Preliminary Report

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DISCLAIMER

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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 to that satisfies such objectives. In certain circumstances, tarps have been applied to critical areas of the launch vehicle to protect against exposure but this process is not considered best/common practice. These objectives materialize due to a series of events caused from sun and rain. Initially, 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 implications that Orbital ATK must handle. 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.

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 involved the design of a completely new launch vehicle environment enclosure. There was no original system when this project began.

2 REQUIREMENTS

This section covers the customer and engineering requirements needed to make this project a success. This is a very important step in the engineering design process. Without determining what our customer wants, 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. This is followed by determining the engineering requirements designated for each of the customer requirements. These 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. A few were added to the list and a few were removed upon request of the customer. This allowed us to further understand what our 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 greatly 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 onto 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. It is important to protect launch vehicles and personnel within the enclosure from high winds, this is not of major concern with 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. In terms of a high ranking against moisture protection, the design team deemed it viable that protection against lightning was also 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 under 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 above, 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, full, complete access to the launch vehicle is needed. This also refers 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. The simpler, the better.
13. **Time of Assembly:** This requirement was ranked an 8/10. This customer need relates to the simplicity of construction. The simpler the design, the easier it is to construct, the faster it is 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 more than likely 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. If a design with a very short lifespan is found, it may be viable if the design proves to be significantly cost effective.
18. **Durability:** This requirement was ranked an 8/10. This requirement depends on 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 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. The larger the factor of safety, the much stronger the system will be designed, reducing 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 and can be found in Table A1 of Appendix A.

1. **Heat Flux Through Enclosure Material (W/m2):** This coincides with solar protection. The target value and tolerance for this engineering requirement is TBD. This engineering requirement must be designed to minimize the amount of heat flux within the enclosure.
2. **Permeability (g/m2/24hr):** This coincides with moisture protection. The target value for this engineering requirement is 0 $g/m^2/24hr$ with a tolerance of ±500 $g/m^2/24hr$. 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 (Pa):** This coincides with protection from debris. The target value is 320Pa with a ±15 tolerance. This value was chosen due to an estimated value of tensile strength caused by 50mph winds.

4. **Volumetric Flow Rate (g/m3):** This coincides with wind protection. The design must be able to withstand a minimum of 50mph winds. Such designs that do not meet this requirement risks the safety of the launch vehicles, personnel, and equipment.
5. **Voltage (V):** This coincides with lightning protection. This engineering requirement must design to deflect any lightning away from personnel and the launch vehicle.
6. **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.
7. **Enclosure Deflection (m):** This engineering requirement relates to launch vehicle contact with the enclosure. This measurement is dependent on the work space target values and tolerances.
8. **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 6 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 6.
9. **Enclosure Footprint (m2):** This requirement corresponds to the customer requirement 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.
10. **Entrance Dimensions (m2):** 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.
11. **Cost per Enclosure Height ($/m):** This corresponds to a scalable design that can be incorporated for the different sizes of launch vehicles. This engineering requirement depends on the target cost and the height needed to provide enough room between the vehicle and the enclosure's wall.
12. **Number of Assembly Steps (#of Steps):** This engineering requirement must be designed to minimize the number of steps needed to assemble the enclosure. The least amount steps define the simplicity and user friendly of the system.
13. **Time to Assemble (min):** This engineering requirement must strive to minimize the time needed to assemble the enclosure. The target value for this requirement is one hour with a tolerance of eight hours.
14. **Time to Disassemble (min):** This engineering requirement is the same as the time to assemble. However, the disassembly target time is half an hour with a tolerance of four hours.
15. **Raw Material Cost ($):** The target value for a full-scaled project is $25,000 with a tolerance of $5,000. The clientele for this design project provided that a full-scale project should strive to be around $30,000.
16. **Bearing Stress (Pa):** 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 and tolerances for this requirement are TBD.
17. **Usage Quantities (#Uses):** This engineering requirement corresponds to the enclosure's lifespan. The targeted value for this requirement is 100 uses without failure with a tolerance of 20 uses.
18. **UV Degradation (Infrared Wave Transmission):** The UV degradation of the system will determine the durability of the enclosure. The lifespan of the design will also depend on the ability to resist exposure and wear.
19. **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 0% failure percentage with a 0% tolerance.

20. **Yield Stress/ Working Stress (FOS#):** The factor of safety standard is 3 for yield strength and 5 for ultimate strength. There is a 0 tolerance for this engineering requirement to ensure the highest possible safe design for the clientele.

2.3 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 to ten provided by the customer. The next section of the HoQ lists the engineering requirements. This determines how the customer's needs will be met. After the engineering requirements are determined, they are related to the customer's 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. Next, the requirements are related among the other engineering requirements. This is in the top section of the HoQ. A positive demonstrates that improvement on one specification will also improve another, while a negative demonstrated that improvement on one will harm the other. At the bottom of the HoQ, the metric units in which the requirements are measure, and their target values are listed. 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. This is done for each technical requirement. 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. 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 to the customer's desire.

1	Heat Flux Through Enclosure Material				
2	Permeability	+			
3	Tensile Strength	-			
4	Volumetric Flow Rate		+		
5	Voltage				

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	Permeability	Tensile Strength	Volumetric Flow Rate	Voltage	1 Poor	2	3 Acceptable	4	5 Excellent
		↑↓	↓	↓	↑	↓	↓					
1	Solar Protection	9	9	1						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					9	AD	C		B	
	Relative Technical Importance		16	17	9	20	15					

Figure 1: Sample House of Quality

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 related to the customer needs are the Arctic Oven Tent, the Rubb CAE EFASS system, the Losberger TMM Inflatable Shelter and the Dupont Tyvek Cargo Covers. 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 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's 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 the project at hand. The following sections will discuss how the team conducted research, what resources were used, the information found, and some 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 our potential design is included in this chapter.

3.1 Design Research

The team began its background research on Orbital ATK's website. A better understanding of Orbitals launch vehicles size, shape, and launch locations was desired. The flight systems link lead us to information and fact sheets on the Pegasus, Minotaur family of vehicles, and the Antares [1]. The launch locations of the Minotaur rocket were found to be in Florida, California, Alaska, and Mid-Atlantic [2]. The team thought it would be a good idea to research the typical weather in those areas so that it could be determined what type of weather the design needs to prevent. According to an article by Dawn Henthorn, the East coast of Florida faces frequent rain storms and lightning [3]. Since most of the launch sites are off of either the east or west coast of the United states, it is assumed that similar weather conditions are present at each of the sights. 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" [4].

In addition to websites, the team utilized the Cline library's databases to search for journals and articles that may contain helpful information. A piece of an article about GORE-TEX was requested from Northern Arizona University to gain more information about this material. Similarly, we found articles on the Vapex material used in the Arctic Oven Tent as part of our background research.

Through the utilization of websites and journal articles from the Cline library databases, the team now has a better understanding of the size of the launch vehicles Orbital ATK uses and the main weather conditions that the design should protect the vehicles from. The team also found devices and materials for weatherproofing that are detailed in the following sections.

3.2 System Level

There are no systems currently in use protecting launch vehicles during countdown however there are several existing systems that perform similar functions in different capacities. Examples of these systems are RUBB portable buildings and hangars [5], camping tents such as the Arctic Oven [6], and inflatable tents [7]. Each of these systems have areas where they excel and areas where they would need improvement to be implemented in this system.

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. The 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 but nylon, plastic sheeting, woven tarp, Tyvek, or any number of other materials could theoretically be used [6]. Our system may have to cover significant vertical distance while supporting itself under wind load. A lightweight frame and fabric type design like this may be optimal for a light, easily deployable, weather management system around some more robust support system.

3.2.2 Existing Design #2: Sunbelt Inflatable Tent

This system can be made larger than a camping tent and demonstrates the potential of using a compressed fluid-based collapsible structure made from lightweight, low cost materials. This system is able to deploy/takedown a 16-foot tent in less than two minutes with a minimum of human handling [7]. The Sunbelt Inflatable Tent System is made from vinyl, but other materials could be considered. An inflatable system may offer tremendous savings in deployment time and task complexity.

3.2.3 Existing Design #3: RUBB CAE Aviation Hangar

The RUBB CAE Aviation Hangar is made to carry larger loads and cover larger areas than the other two existing designs. This product also takes the longest of the three to deploy, with large hangars taking up to 4.5 days to deploy [5]. The hangar is made with trusses to distribute the load of the structure over wide areas. A truss like structure may be a good design to add significant stiffness to the system to prevent it from deflecting in high winds.

3.3 Functional Decomposition

This section is devoted to discussion of system functions. The system must accomplish 6 tasks: resist the forces experienced by 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 team will analyze these tasks and design subsystems that will work together optimally to protect the launch vehicle.

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. It 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 to break down and think deeply about what types of conditions the design will face. This black box was then used to generate a hypothesized functional model.

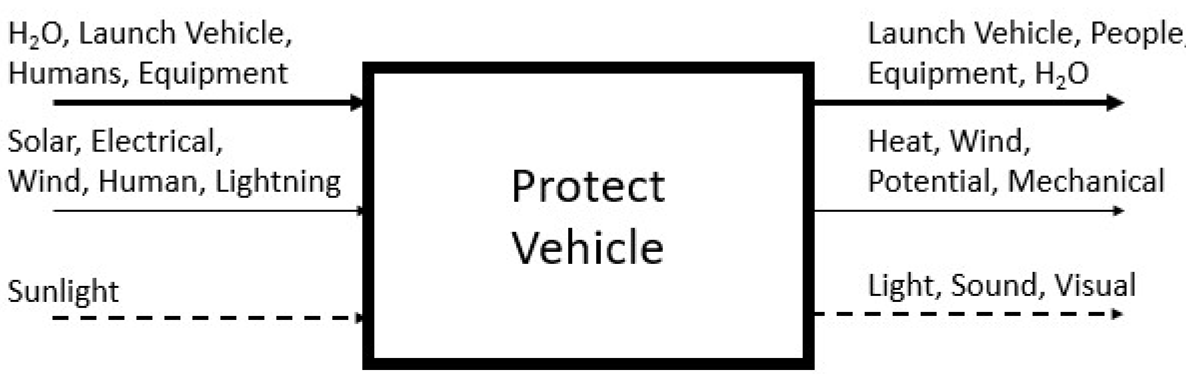


Figure 2: Black Box Model for Enclosure Design

3.3.2 Functional Model

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. The team often asked itself questions such as, "How is the material going to interact with the device?" or "Does this action require human energy?" By asking these questions the team identified the functions the system needs to perform to deal with the inputs. 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.

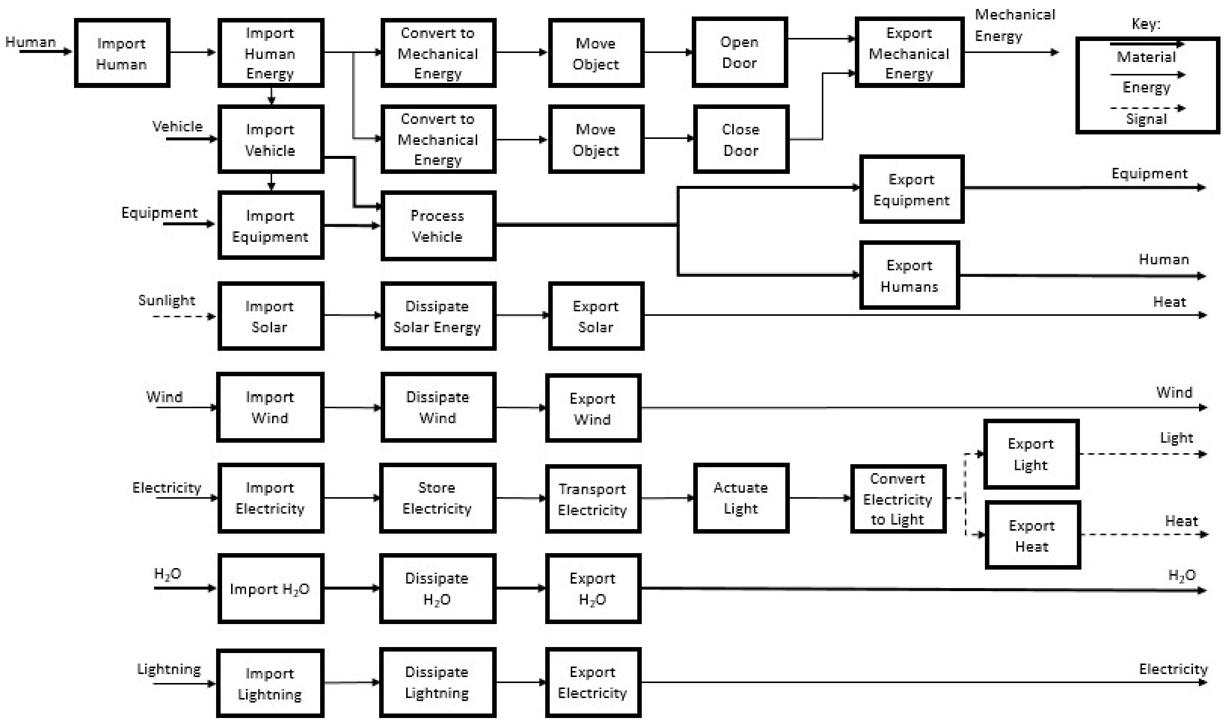


Figure 3: Functional Model of Potential Design

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. To use this system, it must be kept ready or delivered to the 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: Structural Support

This subsystem must support the entire structure under its own load. The Structural Support Subsystem holds the Weatherproofing Subsystem in place, is acted on by the Deployment Subsystem, and attaches to the Positioning Subsystem for movement. The Structural Support Subsystem must be strong enough to enable the structure to withstand 50 mph winds without contacting the launch vehicle and have a considerable factor of safety. The structural support subsystem fulfills several functions in the Functional Model in Figure 3. Its main function is to dissipate wind energy, but it will also be important to Importing and Exporting humans, vehicles, and equipment.

3.4.1.1 Existing Design #1: Tent Poles

Poles slide together and transmit moment throughout their length to provide a stabilizing structure. Tent poles are simple and can resist high winds with a light structure by allowing the structure to deform.

3.4.1.2 Existing Design #2: Inflatable Tent
Tent walls hold pressurized air and support the weight of the structure as well as provide stability. Inflatable structures are deployed easily and can deform significantly without failing relative to other kinds of structures.

3.4.1.3 Existing Design #3: RUBB Tent Trusses
Small trusses are used to quickly deploy very large light structures. The truss design can bear much higher loads and span larger distances with less deformation than tent-like or inflatable structures.

3.4.2 Subsystem #2: 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. This subsystem will also dissipate wind energy into the structural support subsystem.

3.4.2.1 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 [8]. This material is layered in between of various other materials to create a highly impermeable fabric. The properties displayed in this material adequately satisfy the need to create a waterproof barrier. The ability for this material to be combined with alternative materials allows the possibility of combining solutions to Subsystem #2 and Subsystem #3.

3.4.2.2 Existing Design #2: Dupont Tyvek
Dupont's Tyvek is currently used in numerous applications including construction materials, protective apparel, sterile packaging, and cargo protection. Tyvek is material comprised of high-density polyethylene fibers [9]. 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.

3.4.2.3 Existing Design #3: Gore Gore-Tex
Gore's Gore-Tex material 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. [10]

3.4.2.4 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 [11]. A primary application of this system is to protect against rain, directly aligning with our objective of creating a waterproof barrier.

3.4.2.5 Existing Design #5: Hydrobead
Hydrobead is a superhydrophobic 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 [12]. This minimizes rust, ice, and bacterial growth. Using superhydrophobic coatings would create a waterproof structure while increasing its lifespan.

3.4.3 Subsystem #3: Solar Protection/Temperature Regulation
Providing solar protection to the launch vehicle is a primary objective of this design project in order 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.

3.4.3.1 Existing Design #1: Dupont Tyvek

Dupont's Tyvek is currently used in numerous applications including 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

3.4.3.2 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. 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.

3.4.3.3 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 [13]. This material may also be applied to the project design to manage temperature fluctuations within the enclosure.

3.4.4 Subsystem #4: Positioning

The Positioning Subsystem is responsible for moving the system from a location of storage or delivery, such as a hanger on site or a flatbed truck, to the correct position near the launch vehicle. It then allows for moving the system away from the launch vehicle after the system has been taken down. The positioning system will convert human or electrical energy into physical motion and will be the system that imports the launch vehicle.

3.4.4.1 Existing Design #1: Wheels

A simple way to move a frame-based or unibody type design may be to build wheels into the structure to allow it to be rolled across the ground. Deployable bleachers often make use of this kind of system.

3.4.4.2 Existing Design #2: Hovercraft

Moving the structure on a cushion of air may be a viable technique if the structure is inflatable or has a large, rigid surface area underneath it.

3.4.4.3 Existing Design #3: Crane

It may be simplest to position a large structure by moving it via crane. Mobile cranes can move objects more than 60,000 lbs. [14].

3.4.5 Subsystem #5: 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.

3.4.5.1 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.

3.4.5.2 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.

3.4.5.3 Existing Design #2: 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.

3.4.6 Subsystem #6: 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.

3.4.6.1 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. 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.

3.4.6.2 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/attached quickly, providing access/egress to the launch vehicle.

3.4.6.3 Existing Design #3: Industrial Strength Velcro

Velcro manufactures produce 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. [15]

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

This design pulls inspiration from modular concrete forming systems. By taking the modular capabilities of these systems, this design would adapt to the different size requirements of the customers. Each panel would consist of a combination of materials, each serving a specific purpose, that would provide 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 through 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 joined to create “gangs” of panels. Panels will be interconnected using a series of clamping mechanisms. These assemblies can be brought into the launch zone via cranes or forklifts, where they would 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 also allow for entrance dimensions to be varied depending on types of equipment needed in launch vehicle processing.

4.2 Design #2: Inflatable Enclosure

This design 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, the potential for limited air circulation within the workspace will 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 correct area before deployment, requiring the launch vehicle to already be placed on the launch pad prior or the exact location of where the vehicle will be placed needs to be known. Surface materials will be selected for this design based on their abilities to repel water and solar energy. Depending on target values for these abilities, one or more materials may be considered.

4.3 Design #3: The Bear Trap

This design is shown below in Figure 4. It has considered the six needed subsystems to make a functioning system that meets the customer’s needs. More detailed drawings of this design are in Appendix C, Figures C4 and C5. It consists of two strong structural skeletons that connect around the launch vehicle. When connected, 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 with the launch vehicle. The support will have rails in which the eight triangle shaped pieces of waterproof material are roped up, enclosing the launch vehicle. This material will have several openings on the top that allows 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 will be able to access these windows and open and close them as desired as well. 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.

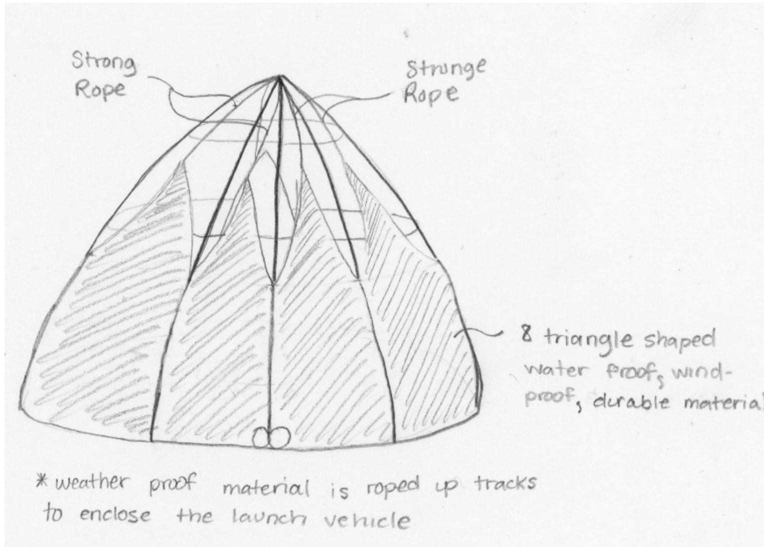


Figure 4: The Bear Trap

This design is extremely mechanically complicated. Though it may be inexpensive and lightweight for it's size, the mechanics behind it must be made with 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

This design 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 where the weather proof material will be stored when not in use. The weather proof material will be brought to the top in which they are deployed to cover the remaining two sides of the rocket and the roof. The material will contain large doors for personnel and equipment allowing access to the launch vehicle.

The cons to this design includes the cost of the material. Construction of the blinds and their operation can be expensive. 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

The design 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 some waterproof material can be hoisted upward to seal the sides of the enclosure. A winch system using synthetic rope rather than steel cable would be used to hoist the sides from a mounting location on the top of the structure. This would provide a sealed enclosure around the launch vehicle giving it shade from the sun, and protection from the elements. One of the sides may have a small door for employee entrance and exit once the enclosure is deployed.

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

The disadvantages to this design are that is does not make accessing the launch vehicle with a scissor lift or truck easy after the sides are hoisted into place. Even when the sides are in the down position, driving on the fabric could cause damage to the sides. Since the sides are separate pieces that are only held up by the tension from the winch, there could be potential openings for the water or sun 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

This design is a variation of Design 5 that gets inspiration from motorhome awnings. It is demonstrated in Figure 5. The design would have a similar skeletal structure for strength. The four corners would have a track system that a roll of waterproof material could follow downward to unroll into sides. When the sides are in the down position 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.

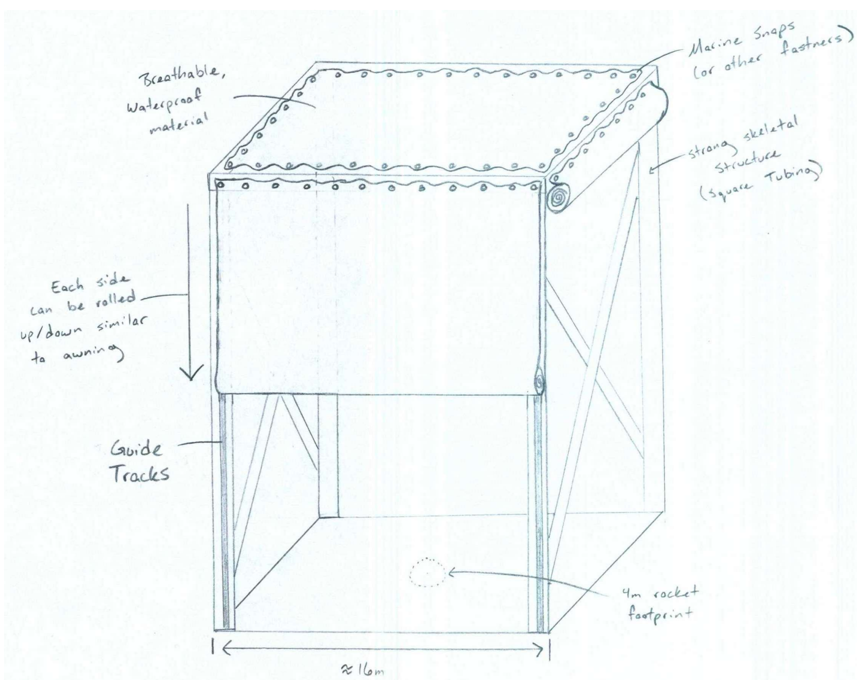


Figure 5: The Rocket Awning

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 allows for full access with scissor lifts, trucks, and employees. It also allows for shaded sides of the enclosure to be rolled up to allow better airflow to cool the enclosure while employees are working.

A disadvantage to this design is it 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. This means that the enclosure is not entirely sealed, however it is protected from the sun and rain with the majority of the rocket being covered. Ideally, water would not contact the vehicle because of the large footprint.

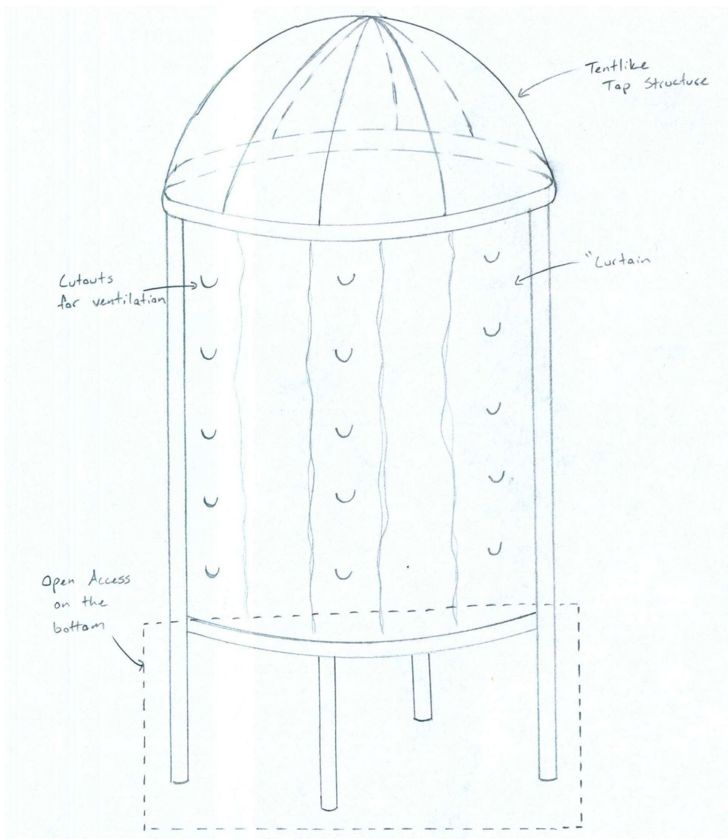


Figure 6: The Curtain

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

The disadvantage to this design is that it is not as 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 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.

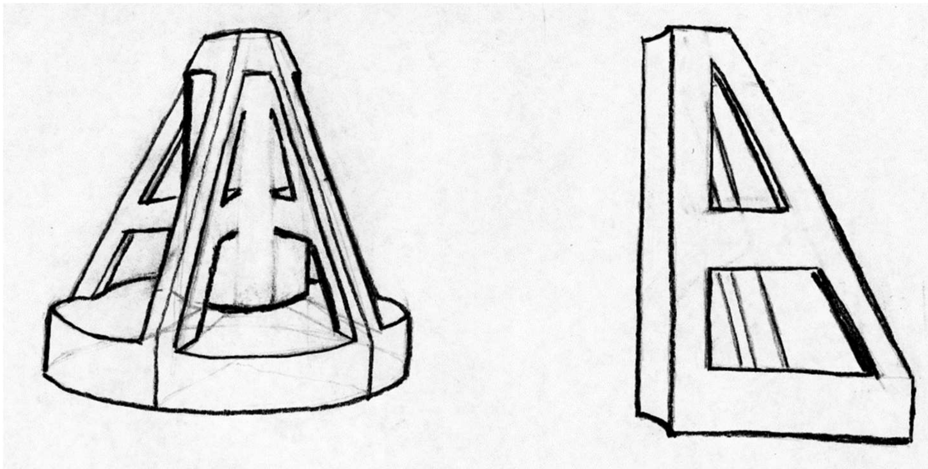


Figure 7: The Cone

4.9 Design #9: The Slider

This system 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. One drawback to this plan 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 failing to deploy properly due to its mechanical complexity.

4.10 Design #10: Stilt Tent

This design is intended to provide maximum coverage with minimum material cost, ease of assembly, and a simple takedown process. This system would fold down the structural legs, 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 and helping to stabilize it. The system could be assembled on the ground, eliminating the need of a crane to hoist structural elements into the air.

5 DESIGN SELECTED

This chapter discusses the process used to select a design from the designs considered in the previous chapter.

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, and if it meets the need worse than the datum 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. The remaining nine designs were ranked against the datum and the total pluses, minuses, and S's were summed. Next, the Stilt Tent and the Blinds were eliminated from the design selection process. These designs had the largest number of minuses and believed to meet most of the customer needs poorly. Then, 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, Figure D.1.

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 on a scale of 100%. The total of the customer needs weight summed 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 is multiplied with their corresponding weighted value. These values are summed together, giving each design a score. The design with the highest resulting score is the design selected for further analysis by the team. The Decision Matrix can be referenced in Appendix D, Figure 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.

6 REFERENCES

[1] Orbital ATK. (2017). *Space Launch Systems*[Online]. Available: http://www.orbitalatk.com
[2] Orbital ATK. *Orbital ATK Minotaur Space Launch Vehicles Fact Sheet,* 2017.
[3] D. Henthorn. (2017, July 30). *Florida's Climate and Weather* [Online]. Available: http://www.tripsavvy.com
[4] W. Eleazer. (2010, July 12). *Weather and Launch Failures* [Online]. Available: http://www.thespa-cereview.com
[5] Rubb Buildings. (2014). *CAE Aviation* [Online]. Available: http://www.rubbuk.com
[6] Alaska Tent and Tarp. (2017). *Arctic Oven Quest* [Online]. Available: https://arcticoventent.com-/tents/all-tents/arctic-oven-quest/
[7] Sunbelt. (2010). *16' Square Inflatable Tent* [Video]. Available: http://sunbeltinflatabletents.com
[8] TextileWeb. (2017). *Vapex* [Online]. Available: https://www.textileweb.com/doc/vapex-0001
[9] DuPont. (2017). *DuPont Tyvek Cargo Covers* [Online]. Available: http://www.dupont.com/
[10] Gore. (2017). *Fabrics* [Online]. Available: https://www.gore.com
[11] Mosquito Curtains. (2017). *Learn* [Online]. Available: https://www.mosquitocurtains.com
[12] Hydrobead. (2013). *Water Will Never Be the Same* [Online]. Available: http://www.hydrobead.com/
[13] Roc-Lon. *Coated Linings: Roc-Lon ThermalSuede.* [Online]. Available: http://www.roc-lon.com/products/coated_linings.html#
[14] A Quick Pick Crane. (2016*). Equipment* [Online]. Available: http://aquickpickcrane.com
[15] Velcro. (2017). V*elcro Brand Business Solutions.* [Online]. Available: https://www.velcro.com/business/industries/

7 APPENDICES

The appendix is made up of four sections. Appendix A contains a table of customer needs and engineering requirements. Appendix B includes the House of Quality. Appendix C contains images of the designs considered. Appendix D includes the Pugh Chart and Decision Matrix.

7.1 Appendix A: Customer Needs and Engineering Requirements

Table A1: Customer Needs and Engineering Requirements

Item:	Customer Need	Description	Related Engineering Requirements	Metric	Target Value	Tolerance	Customer Rank
Concerning Weather							
1	Solar Protection	Ability to limit temperature variance within the enclosure	Heat Flux Through Enclosure Material	W/m^2	Unkn own	Unknown	9
2	Moisture Protection	Ability to limit entrance of moisture into the enclosure	Permeability	$g/m^2/24hr$	0	±500	9
3	Debris Protection	Ability to shroud launch vehicles from airborne debris	Tensile Strength	*Pa*	320	±15	1
4	Wind Protection	Ability to restrict/allow airflows into the enclosure	Volumetric Flow Rate	g/m^3	Unkn own	Unknown	1
5	Lightning Protection	Ability to redirect lightning away from launch vehicles and personnel	Voltage	V	Unkn own	Unknown	9
Concerning Launch Vehicle							
6	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	5
7	Launch Vehicle Contact	Enclosure must not contact at any point (high wind/rain conditions	Enclosure Deflection	*m*	Depen dent on 9	Unknown	10
Concerning Pre-Launch Staff							
8	Work Environment Temperature	Launch vehicle enclosure must remain within a	Dead Space Temperature	*°C*	23.9	18.4-29.4	3

		workable temperature range					
9	Work Space	Suitable space between launch vehicle and enclosure wall to perform necessary pre-launch operations	Enclosure Footprint	m^2	200	±10	8
10	Accessibility	Ability for employee/truck/scissor lift to enter enclosure	Entrance Dimensions	m^2	25	±5	10
Concerning Material Procurement/Manufacturing/Assembly							
11	Scalable Design	Ability for final design to be adapted to full range of launch vehicles	Cost per Enclosure Height	*$/m*	Unknown	Unknown	9
12	Ease of Assembly	Simplicity of enclosure construction at launch site. Minimizing the number of steps.	Number of Assembly Steps	*# of Steps*	TBD	TBD	8
13	Time of Assembly	Time required to construct enclosure at launch site	Time to Assemble	*min*	60	±480	8
14	Time of Disassembly	Time required to remove enclosure from launch site	Time to Disassemble	*min*	30	±160	8
15	Associated Costs	Costs involved in the production, ownership, and operation of the system	Raw Material Cost	*$*	$25,000	±$5,000	6
Concerning Enclosure							
16	Ability to Support Items	Ability for the enclosure to support auxiliary items	Bearing Stress	*Pa*	TBD	TBD	3
17	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*	100	±20	8
18	Durability	Ability for	UV	*Infrar*	Unkn	Unknown	8

		enclosure to resist exposure and typical wear	Degradation	*ed Wave Transmission*	own		
19	Safety	Ability for safety hazards to be minimized during extreme weather events and/or failure	Failure Percentage Across Various Scenarios	*%*	0	±0	10
20	Factor of Safety	Ability for a much stronger system than needed to minimize safety hazards	Yield Stress / Working Stress	*FOS#*	3yield and 5ultimate	±0	10
						Total Points assigned	143

7.2 Appendix B: House of Quality

System QFD

Project:	**Orbital ATK**
Date:	**1-Oct-17**

#	Technical Requirement	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																			
2	Permeability	+																		
3	Tensile Strength	-																		
4	Volumetric Flow Rate		+																	
5	Voltage																			
6	Surface Temperature Delta	+	+		+															
7	Enclosure Deflection			+																
8	Dead Space Temperature	+	+		-		+													
9	Enclosure Footprint							+	+											
10	Entrance Dimensions								+	+										
11	Cost per Enclosure Height							-												
12	Number of Assembly Steps																			
13	Time to Assemble												+							
14	Time to Disassemble												+	+						
15	Raw Material Cost	-		-				-		+		+								
16	Bearing Stress			+	-															
17	Usage Quantity																			
18	UV Degradation																	+		
19	Failure %			-				+					+				-	-	+	
20	Yeild Stress/WorkingStress			+																

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

#	Customer Needs	Customer Weights	Heat Flux Through Enclosure Material	Permeability	Tensile Strength	Volumetric Flow Rate	Voltage	Surface Temperature Delta	Enclosure Deflection	Dead Space Temperature	Enclosure Footprint	Entrance Dimensions	Cost per Enclosure Height	Number of Assembly Steps	Time to Assemble	Time to Disassemble	Raw Material Cost	Bearing Stress	Usage Quantity	UV Degradation	Failure %	Yeild Stress/WorkingStress	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					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					1		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		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	Pa	g/m3	Voltage	C	m	C	m2	m2	$/m	# of Steps	min	min	$	Pa	# Uses	Infrared Wave Transmission	%	FOS#					
	Technical Requirement Targets			0	320			23.9		23.9	200	25		TBD	60	30	25000	TBD	100		0	3y&5U					
	Absolute Technical Importance		105	104	165	47	119	81	264	87	195	120	153	187	146	146	604	141	231	177	402	245					
	Weighted Technical Importance		0.0282	0.0280	0.0444	0.0126	0.0320	0.0218	0.0710	0.0234	0.0524	0.0323	0.0411	0.0503	0.0393	0.0393	0.1624	0.0379	0.0621	0.0476	0.1081	0.0659					
	Relative Technical Importance		16	17	9	20	15	19	3	18	6	14	10	7	11	11	1	13	5	8	2	4					

Figure B1: House of Quality

7.3 Appendix C: Designs Considered

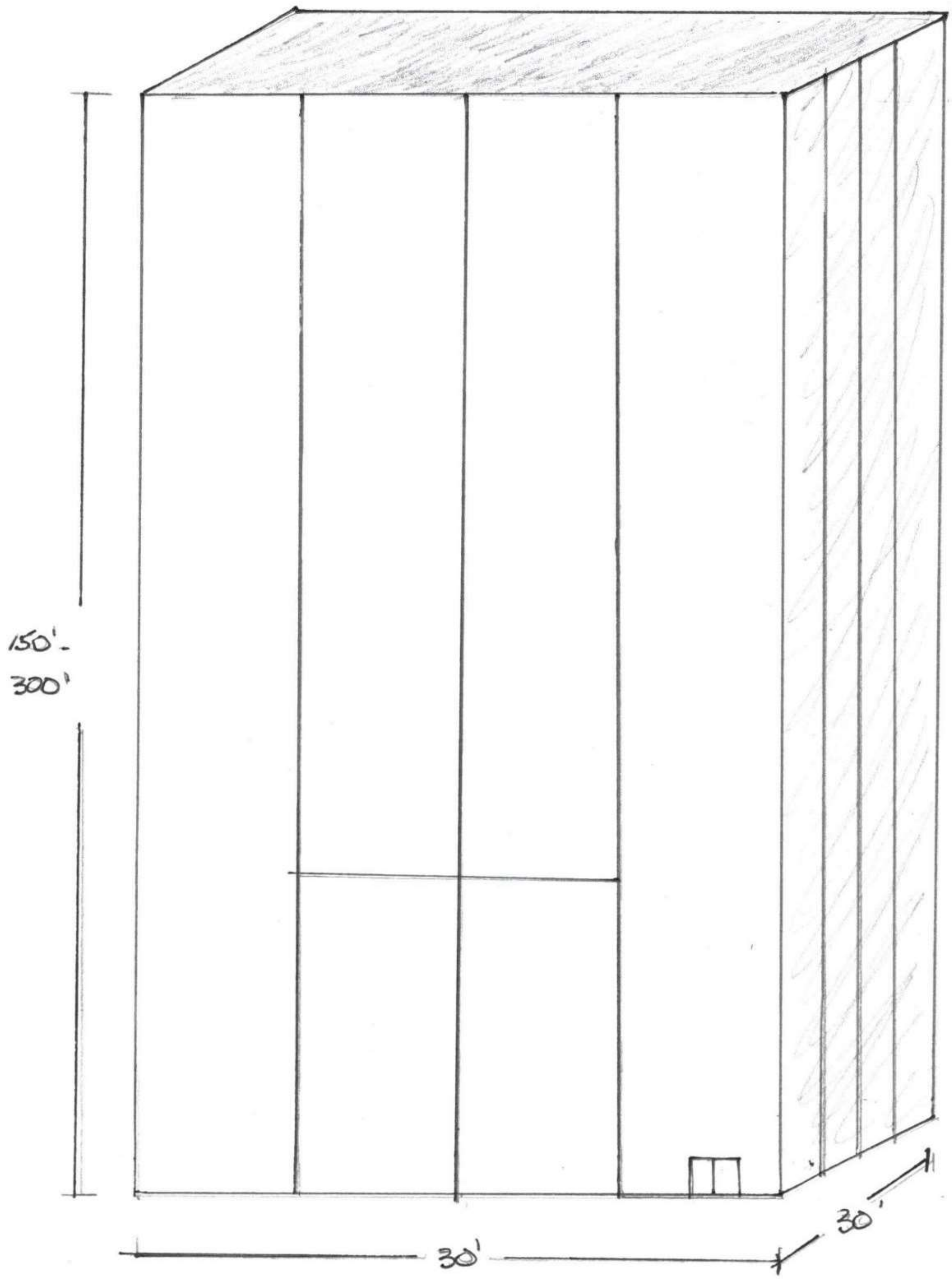


Figure C1: Panel Assembly 1

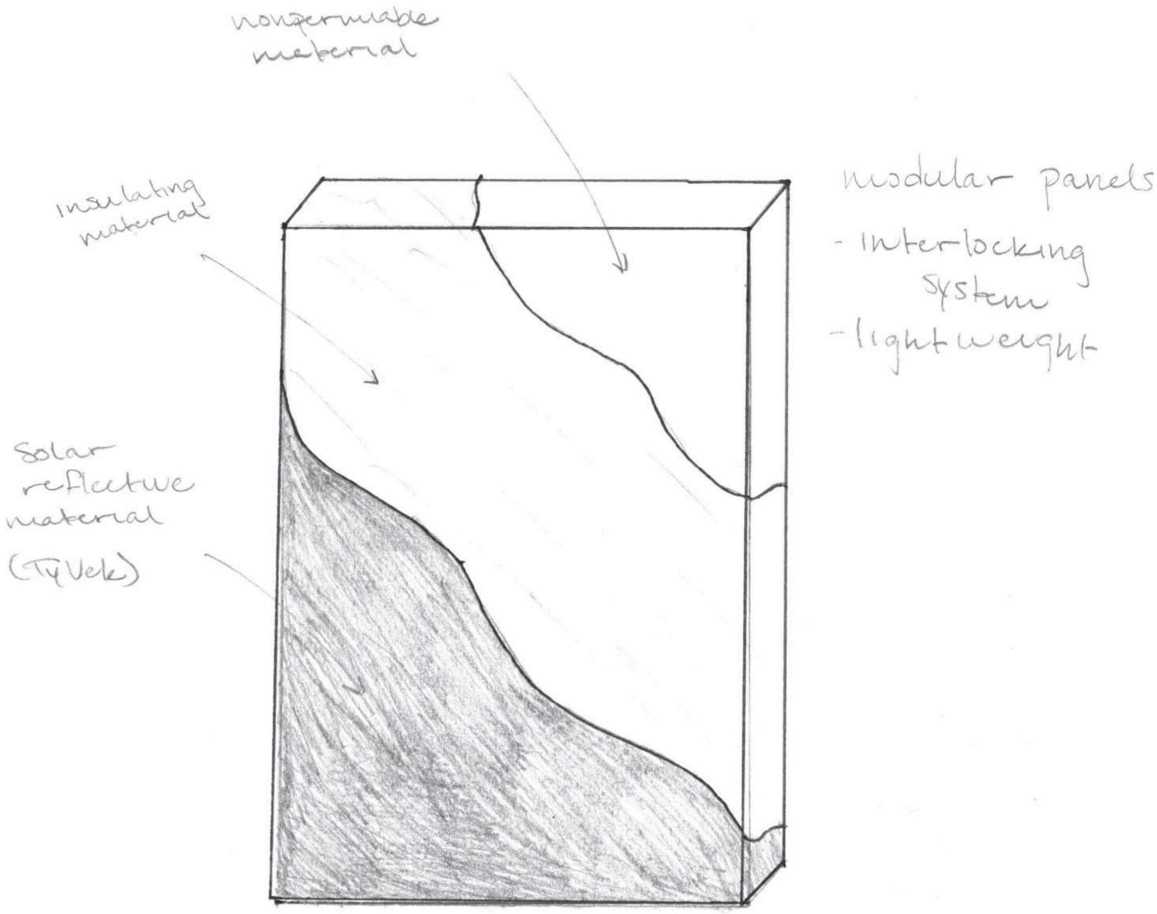


Figure C2: Panel Assembly 2

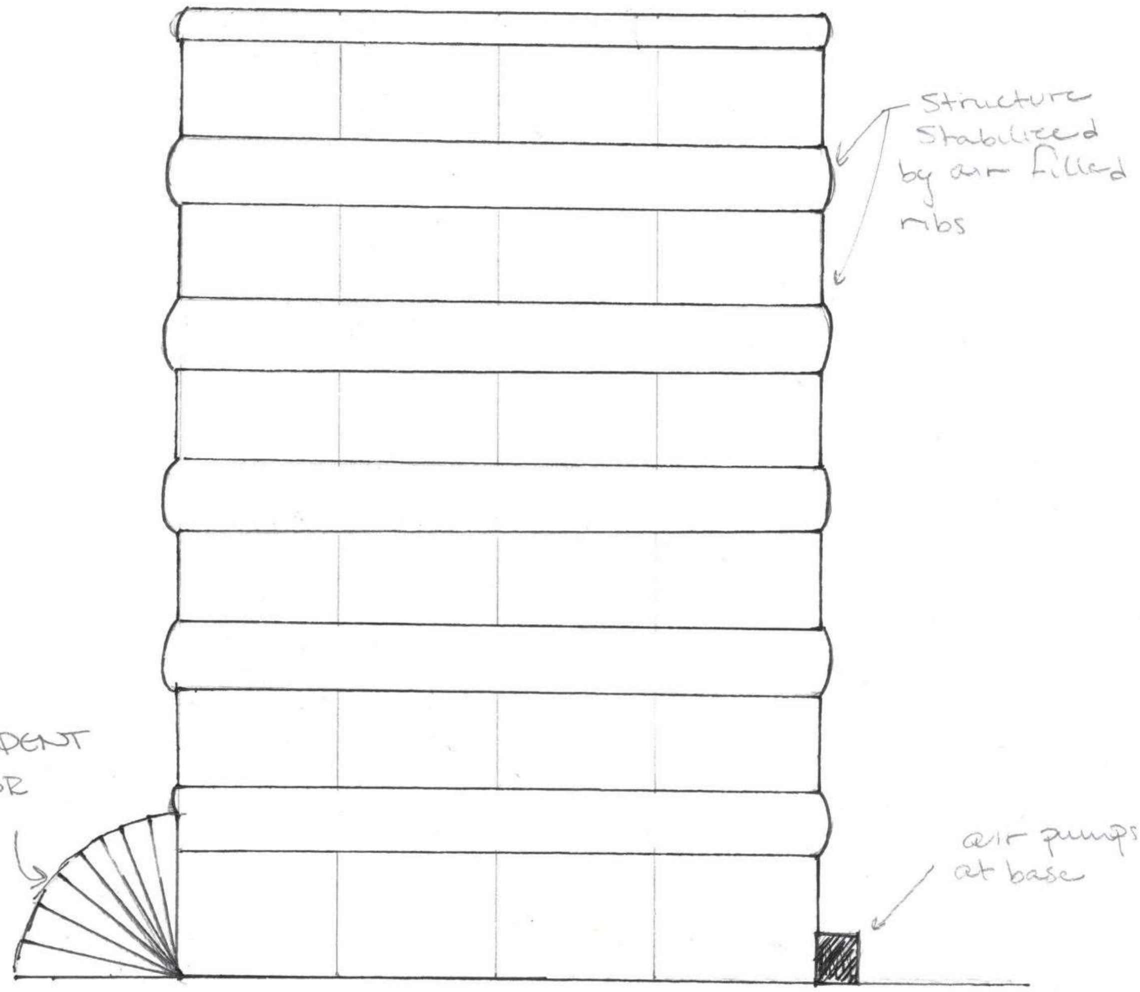


Figure C3: Inflatable Enclosure

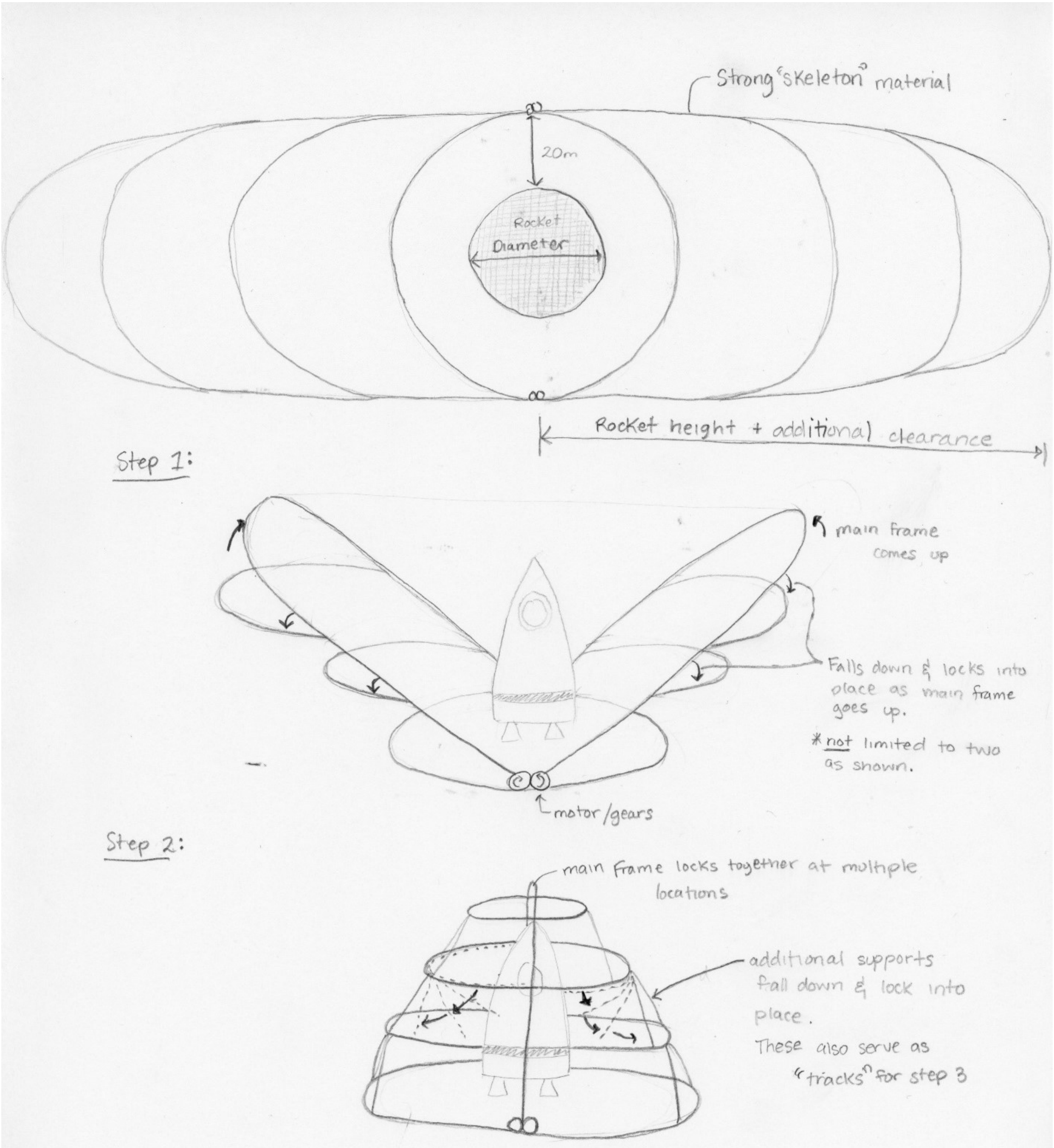


Figure C4: Bear Trap 1

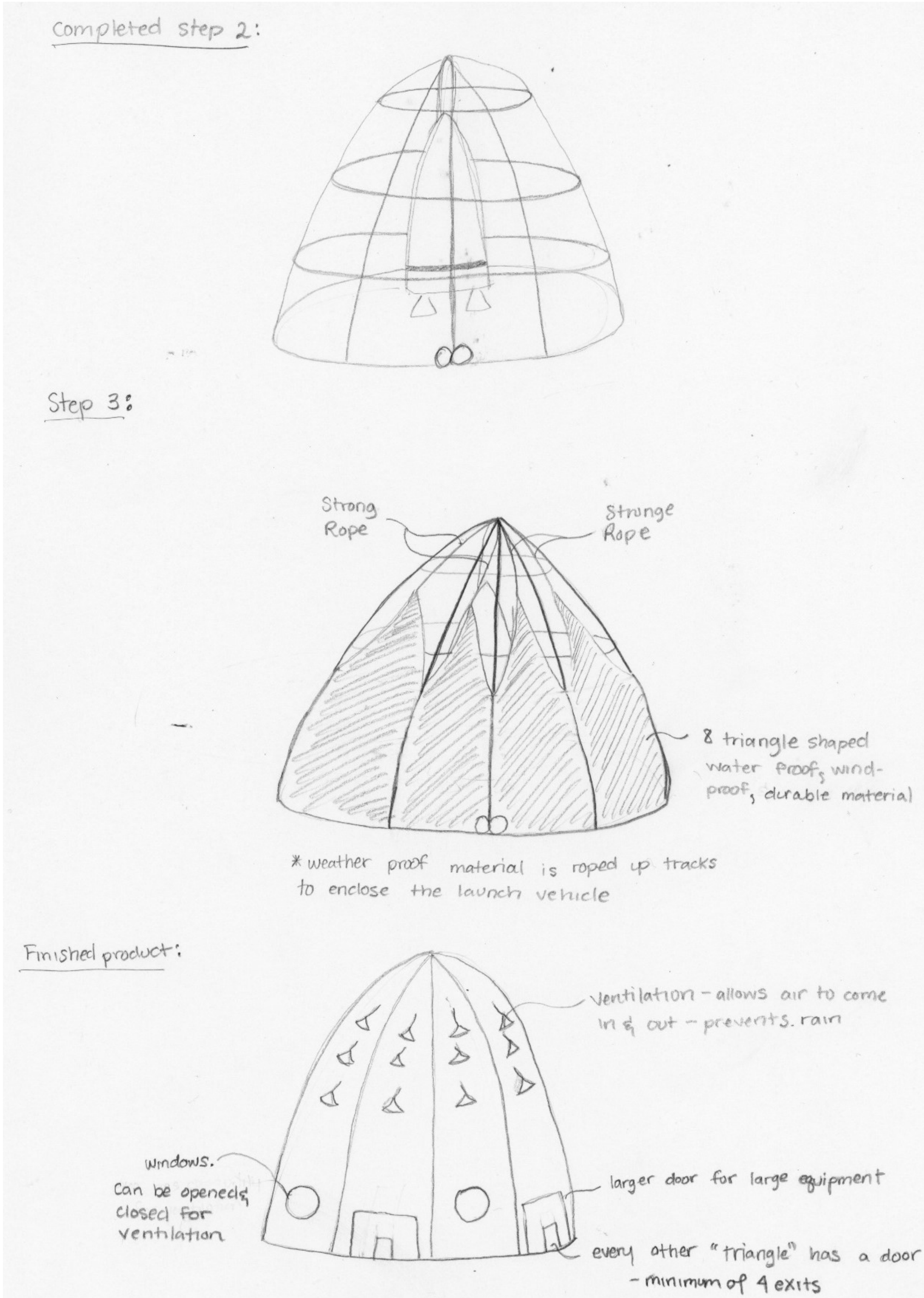


Figure C5: Bear Trap 2

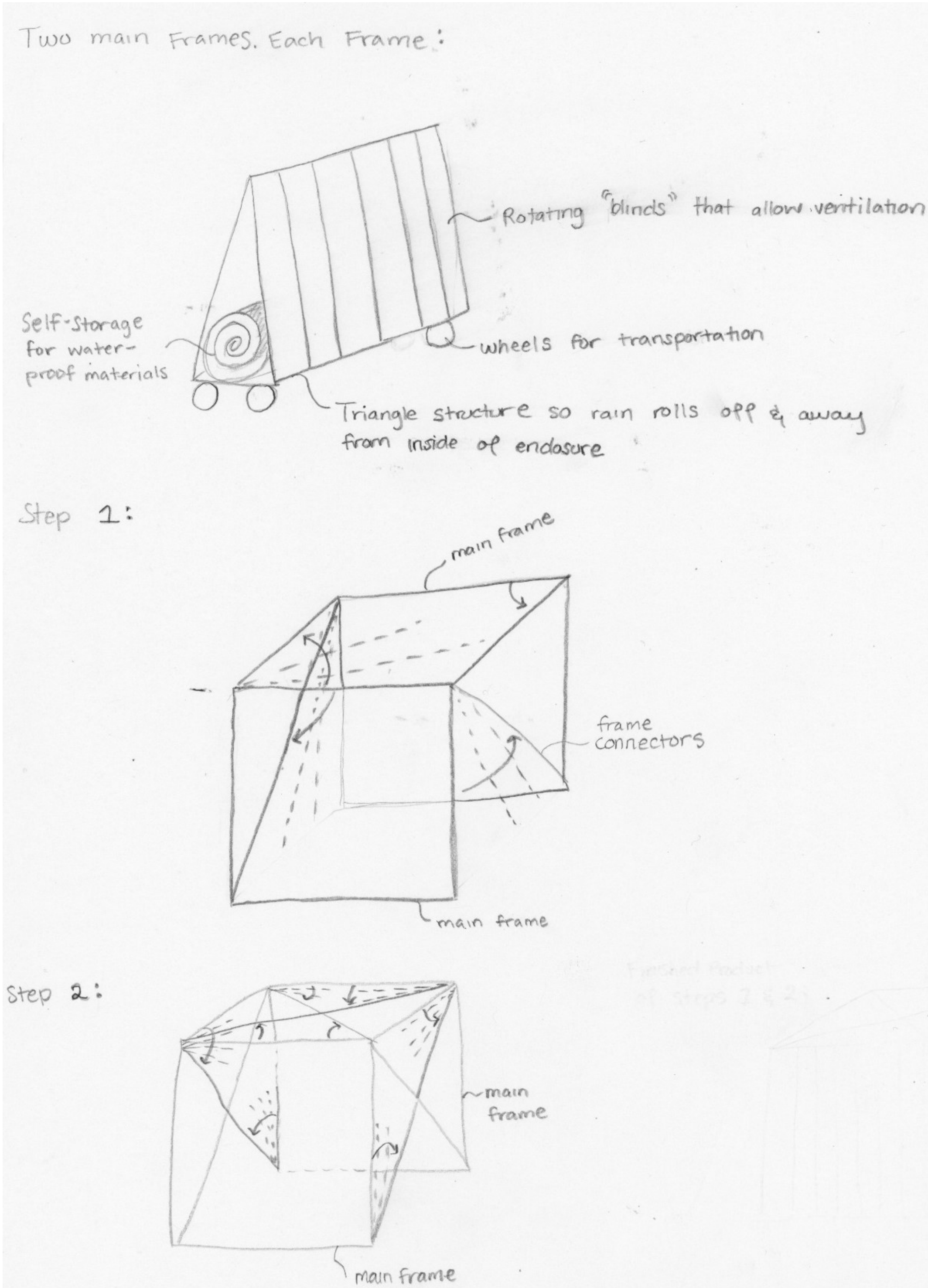


Figure C6: Blinds 1

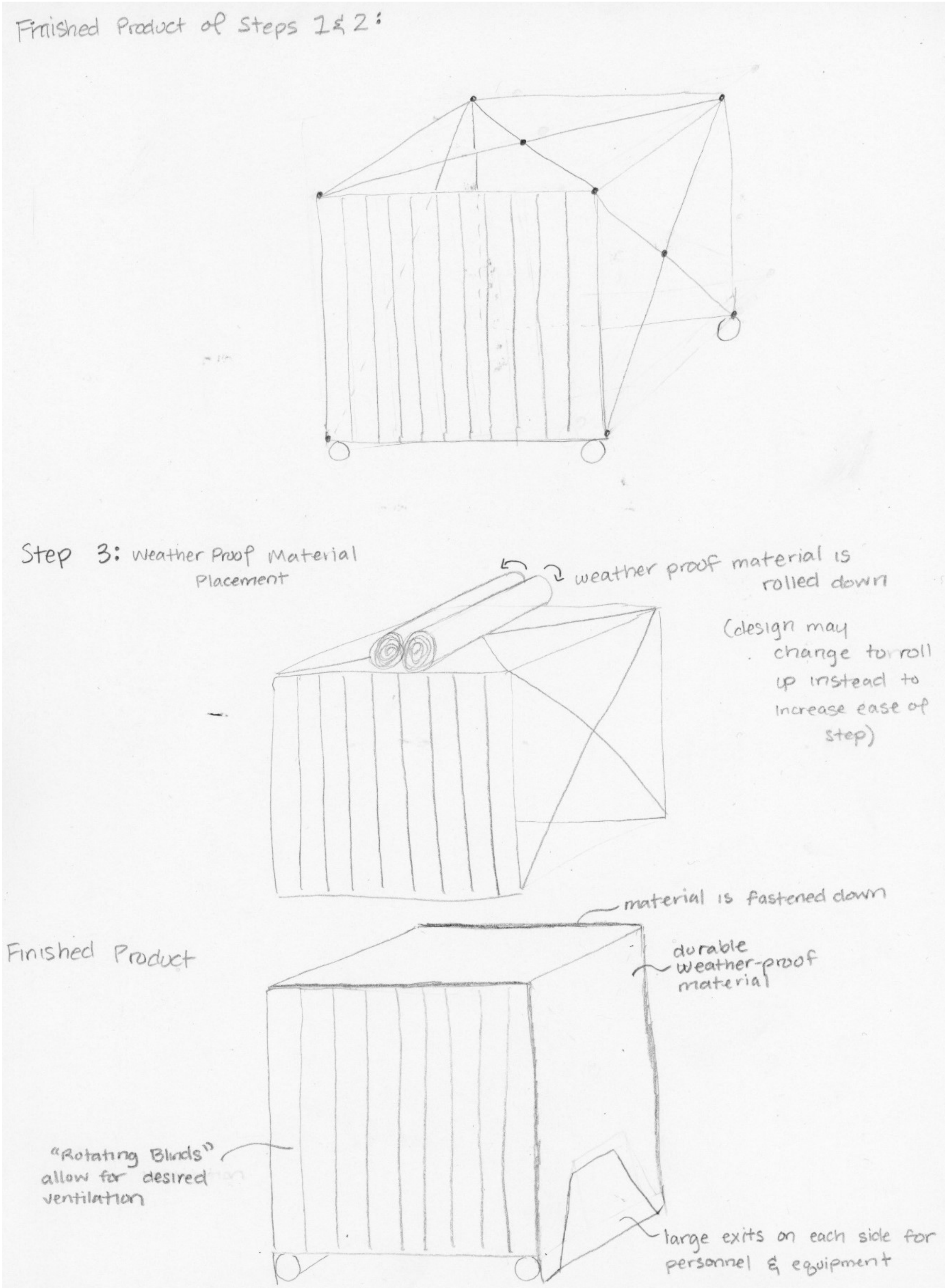


Figure C7: Blinds 2

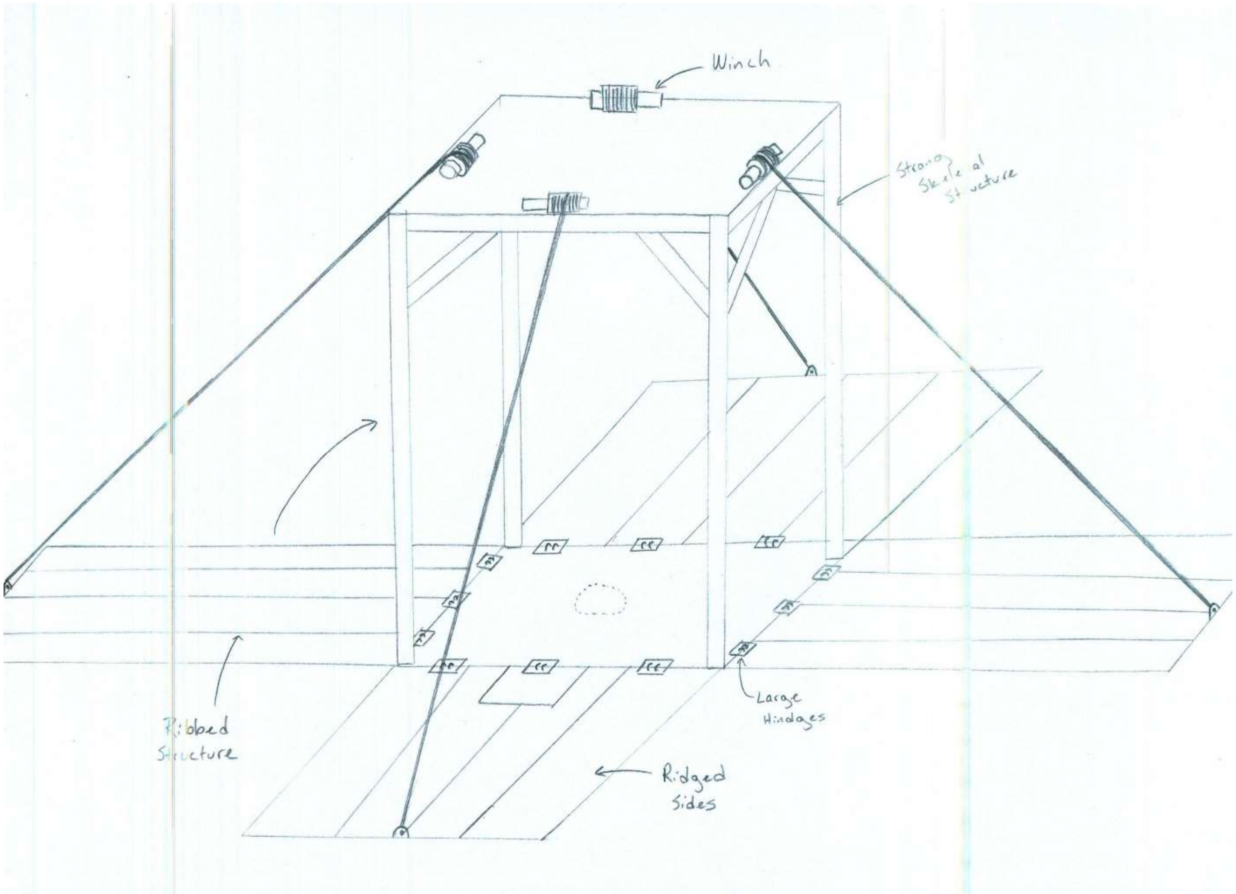


Figure C8: Winch Hoisted Sides

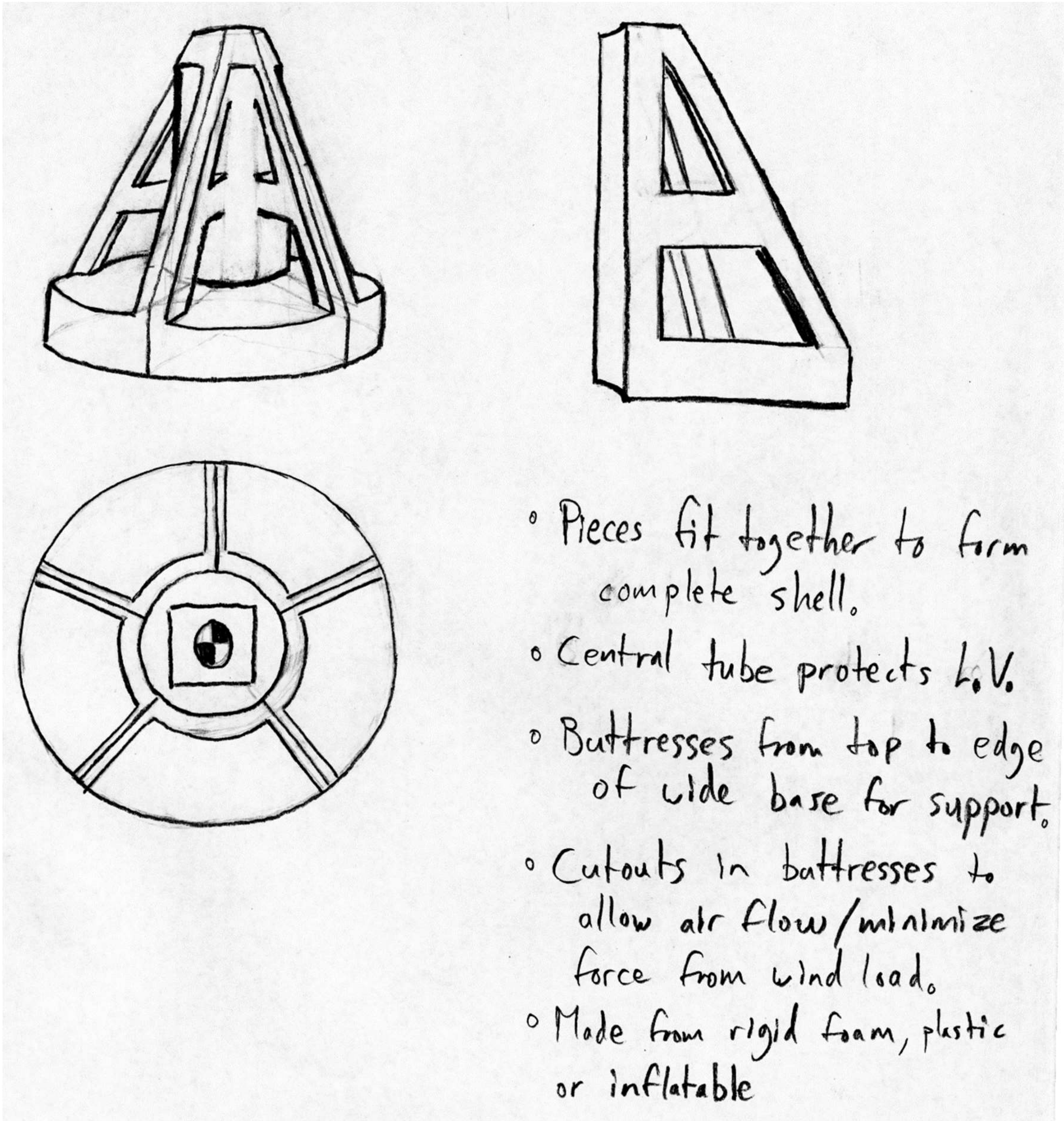


Figure C9: Cone

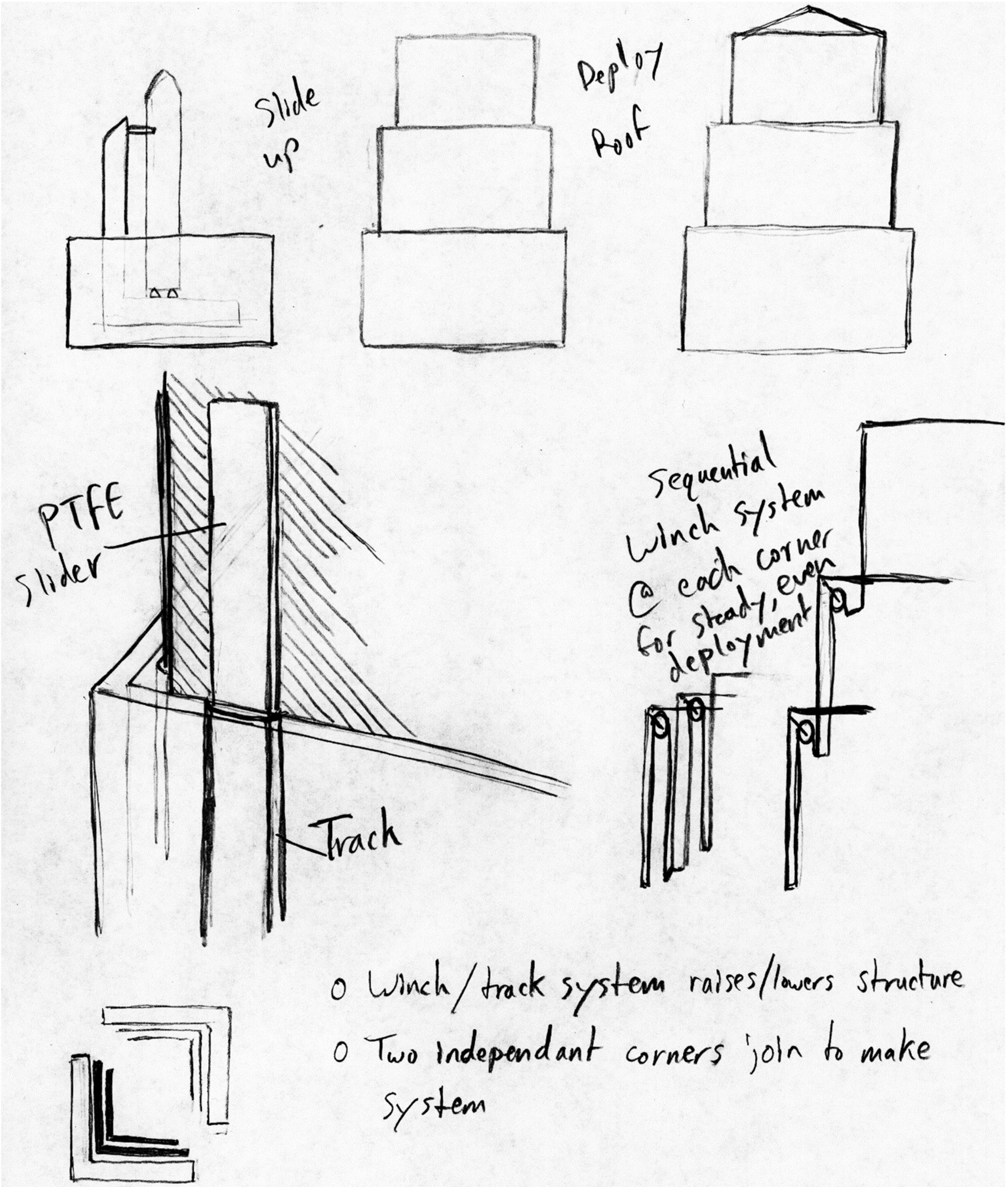


Figure C10: Slider

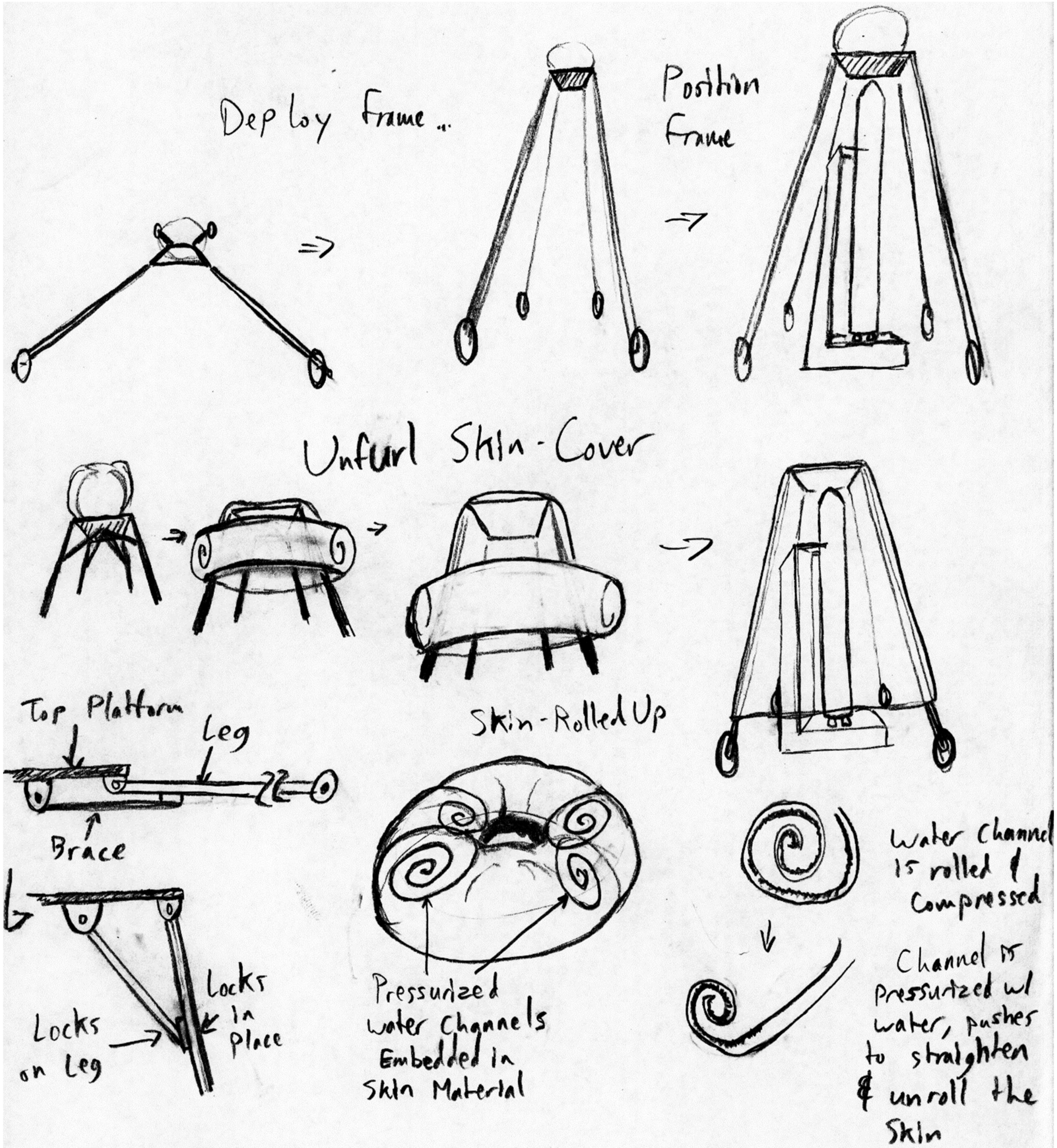
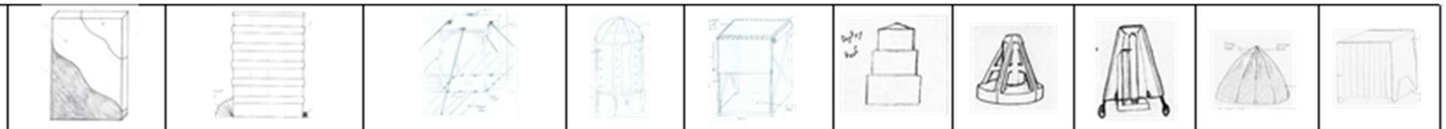


Figure C11: Stilt Tent

7.4 Appendix D: Design Selection Process



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	*	-	-	+	-	-	-	-	-	-
∑+		5	5	8	5	3	5	4	6	6
∑-		7	5	4	5	5	6	9	6	8
∑S		6	8	6	8	10	7	5	6	4

Figure D1: Pugh Chart

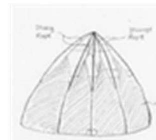
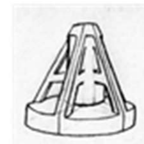
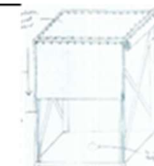
									
		Design: The Curtain		Design: The Bear Trap		Design: The Cone		Design: Rocket Awning	
Criteria	Criteria Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Solar Protection	0.10	8.00	0.80	7.00	0.70	9.00	0.90	7.00	0.70
Moisture Protection	0.10	4.00	0.40	6.00	0.60	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

Figure D2: Decision Matrix