Final Proposal

Brandon Cook

Miriam Deschine

Daniel Edmonds

Joshua Smith

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Project Sponsor: Mr. Steven Hengl, Orbital ATK

Instructor: Dr. Sarah Oman, Northern Arizona University

DISCLAIMER

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EXECUTIVE SUMMARY

Launch vehicles are exposed to weather conditions during the countdown to launch. Sun, wind, and rain can all interfere with the countdown and launch process. There are no existing solutions that function at the scale required to solve this problem. The team must develop a solution to protect the launch vehicles from weather and a scaled demonstration prototype.

The team reviewed commercially available weather protection technologies and temporary, deployable shelters. Designs were created with different mechanisms and emphases to determine which design elements and approaches are most viable. Communication between the design team and the client informed the decision to attempt to design a lightweight structure that can be disassembled, packed, and shipped by truck. The product will be shipped to the launch site, assembled, used, and disassembled there then trucked back to Orbital for storage until the next launch.

There are numerous customer needs the design must fulfill. The primary customer needs are solar protection, safety, and fast takedown time. The team used the list of customer needs to develop a list of engineering requirements and associated target metrics.

Engineering requirements specify that the design must protect the entire height of the vehicle from sunlight to keep engines within the operable temperature range of 65 to 85 degrees Fahrenheit. The design should shed water to prevent the launch vehicle with encountering large amounts of water. The design must be able to withstand winds up to 50 mph, have a factor of safety of 3 for yielding stress, and a factor of safety of 5 for ultimate load. This design solution must be able to be taken down in under 4 hours with a target of 30 minutes.

The team drafted the first round of designs and applied weighted selection criteria to eliminate designs that are not feasible. The team narrowed the field of acceptable designs to 3 designs, each representing a different approach to shielding the launch vehicle.

The Pickle design closes around the launch vehicle and then deploys upwards in stages. The Rocket Awning is assembled on site then rolls into position around the launch vehicle on casters. The Bear Trap design is sprung up around the launch vehicle with a polymer skin around the tent pole style frame.

The team is preparing to meet with the client to discuss design concepts and feasibility. After meeting with the client, the team will further refine and adapt design elements to arrive at a chosen solution. The solution will be prototyped, analyzed, and tested later in the project.

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1 BACKGROUND

1.1 Introduction

Orbital ATK has presented the 2017-2018 Mechanical Engineering Capstone with the opportunity to design an enclosure to be used during launch vehicle processing. Orbital ATK is a global leader in aerospace and defense systems with a strong emphasis on launch vehicles and propulsion systems [1]. Orbital ATK primarily launches vehicles in coastal areas including Virginia, California, Florida, and Alaska, all of which result in high elemental exposure to the vehicles during launch pad processing. Providing protection to the launch vehicles from sun and rain exposure are the primary objectives of this design problem. Orbital ATK does not currently have a system implemented that satisfies these objectives. In certain circumstances tarps have been applied to critical areas of the launch vehicle to protect against exposure, but this process is sub-optimal. These objectives materialize due to a series of events that result from sun and rain. Sun and rain can result in delays in processing the launch vehicle when on the launch pad. Processing that occurs while on the launch pad includes, but is not limited to: final systems checks, vehicle temperature monitoring, and ensuring all components are securely fastened. Such delays can ultimately postpone the launch of these vehicles. Each delay amounts to increased cost to Orbital ATK. For this reason, Orbital ATK is looking for a solution that will minimize the impacts from the elements, allowing for successful launches of vehicles.

Successful development of a design will provide a greater level of protection to Orbital ATK's launch vehicles than is currently being implemented. Cost and risk implications will be dramatically reduced allowing the processing and launch of vehicles to be conducted in a more efficient manner.

1.2 Project Description

Following is the original project description as provided by Orbital ATK:

> Orbital ATK's launch vehicle division has an extensive list of different types and sizes of vehicles. The launch vehicles are processed and launched all over the United States generally in coastal areas. As a result, weather constraints for sun and rain exposure often impede launch vehicle processing and sometimes launches causing significant cost delays. Orbital ATK is interested in developing a method to protect launch vehicles from the environments during launch pad processing. The design shall be scalable to all Orbital ATK launch vehicles, quick to install and remove and be cost efficient. This project will include trades studies, design, analysis, and sub-scale model prototype. As part of the design effort, a Preliminary Design Review (PDR) and Critical Design Review (CDR) will be required. The PDR will entail a presentation of the selected design and will include analysis results, testing plan and manufacturing drawings [2].

A single item of the original project description has been altered by Orbital ATK. "The design shall be scalable to all Orbital ATK vehicles" has been rephrased from "The design shall be universal to all Orbital ATK vehicles". This item was rephrased due to Orbital ATK possessing launch vehicles with dimensions that vary significantly from one to another. Team A and Orbital ATK observed that designing a scalable enclosure would better satisfy the objective of this project rather than a single, universal enclosure.

1.3 Original System

This project involves the design of a completely new launch vehicle enclosure. There was no original system when this project began. The current solution to the design problem is placing tarps on specific areas of the launch vehicle that requires more protection than other areas. In an attempt to fix the current solution, customer needs and engineering requirements were made to begin this project.

2 REQUIREMENTS

Chapter 2 covers the customer and engineering requirements needed to make this project a success. Without determining customer needs, assumptions could only be made and the design team risks creating a design that is completely useless to the customer. The first part of this step is determining the customer requirements. After the customer needs are established, engineering requirements are created for each of the needs. All engineering requirements must have a measurement, and therefore a target value and tolerance that the team designs for. Furthermore, the last section of this chapter is the House of Quality (HoQ). This relates all requirements and ensures that the design problem is well understood.

2.1 Customer Requirements (CRs)

Below is a list of all customer requirements with their description and weightings. A list was made prior to this that was sent to the main client for this design project. The client then weighted the customer requirements on a basis of a one to ten scale. Customer needs were added or removed upon request of the customer. This helped the team to further understand what the customer wanted for this design project.

1. **Solar Protection:** This requirement was ranked a 9/10. Solar protection from the sun for the launch vehicle will give the ability to reduce the temperature within the enclosure. This will also reduce any radiation harm done on the launch vehicle.
2. **Moisture Protection:** This requirement was ranked a 9/10. Moisture protection refers to rain, snow, or hail. The design project must be able to prevent moisture entering the enclosure and therefore reducing moisture damage of the launch vehicle.
3. **Debris Protection:** This requirement was ranked a 1/10. This requirement refers to protecting launch vehicles from airborne debris.
4. **Wind Protection:** This requirement was ranked a 1/10. The design should protect launch vehicles and personnel within the enclosure from high winds, however, this is not of major concern to the customer. This requirement refers to allow airflow within the enclosure as well.
5. **Lightning Protection:** This requirement was ranked a 9/10. The customer did not rank this requirement, but suggested that it was added to the list. The design team deemed it viable that protection against lightning was of major concern. This requirement refers to the enclosure's ability to redirect any lightning away from the launch vehicle and personnel.
6. **Launch Vehicle Temperature:** This requirement was ranked a 5/10. Certain parts of the launch vehicle need to be held within a certain temperature range. This requirement plays in part with the solar protection.
7. **Launch Vehicle Contact:** This requirement was ranked a 10/10. This refers to the enclosure having zero contact with the launch vehicle. The team must design an enclosure that does not rest or support itself on the launch vehicle in any way.
8. **Work Environment Temperature:** This design requirement was ranked a 3/10. The enclosure will also have personnel working on the launch vehicle inside. Therefore, it is necessary to keep in mind the temperature environment for the personnel.
9. **Work Space:** This requirement was ranked an 8/10. As previously mentioned, there will be personnel working on the vehicle inside the enclosure. Eight to ten people must be able to fit within the enclosure.
10. **Accessibility:** This requirement was ranked a 10/10. In addition to an appropriate sized work space for personnel, complete access to the launch vehicle is needed. This also includes to the capability of driving trucks, scissor lifts and other large equipment needed to work on the launch vehicle into and out of the enclosure.

11. **Scalable Design:** This requirement was ranked a 9/10. Launch vehicles vary in size. This design problem does not ask for a "one-size fits all," but instead a design that can be easily scaled to match the required dimensions of other launch vehicles.
12. **Ease of Assembly:** This requirement was ranked an 8/10. This refers to the simplicity of construction for the enclosure at the launch pad. Simpler is better.
13. **Time of Assembly:** This requirement was ranked an 8/10. This customer need relates to the simplicity of construction. A simpler design is easier to construct and faster to assemble.
14. **Time of Disassembly:** This requirement was ranked an 8/10. This design also relates to the time and ease of assembly. If the enclosure is difficult to construct, then the deconstruction will be just as difficult. While these requirements seem similar, they are separate due to the target time associated with each.
15. **Associated Costs:** This requirement was ranked a 6/10. This design requirement refers to costs involved in the production, ownership, and operation of the design.
16. **Ability to Support Items:** This requirement was ranked a 3/10**.** This design requirement refers to the system's ability to support auxiliary items.
17. **System Lifespan:** This requirement was ranked an 8/10. This refers to the system's number of uses without failure. This requirement is dependent on the cost of the design. A design with a very short lifespan may be viable if the design proves to be significantly cost effective.
18. **Durability:** This requirement was ranked an 8/10. This requirement measures the lifespan of the system. It must be able to withstand wind, rain, and UV degradation throughout its entire lifespan. When a system is not durable enough to withstand weather conditions, the system is of no use and therefore reached the end of its lifespan.
19. **Safety:** This requirement was ranked a 10/10. This requirement refers to the minimization of safety hazards during bad weather conditions and design system failure.
20. **Factor of Safety:** This requirement was ranked a 10/10. This requirement was suggested to be added by the client. This ranking was based on the ranking of the safety requirement. A larger factor of safety requires much stronger system to be designed. The better factor of safety will reduce the safety hazards for the launch vehicle and personnel.

2.2 Engineering Requirements (ERs)

The customer requirements listed above have engineering requirements associated with each one. The engineering requirements have a target value for the design team to aim for and a tolerance associated with each requirement. If a design falls outside of the tolerance it must be redesigned to meet the tolerance and strive to get as close to the target value as possible. A concise table has been made that includes all customer requirements and their corresponding engineering requirements, target values, and tolerances which can be found in Table A1 of Appendix A.

1. **Heat Flux Through Enclosure Material (W/m^2):** This coincides with solar protection. The target value and tolerance for this engineering requirement is less than 354 W/m^2. This engineering requirement must be designed to minimize the amount of heat flux within the enclosure.
2. **Permeability ($g/m^2/24hr$):** This coincides with moisture protection. The target value and tolerance for this engineering requirement is less than 603 $g/m^2/24hr$. These values were chosen due to a design requirement of creating a structure that blocks storms and significantly reduces rain, snow, or hail impact on the launch vehicle.
3. **Tensile Strength (kPa):** This coincides with protection from debris and wind. The design must be able to withstand a minimum of 50mph winds. Designs that do not meet this requirement risk the

safety of the launch vehicles, personnel, and equipment. Therefore, the target value is 1 kPa with a ±15 Pa tolerance. This value was chosen due to an estimated value of tensile strength caused by 50mph winds.

4. **Volumetric Flow Rate (m^3/s):** This coincides with wind protection, and the required airflow for a building. Using the Building Airflow Standard (BAF) based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standard 62-89, the target value and tolerance for this engineering requirement is 0.071 m^3/s [3].
5. **Surface Temperature Delta (°C):** This coincides with the launch vehicle temperature. The target value is 23.9°C and has a tolerance range between 18.4-29.4°C. These values were given by the client for this design project.
6. **Enclosure Deflection (m):** This engineering requirement relates to launch vehicle contact with the enclosure. The target value and tolerance are less than 1 m.
7. **Dead Space Temperature (°C):** This corresponds to the customer requirement of the work environment temperature. Fortunately, the designated temperature target and tolerance of engineering requirement number 5 is also a comfortable range for personnel to work in. The target values and tolerances for this requirement is the same of that of number 5.
8. **Enclosure Footprint (m^2):** This requirement corresponds to the customer need of work space. Looking at the researched information about Orbital-ATK's launch vehicle diameters, there is roughly a 2-meter difference between the Minotaur and the Antares diameters. Therefore, the enclosure footprint will remain the same for all launch vehicles. The changing dimension for each rocket will include the height of the enclosure. To provide enough room for trucks and lift equipment to drive around the launch vehicle, an additional 12m in diameter was chosen for the targeted value. This gives an enclosure target footprint of 200m^2 with a tolerance of ±10m^2.
9. **Entrance Dimensions (m^2):** The enclosure must allow personnel access to the launch vehicle. Therefore, the entrances to the enclosure must be large enough to drive certain trucks and other equipment inside. Thus, a 25m^2 entrance is targeted with a ±5m^2 tolerance.
10. **Cost per Enclosure Height ($/m):** This corresponds to a scalable design that can be incorporated for the different sizes of launch vehicles. This engineering requirement depends on the target cost and the height needed to provide enough room between the vehicle and the enclosure's wall. The target value for this specific requirement is less than $2,000 per m.
11. **Number of Assembly Steps (# of Steps):** This engineering requirement must be designed to minimize the number of steps needed to assemble the enclosure. The least amount steps define the simplicity and user friendliness of the system. The target value for this requirement is 10 steps with a tolerance of 5 steps.
12. **Time to Assemble (min):** This engineering requirement must strive to minimize the time needed to assemble the enclosure. The target value for this requirement is one hour with a tolerance of eight hours.
13. **Time to Disassemble (min):** This engineering requirement is similar to the time to assemble. However, the disassembly target time is half an hour with a tolerance of four hours.
14. **Raw Material Cost ($):** The target value for a full-scaled project is $50,000 with a tolerance of $50,000. The client for this design project provided that a full-scale project should strive to be around $30,000 for a 60ft tall vehicle.
15. **Bearing Stress (kPa):** This engineering requirement requires that the design can safely hold/support auxiliary items such as a flood light. This value will incorporate the factor of safety. The target values for this requirement is 1 kPa with a ±15 Pa tolerance.

16. **Usage Quantities (#Uses):** This engineering requirement corresponds to the enclosure's lifespan. The targeted value for this requirement is 5 uses without failure with a tolerance of 20 uses.
17. **UV Degradation (Hours):** The UV degradation of the system will determine the durability of the enclosure's waterproof material. The lifespan of the design will also depend on the ability to resist exposure and wear. The target value and tolerance for this requirement is 5,000 hours or greater for a minimum of 200 days at 2 days a use.
18. **Failure Percentage Across Various Scenarios (%):** The enclosure must be extremely safe and be able to minimize all safety hazards. The targeted value for this engineering requirement is 1% failure percentage with a 0.01% tolerance.
19. **Yield Stress/ Working Stress (FOS#):** The factor of safety standard is 3 for yield strength and 5 for ultimate strength. The tolerance is therefore 3 or greater for yield strength and 5 or greater for yield strength. This engineering requirement ensures the highest possible safety.

2.3 Testing Procedures (TPs)

This chapter will discuss the procedures the team plans to take to analyze the viability of the design. Analysis done should inform the team whether a concept will meet requirements or not and allow the team to make decisions about the design. The team will attempt to combine analyses when possible based on a larger theme. The following sections include the detailed planning of the testing procedures or technical analysis to be completed by the team.

2.3.1 Analysis of Temperature Effects

The temperature of the launch vehicle prior to launch being held constant is a customer requirement that was ranked very highly by the client. The team generated the engineering requirements of launch vehicle surface temperature, dead space temperature, and heat flux into the enclosure. The three requirements are very closely related and can potentially be solved in one rather large heat transfer problem.

The analysis of temperatures inside the enclosure would begin by gathering important constants for the different materials under consideration. These constants include the conductive heat transfer coefficient (h), the convective heat transfer coefficient (k), the material's emissivity, and the material's absorptivity. The next process is to determine the resistive network to represent the system as heat transfer passes from the exterior air, through the material, through the enclosure air, and finally reaches the launch vehicle's surface. This type of system will include all three forms of heat transfer: conduction, convection, and radiation. To aid in the solution to this problem, the Principles of Heat and Mass Transfer 7th Edition can be used. The book can provide useful equations, material properties, and other information that may be needed in a heat transfer problem. Any constants for materials not in the books should be researched elsewhere.

This analysis would provide the team with information about which material in consideration would insulate the enclosure the best, how thick the material should be, or whether an open or closed enclosure would be better (i.e. do convective or radiation factors have a larger role in the system?) [4].

Actual conditions within the design can be tested with the final prototype in an outdoor environment using a water source and a wind source. Temperature within the prototype will be tested against temperature outside to compare to expected surface temperature delta and dead space temperature. Water that gets through the prototype will be measured and compared to expected permeability. Enclosure deflection will be measured and compared to predicted results scaled by Reynold's Number. Data on external and internal temperature will be compared to predicted heat flux measures.

2.3.2 Strength, Stress, and Failure Mode

Structural strength will be analyzed by calculating the stress generated within structural elements. Typical and maximal loading patterns will be analyzed for stress generated in structural beam and column elements, joints and locks, fasteners, tie downs, draw leads, bearings, and areas of stress concentration. A safe operating envelope will be calculated from this data based on material properties or data available for commercially produced parts. Cyclic design life of each part will be calculated based on expected patterns of loading during use and compared to the expected lifetime of the material. If redesign is not a feasible solution or the component is anticipated to be consumable, then attention may be directed at improving maintenance and replacement processes associated with the part. The final design will be designed with a purposeful failure mode that occurs before any other components fail. The polymer skin will be designed to fail above certain wind speeds to allow rapid reduction in load applied to the structure. This will allow the structure to function within the specified conditions while avoiding catastrophic failure if those conditions are exceeded. This failure mode will be determined through analysis and may be physically tested.

2.3.3 Flow Rates Through System

Permeability of the system will be calculated using diffusion flux equations applied to materials in question. The permeability of both water and air through will be examined to identify flow rate values. These values will be driven by a permeability coefficient, pressure differential, and the thickness of material being used. The permeability coefficient gives a relationship between the fluid (water or air) and the material (PTFE, HDPE, etc.). Do to the inability to procure each possible material to be used, physical testing will not be performed. However, by taking an analytical approach to testing the diffusion flux corresponding to water and air through materials allows for variables to be altered without the need to purchase materials and testing equipment. If testing was performed, a large-scale wind tunnel would be needed, along with the ability to introduce water into the flow. The wind tunnel would create enough of pressure differential between the flow and the system to mimic the conditions of actual application. Additionally, multiple materials, each of multiple thicknesses, would need to be acquired to perform sufficient testing.

2.3.4 Costs

Costs for this system will be directly driven by the required raw materials needed. This testing procedure will not include additional costs incurred with maintenance, transportation, and/or assembly, as dictated by the client. Included cost would include but are not limited to covering material, structural items, fasteners, anchors, and accessories. The quantity of each item will be multiplied by its unit price, and summed with all other expenses. The client has provided as rough final price range of 30 – 60 thousand dollars. There is no required equipment for the testing process, as prices for material can be acquired through suppliers and online resources. As the system is to be scalable to different sized rockets, the correlation between the cost of material and the height of the system will be tested. Since pricing guidelines were only provided for a 60-foot rocket height, the test will determine if a linear trend between price and height can be achieved with the selected design.

2.3.5 Material Endurance

UV Degradation will be determined through research on the material in question. The effects of UV rays from the sun on the material will be analyzed to determine the rate of degradation. This rate directly corresponds to the usage quantity of the enclosure. When a material degrades on the molecular level, several things can happen, such as losing its permeability properties and strength. This also directly corresponds to the failure of the enclosure. UV degradation is tested by elongated exposure in the sun, or with usage of an accelerator device. Due to the time limit of this project and inaccessibility to an accelerator, physical testing on different materials will not be constructed. Instead, research on materials will provide an estimated lifespan of the material to conclude the usage quantity of the enclosure before failure. The estimated lifespan will give guidelines for when the material of the enclosure should be replaced. Current research suggests that the selected materials will not degrade appreciably during use and that failure of mechanical parts will have a larger effect on design lifetime. Expected lifetime will be informed by use of the final prototype. If the final prototype encounters problems or failure, they will be noted as a design concern and re-evaluated. The part and implementation failure record of the final prototype will be used to predict the lifetime of the final, full scale launch vehicle enclosure.

2.3.6 Assembly

The steps and time of assembly and disassembly will be calculated during construction and testing of a scaled prototype. One design idea can be constructed multiple ways. The physical construction of a prototype will help determine the easiest construction for a minimum number of assembly steps. As the number of assembly and disassembly steps is minimized, the time of assembly and disassembly will be reduced. The client desires a quicker disassembly than the assembly, however, both must be relatively time beneficial. The target time of assembly is between one hour and eight hours. The target time of disassembly is between half an hour and four hours. The final prototype will incorporate assembly steps congruent with the full size launch vehicle enclosure. Time to complete these steps will be tabulated. Final predicted assembly and disassembly time will be informed by the recorded times.

2.3.7 Accessibility

Accessibility will be tested analytically. The structure must meet any workplace code requirements relevant to the launch pad environment. OSHA standards and current client practices will guide design refinement. Access to the structure will be measured by entrance size and number. Internal work space will be considered and clearance between the launch vehicle, heavy equipment, and the shelter must be adequate for crews to work and move safely. The current requirement for accessibility specifies that a bucket truck or scissor lift must be able to get in the structure, position itself for work, and deploy its equipment and crew, then retract and withdraw from the structure without contacting the shelter or sensitive equipment. The space within the shelter will be evaluated against the physical size and maneuverability limits of these vehicles (turn radius, vertical clearance, reach) to determine if the design is adequately accessible.

2.4 House of Quality (HoQ)

The House of Quality (HoQ) transfers the voice of the client into the voice of the engineer. It creates a clear demonstration for the engineering team to develop specifications the product must reach to satisfy the customer. It is necessary that these specifications measure the needs of the customer. The HoQ also determines how competition or products designed for the same goal meet the design specifications. The HoQ also assigns numerical targets for the design team to work toward.

The first part of the HoQ identifies the customer and their needs. The second part identifies the customer's associated importance with the needs. These weights are applied based on the score of one through ten provided by the customer. The next section of the HoQ lists the engineering requirements used to meet the customer's needs, and are related against the needs. A blank box demonstrates there is no relationship at all, a 1 demonstrates a weak relationship, a 3 demonstrates a medium relationship and a 9 demonstrates a strong relationship between the needs and the requirements. In the HoQ, the engineering requirement that received the most amount of 9's is raw material cost. Raw material cost was given a 9 in relation to the solar protection, moisture protection, associated design costs, the system lifespan, the durability, and the safety and FOS. Raw material cost was given a 9 for these customer needs because the amount spent on certain materials generally has a linear relationship with quality. The stronger and better the material for the job, the more expensive it tends to be. Because the safety, durability, and weather protection are highly weighted customer needs, the more important and demanding it is for the design to fulfill those needs. Each engineering requirement contains at least one 9 for its relation against the customer needs.

Next, each requirement is related among the other engineering requirements in the top section of the HoQ. A positive demonstrates that improvement on one specification will also improve another, while a negative demonstrates that improvement on one will harm the other. There are more positive relations than negative ones for this design problem. At the bottom of the HoQ are the metric units by which the requirements are measured with their target value. Below these is the absolute technical importance. This takes each technical requirement ratings multiplied with their corresponding customer need weight factor and adds the total. The weighted technical importance takes the absolute technical importance divided by the sum of all absolute technical importance values. Lastly, the weighted technical importance is ranked out of the number of engineering requirements. The HoQ determined that the raw material cost has the highest relative technical importance, with percent failure and enclosure deflection following behind. This shows a positive correlation to the engineering requirements that contain the strongest relationships with the customer needs. These values help the design team determine the most important engineering requirements that will help create a product that satisfies all the customer's needs to the best of its ability.

Table 1: Sample House of Quality [5-7]

1	Heat Flux Through Enclosure Material, TP 2.3.1					
2	Permeability, TP 2.3.3	+				
3	Tensile Strength, TP 2.3.2	-				
4	Volumetric Flow Rate, TP 2.3.3		+			
6	Surface Temperature Delta, TP 2.3.1	+	+		+	

Legend	
A	Alaska Tent & Tarp: Arctic Oven
B	Rubb: CAE EFASS
C	Losberger: TMM Inflatable Shelter

	Customer Needs	Customer Weights	Technical Requirements: Heat Flux Through Enclosure Material, TP 2.3.1	Permeability, TP 2.3.3	Tensile Strength, TP 2.3.2	Volumetric Flow Rate, TP 2.3.3	Surface Temperature Delta, TP 2.3.1	Benchmarking: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		↑↓	↓	↓	↑	↓	↓					
1	Solar Protection	9	9	1			3			A	BCD	
2	Moisture Protection	9		9		3					ACD	B
3	Debris Protection	1		3	3	3				ACD	B	
4	Wind Protection	1		3	9	9			C	A	D	B
5	Lightning Protection	9						AD	C		B	
	Relative Technical Importance		15	16	9	19	18					

The HoQ also relates similar products to the customer needs on a scale of one to five, one being poor, three being acceptable, and five being excellent in meeting the needs. The similar products for this design project are the Arctic Oven Tent [5], the Rubb CAE EFASS system [6], and the Losberger TMM Inflatable Shelter [7]. The results in the HoQ show that the Rubb CAE EFASS system meets many of the customer needs at the excellent rating of 5. Above in Figure 1 is a sample HoQ that demonstrates the first five customer needs and engineering requirements along with their relationships and relative technical importance. The competitive devices are also related to the first five customer needs in the sample HoQ. The full HoQ can be referenced in Appendix B, Figure B1. The HoQ has helped the team keep in mind the customer needs and their importance in the design generation. Once several designs are generated, the HoQ will continue to be referenced to aid in the Decision Matrix and the Pugh Chart.

3 EXISTING DESIGNS

This chapter discusses the process and results of the team's in-depth research of existing designs related to this project. The sections will discuss how research was conducted, resources used, information found, and analysis comparing how existing designs meet the requirements of this design. A functional decomposition including a black box model and a hypothesized functional model of the potential design is included in this chapter.

3.1 Design Research

The team began background research on Orbital ATK's website. An understanding of Orbital's launch vehicles size, shape, and launch locations was desired. The flight systems link provided information and fact sheets on the Pegasus, Minotaur family of vehicles, and the Antares [1]. Launch locations of the Minotaur rocket were found to be in Florida, California, Alaska, and Mid-Atlantic [8]. The team thought it would be a good idea to research typical weather conditions in those areas to determine what type of weather the design needs to withstand. According to an article by Dawn Henthorn, the East coast of Florida faces frequent rain storms and lightning [9]. Since most of the launch sites are on either the east or west coast of the United States, it is assumed that similar weather conditions are present at each site. Wayne Eleazer wrote about types of weather that are problematic for launch vehicles prior to and during launch, which include "excessive surface winds, high winds aloft, thunderstorms, cloud thickness, and in some cases rain" [10].

Cline library's databases were used to search for journals and articles that may contain helpful information. An excerpt about GORE-TEX was requested from Northern Arizona University to gain more information about this material. Similarly, articles on Vapex material used in the Arctic Oven Tent were found as part of our background research.

Through the utilization of websites and journal articles from the Cline library databases, a better understanding of the size of the launch vehicles Orbital ATK uses and the main weather conditions that the design faces were established. Devices and materials for weatherproofing are detailed in the following sections.

3.2 System Level

No systems are currently used to protect launch vehicles during countdown however there are several systems that perform similar functions in different capacities. Examples of these systems are RUBB portable buildings and hangars, camping tents such as the Arctic Oven, and inflatable tents [5-7]. Each of these systems have areas they excel and areas where improvement would need to be made.

3.2.1 Existing Design #1: Arctic Oven Tent

This system demonstrates lightweight and portable weatherproofing. A fabric is stretched over a frame of tent poles. Fabric and poles act to hold each other in place and create a semi-rigid shape that repels water and wind. The Arctic Oven uses Vapex treated fabric to repel water [5]. The system may have to cover significant vertical distance while supporting itself under wind load. The lightweight of the tent structure and waterproof Vapex material could be helpful to meet customer needs.

3.2.2 Existing Design #2: Sunbelt Inflatable Tent

Sunbelt inflatable tents builds large custom inflatable tents for events, emergency services, and family tailgates. These tents are made larger than a camping tent and demonstrate the potential of using a compressed fluid-based collapsible structure made from lightweight, low cost materials. This system can deploy/takedown a 16 by 16-foot tent in less than two minutes with minimum human handling [11]. The Sunbelt Inflatable Tent System is made from vinyl. An inflatable system may be applicable to meet cost, deployment, and takedown time customer requirements.

3.2.3 Existing Design #3: RUBB CAE Aviation Hangar

The RUBB EFASS (Expeditionary Forces Aircraft Shelter System) is an aircraft hangar used by the military to keep equipment out of rough environmental conditions. The hangar is made of durable fabric and a collapsible skeletal frame. These large hangars can take up to 4.5 days to deploy [6]. The hangar is made with trusses to distribute the load of the structure over wide areas. A truss like structure may add significant stiffness to the system to prevent it from deflecting in high winds or contacting the launch vehicle.

3.3 Functional Decomposition

This section is devoted to discussion of system functions. The system must accomplish 6 tasks: resist the force of its own weight and the weather acting on it, dissipate that weather away from the launch vehicle, keep sunlight from heating the vehicle above operable temperature, maneuver into and out of position for deployment, deploy/takedown rapidly and safely, and allow for personnel and equipment to flow into and out of the system. The following section analyzes these tasks and design subsystems that will work together optimally to protect the launch vehicle. Figure 1 below demonstrates how the team will break down the system and the existing products that could satisfy each sub-function.

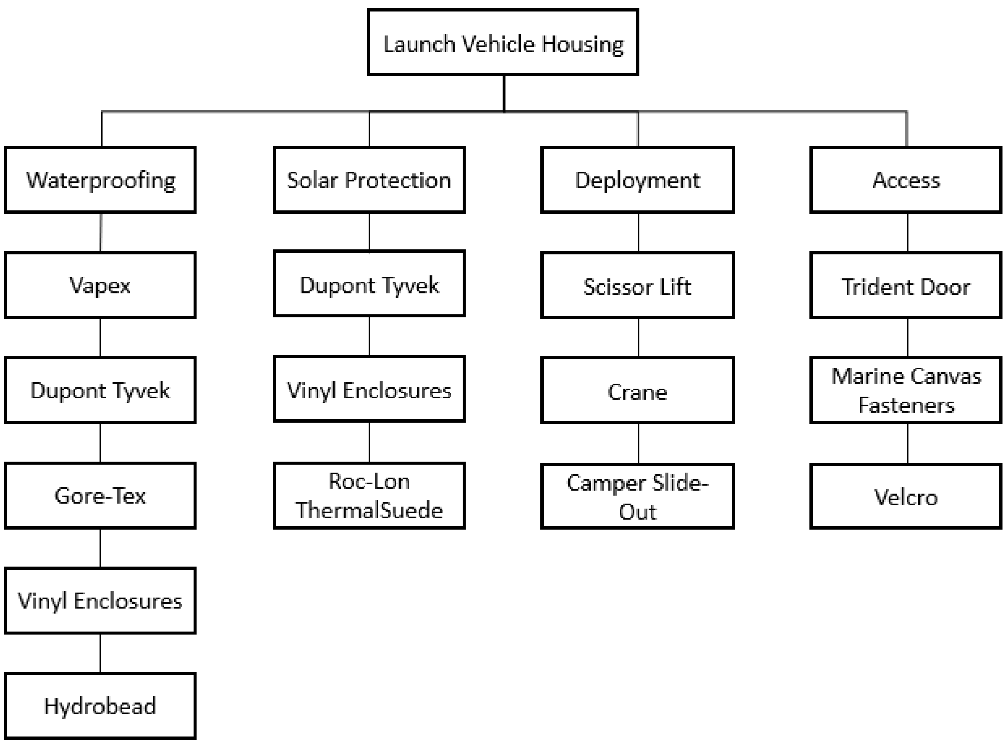


Figure 1: Functional Decomposition Flow Chart

3.3.1 Black Box Model

The Black Box Model is a broad interpretation of the signal, energy, and material flows required of the system and is shown below in Figure 2. Materially, the system will shed water while allowing humans, equipment, and the launch vehicle to pass into and out of the system safely. Workers and equipment will be able to conduct countdown work within the structure. Energetically, the system must dissipate mechanical energy due to wind and lightning strikes. The system must channel the human and electrical energy used to move and deploy it. The system must also dissipate heat due to solar energy to keep the launch vehicle within the optimal temperature window for rocket function. Signal-wise the system will indicate when it is ready to be moved, deployed, taken down, safe to use, etc. This will likely be done by some combination of visual inspection, indicator lights, audible alarms, and voice communications. This process helped the team identify the main purpose of the design. The model also helped the team to break down and examine what conditions the design will face. This black box was then used to generate a hypothesized functional model.

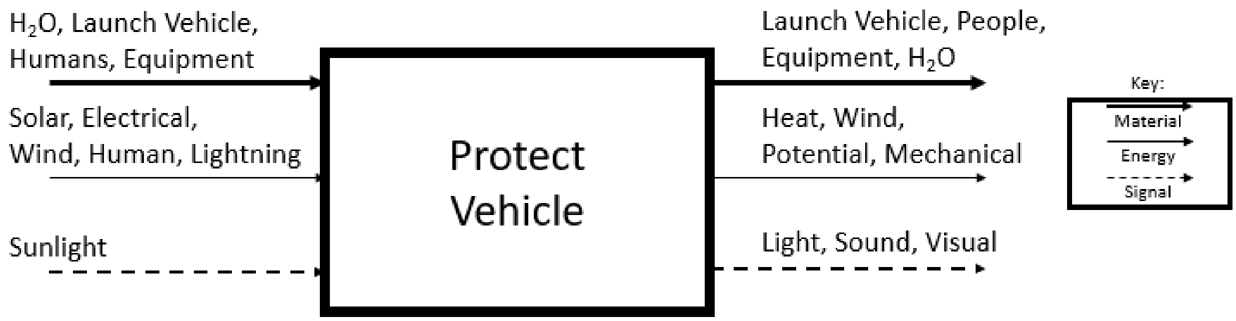


Figure 2: Black Box Model for Enclosure Design

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The functional model shows the breakdown of the black box model to identify how the inputs of the system are transferred to outputs. This model can be seen in Figure 3 below. This process forced the team to think about each aspect of the process. Questions such as, "How is the material going to interact with the device?" or "Does this action require human energy?" were asked. By asking these questions the functions the system needs to perform to deal with the inputs were identified. With functions identified, the team can research different methods of performing the function required. For example, the function "Dissipate Water" will lead the team to research different methods of waterproofing that exist. A similar process will be performed for each of the functions that the design needs to perform in the subsystem discussions below.

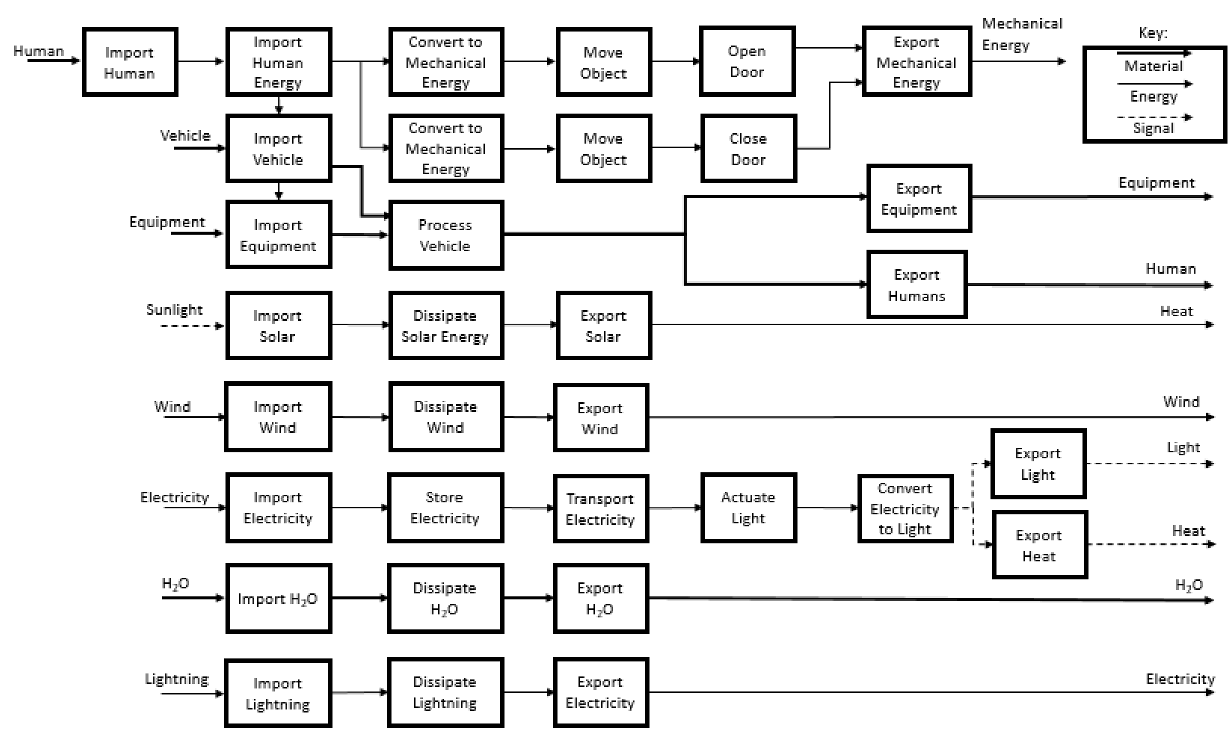


Figure 3: Functional Model of Potential Design

3.4 Subsystem Level

The system must accomplish several tasks to protect launch vehicles from weather conditions. Each major task will be performed and managed by a relevant subsystem. The system must be kept ready or delivered to the launch site. From there it must be moved into position. The support structure and weatherproofing subsystems must be deployed. The whole system will then be taken down and removed late in the launch countdown. An efficient, quick, and easy to deploy system will likely have significant overlap between these subsystems.

3.4.1 Subsystem #1: Waterproof Barrier

Providing a waterproof barrier between the launch vehicle and surrounding environment is critical in meeting customer needs. This subsystem dissipates water as expressed in the functional decomposition of this system.

3.4.1.1 Existing Design #1: Enterprise Coating's Vapex

Enterprise Coating's *Vapex* is most commonly used in Alaska Tent & Tarp's *Arctic Oven. Vapex* is a monolithic membrane of hydrophilic polyurethane [12]. This material is layered in between of various other materials to create an impermeable fabric. The properties displayed in this material adequately satisfy the need to create a waterproof barrier. The ability of this material to be combined with alternative materials allows the possibility of combining solutions to Subsystem #2 and Subsystem #3.

3.4.1.2 Existing Design #2: Dupont's Tyvek

Dupont's Tyvek is currently used in construction materials, protective apparel, sterile packaging, and cargo protection. Tyvek is a material comprised of high-density polyethylene fibers [13]. Specifically, Dupont's W series of cargo covers was examined when researching existing systems. This material is commonly used to protect goods being shipped from the elements, including rain. This material would provide protection to the launch vehicle from rain. This material is also readily available.

3.4.1.3 Existing Design #3: W.L. Gore's Gore-Tex

Gore has created a Gore-Tex material that is used by various clothing manufacturers to provide waterproof characteristics to their products. Gore-Tex is a material membrane of polytetrafluoroethylene, making it an extremely porous. These pores however are exponentially smaller than a single droplet of water, allowing for the material to be waterproof [14].

3.4.1.4 Existing Design #4: Mosquito Curtains' Clear Vinyl Enclosures

Mosquito Curtains' Clear Vinyl Enclosures are used primarily in-home applications to protect from the elements as well as small insects. Clear Vinyl Enclosures consist of a 20-mil thick sheet of vinyl [15]. A primary application of this system is to protect against rain, directly aligning with our objective of creating a waterproof barrier.

3.4.1.5 Existing Design #5: Hydrobead

Hydrobead is a super hydrophobic coating that can be used on multiple surfaces. It beads and repels water-based liquids. Hydrobead keeps water moving and physically separates liquids from surfaces [16]. This minimizes rust, ice, and bacterial growth. Using super hydrophobic coatings would create a waterproof structure while increasing its lifespan.

3.4.2 Subsystem #2: Solar Protection/Temperature Regulation

Providing solar protection to the launch vehicle is a primary objective of this design project to meet the customer needs. In parallel with providing solar protection the enclosure must maintain the temperature of the launch vehicle within a specified range. This subsystem satisfies the dissipation of solar energy expressed in the functional decomposition of the system.

3.4.2.1 *Existing Design #1: Dupont's Tyvek*

Dupont's Tyvek is currently used in construction materials, protective apparel, sterile packaging, and cargo protection. In addition to Tyvek's waterproof abilities, Tyvek also serves as a protectant from solar radiation. Specifically, Dupont's W series of cargo covers was examined when researching existing systems. These cargo covers provide solar protection primarily to perishable goods such as medicine and produce.

3.4.2.2 *Existing Design #2: Mosquito Curtains' Clear Vinyl Enclosure*

Mosquito Curtains' Clear Vinyl Enclosures are used primarily in-home applications to protect from the elements as well as small insects. Clear Vinyl Enclosures consist of a 20-mil thick sheet of vinyl [15]. The layer of vinyl provides protection against extreme temperatures both hot and cold. Applying this material to our system would allow for vehicle temperatures to be maintained within the desired range.

3.4.2.3 *Existing Design #3: Roc-Lon ThermalSuede*

Roc-Lon ThermalSuede is a polyester-cotton blend material that is primarily used for in-home applications, specifically curtains. This material is combined with a thin layer of insulating foam, providing thermal insulation to spaces in which the material is applied [17]. This material may also be applied to the project design to manage temperature fluctuations within the enclosure.

3.4.3 Subsystem #3: Deployment

The system must be capable of being deployed and taken down in under 4 hours. The deployment subsystem takes place after the positioning subsystem. It prepares the structural support for the weatherproofing subsystem. The deployment subsystem is responsible for converting energy from human or electrical sources into mechanical movement within the system.

3.4.3.1 *Existing Design #1: Scissor Lift*

Can be moved or positioned while retracted then scissors upwards to cover considerable vertical area. The scissor lift uses a mechanical linkage to extend and contract along the vertical axis. This could be a useful technique to deploy a structure from the ground around the vehicle straight up around it.

3.4.3.2 *Existing Design #2: Crane*

Raising the structure from the ground or dropping it from above via crane may be a viable deployment solution. The system would not have to contain powered equipment to erect itself and could rely on the crane to provide the force necessary to prop its structure into position.

3.4.3.3 *Existing Design #3: Camper Slide-Out*

Camper slide-outs fold into the main body of a camper and slide out on tracks when they need to deploy. They allow a weatherproof structure to fold into a smaller space and be portable. They tend to be built to be lightweight yet withstand high loading transverse of the track direction. This system also tends to suffer binding if allowed to deploy unevenly.

3.4.4 Subsystem #4: Enclosure Access and Egress

Providing access and egress to the enclosure is a primary objective of this design project to meet the customer need of being able to process the launch vehicle while on the launch pad. This subsystem satisfies the import of vehicle, people, and equipment as expressed in the functional decomposition of the system.

3.4.4.1 *Existing Design #1: Rubb Building Systems Trident Door*

Rubb Building Systems has designed a door to be used in their Expeditionary Forces Aircraft Shelter System (EFASS) titled the Trident. This door is comprised of three PVC panels that are operated via motorized folding mechanism. On current EFASS, the door allows for a 20.4m wide span with the height dependent on which model is selected [18]. This system allows for aircraft to be rapidly deployed from within the hangar. Currently this system would accommodate the access and egress of the launch vehicle enclosure, however modifications would need to be made to allow for the access and egress of the launch vehicle itself.

3.4.4.2 Existing Design #2: Marine Canvas Fasteners

Marine canvas fasteners are manufactured by multiple companies and are used in numerous applications. The main purpose of these fasteners is to tightly attach two separate materials. This can include connecting two soft materials or a soft material to a rigid system. Applying this system to the launch vehicle enclosure would allow for sections of the enclosure to be removed or attached quickly, providing access to the launch vehicle.

3.4.4.3 Existing Design #3: Industrial Strength Velcro

Velcro manufactures several different lines of reusable fasteners. Much like canvas fasteners, Velcro fasteners can attach to various types materials. Velcro fasteners have different mounting options depending on what materials are being used [19].

4 DESIGNS CONSIDERED

This section will illustrate full system concepts that have been generated to satisfy critical customer needs and engineering requirements. All systems are composed of smaller subsystems, each of which targets an individual need or requirement. The concepts described in this section will likely change as the project moves forward, however the information provided highlights the approach taken by team members to solve this design problem. All images of the designs not included in this section can be found in Appendix C.

4.1 Design #1: Panel Assembly

Design one pulls inspiration from modular concrete forming systems. By taking the modular capabilities of these systems, this design would adapt to the different size requirements for each launch vehicle. Each panel would consist of a combination of materials, each serving a specific purpose, that would protect launch vehicles from the elements. The three main materials that would be utilized in this design include a reflective material, insulating material, and non-permeable material. The reflective and insulating materials would work in unison to maintain the temperature of the launch vehicle by blocking solar radiation. Tyvek cargo covers employ a similar system to provide perishable items protection from large temperature gradients. The non-permeable material would serve as a waterproof barrier between the outer environment and the launch vehicle. Multiple panels would be interconnected to create “gangs” of panels using a series of clamping mechanisms. These assemblies can be brought into the launch zone via cranes or forklifts, to be assembled into the final system. In doing so, the amount of assembly/disassembly time required on the launch pad could be reduced considerably. Different sized panels will allow for variable entrance dimensions. Sketches of this design can be found in Figure C1.1 and C1.2 of Appendix C.

4.2 Design #2: Inflatable Enclosure

Design two is based on concepts seen in inflatable play houses. The system will be dependent on an airflow being forced through cells of the system. With a high enough flow rate, the cells will become rigid in nature. Additional supports will be inserted into the system in the event of pump failure to the system. With a constant flow of air entering the system, limited air circulation within the workspace can be eliminated. A major drawback to this design is the necessity for a large quantity of seams to be sewn and sealed, resulting in increased manufacturing costs. This system would need to be placed in the proper area before deployment, requiring the launch vehicle to be placed on the launch pad prior, or the exact location of where the vehicle will be placed must be known. Surface materials will be selected for this design based on their abilities to repel water and solar energy. One or more materials may be considered. The Inflatable Enclosure can be seen in Figure C2 of Appendix C.

4.3 Design #3: The Bear Trap

Design three is shown below in Figure 4. More detailed drawings of this design are in Appendix C, Figures C3.1 and C3.2. This design considers the six subsystems to make a functioning system that meets the customer’s needs. It consists of two strong structural skeletons that connect around the launch vehicle. The structural support is mechanically capable to deploy and un-deploy in a reasonable amount of time. The completed setup of the structural skeleton creates a durable support that prevents contact between a waterproof material and the launch vehicle. The support will have rails in which the eight triangle shaped pieces of the waterproof material are roped up, enclosing the launch vehicle. This material will have several openings on the top that allow ventilation to the enclosure, while still navigating rain droplets away from entering. These ventilation gaps will be able to close or open as desired. In addition, the material will have larger windows on the bottom. Personnel inside the enclosure can access these windows to open or close them as desired. There will be a minimum of four doors to allow ingress and egress for personnel and equipment. This design will need a large clearance around the launch vehicle for both assembly and disassembly.

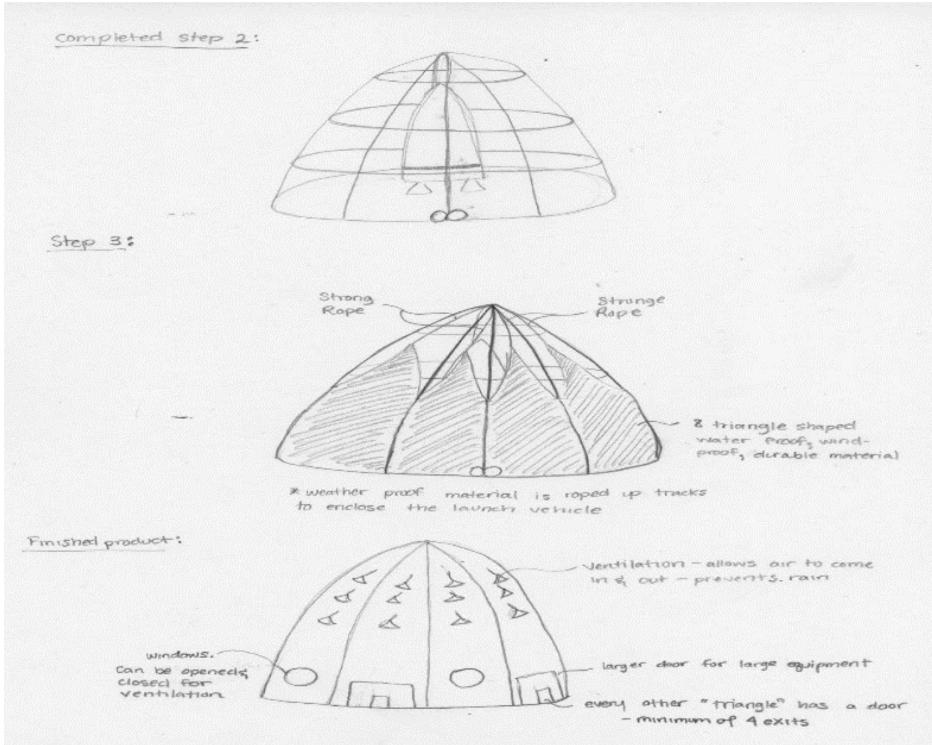


Figure 4: The Bear Trap

This design is mechanically complicated. Though it may be inexpensive and lightweight for its size, the mechanics behind it must be made keeping the safety of the launch vehicle and personnel in mind. The different mechanically functioning parts will increase the risk of failure as well. This considered design must satisfy the customer needs of safety.

4.4 Design #4: The Blinds

Design four was inspired by vertical blinds. There are two large walls on wheels that sits at an angle. These walls are made of metal fashioned like vertical blinds. They will have the capacity to be rotated open and closed for desired air flow. These two structures will be placed around the launch vehicle and have support beams that rotate out connecting the two walls together and creating a strong structure around the launch vehicle. These walls will also have self-storage units for the weather proof material will be stored when not in use. The weatherproof material will be brought to the top in which they are deployed to cover the remaining two sides of the launch vehicle and the roof. The material will contain large doors for access to the launch vehicle for personnel and equipment. This design can be viewed in Figure C4.1 and C4.2 of Appendix C for better understanding of the design and its deployment.

The cost of this design is predictably high. Construction of the blinds and their operation can be expensive and will need constant maintenance. Another con of this design is the weight. The two walls will be very large, making it very difficult to position into place around the launch vehicle. A benefit to this design is the large ventilation capability, allowing the enclosure to withhold OSHA standards.

4.5 Design #5: Winch Hoisted Sides

Design five is based on the idea of a simple yet strong skeleton structure that can be assembled and disassembled on the launch pad within the specified time provided by the client. Once the main structure is in place, lightweight sides made of waterproof material can be hoisted upward to seal the sides of the enclosure. A winch system using synthetic rope rather than steel cable can be used to hoist the sides from a mounting location on the top of the structure. This would seal the enclosure providing shade from the sun, and protection from the elements. One of the sides will have a door for employee entrance and exit once the enclosure is deployed. The design can be seen in Figure C5 of Appendix C.

An advantage to this design is its simple geometry of a cube constructed of straight beams. With the use of a scissor lift, the employees at Orbital could construct this easily bolt together the main structure. The use of a winch system makes for easy raising of the four sides.

This design does not make access to the launch vehicle with a scissor lift or truck easy after the sides are hoisted into place. With the sides in the down position, driving on the fabric will also cause damage to the sides. Since the sides are separate pieces held up by the tension from the winch, there could be potential gaps for the sun or water to penetrate the enclosure. Another disadvantage is that a winch system requires a power supply and introduces an additional potential wear item.

4.6 Design #6: Rocket Awning

Design six is a variation of Design 5 that gets inspiration from motorhome awnings. It is demonstrated in Figure 5. The design has a similar skeletal structure for strength. The four corners would have a track system that a waterproof material could follow downward to unroll into a wall. When the sides are down, it provides protection from the rain and sun. The process of rolling the sides up and down can either be an electrical or manual process depending on the feasibility of reaching the roll as it approaches the top of the structure for taller launch vehicle enclosures.

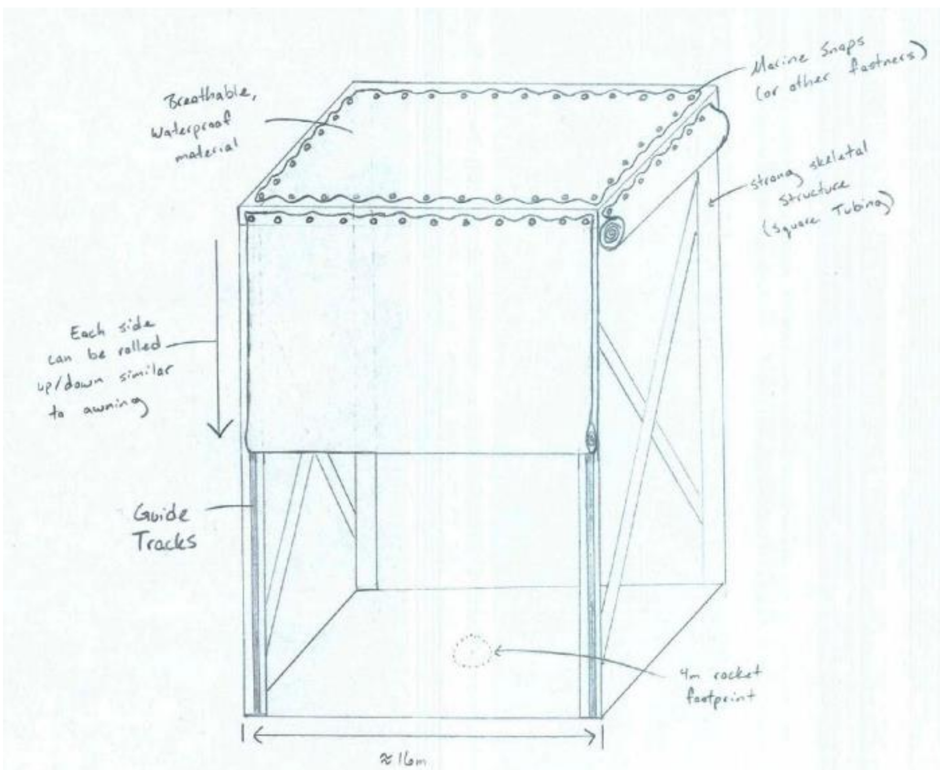


Figure 5: The Rocket Awning

An advantage of this design is the same simple geometry as Design 5 for easy construction and material purchasing. With each side being able to roll up individually, it provides full access for scissor lifts, trucks, and employees. It also allows the shaded sides of the enclosure to be rolled up for better airflow to the enclosure while employees are working.

A disadvantage to this design is not fully sealed because each side is individually covered. The constant up and down motion along the tracks could also lead to mechanical failure. Another disadvantage is the flat roof where rain water could puddle up. This could be easily addressed by adding a pointed roof.

4.7 Design #7: The Curtain

The Curtain design inspired by the Mosquito Curtain is in Figure 6. It utilizes the idea of a waterproof curtain that hangs from a track above the launch vehicle. To keep the curtain from interfering with the launch vehicle, a second track connected to the bottom of the curtain is used. The curtain does not meet the ground. To allow for accessibility of the launch vehicle, the bottom track would be 10-15ft above the ground. The enclosure is therefore not entirely sealed. However, much of the rocket is covered and protected from the sun and rain. Ideally, water would not contact the vehicle because of the large footprint.

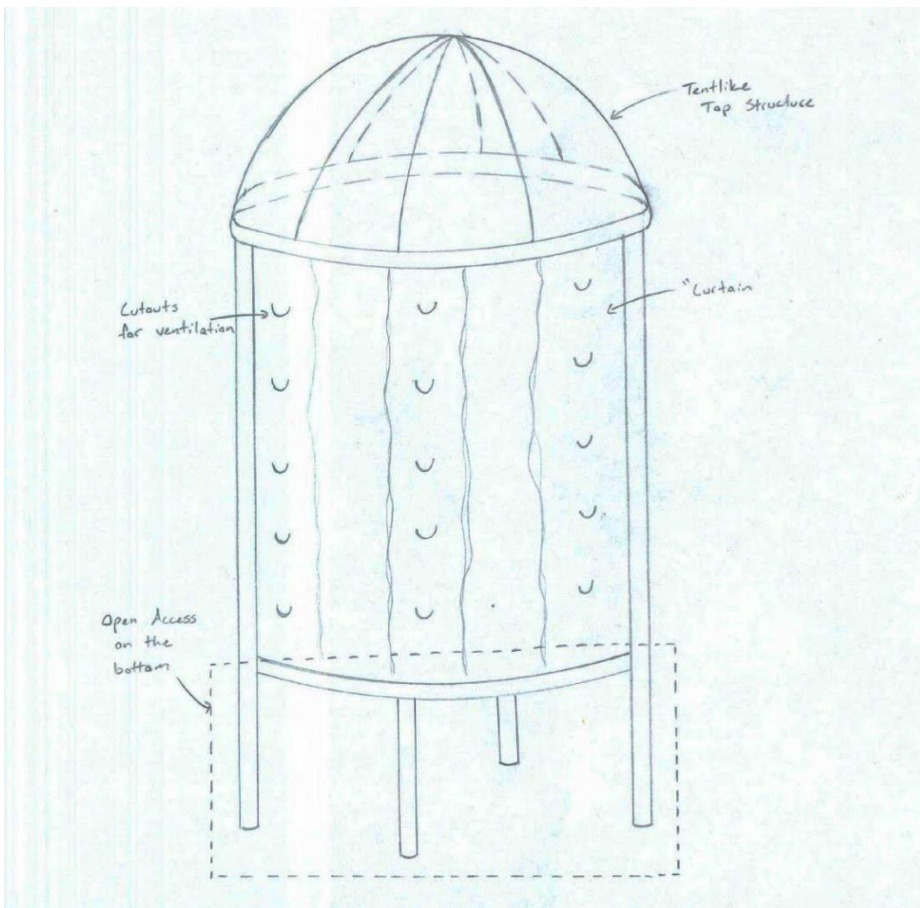


Figure 6: The Curtain

The advantages to this design are that it provides easy accessibility, shades the launch vehicle from the sun, can be deployed quickly, and allows air flow.

A disadvantage to this design is that it is not structurally secure. Most of the structure is soft, apart from the legs it stands on. Another disadvantage is that it does not entirely cover the launch vehicle from top to bottom. Lastly, if the device is a solid circular track, the problem is getting it into position around the vehicle.

4.8 Design #8: The Cone

The purpose of the Cone design in Figure 7 is to minimize the number of deployment steps and simplify the structure as much as possible. The structure acts as the wind barrier and waterproof layer. The external support could be implemented as a solid cone surface or with cutaways to minimize wind load and material usage. The large volume between the interior cylinder and exterior cone surface allow the system to be insulated against solar heating. The structure would be deployed by moving its separate sections into place and then locking it down. The sections could be moved on wheels if they were made from a rigid material. If the sections were made inflatable, they could float on a cushion of pressurized air from the inflation mechanism and be pushed or towed into place. Access to the interior would require doorways in the lower part of the wedge sections. For more detailed views of the Cone look to Figure C6 of Appendix C.

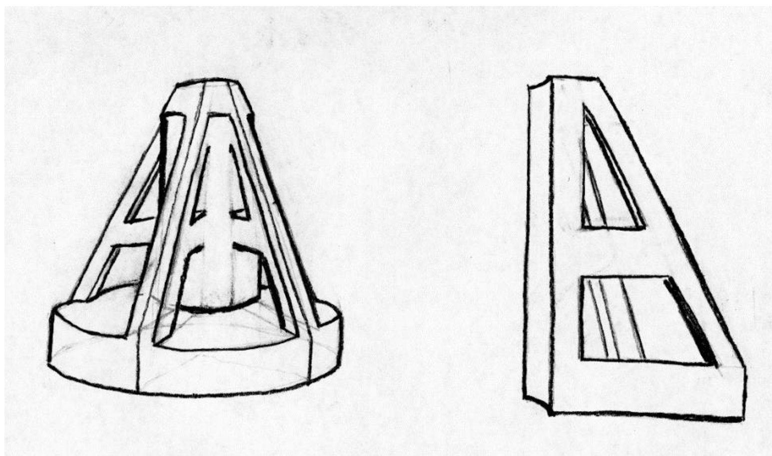


Figure 7. The Cone

4.9 Design #9: The Slider

Design 9 is meant to eliminate the risks inherent to moving a tall structure into position around a launch vehicle in a high wind scenario. This system would be heavy and low during positioning to avoid tipping or being blown off course. This system's two halves would be moved into place, secured to the ground and each other, then deploy upwards to cover the launch vehicle's sides. A roof could be extended from the top section to shed rain. The Slider design can be seen in Figure C7 of Appendix C. One drawback to this design is that multiple steps are required to deploy or remove the system. Another is the mechanical complexity of the system required to make the system extend. The system would need to be regularly maintained and would still have a risk of deployment failure due to the mechanical complexity.

4.10 Design #10: Stilt Tent

Design 10 is intended to provide maximum coverage with minimum material cost, ease of assembly, and a simple takedown process. This system's structural legs fold down, position itself over the launch vehicle, then deploy fabric coverings down the sides to shed rain and block solar heating. The system would then be anchored around the launch vehicle. Removing the system from the launch area is a simple and ideally quick process: The fabric is rolled back up or even removed, the structure is unanchored and then rolled away from the launch pad. This system could be positioned by rolling, with the wheels and powered equipment adding ballast to the bottom of the structure to help stabilize it. The system could be assembled on the ground, eliminating the need of a crane to hoist structural elements into the air. This design can be seen in Figure C8 of Appendix C.

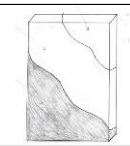
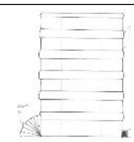
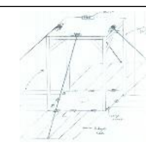
5 DESIGN SELECTED

This chapter discusses the design selected for this project and the process used to select it. The processes used to select the design include the use of a Pugh Chart and Decision Matrix. The Pugh Cart is used first to narrow the number of designs down to four. The Decision Matrix then takes these four designs and selects the top design to meet many of the customer needs.

5.1 Rationale for Design Selection

The design team first utilized a Pugh Chart in the design selection process. The Pugh Chart sets one design as a datum for meeting the customer needs. All other designs are rated against the datum. If one design meets a customer need better than the datum it is given a plus. If it meets the need worse than the datum it is given a minus. If a design meets the customer need equally as much as the datum, it is given an “S”. When all designs have been ranked against the datum the pluses, minuses, and S’s are summed separately below each design. The Panel Assembly design was chosen as the datum for the Pugh Chart. This can be seen below in Table 2. The remaining nine designs were ranked against the datum and the total pluses, minuses, and S’s were summed. The Stilt Tent and the Blinds were eliminated from the design selection process. These designs had the largest number of minuses and are believed to meet most of the customer needs poorly. The next four designs with the largest number of pluses were chosen to be further analyzed in the Decision Matrix. The Pugh Chart can be referenced in Appendix D, Table D.1.

Table 2 – Pugh Chart Excerpt

			
Criteria	Panel Assembly	Inflatable Enclosure	Winch Hoisted Sides
Solar Protection	D	S	-
Moisture Protection	A	+	-
Debris Protection	T	-	-
Lightning Protection	U	S	S
Vehicle Temperature	M	+	+
Vehicle Contact	*	-	S
∑+	-	5	5
∑-	-	7	5
∑S	-	6	8

The top four designs selected from the Pugh Chart for the Decision Matrix are the Curtain, the Cone, the Bear Trap, and the Rocket Awning. First, the team weighted the customer needs so that the sum of the individual needs is equal to 1, or 100%. Next each selected design is ranked on a scale of one to ten for how well it satisfies the customer needs. Each designs’ customer needs rankings are multiplied with their corresponding weighted value. These values are summed together, giving each design a score. A small excerpt of the Decision Matrix used can be seen in Table 3. The design with the highest resulting score, the Cone, was selected for further analysis by the team. The Decision Matrix can be referenced in Appendix D, Table D2. The design that scored the highest is the Cone. The team will present the designs considered, the design selection process, and the selected design to the clientele to ensure that the customer needs are continuing to be met.

Table 3 – Decision Matrix Excerpt

Design:		The Curtain	
Criteria	Criteria Weight	Score	Weighted Score
Solar Protection	0.10	8.00	0.80
Moisture Protection	0.10	4.00	0.40
Debris Protection	0.01	3.50	0.04
Lightning Protection	0.06	5.00	0.30
Vehicle Temperature	0.05	7.00	0.35
		Total Score	6.61

The team met with the client to discuss design selection. The weighted design criteria the team chose to use in the Decision Matrix were focused on preventing launch vehicle contact and providing safety to the crew. This favored the relatively stable and high strength characteristics of the cone. The client expressed a preference for a more portable design. The design should be able to be transported via truck to and from the launch site. If it is large it will have to be assembled there. The client gave latitude to design rails into the launch pad, as well as other features beyond simple anchors if necessary.

5.2 Design Description: The Bear Trap

The Bear Trap's main structural feature are two high arches. They start laid on the ground and are raised via a pulley system on each side. As the two arches are raised semi-circle rings pivot into place on the outside faces of the arches. The supports and semi-circles close around the launch vehicle when fully deployed. Material is pulled taut between each ring of the structure to shield the launch vehicle from sun and rain. The two arches are locked vertically when fully deployed for safety. The main arches are pinned and locked within a base structure. The main arches and bases are shown below in Figures 8-11.

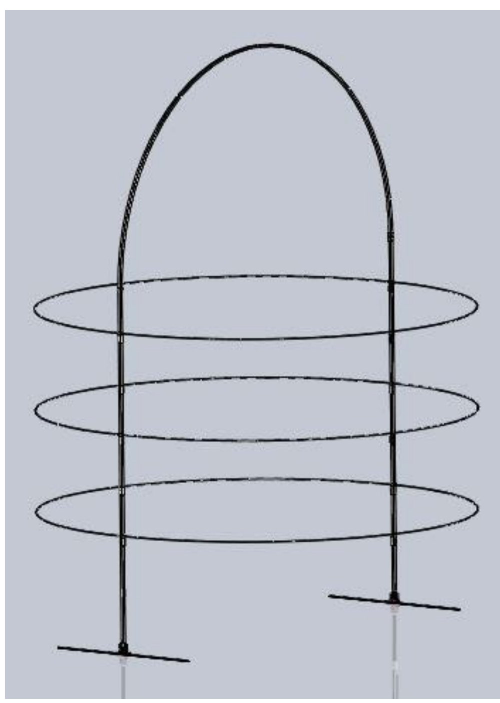


Figure 8 – Fully Closed Launch Vehicle Enclosure

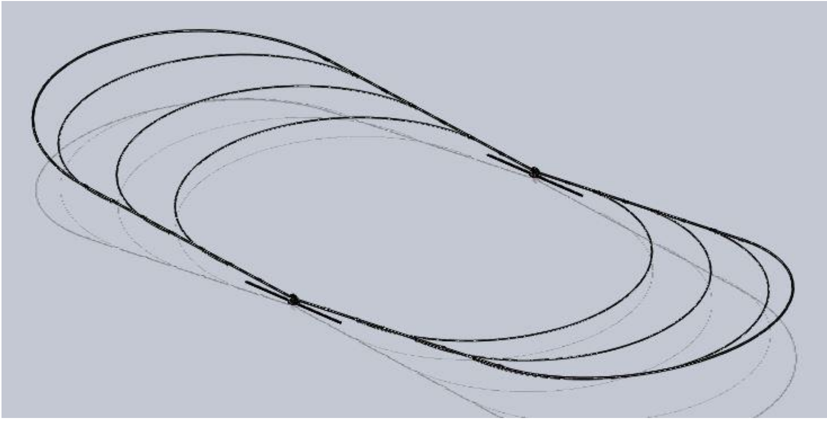


Figure 9 – Fully Opened Launch Vehicle Enclosure

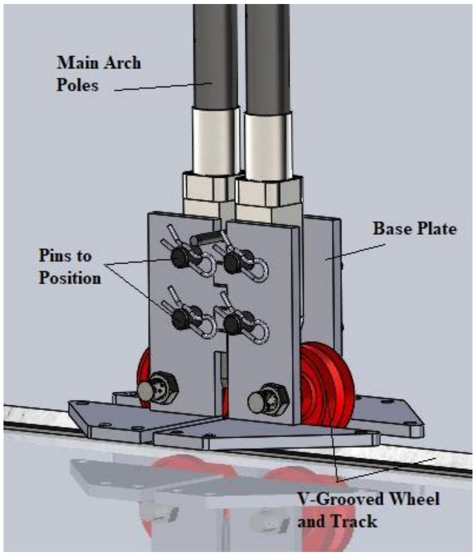


Figure 10 – Closed Base Assembly for Launch Vehicle Enclosure

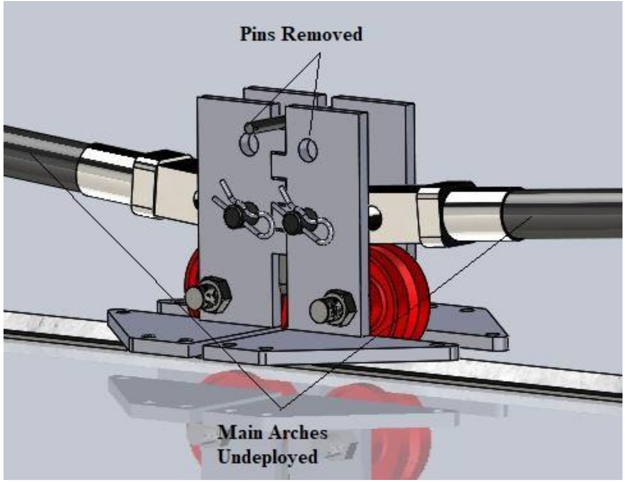


Figure 11 – Open Base Assembly for Launch Vehicle Enclosure

The base structure rolls into place on a rail secured to the launch pad. The enclosure is assembled in its down position and rolled into place around the launch vehicle on the rails. The structure rolls away on the rails to facilitate disassembly and vehicle launch. The side rings will be fixed to hinges allowing for them to open and close as the system is opened and closed by a winch and pulley system. The way in which the sides are attached to the main sides is shown below in Figure 12.

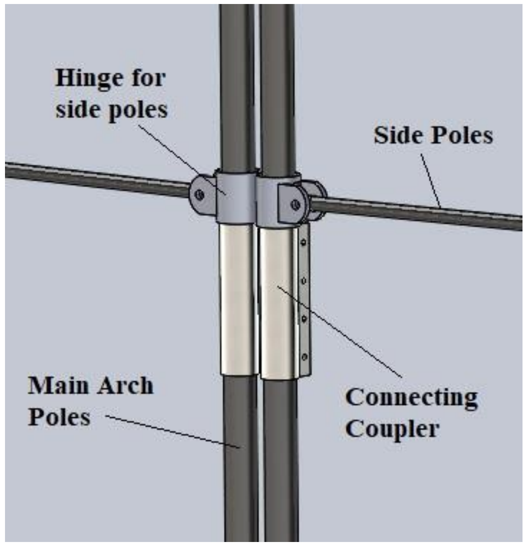


Figure 12 – Main & Side Pole Connections

The two main arches will be constructed carbon fiber. This gives the system a strong, lightweight frame. The material attached between the rings is HDPE for rain and sun protection. The base components will be constructed from steel. The base is secured to the launch pad with concrete anchors once the system in in its final position. This design will be discussed further in Chapter 6.

6 PROPOSED DESIGNS

Chapter 6 will introduce the requirements to implement a final selected design and a Bill of Materials. As previously discussed, the final design selected is the Bear Trap. The implementation process of the Bear Trap is written in depth to explain the basic steps and the dates selected for when certain parts will be completed for the following spring semester. The Bill of Materials discussed in this chapter will introduce all materials intended to be used in the full size launch vehicle enclosure, pricing, and vendors.

6.1 The Bear Trap

To begin implementation of this design, several changes were made to the original design. The original design used ring sizes that decreased in radius as the height increased. The current design now uses the same sized rings throughout the entire structure to simplify the manufacturing of the parts, and to provide more clearance to the launch vehicle. The original design also used a gear motor and hydraulic rams to bring the two main structure arches upward and into place. The current design now uses a pulley system with two motorized winches to pull the main two arches up and together. The winches used have a pulling capacity of 3,000 pounds. [20]. With multiple pulleys used, and each half of the structure weighing roughly 2,300 pounds, two winches of this strength prove to be more than capable of its intended use. This design will be constructed in multiple parts that are easily assembled and disassembled on the launch pad. The maximum individual beam length is 74 inches. This allows the enclosure to be broken down, and compacted into a small space for ease of storage when not in use. First, all side poles will be attached together with the HDPE fabric. Next, with the vehicle on the launch pad, v-tracks will be laid down in which 6 inch casters connected to the base plates of the design can roll on. The base will then roll to the launch vehicle. Six inch casters were selected due to the overall weight of the structure. Two casters will support each half of the structure, which equates to roughly 2,300 pounds. Each caster is rated for a working load of up to 2,500 pounds [21]. Then, the two sides will be attached together via the pulley system. The final step includes securing the guy wire tie downs at permanent locations on the launch pad. Each guy wire used has a breaking strength of 14,400 pounds and a working load limit of 2,880 pounds [22]. Currently, a minimum of 4 guy wires are to be used, but more may be added depending on the stress and information found via the testing procedures.

To implement this design, the team will construct a scaled prototype. The prototype will be one-sixth of the intended overall design, making it a proposed height of 12 ft. and a diameter of 8 ft. Certain parts such as the base plates, the pole adaptors, and the guy wire angle blades will need to be manufactured. The items for these parts will be ordered first and must be delivered no later than the 22nd of January 2018. When these items are received, they will be manufactured as the other parts of the prototype are being shipped. Northern Arizona University's machine shop may be utilized during the manufacturing process, however the design team has a majority of the necessary equipment. When the manufactured parts are complete and all other parts delivered, full construction of the design must be completed no later than March 5, 2018. The greatest concern for manufacturing is placed on the HDPE fabric skin. The fabric must be altered to have loops that the carbon fiber side poles will be laced through. Due to the tedious nature of this part, substantial time will be needed for fabrication. The supplier for the HDPE is located locally in Arizona, which will help reduce lead times for product acquisition. When the prototype is fully constructed, the team will move forward with testing procedures.

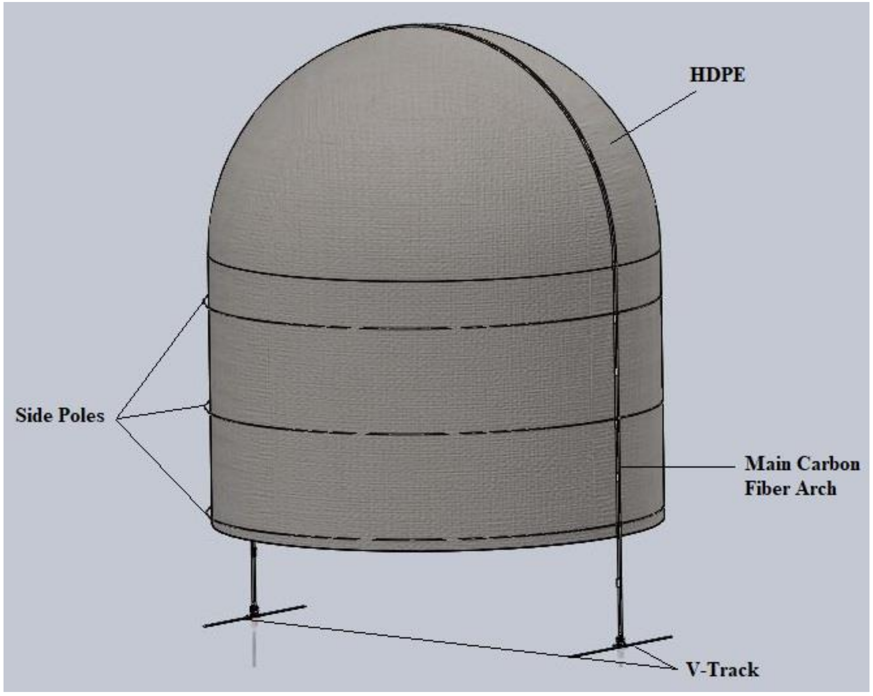


Figure 13 – Fully Deployed Launch Vehicle Enclosure with HDPE Fabric

6.2 Bill of Materials

An estimated Bill of Materials (BOM) was created for the Bear Trap design. Below shows a small excerpt from the full BOM. The excerpt shows the vendor, the item number, the part name and description, the quantity, the total cost, and the website in which the parts can be found. The item number listed correlates to the team's assigned drawing number. This BOM also includes the estimated costs and information for manufacturing/fabrication. The full BOM can be found in Appendix E. The full BOM includes all of that in the excerpt plus the part number from the vendor, the dimensions, and the cost per unit item. The estimated project total cost came out to be $52,696.39. This is $2,606.39 over the target value but well within the tolerance range. Recall that the client informed the team that anything under $100,000 would be under their targeted value.

Table 4 – Bill of Materials Excerpt

	Project Name			Orbital ATK Launch Vehical Enclosure			
	Team			Team D3: Brandon Cook, Miriam Deschine, Daniel Edmonds, Joshua Smith			
Parts and Materials	Vendor	Item #	Part Name	Qty	Description	Total Cost ($)	URL
	Hamilton	HA001	V-Grooved Wheel	4	Heavy Duty Track Guided Wheel	$282.36	www.hamilton.com
		HA002	Caster Axle	4	Bolt and nut for V-Grooved Wheel	$162.00	
					Total:	$444.36	
	Vendor	Item #	Part Name	Qty	Description	Total Cost ($)	URL
	Rock West Composites	RWC001	Main Vertical Beam	28	Main Vertical Beam Components	$12,000.52	www.rockwestcomposites.com
		RWC002	Side Pole	510	Interlocking Poles for Side Components	$11,928.90	
		RWC003	Top Arch	28	Main Top Arch Components	$7,324.52	
					Total:	$31,253.94	
	Vendor	Item #	Part Name	Qty	Description	Total Cost ($)	URL
	Discount Steel	DS001	ASTM A500 Bare Steel Pipe (3" SCH 80)	1	Side Pole Adaptor Sleeve pipe	$159.96	www.discountsteel.com
		DS002	ASTM A36 Hot Rolled Steel 3/4" Plate	1	Base Plate	$345.41	
		DS003	ASTM A36 Hot Rolled Steel 3/4" Plate	1	Base Plate	$180.17	
		DS004	ASTM A36 Hot Rolled Steel 1/4" Plate	1	Anchor Plate	$20.42	
		DS005	ASTM A36 Hot Rolled Steel Round Bar	1	Side Pole Adaptor	$22.87	
					Total:	$728.83	
Fabrication	Vendor	Process		Hrs	Description	Total Cost ($)	URL
	Eagar Welding	Surfacing		5	Finishing surfaces after welding parts together	$450.00	http://eagarwelding.com
		Welding		10	Welding plates together, adaptor parts	$900.00	
		Powder Coating		3	Finish coating after surfacing for rust resistance	$270.00	
		Stamping		10	Cutting Steel Plates	$900.00	
		Estimated Hours			Total:	$2,520.00	
					PROJECT TOTAL:	**$52,606.39**	

7 References

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8 APPENDICES

8.1 Appendix A: Customer Needs and Engineering Requirements

Table A1: Customer Needs and Engineering Requirements

Item:	Customer Need	Description	Related Engineering Requirement	Metric	Target Value	Tolerance	Customer Rank
1.0 Concerning Weather							
1.1	Solar Protection	Ability to limit temperature variance within the enclosure	Heat Flux Through Enclosure Material	W/m^2	354	<354	90
1.2	Moisture Protection	Ability to limit entrance of moisture into the enclosure	Permeability	$g/m^2/24hr$	603	<603	90
1.3	Debris Protection	Ability to shroud launch vehicles from airborne debris	Tensile Strength	kPa	1	±.015	10
1.4	Wind Protection	Ability to restrict/allow airflows into the enclosure	Volumetric Flow Rate	m^3/s	0.071	±.005	10
2.0 Concerning Launch Vehicle							
2.1	Launch Vehicle Temperature	External vehicle temperature must remain within provided temperature ranges during pre-launch processing	Surface Temperature Delta	°C	23.9	18.4 - 29.4	50
2.2	Launch Vehicle Contact	Enclosure must not contact at any point (high wind/rain conditions	Enclosure Deflection	m	1	<1	100
3.0 Concerning Pre-Launch Staff							
3.1	Work Environment Temperature	Launch vehicle enclosure must remain within a workable temperature range	Dead Space Temperature	°C	23.9	18.4 - 29.4	30
3.2	Work Space	Suitable space between launch vehicle and enclosure wall to perform necessary pre-launch operations	Enclosure Footprint	m^2	200	±10	80
3.2.1	Accessibility	Ability for employee/truck/scissor lift to enter enclosure	Entrance Dimensions	m^2	25	±5	100
4.0 Concerning Material Procurement/Manufacturing/Assembly							
4.1	Scalable Design	Ability for final design to be adapted to full range of launch vehicles	Cost per Enclosure Height	$/m	2000	<2000	90
4.2	Ease of Assembly	Simplicity of enclosure construction at launch site. Minimizing the amount of steps.	Number of Assembly Steps	# of Steps	10	±5	80
4.2.1	Time of Assembly	Time required to construct enclosure at launch site	Time to Assemble	min	60	±480	80
4.2.2	Time of Disassembly	Time required to remove enclosure from launch site	Time to Disassemble	min	30	±160	80
4.3	Associated Costs	Costs involved in the production, ownership, and operation of the system	Raw Material Cost	$	$50,000	±$50,000	60
5.0 Concerning Enclosure							
5.1	Ability to Support Items	Ability for the enclosure to support auxiliary items	Bearing Stress	kPa	1	±.015	30
5.2	System Lifespan	Ability for the enclosure to be deployed multiple times without failure. *Unless a single use system is determined to be more cost effective	Usage Quantities	# Uses	5	±20	80
5.3	Durability	Ability for enclosure to resist exposure and typical wear	UV Degradation	Hrs	5000	>5000	80
5.4	Safety	Ability for safety hazards to be minimized during extreme weather events and/or failure	Failure Percentage Across Various Scenarios	%	1	±0.01	100
5.5	Factor of Safety	Ability for a much stronger system than needed to minimize safety hazards	Yeild Stress / Working Stress	FOS#	3yeild & 5Ult	>3yeild & >5Ult	100
					Total Points Assigned		1340

8.2 *Appendix B: House of Quality*

System QFD

Project:	Orbital ATK
Date:	1-Oct-17

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Heat Flux Through Enclosure Material, TP 2.3.1																			
2	Permeability, TP 2.3.3	+																		
3	Tensile Strength, TP 2.3.2	-																		
4	Volumetric Flow Rate, TP 2.3.3		+																	
6	Surface Temperature Delta, TP 2.3.1	+	+		+															
7	Enclosure Deflection, TP 2.3.2			+																
8	Dead Space Temperature, TP 2.3.1	+	+		-	+														
9	Enclosure Footprint, TP 2.3.7						+	+												
10	Entrance Dimensions, TP 2.3.7							+	+											
11	Cost per Enclosure Height, TP 2.3.4						-													
12	Number of Assembly Steps, TP 2.3.6																			
13	Time to Assemble, TP 2.3.6											+								
14	Time to Disassemble, TP 2.3.6											+	+							
15	Raw Material Cost, TP 2.3.4	-		-			-		+		+									
16	Bearing Stress, TP 2.3.2			+	-															
17	Usage Quantity, TP 2.3.2 & 2.3.5																			
18	UV Degradation, TP 2.3.5																+			
19	Failure %, TP 2.3.2 & 2.3.5			-			+					+				-	-	+		
20	Yeild Stress/WorkingStress, TP 2.3.2			+																

Legend	
A	Alaska Tent & Tarp: Arctic Oven
B	Rubb: CAE EFASS
C	Losberger: TMM Inflatable Shelter
D	Dupont: Tyvek Cargo Covers

			Technical Requirements																			Benchmarking				
	Customer Needs	Customer Weights	Heat Flux Through Enclosure Material, TP 2.3.1	Permeability, TP 2.3.3	Tensile Strength, TP 2.3.2	Volumetric Flow Rate, TP 2.3.3	Surface Temperature Delta, TP 2.3.1	Enclosure Deflection, TP 2.3.2	Dead Space Temperature, TP 2.3.1	Enclosure Footprint, TP 2.3.7	Entrance Dimensions, TP 2.3.7	Cost per Enclosure Height, TP 2.3.4	Number of Assembly Steps, TP 2.3.6	Time to Assemble, TP 2.3.6	Time to Disassemble, TP 2.3.6	Raw Material Cost, TP 2.3.4	Bearing Stress, TP 2.3.2	Usage Quantity, TP 2.3.2 & 2.3.5	UV Degradation, TP 2.3.5	Failure %, TP 2.3.2 & 2.3.5	Yeild Stress/WorkingStress, TP 2.3.2	1 Poor	2	3 Acceptable	4	5 Excellent
		↕	↓	↓	↑	↓	↓	↓	↓			↓	↓	↓	↓	↓	↑	↑	↓	↓	↑					
1	Solar Protection	9	9	1			3		3							9		3	9	3				A	BCD	
2	Moisture Protection	9		9		3										9		3		3					ACD	B
3	Debris Protection	1		3	3	3		3		3						1	3	3		3	1			ACD	B	
4	Wind Protection	1		3	9	9		3		3						3	3	3		3	1		C	A	D	B
5	Lightning Protection	9														1		3		3		AD	C		B	
6	Launch Vehicle Temperature	5	3	1		1	9		3															A	CD	B
7	Launch Vehicle Contact	10			3			9		3										3		D		AC		B
8	Work Environment Temperature	3	3	1		1	3		9															A	CD	B
9	Work Space	8						3	1	9						3						D		A	C	B
10	Accessibility	10						3		3	9											D			AC	B
11	Scalable Design	9						3		3		3	3			3									ABCD	
12	Ease of Assembly	8								1		3	9	3	3								B	C	A	D
13	Time of Assembly	8								1		3	3	9	3								B	C	A	D
14	Time of Disassembly	8								1		3	3	3	9								B	C	A	D
15	Associated Costs	6			1					1		9		3	3	9		3			1		B	C	A	D
16	Ability to Support Items	3			3			1									9			3	3		D	A	C	B
17	System Lifespan	8			3											9	3	3	3	3	3			D	AC	B
18	Durability	8			3			3						1	1	9	3	9	9	9	3			D	AC	B
19	Safety	10			3			3	1		3		3			9	3	3		9	9			ABCD		
20	Factor of Safety	10			3			3					1			9	3			9	9		D	A	C	B
	Technical Requirement Units		W/m^2	g/m2/24hr	kPa	m3/s	C	m	C	m2	m2	$/m	# of Steps	min	min	$	kPa	# Uses	hrs	%	FOS#					
	Technical Requirement Targets		<354	<603	1	0.071	23.9	1	23.9	200	25	2,000	10	60	30	25000	1	100	5,000	1	3y&5U					
	Absolute Technical Importance		105	104	165	47	81	284	87	195	120	153	187	146	146	604	141	231	177	402	245					
	Weighted Technical Importance		0.0292	0.0289	0.0458	0.0131	0.0225	0.0733	0.0242	0.0542	0.0333	0.0425	0.0519	0.0406	0.0406	0.1678	0.0392	0.0642	0.0492	0.1117	0.0681					
	Relative Technical Importance		15	16	9	19	18	3	17	6	14	10	7	11	11	1	13	5	8	2	4					

Figure B1: House of Quality

8.3 Appendix C: Designs Considered

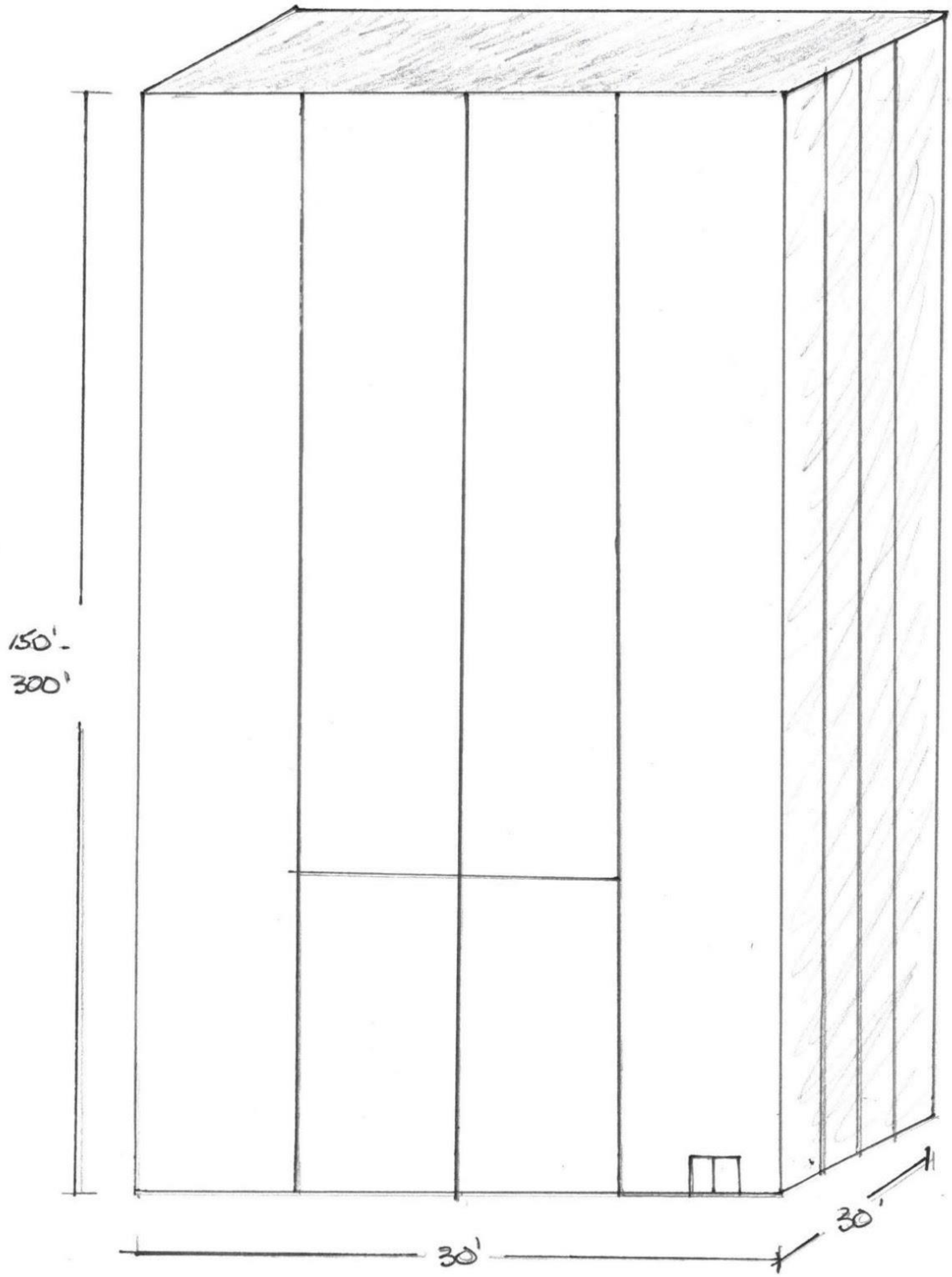


Figure C1.1: Panel Assembly 1

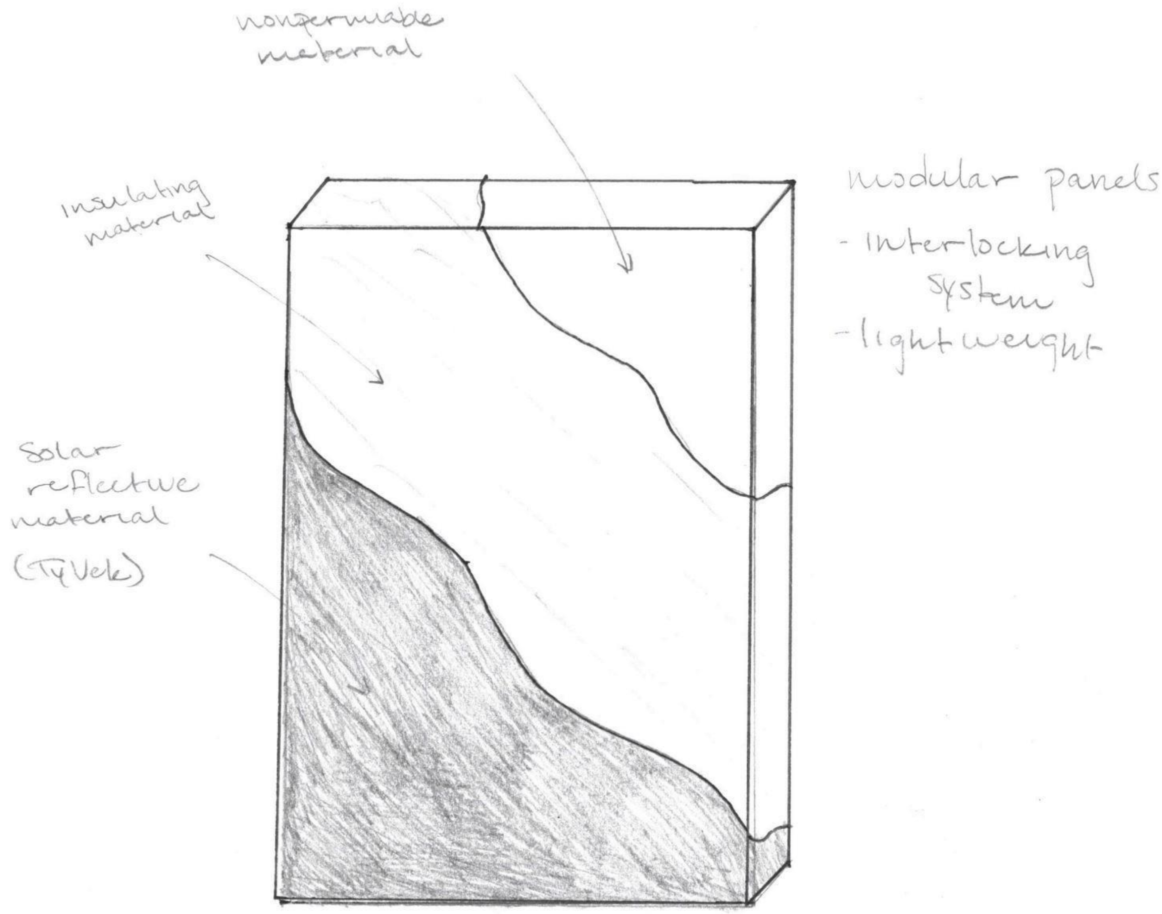


Figure C1.2: Panel Assembly 2

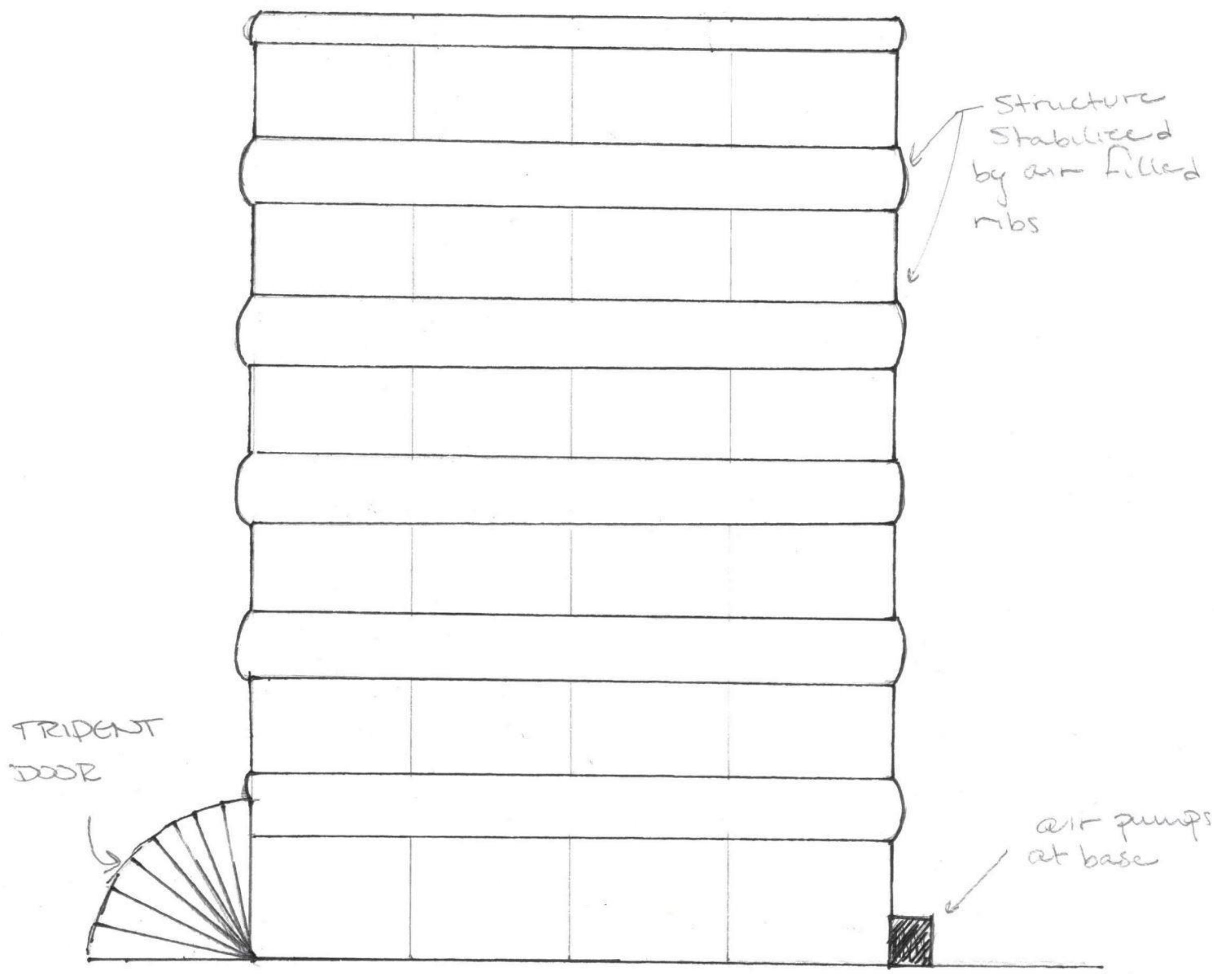


Figure C2: Inflatable Enclosure

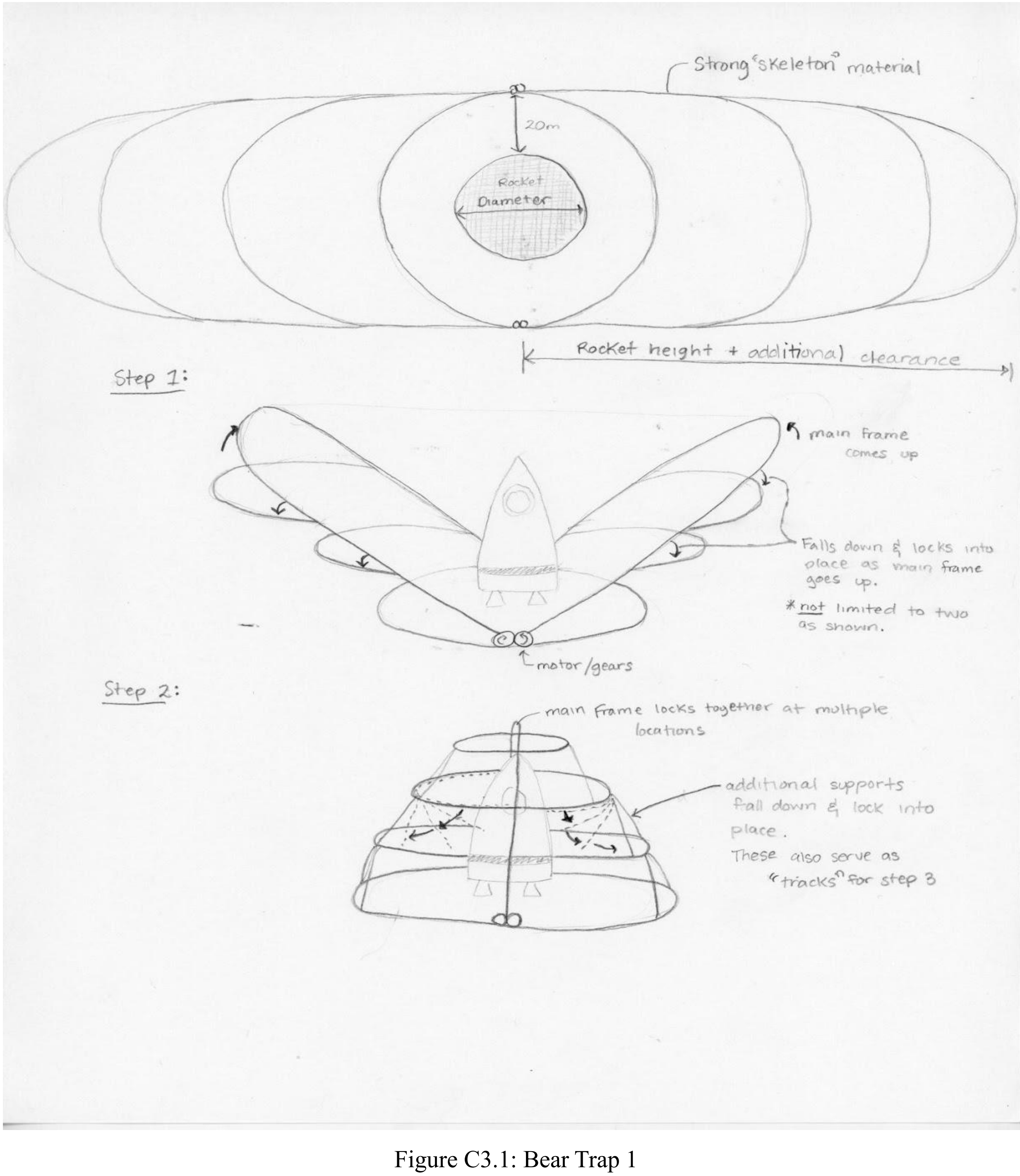


Figure C3.1: Bear Trap 1

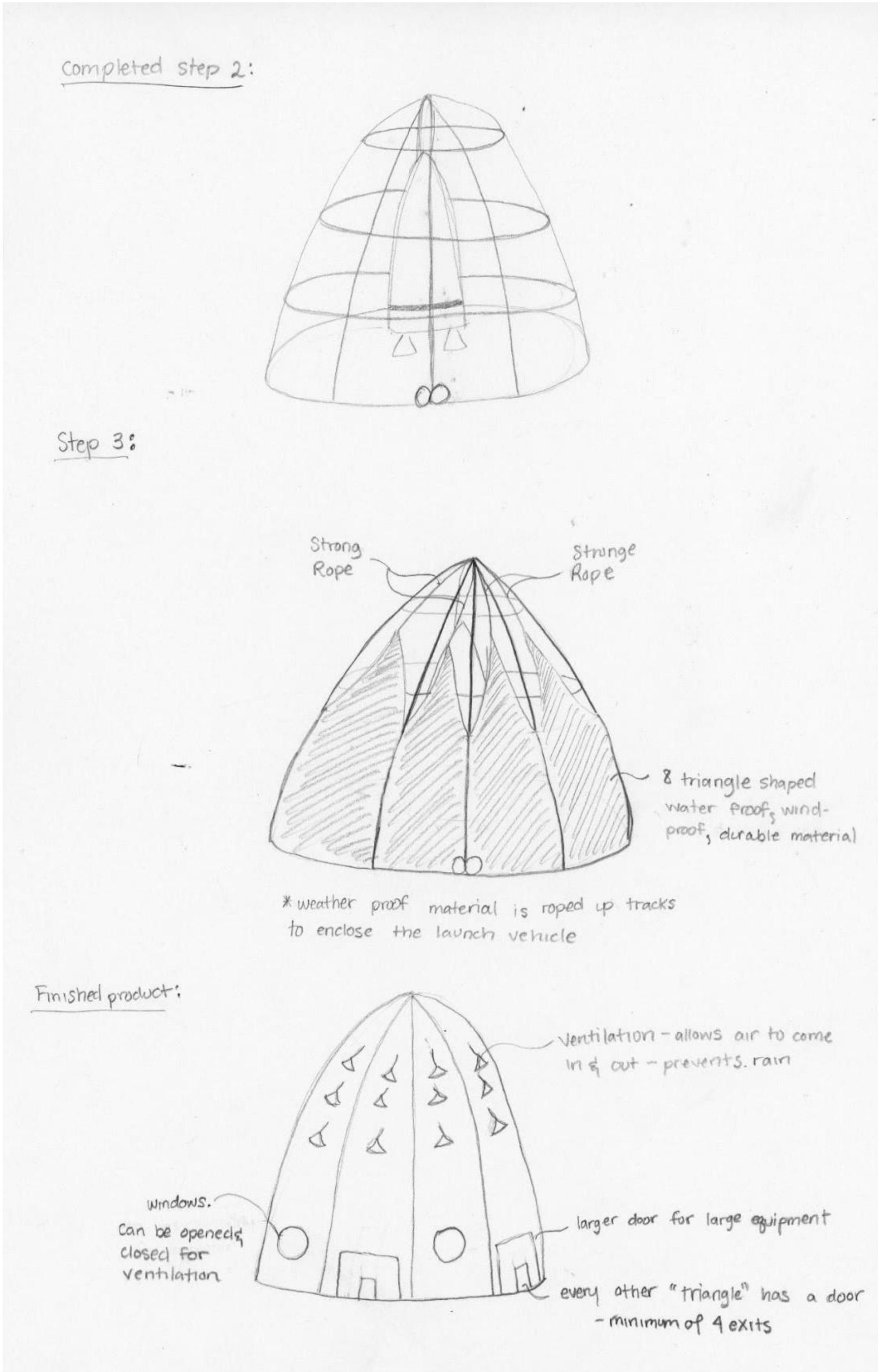


Figure C3.2: Bear Trap 2

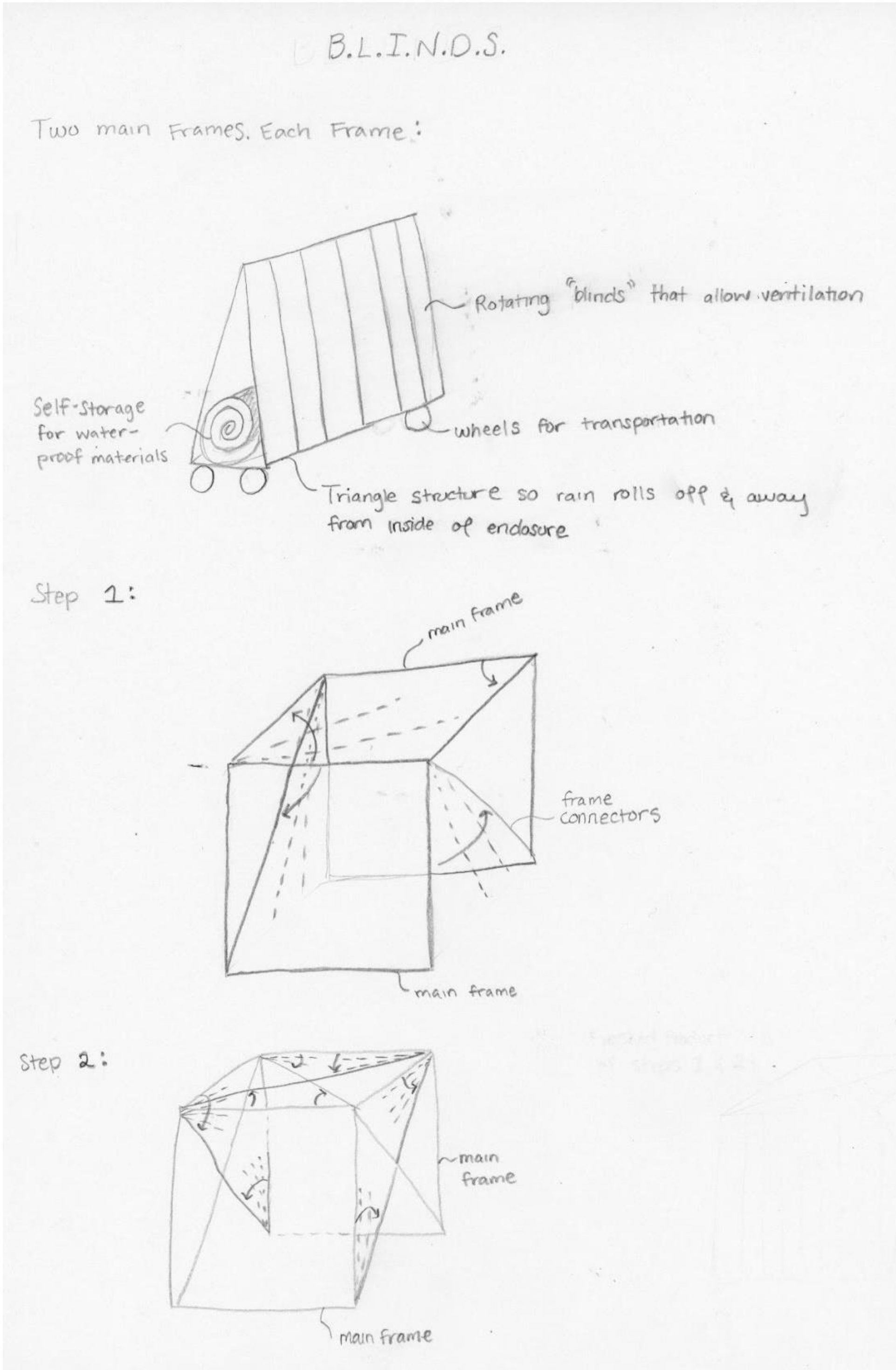


Figure C4.1: Blinds 1

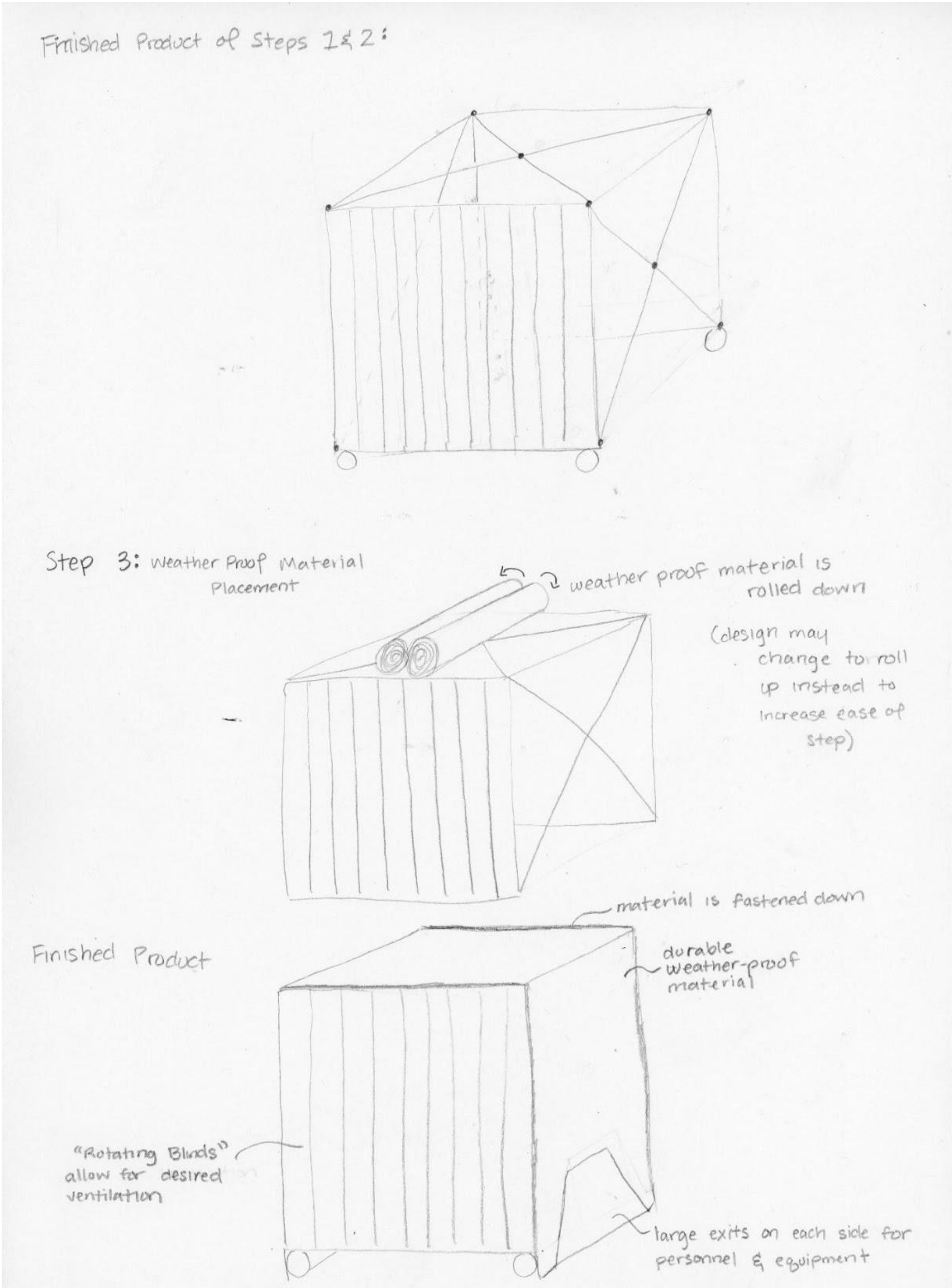


Figure C4.2: Blinds 2

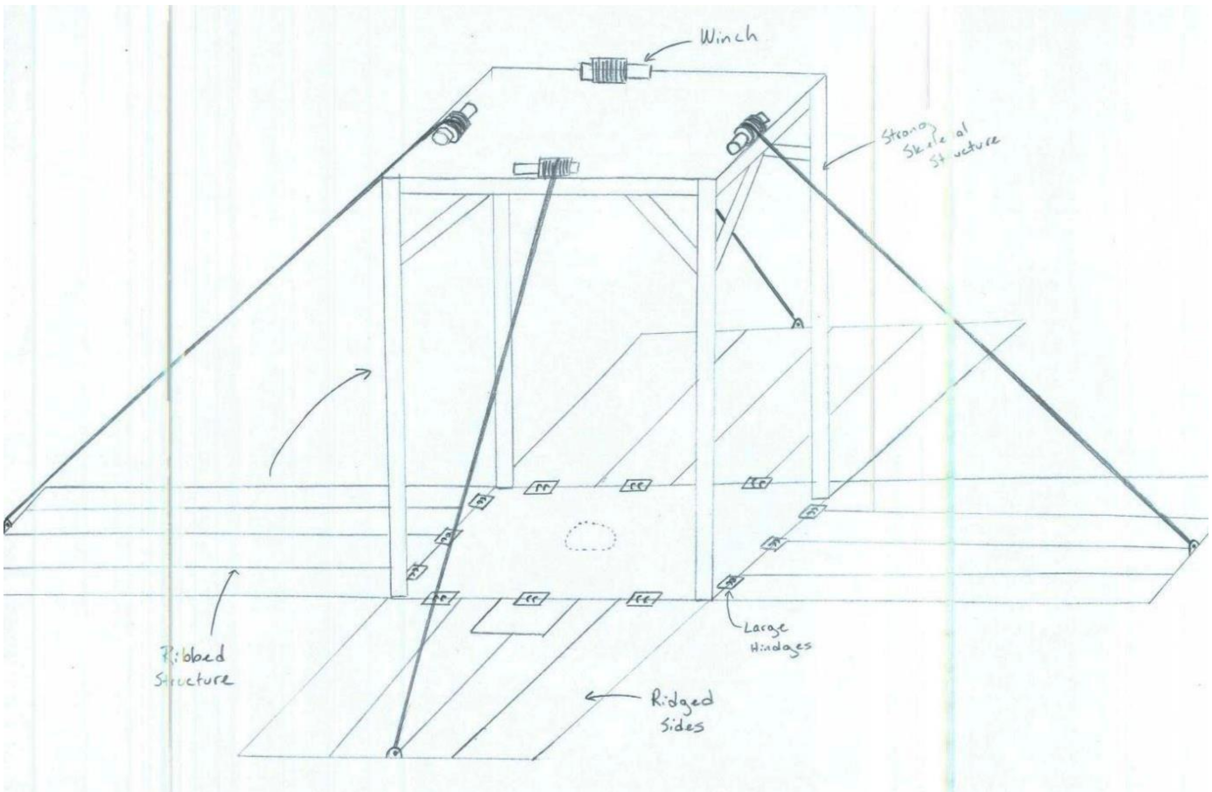


Figure C5: Winch Hoisted Sides

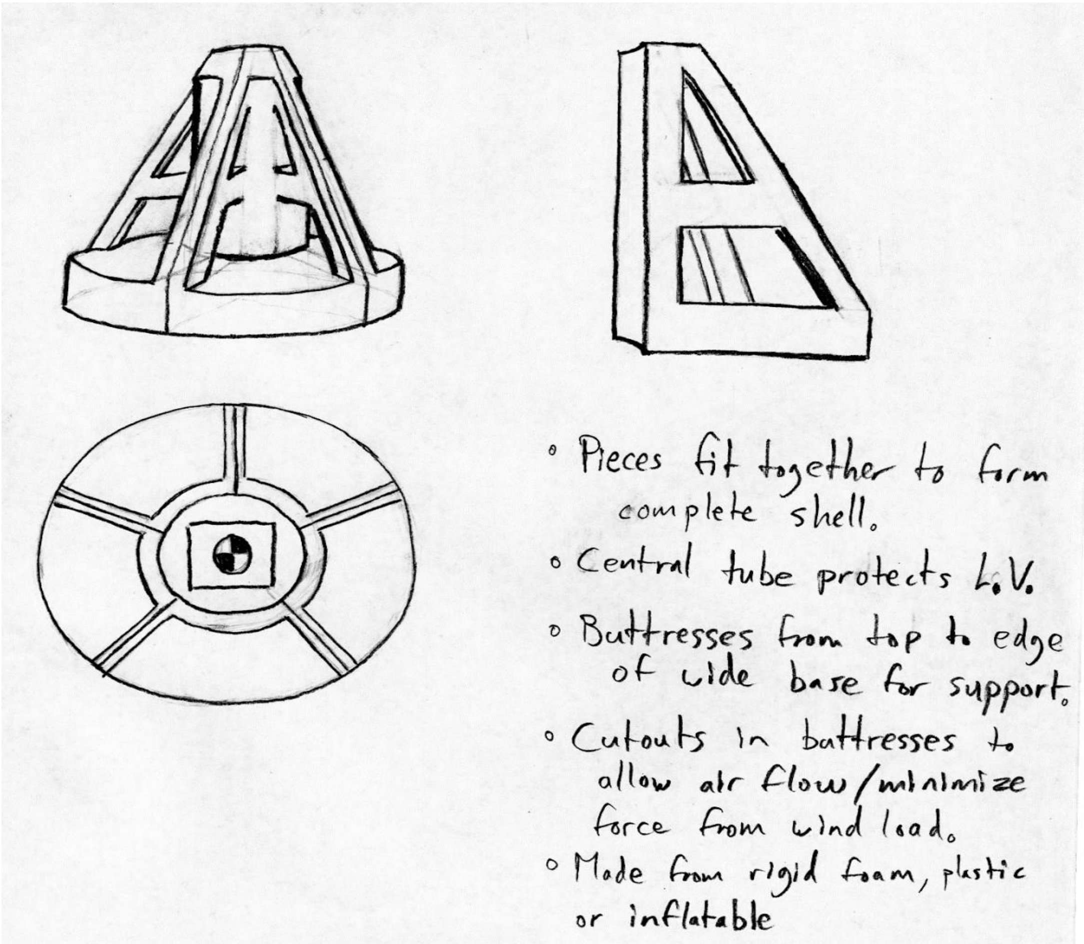


Figure C6: The Cone

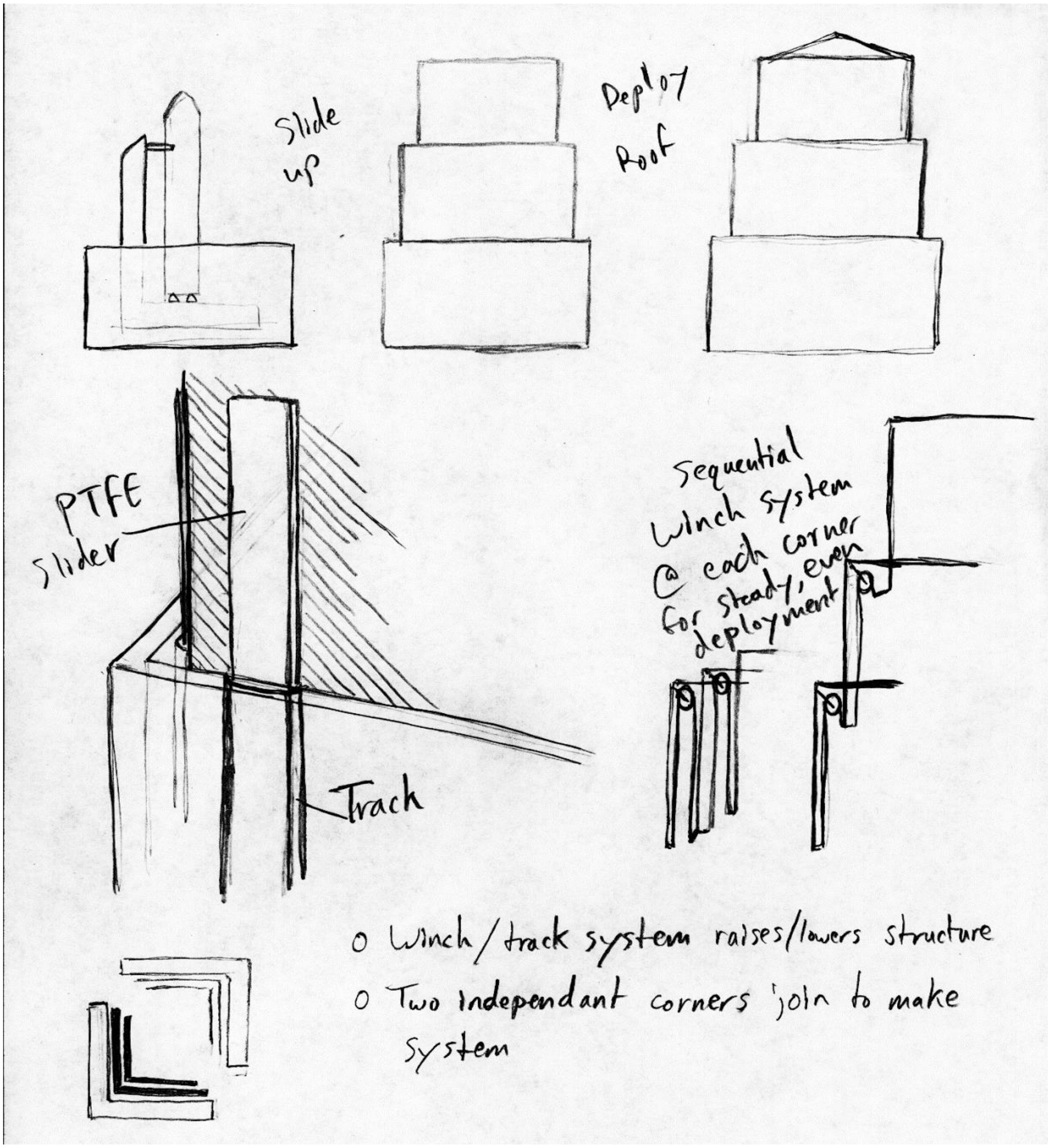


Figure C7: The Slider

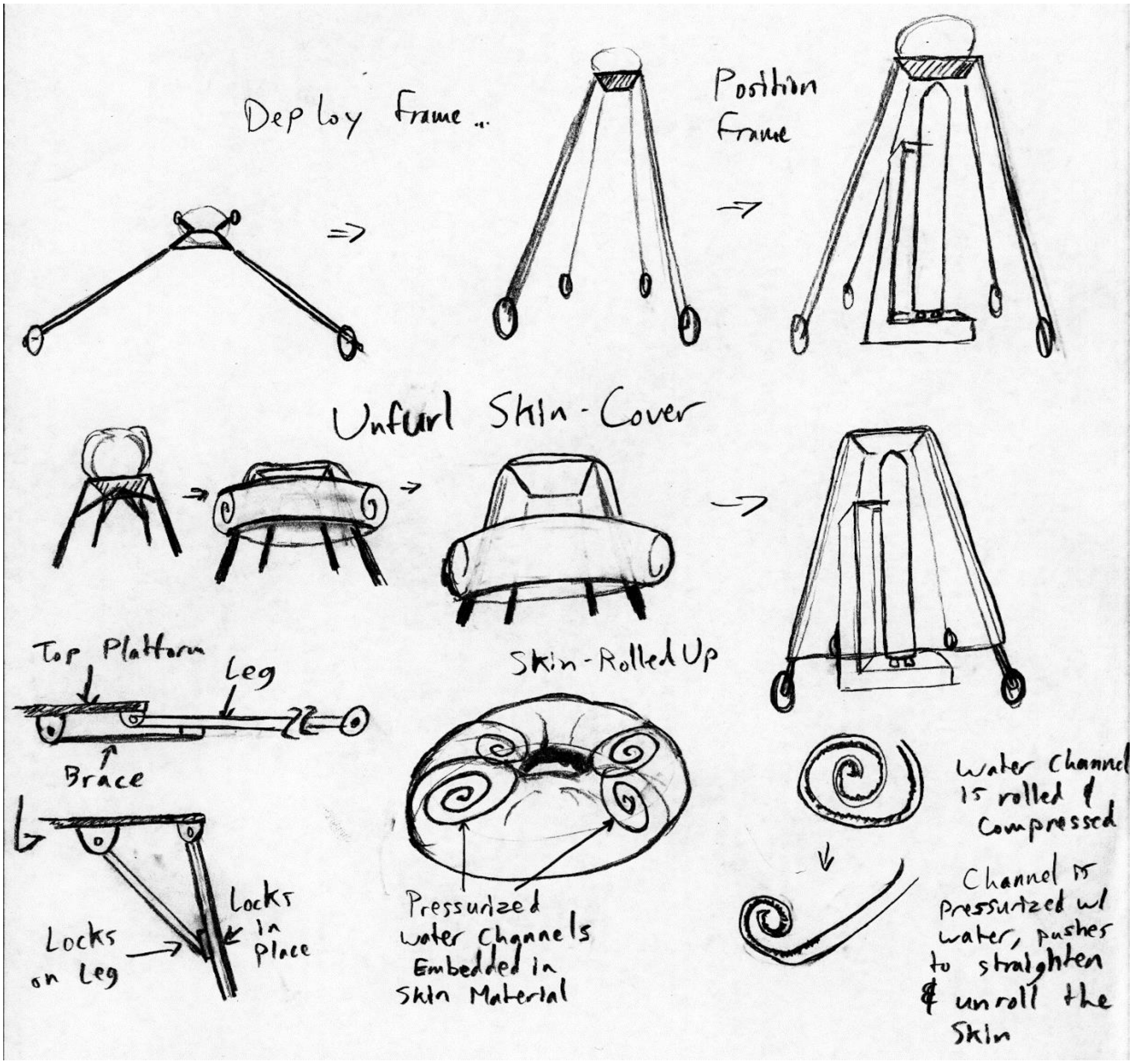


Figure C8: The Stilt Tent

8.4 *Appendix D: Design Selection*

Table D1: Pugh Chart

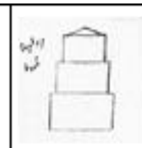
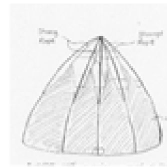
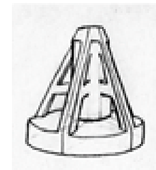
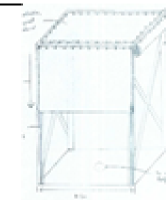
										
Criteria	Panel Assembly	Inflatable Enclosure	Winch Hoisted Sides	The Curtain	Rocket Awning	The Slider	The Cone	Stilt Tent	The Bear Trap	The Blinds
Solar Protection	D	S	-	-	-	+	S	-	-	-
Moisture Protection	A	+	-	-	+	-	-	-	-	-
Debris Protection	T	-	-	-	-	+	+	-	-	-
Lightning Protection	U	S	S	S	S	S	S	S	S	S
Vehicle Temperature	M	+	+	+	+	S	-	S	+	+
Vehicle Contact	*	-	S	S	S	S	S	-	-	-
Environment Temperature	D	+	+	+	+	S	-	S	+	+
Work Space	A	S	S	S	S	S	-	S	S	S
Accessibility	T	+	S	+	S	-	-	+	S	S
Scalability	U	S	S	S	S	S	S	S	S	S
Ease of Assembly	M	+	S	S	S	S	+	+	+	-
Time of Assembly	*	S	+	+	-	S	+	+	+	+
Time of Disassembly	D	S	+	+	-	S	+	+	+	+
Associated Costs	A	-	-	+	+	-	S	-	+	-
Support Ability	T	-	+	+	+	+	S	-	S	+
Lifespan	U	-	S	S	S	-	+	-	S	-
Durability	M	-	S	-	S	S	S	-	-	+
Safety	*	-	-	+	-	-	-	-	-	-
$\sum$+		5	5	8	5	3	5	4	6	6
$\sum$-		7	5	4	5	5	6	9	6	8
$\sum$S		6	8	6	8	10	7	5	6	4

Table D2: Decision Matrix

									
		Design: The Curtain		Design: The Bear Trap		Design: The Cone		Design: Rocket Awning	
Criteria	Criteria Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Solar Protection	0.10	8.00	0.80	7.00	0.70	9.00	0.90	7.00	0.70
Moisture Protection	0.10	4.00	0.40	6.00	0.60	6.25	0.63	5.00	0.50
Debris Protection	0.01	3.50	0.04	4.00	0.04	8.00	0.08	4.50	0.05
Lightning Protection	0.06	5.00	0.30	5.00	0.30	5.00	0.30	5.00	0.30
Vehicle Temperature	0.05	7.00	0.35	6.00	0.30	7.50	0.38	7.00	0.35
Vehicle Contact	0.12	8.00	0.96	7.50	0.90	6.75	0.81	7.50	0.90
Environment Temperature	0.02	4.00	0.08	6.00	0.12	7.50	0.15	7.50	0.15
Work Space	0.04	8.00	0.32	7.00	0.28	3.50	0.14	6.00	0.24
Accessibility	0.11	9.00	0.99	9.00	0.99	5.50	0.61	8.50	0.94
Scalability	0.06	8.50	0.51	4.00	0.24	7.00	0.42	6.50	0.39
Ease of Assembly	0.02	8.00	0.16	7.00	0.14	8.00	0.16	5.00	0.10
Time of Assembly	0.02	6.00	0.12	7.00	0.14	6.00	0.12	3.50	0.07
Time of Disassembly	0.02	6.00	0.12	3.00	0.06	9.00	0.18	4.00	0.08
Associated Costs	0.03	4.00	0.12	5.00	0.15	4.50	0.14	7.00	0.21
Support Ability	0.01	5.00	0.03	0.00	0.00	4.00	0.02	7.00	0.04
Lifespan	0.05	4.00	0.20	5.00	0.25	7.00	0.35	6.50	0.33
Durability	0.06	5.00	0.28	6.00	0.33	7.75	0.43	6.50	0.36
Safety	0.13	6.50	0.85	3.00	0.39	8.00	1.04	5.00	0.65
			6.61		5.93		6.84		6.34

8.5 *Appendix E: Bill of Materials*

Table E1: Bill of Materials

	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Project Name					**Orbital ATK Launch Vehical Enclosure**					
	Team					**Team D3: Brandon Cook, Miriam Deschine, Daniel Edmonds, Joshua Smith**					
Parts and Materials	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Hamilton	HA001	W-626-V-1-1/4	V-Grooved Wheel	4	Heavy Duty Track Guided Wheel	Iron	6" x 2 3/4"	$70.59	$282.36	www.hamilton.com
		HA002	321440	Caster Axle	4	Bolt and nut for V-Grooved Wheel	Medium Carbon Steel	1.25-12" x 6.75"	$40.50	$162.00	
									Total:	$444.36	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	L.A Ornamental	LAO001	vtack-g	V Track	6	V-Shaped Sliding Gate Track	12 gauge Galvanized Steel	9' x 4"	$29.95	$179.70	www.laornamental.com
									Total:	$179.70	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Rock West Composites	RWC001	46418-HM-GROUP	Main Vertical Beam	28	Main Vertical Beam Components	High Mod-Plain Weave Carbon Fiber	2.6" x 74"	$428.59	$12,000.52	www.rockwestcomposites.com
		RWC002	45540-F	Side Pole	#	Interlocking Poles for Side Components	Unidirectional Ferrule Carbon Fiber	0.99" x 11.75"	$23.39	$11,928.90	
		RWC003	45651	Top Arch	28	Main Top Arch Components	Unidirectional Carbon Fiber	2.628" x 72"	$261.59	$7,324.52	
									Total:	$31,253.94	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	A&A Manufacturing	AAM001	AA-317-A	AA-317-A Chassis Tab	24	Side Pole Adaptor Hinge Tab	Steel	3/16"	$1.56	$37.44	www.aa-mfg.com
									Total:	$37.44	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Discount Steel	DS001	15883	ASTM A500 Bare Steel Pipe (3" SCH 80)	1	Side Pole Adaptor Sleeve pipe	ASTM A500 Steel	3.5"OD x 2.78"ID x 12'	$159.96	$159.96	www.discountsteel.com
		DS002	2648	ASTM A36 Hot Rolled Steel 3/4" Plate	1	Base Plate	ASTM A36 Hot Rolled Steel	1'1" x 10'	$345.41	$345.41	
		DS003	2648	ASTM A36 Hot Rolled Steel 3/4" Plate	1	Base Plate	ASTM A36 Hot Rolled Steel	1'1" x 4'	$180.17	$180.17	
		DS004	2563	ASTM A36 Hot Rolled Steel 1/4" Plate	1	Anchor Plate	ASTM A36 Hot Rolled Steel	1' x 7"	$20.42	$20.42	
		DS005	10672	ASTM A36 Hot Rolled Steel Round Bar	1	Side Pole Adaptor	ASTM A36 Hot Rolled Steel	1.5"D x 3.5'	$22.87	$22.87	
									Total:	$728.83	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Hilti	HI001	2141961	Stud Concrete Anchor	4	Guy Wire Tie Downs	Steel, Zinc-plated	3/4" x 7"	$7.88	$31.50	www.hilti.com
		HI002	336932	Drop In Concrete Anchor	24	Base Plate Anchor	Steel, Zinc-plated	3/4" x 3-3/16"	$2.32	$55.63	
									Total:	$87.13	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Copper State Bolt&Nut Co.	CS001	03CSCP-0750350	3.5" x 3/4" Bolt	24	Bolt for Hinges on the	Medium Carbon Steel	3/4-10 x 3.5	$1.06	$25.51	https://www.copperstate.com
		CS002	08G8CP-075	3/4" Nut	4	Nuts for Part 9	Medium Carbon Alloy Steel	3/4"-10	$0.75	$2.99	
		CS003	01TBCZ-0250250	2.5" x 1/4" Bolt	#	.25x2.5 bolt	Low Carbon Steel, Zinc-plated	1/4-20 x 2.5	$0.11	$23.94	
		CS004	08FNCG-025	1/4" Nut	#	.25" nut	Low Carbon Steel, galvanized	1/4"-20	$0.02	$4.94	
		CS005	01TBCZ-0500225	2.25" x 1/2" Bolt	12	.5x2.25 bolt	Low Carbon Steel, Zinc-plated	1/2-13 x 2.25	$0.41	$4.90	
		CS006	08FNCG-050	1/2" Nut	12	.5" nut	Low Carbon Steel, galvanized	1/2"-13	$0.09	$1.13	
		CS007	09LNZ-025	1/4" 2 Piece Washer	0	.25" washer	Steel, Zinc-plated	1/4"	$0.50	$0.00	
		CS008	09LNZ-050	1/2" 2 Piece Washer	12	.5" washer	Steel, Zinc-plated	1/2"	$0.96	$11.51	
		CS009	09LNZ-075	3/4" 2 Piece Washer	28	.75" washer	Steel, Zinc-plated	3/4"	$2.09	$58.62	
									Total:	$133.52	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	WinchesInc.	W001	52447 DP	Model SA300B Winch	2	Winch	Steel	34.10"x18.69"	$5,291.25	$10,582.50	http://www.winchesinc.com
		W002	Misc	Wire Rope, 3/8" x 725'	2	Winch Wire	Steel	3/8"D x 741'	$687.18	$1,374.36	
									Total:	$11,956.86	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Grainger	G001	5RTE9	Sheave, Wire Rope, 1850lb Load Cap.	8	Sheave pulley for 3/8"	Steel with Bronze bearing	5"OD x .75"ID	$21.60	$172.80	www.grainger.com
									Total:	$172.80	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Tractor Supply Co.	TS001	269036	Hitch Pin	8	Hitch Pin for Baseplate	High Tensile Steel, Grade 5	5/8"D x 5.75"	$7.99	$63.92	www.tractorsupply.com
									Total:	$63.92	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	CarrLane	C001	CL-34-LP	L Pin	4	Drop Pin for Baseplate	12L14 steel, carburized-hardened	1/2"D x 9"	$9.95	$39.80	www.carrlane.com
									Total:	$39.80	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	E-Rigging	ER001	51302081	3/8" Drop Forged Wire Rope Clip	16	Guy Wire Clip	Steel, Zinc-plated	1.94" x 1.5" x 1.56"	$1.09	$17.44	www.e-rigging.com
		ER002	21030025	Galvanized Cable Reel	1	Guy Wire	Hot Dip Gal. Steel Wires	3/8" x 250'	$88.49	$88.49	
		ER003	51600225	Screw Pin Anchor Shackle	4	Guy Wire Shackle	Stainless Steel Drop Forged	1/2"	$24.54	$98.16	
									Total:	$204.09	
	Vendor	Item #	Part #	Part Name	Qty	Description	Material	Dimensions	Cost Per Unit ($)	Total Cost ($)	URL
	Arizona Sun Supply	ASS001	95 340	COMMERCIAL 95™ 340 SHADE CLOTH	8	HDPE material	HDPE fabric	131' x 9'10"	$598.00	$4,784.00	www.arizonasunsupply.com
									Total:	$4,784.00	
Fabrication	Vendor	Process			Hrs	Description			Hourly Rate ($/HR)	Total Cost ($)	URL
	Eagar Welding	Surfacing			5	Finishing surfaces after welding parts together			$90.00	$450.00	http://eagarwelding.com
		Welding			10	Welding plates together, adaptor parts			$90.00	$900.00	
		Powder Coating			3	Finish coating after surfacing for rust resistance			$90.00	$270.00	
		Stamping			10	Cutting Steel Plates			$90.00	$900.00	
						Estimated Hours			Total:	$2,520.00	
									PROJECT TOTAL:	**$52,606.39**	