum bulk plates with 6 locking nuts for retention. The GoPro section uses a 3D Printed housing that puts all 3 GoPro Hero 9's each at a 120 degree angle from each other. The section uses the threaded rods for alignment. The PCB section uses a 3D Printed housing that holds the electronic board in place, and allows for wiring of power for the GoPro section to pass through into the Battery Section. Figure 4.3.3 shows this design.

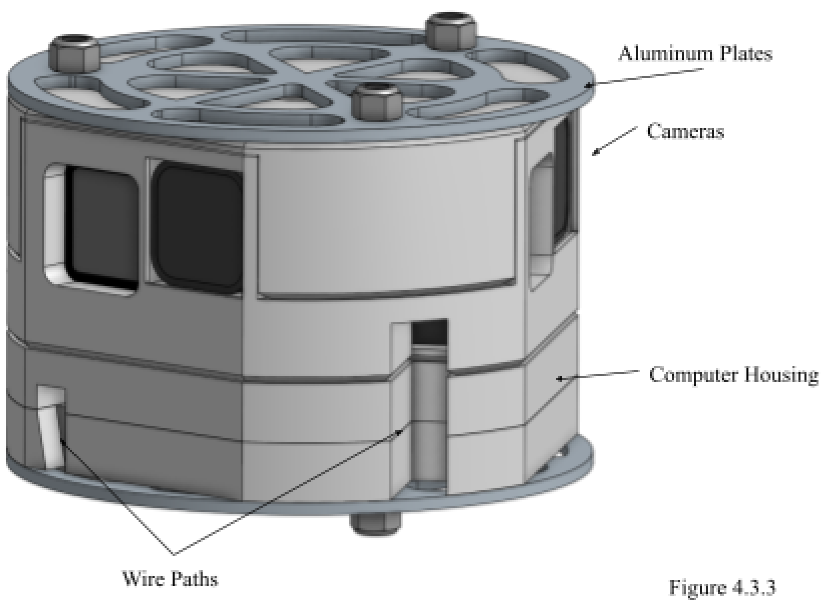

Figure 4.3.3

The Battery section consists of 2 x 10,000 mAh Charmast portable batteries, both with two USB ports for ease of access to plug in electronics. There are two aluminum plates which hold everything together into place, and two more centered on each battery which prevent lateral movement in the compartment. They are held in the correct location by 3D Printed spacers & locking nuts to hold the whole section into place. Figures 4.3.4 and 4.3.5 show this design (batteries are colored orange).

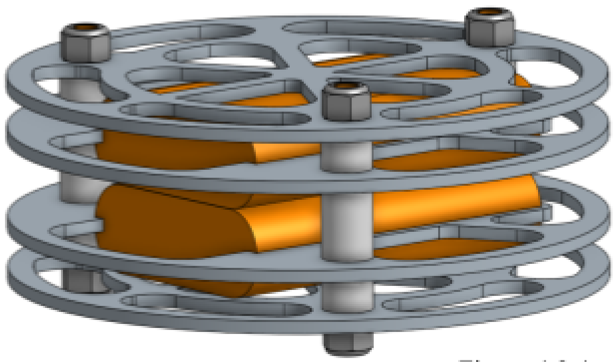
Figure 4.3.4

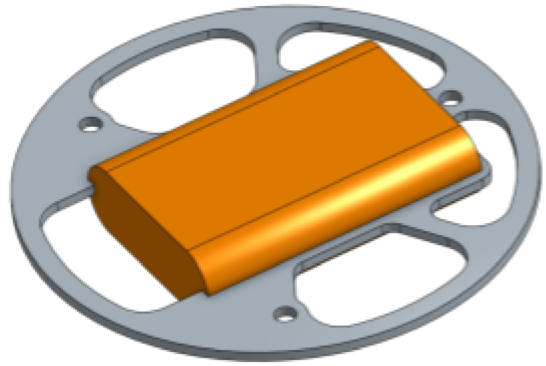
Figure 4.3.5

The fully assembled payload retention design is shown below in Figure 4.3.6.

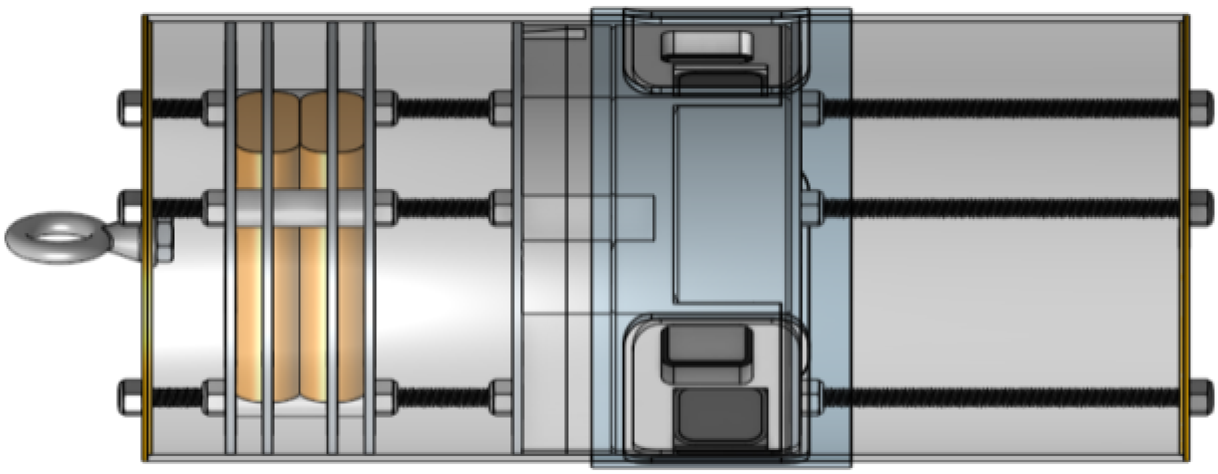
Figure 4.3.6

5. Updated Budget

Item:	Cost:	Quantity:	Total Cost:	Vendor(s):
Cesaroni K1440 Motor	$196.26	3	$588.78	Off We Go Rocketry
6" Dia. Fiberglass body tube (per linear ft)	$46.25	6	$277.50	Wildman Rocketry
Cesaroni 54mm 6-Grain Hardware Set	$135.00	1	$135.00	Apogee Components
5:1 Ogive Filament Wound Fiberglass 6" Dia. nosecone	$149.00	1	$149.00	Wildman Rocketry

Fruity Chutes 72” Iris Ultra	$284.88	1	$284.88	Fruity Chutes
Fruity Chutes 24” Elliptical Drogue	$51.20	1	$51.20	Fruity Chutes
6" Dia. Fiberglass body tube coupler (per inch length)	$4.89	28	$136.92	Wildman Rocketry
RocketPoxy structural adhesive	$65.00	1	$65.00	Wildman Rocketry
G10 Fiberglass 12"x12"x0.1875" sheet (for fins)	$28.00	3	$84.00	Wildman Rocketry
Kevlar Shock Cord - 3600#- Main Chute (per linear yd.)	$2.50	9	$22.50	Wildman Rocketry
Kevlar Shock Cord - 3600#- Drogue Chute (per linear yd.)	$2.50	9	$22.50	Wildman Rocketry
Coupler Bulkhead - 6" Dia.	$9.00	4	$36.00	Wildman Rocketry
1/4" zinc plated flat washer (6 pack)	$1.28	1	$1.28	Home Depot
1/4" - 20 stainless steel lock nuts (3 pack)	$1.28	6	$7.68	Home Depot
3/8" eye-bolts	$5.49	3	$16.47	Menards
Motor Mount Tubing - 54mm Dia. fiberglass	$27.00	1	$27.00	Wildman Rocketry
Centering Ring - 6" OD x 54mm inner dia. Fiberglass	$20.75	3	$62.25	Apogee Components
AeroPack Retainer - 54mm	$36.16	1	$36.16	Wildman Rocketry
1/4" quick links	$1.15	4	$4.60	Home Depot
2-20 Nylon shear pins (20-pack)	$1.00	2	$2.00	Home Depot
Removable 2-piece Plastic Rivets (10-pack)	$5.00	5	$25.00	Home Depot
1/4" x 6” x 12" aluminium sheet	$19.99	3	$59.97	Amazon
1/4" threaded aluminium rod (6 ft length)	$21.93	1	$21.93	Fastenal
PerfectFlight StrattologgerCF altimeter	$54.95	2	$109.90	PerfectFliteDirect
GoPro HERO9	$359.99	3	$1,079.97	GoPro website
Electronic Circuit Board (Oshpark)	$41.33	1	$41.33	Oshpark
Charmast 10,000 mAh Portable Charger	$22.99	2	$45.98	Amazon
Electronic Parts	$117.60	1	$117.60	Various Locations
Scale Model	$500.00	1	$500.00	Various Locations

Cesaroni Motor for Scale Model	$50.00	1	$50.00	Apogee Components
Rocket Tracker Transmitter	$150.00	1	$150.00	Off We Go Rocketry
3-D Printing	$100.00	1	$100.00	Various Locations
Tax (0.07)	$347.22	1	$347.22	Based on Iowa Tax Rate
Shipping and Hazmat	$200.00	1	$200.00	
Total Cost	$4,859.62			