Advanced **T**echnology **L**ift **A**ssist **S**ystems – **ATLAS**

Final Design Report

By

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Abstract
EMS personal work hard every day to save lives. A big part of the job is helping to lift people who are not injured but have fallen and can't get up by themselves. There are currently no procedures or tools that are consistently used by EMS in this specific situation. This leads to the response often being ad hoc costing more time, resources, and manpower that can be vital if multiple emergencies happen at the same time. Along with this the job of lifting an individual that is overweight is no easy feat and is one of the primary factors that leads to EMS personal having one of the highest back injury rates of all professions. The goal of this project is to design and manufacture a marketable product that can be used by EMS personal as a lift assist device for these situations. The product should be able to safely lift the person to a seated or standing position with little to no effort by the EMS team.

1 Introduction
Most of the injuries experienced in the field of Emergency Medical Services (EMS) are the neck, back, and knee related injuries. These injuries make up approximately 30% of all injuries sustained by EMS personnel, specifically by firefighters and paramedics. Of all the head, neck, and back related injuries, 25% are due to lifting overweight patients who have fallen over and can't get up by themselves. [1] Lifting heavyweight objects and overweight people is not an uncommon call for EMS personnel and is one that can happen multiple times a day, sometimes even back to back. In addition to the injuries sustained from these calls, time and resources get taken up in trying to figuring out the best way possible to lift the patent. Time spent lifting patients can fatigue the team quickly and or delay other tasks for firefighters and paramedics. With about 4 calls average per day across the US both time and rest are vital for firefighters and paramedics. [2] John, a firefighter in San Luis Obispo says sometimes if the person is too heavy for the team, an additional team will be called to assist in the lift. This means that less of the city is accounted for if another emergency were to occur. According to Brian Lewis, a captain paramedic in Paso Robles, there are no current tools or procedures used in the field to assist in the lifting of overweight people. Firefighters and paramedics work day in and day out to save lives. By creating a device to help lift patients that have fallen over and can't get themselves up we can save the amount of time and energy exerted in these rescues and reduce the number of injuries on the job.

The overall goal of the project is to create an easy to use device that can quickly and safely assist in the lifting of overweight people in non-emergency situations. This device will be used by EMS personnel in situations where overweight people have fallen, are not injured, and can't get up by themselves.

This paper will present the background research and scope of the design project as well as the design iteration and final detailed design. This will include a detailed report of what exists on the market currently as well as any patents that go along with the current designs. The paper will show a list of the customer needs and wants that were established through in-person interviews and extensive background research. These needs and wants will be compared against the current solutions that exist to show where the focus of the project will be. The comparison of the design solutions will demonstrate that there is in fact marketability for the project and will discuss some of the weak points in the current design. This will lead to a detailed statement of the project at hand along with the goals and challenges for achieving the statement. Finally, this paper will go over the design process leading to a detailed design with any calculations and analysis all the way to cost and weight breakdown of the final detailed design. It should be noted that the final product detailed in this paper is for a structural prototype. Further iterations and design verification laid out in this paper will need to be implemented for a final product build.

2 Background
Assisted lifting devices are not an uncommon need, they are in use almost every day. From a simple jack used to change a spare tire on the side of the road to huge industrial cranes, assisted lifting is a very sought-after task. Despite being such a common idea, there are only a few options available when it comes to being able to lift humans. For this project, the device is one that can assist EMS personnel in lifting patients that

have fallen and can't get themselves up. In this section of the paper, a list of customers' needs and wants gathered from research and interviews will be listed out. Next, existing products and patents for current solutions and their effectiveness will be discussed. Finally, the paper will present some technical research on what goes into the design and manufacturing of these products.

2.1 Customer Wants

From the first sponsor and team meeting an initial outline of the goals of the project were established. The goals further developed through research and interviews along the way. The goals listed below are for the overall main target of the project and were established at the first sponsor meeting for the project. Further research and project goals are discussed in section 5 and 6 of the Report.

- **The product must be able to lift 700 lb –** This device is to be able to lift overweight individuals and must be able to accommodate for all ranges of weight.
- **The product must provide a 'hands-free' lift to prevent injury –** An important component of this project is to help prevent injury sustained by EMS personnel.
- **The product must have a distinguishable orientation**. **–** The product must be easy to use in stressful emergency situations. Orientation is a key aspect in making sure everything goes smoothly.
- **Separate power supply for the device.** – The device can't always be near a power source so must rely on an individual transportable power supply.
- **Must be small and compact. –** When the device is packed away it must be small to accommodate for easy transportation and to make fitting on an emergency vehicle easier.
- **The product must be usable by 2 people or less –** Another main goal is to reduce the manpower needed in these kinds of situations.
- **The lift must support the patient –** The product must be safe to use for everyone
- **The lift must be quick –** EMS personnel's time is very important. The faster the product is, the better.

2.2 Existing Products

There are a few products that exist on the market today that are designed to assist in the lifting of elderly or overweight people. Looking at these products can help in figuring out the design goals of the project as well as give some insight as to what materials, shapes, and functionality are good for the design of a lift assisting device. By comparing each part of each design to the wants and needs list of the project detailed in *Section 5.1*, the project goal and main ideas can be further defined.

One of the most common solutions to this problem is the Hoyer lifting device.[3] Shown below in figure 1. This device uses hydraulic, electric, or manually actuated piston to raise and lower an arm that reaches out and over the patent. This product exists in a wide range of shapes and sizes, however, can be very limiting in weight and size.

Figure 1: Hoyer Lift

Additionally, the lift is not designed for transportation in emergency situations. It is used as a permanent installation home lift. Although this lift is a solution to a slightly different design problem, it is still helpful to look at the technology used by the lift to explore solutions with more detail. By noting the materials used and the configuration of the lifting mechanism a better idea of what capabilities are needed to lift a person can be formed.

The next device on the market is the Binder Lift. The Binder Lift system, shown in figure 2, is a vest with various handles worn by the patent to provide an ergonomic lifting solution for the EMS personnel. [4] The vest is available in two models and is a relatively cheap solution to the design problem.

Figure 2: Binder Lift

Although a cheap and ergonomic lifting solution, the Binder Lift, does not allow for EMS personnel to have a hands-free assist. Depending on the weight of any given patient, the lifting process may involve a team of more than two members and does not solve the problem of cutting out time, resources, and potential injuries. By looking at the structure of the vest, a better idea can be formed about what kinds of features would be nice to have on a lifting device. For example, adjustable straps to fit a variety of sizes and shapes is very useful in a device like this.

Similar to the Binder lift is the Doty belt.[5] The Doty belt is a harness that when worn by a person, gives them key lifting points to assist in the lifting of said person. The belt is shown below in figure 3.

Figure 3: Doty Belt Design

Though the Doty belt design is not a solution to the design problem, because it requires lifting to be performed by the paramedics, it is still an important case study to observe for the same reasons as the Binder Lift device. Again, it gives good insight to the features and aspects of lifting devices that are helpful.

The next product, shown below in figure 4, is the Raizer lift chair.[6] The chair is designed by the company Lift Up and uses a motorized system on an external power supply to lift the chair. The lifting process is such that the chair gets assembled around the patient while they are on the ground. The device then uses an internal motor to gradually rotate the legs in a scissoring motion effectively lifting the patient into a seated position.

Figure 4: Raizer lift chair

While this design is lightweight and compact, its safe working load is limited to 300 pounds. Additionally, there is also a size limit on the chair that couldn't accommodate patients of all sizes. On top of this, the Raizer device's selling point is $4,500-$5,500; making it one of the most expensive assist devices available. This device provides additional insight into a possible design solution. For example, Lift Up uses an electrical system which works for this design, however, this could be the reason for the high cost and low lift loads. This is good information that can be used for the project.

The final device to look at is the ELK and CAMEL chair systems by Manger [7] shown in figure 5. This company has been in the industry for a while and their most recent product is made to help lift overweight persons in an inflatable chair design. The Manger Elk/Camel lifts using an external pump attached in parallel to valves connected to each section of the inflatable. A controller on the other end allows for control over each section until the full device is inflated.

Figure 5: Manger ELK and CAMEL

The larger CAMEL model can lift patients up from a laying to a seated position without requiring extra support. However, the ELK can only get the patient up from the ground in the seated position. The ELK system has a 1000+ pound lift capacity whereas the CAMEL is rated for roughly 700 pounds. Both products take on average 6 minutes to fill. These designs are adequate solutions to the design problem. However, by doing a thorough background search, it can be noted that some of the wants and needs of the customers are not met. This will be discussed further in section 5.1

All the devices listed above contain valuable information for the design problem. Materials, styles, power, abilities, sizes, weights, costs, and manufacturability are all key factors for each product. Each product uses some variation of rubber, foam, or fabric because of its durability, strength, how easy it is to form fit, and the fact that it can be washed. Further aspects of what each product has to offer is tabulated in the Quality Function Deployment (QFD) attached in Appendix A.

2.3 Existing Tools

A piece of equipment to look at is the airbag car lifting system. This system is used to lift heavy objects of up 1,000+ lbs. The airbag itself is a Kevlar rubber composite bag. The bag is inflated through a hose and regulator system attached to a control valve. The air supply used to fill the bag is from the onboard air tanks that firefighters use during rescue each bottle is rated to 4500 psi and can supply 40 minutes of breathing time. This could be a very useful tool in the design of the project as it would allow for the device to harness already used, tested, and rated components.

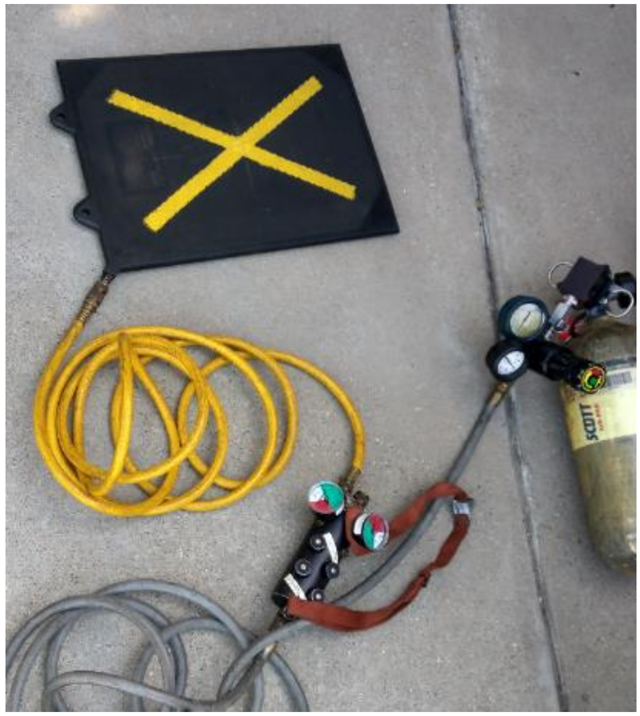


Figure 6: Air Bag System

2.3.1 Patent Searches

Research was done for existing patents as an additional method for exploring existing products. A secondary, but particularly important, reason for using patents searches was to begin to understand how patents are created and operate. As a design team, the group would like to avoid any possible patent infringement situation. To avoid infringing on any patent, patent research is part of an ongoing active action that is being perused. The following are the patent searches with topics related to lifting a patient. A more detailed account for all the patents is attached in Appendix B.

Patent No. 5970545 is assigned to Manger International Ltd. This patent describes an inflatable apparatus bag structure that is comprised of two hollow limbs constructed and connected to assume a stable configuration when fully inflated. To better understand how a competitor's device will meet the functions and attributes of the problem statement, the products are compared with one another according to wants and needs specified by the various customers. This product is waterproof, easily operable through a remote, durable, washable, fits most body shapes, and easily stored. The product is limited to body weights under 300 lbs. and, for the purposes of operation, cannot completely lift a person off the ground.[13]

Patent No. US20090178194A1 is assigned to Delia Story. This patent describes a manual lifting pelvic harness for lifting or otherwise assisting debilitating patients has an adjustable belt, adjustable straps for encircling the thighs adjacent the buttocks, and fasteners such as tongues and buckles for securing the belt around the patient and securing the straps to the belt. This product is robust, adjustable to any body type, and stores easily. The product requires manual labor and multiple people to operate.[14]

Patent No. US6449785B is assigned to Liko Research and Development AB. The patent is an aid apparatus for raising a disabled person from a sitting position to a standing position including a wheeled base in the form of a U-shaped frame with a post, which surrounds at least partly the body of the person. A figure of the patent is shown in Appendix B. This product requires minimal manual labor from the operator and is mobile with a patient onboard from a seated and standing position. This product requires patients to already be in a seated position, is a relatively large device, and not easy to store.[15]

Patent No. US6015471A is assigned to Manger International Ltd. The patent describes an inflatable cushion made up of two welded segments in the shape of a ring. The cushions are joined together between a central chamber. An inlet fitting is attached to the bottom cushions for simultaneous inflation. This patent fulfills the following categories. A figure of the patent is shown in Appendix B. This product is robust, lifts up to 1000 lbs, portable, simple to use, and can be used in confined spaces. This product is sometimes unstable for patients requires at least one non-operator for stability, and not wide enough for larger patients.[16]

Patent No. US6199827B1 is assigned to Manger International Ltd. This patent is for a valve assembly having a rigid mounting that allows fluid under pressure to flow past the flange of the first head accumulating fluid pressure in the opening behaving as a self-seal. A figure of the patent is shown in Appendix B. This product is a robust valve designed to perform efficiently with a small compressor. This product requires multiple levels of manufacturing. [17]

2.4 Technical Research

This section of the report goes over the technical research done for the project. Research on lifting criteria, materials used, engineering challenges, design requirements, and other overarching engineering techniques for the project are listed here. This research is to better understand how the overall project timeline and flow will go as far as things to consider and challenges along the way.

2.5 National Institute for Occupational Safety and Health (NIOSH) Lifting Equation

NIOSH Lifting Equation is an assessment tool to determine the recommended weight limit for two-handed lifting tasks. The equation is as follows:

NIOSH Lifting Equation: $LC \times HM \times VM \times DM \times AM \times FM \times CM = RWL$

Where LC is the load constant which is 51 lb for an ideal lifting condition. H is the horizontal location of the object from the body. V is the vertical location of the object from the floor. D is the distance the object moves vertically. A is the angle of twisting required for lifting the object. F is the frequency of lifting the object. C is the quality of the grip. M is the multiple for any condition. RWL is the recommended weight limit.[7]

An index value between 1 and 3 indicates a lift has increased risk but is still acceptable if performed properly. A lifting index value above 3 indicates a lift should not be performed as it can potentially result in musculoskeletal injuries for the lifter. The index value for lifting a 600-pound person vertically from floor to hip height returned a value of 15.08, which is significantly greater than 3. The recommended max weight limit for the same lift would be 37.39 lbs. This further emphasizes the dangers of lifting a heavy person without proper equipment.

2.6 Human Biometrics and Ergonomics

Human biometrics play an important role in adequately designing a device that will interact with the human body and do so in a comfortable and safe manner. Understanding the human body's composition is necessary to further understand loads and stresses a device will have to accommodate. According to the book "Human Body Dynamics: Classical Mechanics and Human Movement" the Weight of the human body is divided as follows: 43% torso, thighs, lower legs and feet 37%, head and neck 7% and upper limbs 13%.[8] According to the University of Rhode Island: Department of Electrical, Computer and Biomedical Engineering[9] the division of the human body per body part is as follows: head and neck 13%, torso, and arms 34% and legs 53%. Introducing a specified weight, it is then possible to model the weight distribution of the human body per body part. This will be important when analyzing how different body positions will affect the loads on the structure of a lifting device.

In addition to the percentage of body composition, lower body dimensions for different percentiles of the US population are also important as a lift device will have an emphasis on the movement and contact with the lower portion of the human body. Table 1 displays values for the 5th, 50th and 95th percentile of US citizens [9]

Table 1: Anthropometric Data on Lower Body

	5th Percentile	50th Percentile	95th Percentile
Lower Leg Length (ft)	1.66	1.81	1.97
Upper Leg Length (ft)	1.83	1.98	2.17
Buttocks Height (ft)	2.50	2.75	3.02
Waist Height (ft)	3.26	3.62	3.83

Anthropometric data for people who weigh above 400 pounds is not well or credibly documented, thought the Center for Disease Control (CDC) provides credible documentation for those in the upper 95th percentile of the US population. These values do not represent the dimensions of a 750-pound person but provide a lower bound and some guidance to dimension our designs adequately. According to the CDC: Anthropometric Reference Data 2011-2014[19] the weight of men 20 years of age or older in the 95th percentile weighs 302.6 pounds. This value is significantly less than our 750-pound target weight but demonstrates the frequency that one might encounter a person weighing 750 pounds. Waist circumference for the same demographic of the population is 53.5 inches.

Research of pre-existing medical equipment designed for bariatric patients' shows that we should use a seat width of 30" and a depth of 22". We will take this into consideration when determining the geometries of our air chair.

2.7 Fire Engine Standards and Regulations

NFPA 1901 Fire engine standards outline the minimum required items onboard a fire engine, though don't specify any standards for those devices nor do they address additional items added to the fire engine [10]. Further interviews with San Luis Obispo County firefighters confirmed a lack of established standards for equipment onboard, thus allowing fewer constraints on the design.

2.8 Controls

When considering any design, a reliable method of control must be implemented. A controller is any device that allows its user to operate a system with ease. A proper controller system is made up of a controller, the system, and a sensor in a feedback loop. The controller can be produced in many different formats. An example is the controller of a pneumatic system might be made up of a regulator valve designed to relieve overpressure and allow for the system to stay properly pressurized under load. Similarly, the controller of an electro-mechanical system might be made up of a microcontroller, electrical sensors that translate analog to digital signals, and a device that grants mechanical advantage.

Based on an interview conducted with a firefighter at Fire Station #2 in San Luis Obispo, California, the type of controllers typically used by first aid responders are pneumatic valve controllers with a few large unambiguous buttons. The controller currently being used is part of an air powered jack lifting system. The air controller in the fireman's system is used to regulate pressure, air flow, and flow rate.

Electro-mechanical controllers largely have the same end result pneumatic systems do but they operate differently. Electro-mechanical controllers employ the use of analog to digital sensors that can relay information back to a microcontroller. A microcontroller is the central processor that interprets data coming in from the sensor and corrects for any error introduced to the system. Electro-mechanical systems require more development and planning but can offer greater control of a system. For example, fail-safe states can be implemented as part of an electro-mechanical system that would keep both operator and patient safe in an event of catastrophic failure of a component of the system or any other external event.

Further research needs to be done into the controllers that are currently in use to determine if they are suitable for our system. This would eliminate the need to develop a controller reducing the overall cost and size of the system.

2.9 Materials and Manufacturing

Common materials used in durable inflatable produces are heat sealable nylon fabrics that are usually backed with other materials depending on the use. Most heat sealable fabrics at the industrial level are sealed together using heated rollers to melt and fuse the fabric. At a scale more comparable to the project at hand, these fabrics can be fused using standard household irons, hair straightening irons, or even with a soldering iron. Fabric strength comes in many forms but the most recognized is by the amount of Denier the fabric has.

Fabrics that we have found suitable for this application include heat sealable nylons mentioned above and heavy-duty vinyl (PVC). Both these materials have industrial applications as the materials that bounce houses and high-end wake boat tubes are made of and each have their own benefits over each other. The nylon used in these applications is normally 420 or 600 denier though thicker material can be used as well. Vinyl, on the other hand, is normally a mix of gauges from 7.5, 12, and 18-ounce thicknesses where more strength is needed. Both fabrics can be made entirely waterproof, but it is dependent on the weave and coatings that the material may need. Vinyl is more durable, increasing the products life, but has a rough surface possibly making it uncomfortable if it was to rub against the person sitting in the chair. This is typically combated by using the vinyl as an internal bladder with an external layer as a barrier between the user and the bladder, which also protects it increasing longevity.

With regards to manufacturing the main difference between the two materials is in how you decide to assemble the device. Vinyl is more reliable when using adhesives for any part of the assembly. Both materials, however, can be heat sealed and stitched together as well if it is required though this could jeopardize its airtight capabilities. For the prototype model, the nylon fabric was chosen because it was more cost effective. It should be noted that after the manufacturing phase, it was realized that the strength of the adhesives on the bare nylon fabric was not suitable for the final product. Further research confirmed that the nylon fabrics can still be used, however, if a polyurethane coating is applied to the outside of the fabric.

3 Objectives

After researching current products and speaking with the sponsor and several other EMS personnel a compiled a list for both wants and needs of the product was created. This list lays out what kind of things are an absolute need for an EMS lift assisting products and, shows what thing customers want most on top of the minimum needs of the product. A more detailed list of wants and needs is attached in Appendix D.

- Needs
  - **Reduced strain** – The device must reduce the strain that is placed on EMS members tasked with lifting a fallen person up.
  - **Lift capacity** – Due to the wide range of individuals’ weights the device must lift up to 700lb
  - **Size** – With space on fire trucks being very limited the device must be compact.
  - **Rugged** – Firefighter equipment often sees harsh working conditions. A product that can withstand these conditions and has a long life is required for use in the field.
  - **Speed** – With emergency services every minute matters.
  - **Required Personal** – EMS teams sent out for lifts are often comprised of only 2 members. The device should not require more than this.

- Wants
  - **Easy to use** – Many of the devices currently on the market require several minutes just to get in place or are complicated to use.
  - **Versatility** – As people can fall anywhere the product needs to be usable on different terrains including carpet, tile, and grass as well as slope surfaces. This also means the product should be self-powered.
  - **Marketability** – Ideally the product should be able to enter the market as a prime competitor for the EMS lift assist devices.
  - **Weight –** With only a few team members using the device, it must be lightweight so that transportation from the truck to the person can be made easy.
  - **Washable –** Often times, equipment used by EMS personnel experience a variety of environments that can cause them to become dirty.
  - **Cheap –** One of the biggest setbacks to existing products on the market is how expensive they are. Making the product cheap will allow for more places to use it and more lives to be saved.
  - **Comfortable –** From the standpoint of the victim, the device would need to be comfortable to sit in.

3.1 Problem Statement

Design, prototype, and manufacture an easy to use the device that safely and quickly lifts elderly and overweight people in an emergency. This device should be easy to manufacture as the sponsor wants to take it to market for sale after completion.

3.2 Specification Table

Table 1 below shows the main specifications of the project. This table lays out the main goals of the project that are measurable and required for the project to be successful. In the table the description of each task is shown along with the goal to meet for said task. Each task has an associated risk factor on how hard will be to achieve the goal. Finally, the compliance column shows the method to make sure each goal is met. This includes Testing, Inspection, and Analysis. A detailed summary of each project specification is shown in Appendix A.

To make sure that the product meets the goals stated in table 1, several testing requirements and plans will need to be put in place. Because the main goal of the project is to assist in the listing of overweight people, the final design and product prototypes will be put through a series of compression and weight lifting test. The produce should be able to lift 700lb with a factor of safety added for safety precaution.

The hardest goals for the project will be the speed and overall weight of the products. These are the most complicated part of the design as they are proportional to each other. As the speed of the product increases, the overall weight will increase too. To make sure the product is staying under the goal weight and at the goal speed, several analysis steps will be made along the way to make sure we are on target. After prototyping the product, physical testing can be don’t to make sure that the product meets the final goal.

Table 2: Basic Project Specifications

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Lifting Capability	700 lb	+	L	T
2	Packed Size	2.5 ft^3	1ft^3	L	A, I
3	Overall Weight	> 20lb	2lb	H	T
4	Time to inflate	2min	+/- 1min	H	T

5	Water Proof	Must be washable		L	T I
6	Easy to Use			M	T
7	Safety/ Stability	Verification*		L	T, A
8	Cost	800$	+/- 200$	L	

*The device must be tested and verified by a professional engineer before being used.

After ensuring that the project meets its most basic requirements, several customer interaction tests will be done with EMS personnel as well as willing volunteers to play the victim in theoretical scenarios. These tests will look at the functionality, ease of transportation, ease of set up and use, and overall comfortableness of the product.

4 Concept Design and Development

After initial brainstorming and ideation of the project, a matrix of all the ideas was put together to start comparing and narrowing down the design. Once the design had been narrowed down to a list of top 4 ideas, the prototyping phase would start. This entailed more, further in-depth research on the materials, strength, manufacturability, size, and functionality of each design.

4.1 Design Matrix

After listing all the initial ideas out, a narrowed down list of final ideas was created using a system of decision matrices. Appendix E – Pugh Matrices shows the initial compiled pugh matrix consisting of all the initial concept ideas. These ideas were compared against the lead competing market product (Manger ELK and Camel). A list of key items from the customers' needs and wants list was used to compare the designs (+1 meaning that is does better than the current market design, 0 meaning it is equivalent, and –1 meaning it does worse than the current market design). After adding up all the scores and taking the top few design ideas, a new matrix consisting of the top ideas along with combinations of products using aspects that were strong in each design idea. The process was done once more until only a grouping of the strongest ideas survived. The next step was to compile all the final designs into a weighted decision matrix. Table 3 shows a fully compiled matrix of final ideas. From this step, the weighted decision matrix was used to declare the top ideas. Using the same customer wants and needs list from the pugh matrix method, assigned weights were attributed to each category depending on the importance of the need. By assigning a rank of how well each design does when compared to the wants and needs list, the score can then be multiplied by the weight and a final score can be summed up for each design idea.

Table 3: Decision Matrix

		Designs								
Engineering Specs	**Weight**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
stable	14	5	10	8	8	8	9	9	9	9
Max Load (lbs)	15	8	8	7	8	7	8	8	8	8
Lift time (minutes)	11	9	8	8	8	7	6	7	6	8
Packed Geometry (Volume)	12	7	9	9	9	7	6	7	7	8
Weight (lbs)	9	6	7	9	9	7	7	7	8	8
ease of waterproof	8	7	9	9	9	8	8	8	9	8
product life	5	7	8	7	8	8	8	8	8	8
manufacturability	4	5	6	6	6	5	7	7	7	6
uses per bottle	7	9	7	10	7	5	6	6	6	7
no patents/unique	6	8	9	10	10	10	7	3	10	9
angular ground surfaces	3	4	6	6	4	4	4	4	6	6
raise to seated	15	10	10	8	6	9	9	9	10	10
raise to standing	15	0	0	0	2	0	9	0	8	7
easy to use	10	5	8	8	8	5	6	8	8	9
minimum effort required	13	5	9	5	6	5	8	8	9	9
FINAL NORMALIZED SCORE		0.76	0.93	0.86	0.86	0.76	0.91	0.82	0.99	1.00
			3		**4**				**2**	**1**

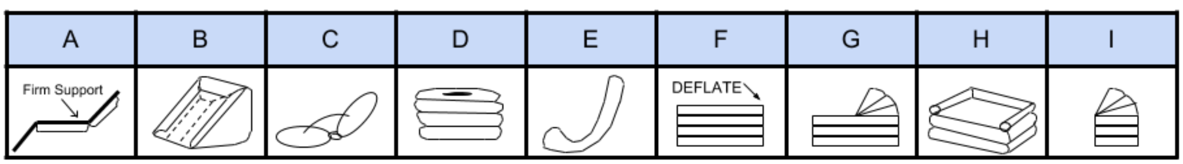


Figure 7: Design Sketches

4.2 Design Modeling

After compiling a list of top ideas, the prototyping phase began. The team first came up with initial CAD drawings of the top design ideas. This was to get a general idea on the shapes and sizes needed by each design and helps to better form ideas about the feasibility and functionality of each design. Figure 8 shows the initial CAD concept model for design B. This model gives insight on the overall feasibility of and challenges to expect about the design.

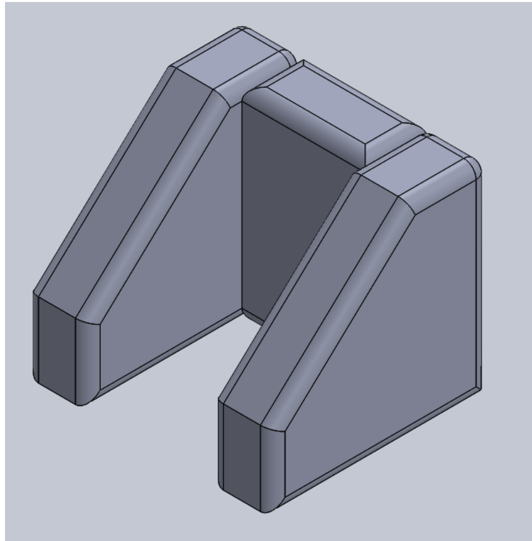


Figure 8: Design B

From this initial CAD model of the design, using this geometry could make the lifting device very stable and strong. The initial concerns with the design, however, would be that it might be more of a challenge to find a good way to attach a person to this inflatable structure. Another question that comes up is about the strength of the walls and how inflatable shapes like this are manufactured so that they can support weight and maintain their shape. All in all, this design does meet a lot of the important items on the wants and needs list and is a valid design option that can give rise to further insights and future design ideations. Another top idea was design D from the matrix. This design is shown in Figure 9: Design D**.**

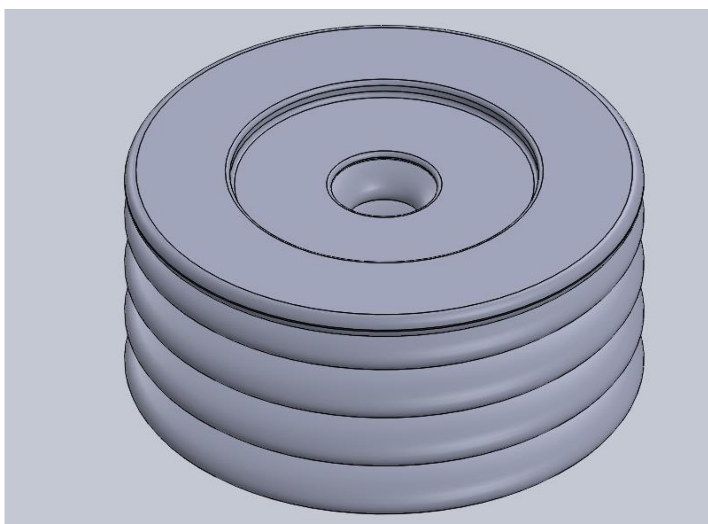


Figure 9: Design D

This model again gives insight to the challenges and strengths of the design. The overall shape makes it easier to manufacture as a donut shape is very common among inflatables. It also might be a stronger shape as it will not have and sharp corner seams. This is one thing that can be tested and investigated further. One concern with the design could be stability, stacking rounded objects could make the structure unstable. Again, this design meets a lot of items on the wants and needs list and deserves further investigation into how feasible the design is as well as brings up good questions to further investigate as the designs start to narrow down to the final design. Another top idea, design H is shown in Figure 10**.**

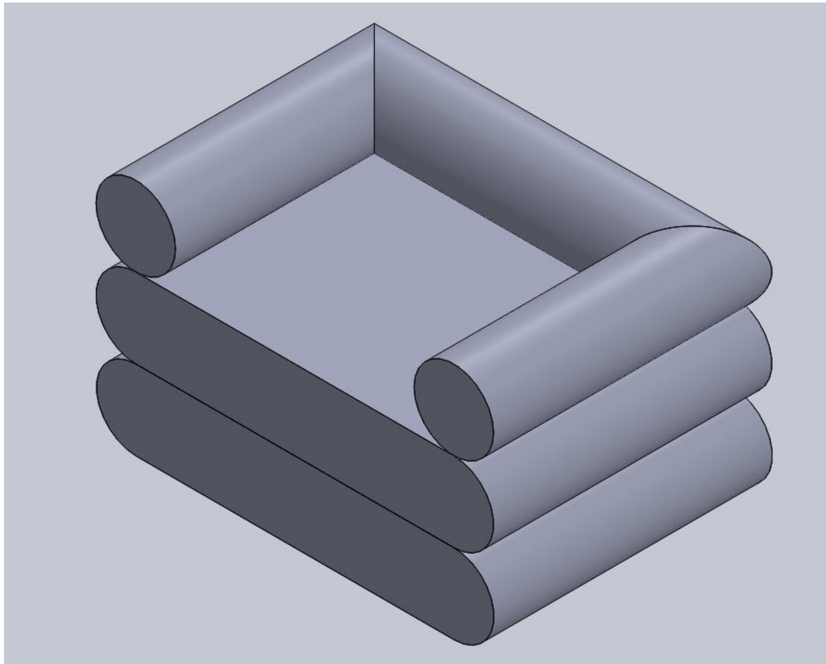


Figure 10: Design H

This design is a top design as it combines some of the functionalities from design D in Figure 9 and design B shown in Figure 8**.** This design is stable and has the added support of the tube shapes running along the back half of the chair. This design seems easy to make and can be very strong and stable. One concern with this design could be the overall size however, it might become very large depending on what geometry is used causing the cost to increase, lift time to decrease, and the number of uses per bottle to go down. Again, the design is one that meets a lot of the customers' wants and needs and is one that will need to be investigated further for more information. The final top design, design I is shown in Figure 11.

This design is yet other that meets a lot of the items on the customer wants and needs list. The overall design seems stable and gets the patents up to standing position without being too large of a structure. Some concerns, however, might be that the person might not be constrained from falling off the device or that when fully extended, the structure may become top heavy and unstable. Again, further research and development of the idea will be needed to make further judgment.

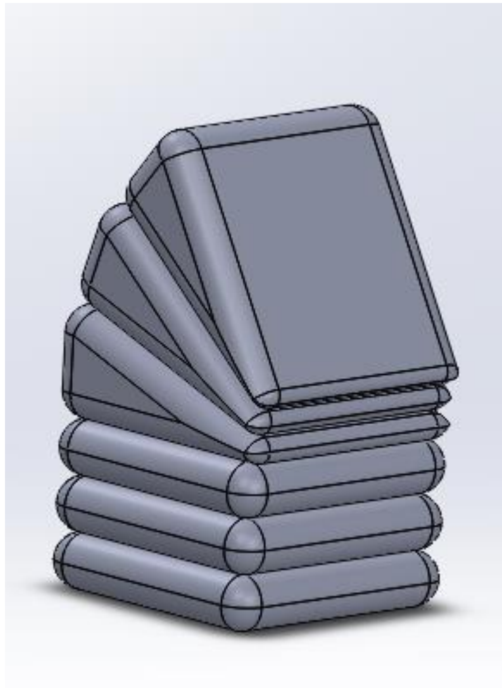


Figure 11: Design I

All the top ideas have their pros and cons. The next step was to do some further in-depth research and prototype some key aspects of the designs to get a better understanding of what the future challenges will be and possibly see if combining ideas from each of these designs can work to create an even better design.

4.3 Prototyping

For prototyping of the design, cheap inflatable objects were purchased so that design ideas could be constructed to test multiple shapes. The prototyping also allows for exploration of the construction of the pre-made inflatables, and to see what design challenges are going to be presented in the future. Below is tabulate pictures and descriptions of the prototyping done for the project.

Table 4: First Inflatable Prototype

	Flotation devices are very similar to design D from Figure 9. This initial prototype concept consisted of two donut-shaped flotation devices to test the complexities and feasibility of the design. The shape itself seems very easy as far as manufacturability and is very stable when stacked together. Overall this design idea is something to explore.

Using an old bike tube valve, a new valve was to be tested in a pre-made inflatable beach ball. The ball was cut open and the valve was installed. After multiple attempts of heating up the material and trying to re-seal the ball, it was realized that one design challenge might be on the material choice. In this prototype, it was discovered that not all plastics melt and the same temperature and even when melted do not form great seals. This means that when searching for fabrics in the future, we will need to keep in mind the manufacturing process as well and think about how we will be able to seal and fuse any materials.

After having realized that this material was not fit for an at home heat sealing, the team decided to go with epoxy. To add to the complexity of the prototype the team decided to test the ability to attach both tubes together to form one pressure vessel. To do this, holes were cut on both tubes and the epoxy was applied around the holes.

The holes were then fuser together to form one pressure vessel design. Once the epoxy was dry, the seals were tested for leaks b inflating the tubes and listening/observing any air leaks.

After the team had fused together both inflatable tubes and made sure everything was sealed, the next step was to add a valve to the system. The change that was realized here was the inner black part of the valve must be on the inside of the pressure vessel. This would have been easier if we had attached the valve before sealing the whole thing. This then brings up another good point when thinking about the design. The order of the steps in the assembly process matters especially with epoxy or heat sealable materials.

The final prototype was inflated through the newly affixed valve and the innertubes both successfully inflated as one chamber.

After being able to explore some of the key design aspects, a lot could be learned that can and should be applied to the final design. When considering a design, it is very important to think about the overall structure of the inflatable. This is because the structure and manufacturing are not trivial. Seams must be applied in the right order and right place so that the shape can be maintained and so that the proper fitting can be put into place. Once the fabric is fused, it is very hard to get apart and some fabrics may also not be able to be re-fused. Another thing to investigate is the types of materials available and what the properties are. Some materials are heat sealable while others must use epoxy. Some fabrics may even be able to do both. Having this knowledge can help to better design and plan out the final product. Understanding this then gives rise to the need for further researching of material types and material properties.

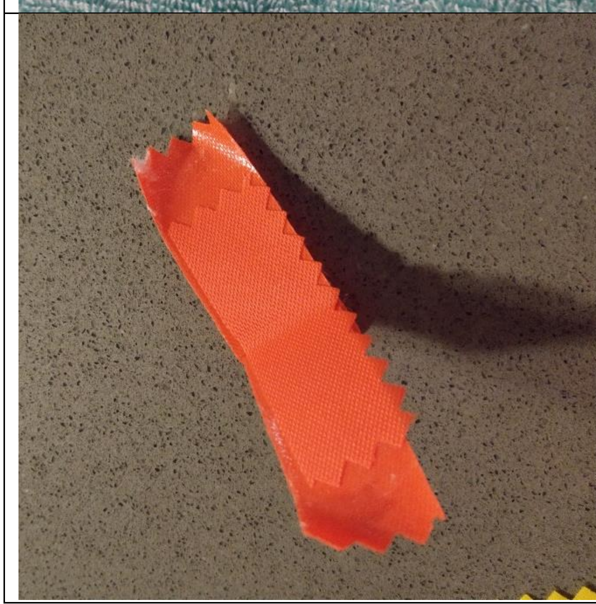
4.4 Further Research

As the ideation begins to become more refined, further development and understanding of the sizes, capacity, and material properties need to be researched. This section of the report details the steps taken to test the fabric samples and manufacturing process.

4.4.1 Material Testing

After looking around and performing initial material research, a sample book of materials was acquired. To test these materials, each sample was cut into strips and then fused together into several different seam configurations. For the testing of sample fabrics, heat sealable fabric samples from Seattle Fabric Company [18] were tested.

Table 5: Initial Fabric Testing

	Each sample of fabric was cut into several smaller strips to be fused together. The fabrics for this test were heat sealable fabrics that were meant to be fused using a standard household iron.
	Each of the strips were fused together into two or three different seam configurations shown in Figure 12**.** The reason for the multiple seam configurations was to get a better idea of the strong and weak points of using heat sealable fabrics. This gives rise to a better understanding of how the seams should be designed and constructed to ensure maximum safety while keeping the martial costs and weight to a minimum.

Each seam configuration was clamped down using an aluminum clamping fixture. A similar fixture was used on the other side of the fabric seam and was then attached to a force gauge that read the maximum force value when the sample broke. Force values for each seam type are laid out below in Figure 12**.**

Figure 12 shows a picture of each seam configuration used and tested. Once the seams had been made, each sample was clamped down and pulled, using a force gauge to measure the pulling force, until the same broke Table 6 shows the tabulated results of the relative strength of each seam and material type. It should be noted that some of the samples failed due to the fabric ripping at the edges of the calming device. This means that the fabric and the seam may have been able to take more force than tabulated. It should also be noted however that the estimated material strength for the seams is comparable to the documented material and seam properties available online. It should be noted that some of the samples failed as a result of the fabric ripping at the edges of the clamping device. This means that the fabric and the seam may have been able to take more force than tabulated, however, the fabric strengths that were still comparable to the published values by the manufacturer, therefore, giving us a good baseline for the fabric strength.

Table 6: Testing

Material	Seam A Force [lb]	Seam A Area [in^2]	PSI - A	Seam B Force [lb]	Seam B Area [in^2]	PSI - B	Seam C Force [lb]	Seam C Area [in^2]	PSI - C
Black Pack Cloth	20.09	0.5	40.18	42.60	0.5	85.20		0.5	
Diamond Rip Stop	40.03	0.5	80.06	68.30	0.5	136.60		0.5	
Red Oxford	39.00	0.5	78.00	66.80	0.5	133.60		0.5	
Black Rip Stop	35.20	0.5	70.40	58.03	0.5	116.06		0.5	
Taffeta	28.60	0.5	57.20	58.20	0.5	116.40		0.5	
Yellow Oxford	38.03	0.5	76.06		0.5		12.04	0.5	24.08
Royal Blue Oxford	39.05	0.5	78.10		0.5		16.57	0.5	33.14
Blaze Orange Oxford	27.65	0.5	55.30	60.20	0.5	120.40		0.5	
White Oxford	31.10	0.5	62.20	62.10	0.5	124.20		0.5	
Yellow Pack Cloth	22.30	0.5	44.60		0.5			0.5	
Nickel Grey Oxford	24.60	0.5	49.20	48.60	0.5	97.20		0.5	
Red Pack Cloth	36.09	0.5	72.18		0.5		8.7	0.5	17.4
Royal Pack Cloth	38.67	0.5	77.34	65.30	0.5	130.60	9.3	0.5	18.6

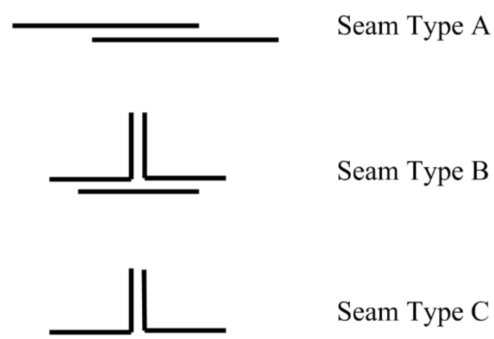


Figure 12: Seam Configuration

4.4.2 Air Tank Specifications

After meeting with the firefighters in San Luis Obispo's Fire Station #2 we found that we would be able to fill our chair utilizing the air tanks they already have on board the fire engines. These tanks vary in size and pressure but are used for supplying air during emergencies and for air-bags used to lift cars up from a victim. We found that the most common tank is the 4500 PSI – 45-minute tank. This tank holds 0.2156 ft3 at 4500 PSI or 66 ft3 of air at atmospheric pressure. This information allows us to determine what the maximum internal volume/pressure of our chair can be and how many fills we could theoretically get out of one tank. Other common tank sizes include a 45 ft3and 88 ft3 tanks.

4.4.3 Inflatable tests

Using the sample material provided by Lamcotec we were able to create a 6x3 inch pocket with a half inch seal around the outside. We then tested this pocket by stacking weights on it to see at what pressure the seams would fail. The maximum weight that we were able to safely place on the pocket was 750 pounds.

Figure 13: Weight Testing the Inflatable Pocket

4.5 Preliminary Calculations

After exploring the material properties preliminary calculations were done to put more context and feasibility to each design. Two of the biggest design considerations for this project are device lift and inflation safety. To ensure that the design is feasible in these areas, calculations will be made from the initial CAD model to approximate the surface area for the lifting action and the total volume of the inflatable. Additionally, calculations will be done to find the required pressures and volumes will be compared in order to compare lift times. Note, a smaller volume inflatable requires less lift time. Another big consideration for the project is the method of inflating the device. As discussed earlier in section 3.3, and again in more detail in 7.4, firefighters and EMS personnel have access to pre-pressurized air tanks that are always on-board the truck. One design option is to utilize the pressurized tanks and controllers that are already in use by emergency service teams. In the initial calculations, an estimate using the volume of each tank will be done to approximate the number of inflates achieved using one tank.

The first thing to consider in the initial calculations is that the internal geometry of the inflatables consists of support and columns that run through the middle of the device. This means that the net volume of the CAD model will not be the actual volume of the product. To account for this, we will be taking several percentages of the net volume to consider various internal structure designs.

$$V_{net} * \left(\frac{\%Fill}{100}\right) = V_{Chamber} \tag{1}$$

It should be noted that the decreased volume due to internal support will also cause a decrease in the surface area for the lifting. This surface area is then directly related to the pressure needed to lift the person.

$$A_{surf} * \left(\frac{\%Fill}{100}\right) = A_{lift} \tag{2}$$

In order to find the pressure needed to lift the 700lbs needed, we need to use the surface area equation.

$$P_{abs} = \left(\frac{700lb}{A_{lift}}\right) + 14.7psi \tag{3}$$

In order to check the number of lifts available per bottle, ideal gas law equations will be used in conjunction with the volume of the gas cylinders.

$$\frac{P_1V_1}{R_1T_1} = \frac{P_2V_2}{R_2T_2} \tag{4.1}$$

$$P_1V_1 = P_2V_2 \tag{4.2}$$

$$V_2 = \frac{P_1V_1}{P_2} \tag{4.3}$$

$$\#_{uses} = \frac{V_{tank}}{V_{Chamber}}\left({}^{P_1}/_{P_2}\right) \tag{4.4}$$

Where: P_1 = Atmospheric Pressure

Table 7 below shows the preliminary calculations for the inflatable designs using equations 1-4. It should be noted that as the volume of the chamber decreases the pressure required to lift increases and the number of lifts available increases. This information is useful to us because it means that to maximize the potential of the design, we must safely decrease the chamber volume while maintaining a safe amount of support and stability. Another thing to pay attention to is that as the chamber volume decreases, the lift pressure required increases which puts more stress on the seams of the material. This will need to be considered in the design moving forward as it will greatly affect the safety and lifetime of the lifting device.

Table 7: Preliminary Design Calculations

Design	Volume [in^3]	Fill [%]	Surface Area [in^2]	Pressure Required [psi]	Number of uses [#]
D	25581	100	905	15.47	4.24
	25581	80	724	15.67	5.23
	25581	60	543	15.99	6.83
	25581	40	362	16.63	9.85
	25581	20	181	18.57	17.65
	25581	10	90.5	22.43	29.21
I	101561	100	895.00	15.48	1.07
	101561	80	716.00	15.68	1.32
	101561	60	537.00	16.00	1.72
	101561	40	358.00	16.66	2.48
	101561	20	179.00	18.61	4.43
	101561	10	89.50	22.52	7.33
H	100397	100	1843.20	15.08	1.11
	100397	80	1474.56	15.17	1.38
	100397	60	1105.92	15.33	1.82
	100397	40	737.28	15.65	2.67
	100397	20	368.64	16.60	5.03
	100397	10	184.32	18.50	9.03
B	24509	100	120	20.53	3.33
	24509	80	96	21.99	3.89
	24509	60	72	24.42	4.67
	24509	40	48	29.28	5.84
	24509	20	24	43.87	7.80
	24509	10	12	73.03	9.37

4.6 Pneumatic Structures

When constructing load bearing pneumatic structures made of flexible membranes, the stressing medium becomes a supporting medium and therefore a structural element. For the purpose of modeling closed cavity chambers Shigley, of *Mechanical Engineering Design*, suggest using the thin vessel model in which thin-walled pneumatic structures of thickness less than one-tenth of the radius or less can be used to approximate flexible structural membrane loads. Pneumatic structures observed in the natural world inherently default to occupying the largest possible volume while having the smallest possible surface area, resulting in shapes that are spherical in nature. To use the model, any pneumatic design will take into consideration the spherical nature of ideal pneumatic structures.

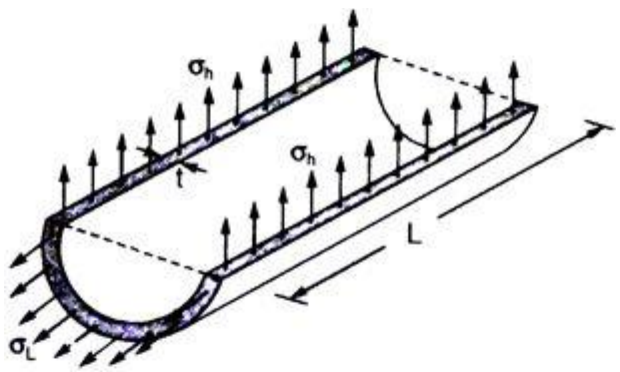


Figure 14: Membrane Stress

Using the thin-walled vessel model, all loads are carried through flexible membranes as tangential and radial loads. When considering cylindrical members, adding two spherical segments to terminate the ends will allow loads to pass tangentially over the surface of the spherical segments. The radial stress traces the length of the cylindrical member and is denoted by σ_l. The tangential stress, or hoop stress, is the stress tangential to the radial position of the cylindrical vessels thickness σ_t. The stress behaviors are as follows.

$$\sigma_{h(max)} = \frac{p(d+t)}{2t} \tag{5}$$

$$\sigma_l = \frac{p * d}{4t} \tag{6}$$

Where

σ_h = tangential stress (hoop stress)

σ_l = longitudinal stress

p = pressure inside vessel

d = inside diameter of cylindrical vessel

t = wall thickness

5 Final Design

After testing and iteration, our final design became a compilation of the results. This final design was made based on the premise that it would be a precursor to the prototype that could later be redesigned for large scale manufacturing.

5.1 Description & Layout

The overall design consists of five inflatable layers, the bottom four are identical tubes with diameters of seven inches that form four stacked rectangles around the edge of the lifting surface. The top layer is an air cushion that will be the lifting surface and covers the entire lifting area. Valves are attached on the outside seam of each of the inflatable's layers to allow for individual control of each layer. For this prototype, each layer has its’ own valve to be individually filled. There are handles located on the third layer from the bottom, one on each side of the chair to help maneuver it. These handles are made of soft nylon fabric to avoid hard structures that would make it more difficult to place under a patient and to help with uninflated storage size. Handles are color coded to assist in identifying the orientation quickly and easily.

Figure 15: Air Chair Rendering

5.2 Detailed Design Description

The main body of the inflatable consists of 4 equal size layers of 400 Denier heat sealable nylon fabric. Appendix I, Drawing 1 shows a detailed layout of the layers. Each layer is approximately 37” x 55” when fully inflated. These layers consist of two pieces of fabric cut to size as per Drawing 21. Each layer will then be heat sealed with a 1” seam. The Valve will be installed onto each section on the seam towards the corner of the inflatable. All 4 identical layers will then be adhered together using clear RTV silicone adhesive along the 2 inches wide section marked on Drawing 1. The top of the inflatable will consist of a full inflatable layer that is reinforced with interior parallel seams for added rigidity and to maintain a flat profile for the lifting surface. Drawing 2, or the top inflated layer shows that the layer will fully cover the top section of the device. The inflated layer has 7” diameter borders, 5” diameter interior rounds and 2” flat seams separating the interior rounds. This layer will also be made from the 400-denier heat sealable nylon fabric and will consist of a single valve for inflation and deflation. The overall assembly is shown in Drawing 3. This drawing shows each layer put together with the approximate location of the handles. The drawing does not include details for the manifold block and hoses as this design is for a functional prototype and not to full marketable design. The color of the fabric on all sections is a blue color to evoke a calming feeling to the patient while not being too light of a color that will expose any dirt or other discoloration. The material is a durable heat sealable fabric that can be inflated and used multiple times without any worry of fatigue. This fabric is also lightweight, low cost, and can be washed using any household cleaning detergents without degrading the quality of the fabric. The overall shape is designed to minimize the volume of the chamber thus minimizing the time required to fill the chamber while maintaining good structural stability.

5.3 Analysis Description & Results

With the new design in mind, the surface area and volume can be calculated and tabulated in a similar manner to section 4.5. Table 8 shows the surface area, volume, and lifting area of the new design. The lifting area was taken to be the 2" thick adhesive seam around the center of the border of the inflatable. This 2" width band is then taken as the worst-case loading on the inflatable as any compression would increase that thickness. Using equation 3 from section 4.5, the required lifting pressure for a 700lb load with a lifting area of 300 square inches is 2.33 psig which is roughly 17 psia. The lifting time required is an estimated value based on the about of time it takes to fill the airbag system in Figure 6. Using equations 4.1-4.4 we were able to take the volume of the chamber and the lifting pressure required to approximate the number of uses per air bottle with the assumption that the full 700 lb load is lifted each time.

Table 8: Final Deign Calculations

Volume [in^3]	Surface Area [in^2]	MAX Lifting Pressure [psi]	Uses Per Bottle [#]	Lift Time [sec]
25653.0	17802.7	17.0	3.2	48.0

The calculated lifting pressure can then be used to verify the strength and pressure retention by the fabric. By making the 3" x 6" pockets shown in Figure 16 the maximum pressure can be read to determine when the pocket bursts. These tests also help to verify that the added sewn seam along the edge of the inflatable creates a leak before burst condition.

Figure 16: Sample Pockets for Proof Loading Verification

The tests concluded the average rupture pressure of the pockets occurs at about 35psia for the 200D fabric and about 60psia for the 400D fabric which, when compared to the rated adhesion pressure from the manufacturer is within 8%. This proves that the 400D fabric will be enough to hold 17psia repeatedly and that the method for manufacturing is viable.

Several adhesives were tested for the structural prototype detailed in this paper. With the nylon fabric used for the prototyping, the strongest adhesive found was an RTV silicone adhesive which provided the layers with a maximum 'pull-apart' force of 40 lb. This proved to be suitable for a structural prototype however final designs will require further testing. For stronger epoxy use, the fabric supply company offers a 'kiss-coating' (a coating of polyurethane) to the outside of the nylon fabric. This kiss coating would allow for a much stronger bond when using urethane-based adhesives.

For calculating the lifting time of the device, several assumptions were made. The flow into the chair is assumed to be incompressible which is a valid assumption because the limiting flow rate on the pressure regulator slows the flow down enough that compressibility effects are negligible. Next, because the tube is thick, and the flow rate is low, there is negligible temperature variation to the flow so the isothermal flow assumption can be made. Using these assumptions analysis is done to calculate the total lifting time which comes in 3 stages. 1st the initial volume of the inflatable that is not being taken up by the patient which is a constant pressure process. Next, the stage where the patent is starting to be lifted until they are just hovering off the ground, which is a constant volume process, Finally the lifting of the patent to the final positions which again is a constant pressure process. For an upstream pressure of 15 psi and a tube diameter of 0.5", the total lifting time for a 700 lb load is 48 seconds.

Based on the max rated operating range of pressures of the Halkey-Roberts (HR) valve, and its' adapter, our device's valve is able to achieve our desired lifting pressure safety with a factor of safety of about 5. The HR valve's rated maximum operating pressure has been rated from 15 –20 psi by the manufacturer. The adapter's rated maximum operating pressure is 20 psi. Since the calculated operating pressure inside the inflatable during the lift is about 2.5 psi there is no concern for a failure of the valve due to pressure.

5.4 Cost Analysis (a detailed budget and description of assumptions)

The total cost of our device will be determined through the sum of the component cost. Since this is being manufactured by the team and is a prototype the cost of manufacturing and ordering in bulk was considered irrelevant at this stage of the process. It can be assumed that if ordered in bulk, the overall cost would be lower than our cost presented. Also, many of the components that are currently being used will be replaced for a full manufacturing run. Below is a table comprised of all the necessary components along with their total cost.

Table 9: Cost Breakdown per Chair

ITEM	DESCRIPTION	VENDOR	QTY	COST
Heat Sealable Nylon	400D Ripstop (5ft by X yards)	Lamcotec	13	$302.50
Valves/Wrench	HR Valves	NRS	5	$97.75
Handles	Nylon Webbing	Beverly's	1	$3.00
Sealant	Clear RTV Silicone Adhesive	Harbor Freight	3	$9.67
Adaptor	Schrader to HR valve	Amazon	1	$19.95
Neoprene	Boot for valve to create seal	Amazon	1	$10.19
			Total	**$443.06**

With a total cost including tax and shipping per prototype of $443.06, we can create several prototypes with our current budget.

5.5 Explanation of Material, Geometry, & Component Choices

When picking the material for the air chair lift device we need an airtight, lightweight, durable, and reliable fabric. The Lamcotec 400D heat sealable nylon backcloth is exactly that. The fabric is very durable and can be used indoors as well as out. The heat-sealability makes for easy manufacturing using a standard household hair straightening iron. The fabric comes in a variety of colors however, for this model blue was chosen to invoke a calming feeling to the patent who may be in a high-stress situation. The color also allows for one to see when it needs to be cleaned and will mask any long term stains or dirt. The material can be washed by all standard household cleaners without degrading the material which is a bonus as patients occasionally may have already soiled themselves prior to the EMS personnel arrival. This fabric is also water resistant and can have added protective sprays and coatings such as fire retardant as necessary.

The shape of the main chamber of the lifting device was determined based on the lifting area and pressure required to lift a person that weighs up to 700 lbs. The design allows the required lifting pressure to be well below that of the max pressure limit of the seams by a factor of about 3.5. The top inflatable layer will be sealed into several divided sections in order to keep the full inflation from ballooning outward and to make it less prone to shear.

For a final product version of this inflatable lifting device, the entire assembly would only have 1 seam along the outside of the chamber. This would limit the number of failure points as well as make any leaks or repairs much more accessible. For this design, however, a two-seam configuration will be used to make manufacturing and assembly much easier. Each layer will then be adhered together in the middle of the sections with a 2" wide layer of clear RTV silicone adhesive. This thickness provides two benefits. It creates a high amount of resistance to shear in the transverse direction that is enough to add the capability of moving and lifting the device with no harm of breaking it as well as adds structural support. The second benefit of this adhered section is that it ensures that there will be a minimum lifting area of 300 square inches on each layer of the device which ensures that the pressure required to lift 700 lb will not exceed 2.33 psig.

The handle material was chosen with the consideration that when the device is deflated you do not want added protrusions or hard surfaces when rolling the patient onto the inflatable. This means that the handles need to be soft, flexible, and durable. Another consideration was the installation of the handle, a sewn handle onto the inflatable chamber would need to be reinforced from the back to seal any holes made from sewing. This also adds extra manufacturing steps and makes any handle repair much harder. The handles chosen are designed to be epoxied directly onto the outside of the device making assembly and repair much easier and more reliable. Each set of handles is color-coded to easily determine the orientation of the device when it is deflated.

When determining an appropriate air valve for the inflatable the use of a decision matrix was employed. The valves fitted to the final design of the prototype were all sourced on the premise that the purpose of the inflatable was to be used as a prototype that would later be improved upon as later iterations may use different valves if large scale manufacturing is required. The valves considered for the prototype were the Schrader, Boston, Military, and Halkey-Roberts. Based on a weighted decision matrix, the Halkey-Roberts (HR) valve proved to be the best option for our prototype; scoring the highest in the installation, replaceability, life of valve, and profile categories. The HR valve requires minimal use of a binding agent that makes the installation of this type of valve relatively easier than the other valves considered. The valve consists of two parts, a plastic locking nut that is positioned inside a fabric chamber and the threaded valve that screws into the nut. The lock nut and threaded valve are aligned through a pre-cut hole in the fabric and neoprene backing and are threaded together. The valve creates an airtight seal as the fabric is clamped between the two valve components. The installation nature of this valve is such that the gripping strength of the two circular plates is large enough to hold the pressure inside the inflatable without the use of any adhesive/epoxy though adhesives may be used for additional leak protection. To ensure the seal is airtight we added an adhesive around the outside of the circular plates. The ease of installation of this valve also contributes to their replaceability if any valve was to fail or wear out. Its robust design gives it adequate life for repeated use in emergency situations. Made up of only a body, stem, stainless steel spring, nut and cap, the valve seals mechanically shut with the aid of its spring-loaded push-pin style valve mechanism. When the push-pin is up, the valve is closed, only allowing air to enter in one direction, ideal for inflation. When the push-pin is down and locked in, the valve is open, allowing air to flow in either direction which allows for easy deflation. An additional feature to the HR valve, that set it apart from the rest, was its' recessed surface profile. The entire valve is below the surface of the inflatable shielding it from any potential damage when in operation. Location of the valves was determined based on the geometry of the layers and access to the valves. The outer perimeter on the seam was chosen as it allows for easy access and avoids obstructions from other layers that may present themselves if oriented slightly higher or lower. To inflate the final prototype, an adaptor is required that converts the propriety HR valve inlet to the more common Schrader valve inlet. This allows the air chair to be inflated with more widely available bike pumps or compressors.

5.6 Flowcharts, Schematics, Pseudo-Code, Wiring Diagrams

Proper inflation procedure is necessary to ensure the safety of the person in need of lifting as well as those involved in the processes of aiding the fallen person. The following figure depicts the proper procedure for use of the air chair prototype design in assisting a fallen person back into a standing position.

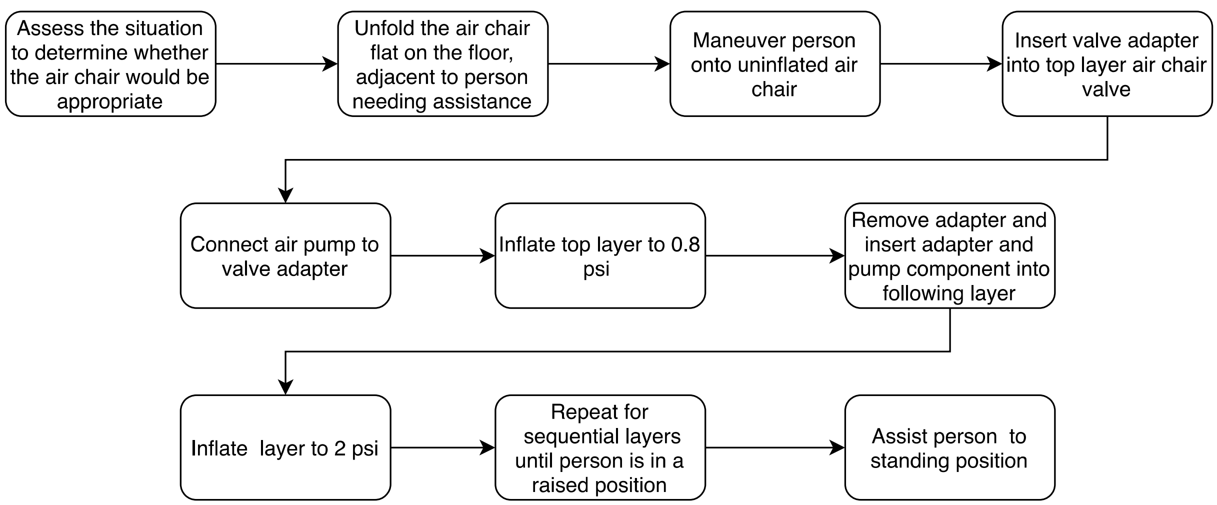


Figure 17: Lifting Procedure Flowchart

5.7 Safety, Maintenance, & Repair Considerations

For general safety, maintenance, & repair issues detailed out in this section of the report please refer to Appendix I for detailed drawing and part locations and Appendix J for the detailed operational manual.

- Checking for Leaky Valves

For safe repair of a non-functional valve, the optimal protocol would be to replace the entire valve, as a leaky valve is an indication of wear that could cause potential failure. To prevent failure during operation, test the seal for leaks with a soap wash. Inflate the device until is 75% inflated and spray the seal around the valve. If the seal exhibits any bubbles or there is an audible hiss coming from the site, there is a leak in the valve and a replacement is needed.

- Replacing an Entire Valve

If a complete replacement of a valve is needed, the following are the steps to take to safely remove and replace a valve. First, loosen the top of the valve from its internal counterpart by inserting the appropriate HR valve wrench into the square keyholes. Turn the wrench counterclockwise to loosen the valve until both parts of the valve are free. Remove the top of the valve and retrieve the bottom of the valve from the inside of the inflatable so it doesn't get trapped inside once the new valve is installed. Inspect the clamping site of the valve and make sure no debris was trapped in that site as that may be the cause of potential leaks. Once you have exposed the clamping site, clean both the inside and the outside of the site as well as the clamping surfaces of the new valve. Dry off all surfaces and install the new valve by first placing replacing the bottom part of the assembly into the inflatable through the opened site. Center both parts such that there is no exposed hole and tighten down the valve until it cannot be further tightened by hand. Continue tightening the valve using the appropriate HR valve wrench until the valve is appropriately installed. Lastly, fill the inflatable to about 75% of its maximum and check the valve and the surrounding clamping area for leaks. Repeat the process if needed on any valves that display signs of failure or leaks.

- Patching the Fabric

If any surface of the fabric, other than the seams, displays any form of a leak or puncture an appropriate temporary solution would be to install a patch. A patch material should be of the same or similar denier. The application method used will largely the same through all cases, however, the preparation will be chosen on a case per case basis. The two preparation methods are categorized as chemical or mechanical. The chemical preparation method requires specific treatments and precautions based on the manufacturer's specifications. The mechanical preparation method requires an abrasive material that will prepare the fabric for a better seal. Patches for inflatable devices depend on the manufacturer and should be reviewed to make sure they are suitable for the device fabric (urethane coated nylon). Patching the device should follow the specifications and application process detailed out by the patch manufacturer.

Appendix G shows an updated Failure Modes and Effects Analysis (FMEA) for the air chair system for any other possible failures, their severity, and the future testing and verification plans.

6 Manufacturing Plan

The air chair product is unique and there are few ways to manufacture inflatable devices. The fabric that we have chosen is most commonly adhered with a flame heated roller press or by using RF welding. Such methods should be used for the final design and marketable product. For the prototyping design of the air chair product, all fabric and components are assembled and tested to verify the design and manufacturing steps. This section lays out the detailed plan for procurements, assembly, and verification.

6.1 Procurement

All the air chair parts have been ordered online or on the phone. Below, Table 10 shows a detailed list that states what components have been purchased for our project along with their costs and delivery time.

Table 10: Procurement and Cost Breakdown

ITEM	DESCRIPTION	VENDOR	QTY	COST	LEAD TIME
Heat Sealable Nylon*	400D Nylon @ 5 ft by X yards	Lamcotec	15	$70.00	4-8 Days
Valves/Wrench	Halkey-Roberts Short Valve	NRS	5	$97.75	4-8 Days
Sealant	Clear RTV Silicone Adhesive	Harbor Freight	4	$12.67	Day of
Neoprene	Boot for valve to create seal	Amazon	1	$10.19	2 Days
Adaptor**	Schrader to HR valve	Amazon	1	$19.95	2 Days
Handle	Nylon Webbing	Beverly's	1	$3.15	Day of

Hobby Flat Iron	Small 2" wide iron	Amazon	1	$22.99	2 Days
Cardboard	60"*48" cardboard for template	Cal Poly Student Store	1	$10.00	Day of
Masking tape	1" Wide blue masking tape	Cal Poly Student Store	1	$10.00	Day of
Rulers	Right angle and 48" rules	Home Depot	1	$15.00	Day of
			Total	**$271.7**	

* The nylon used for this prototype did not have any protective or adhesive coating. If any kind of coating is needed, the cost and lead times will vary per the manufacturer.

** For the final product, a valve adaptor for the firefighter air tanks needs to be purchased.

6.2 Detailed Plan for Procuring All Materials, Components

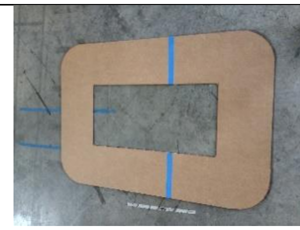
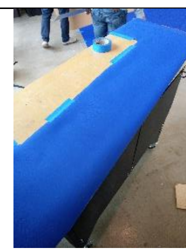
All the materials and components for the design of the air chair device use COTS (Commercial Off the Shelf) parts. This made procurement of any material needed to make the air chair device relatively cost effective and easy. It should be noted that the product made is a proof of concept model and the final design product can be upgraded to have specialized coatings on the fabric of the inflatable to help with adhesion during assembly or that can make the device more heat or puncture resistant. These specialized coating can add slightly more cost and lead times to the product procurement and should be discussed with the vendor prior to the purchasing of the material. For this prototype design, the valves used were the Halkey-Roberts boat valves with a bike valve adaptor. The final design will require finding a valve and manifold system that can be used to integrate the inflatable with the SCBA tanks. This could add additional cost and time to the procurement of the parts.

6.3 Manufacturing

Manufacturing and verification of the final prototype design for the air chair device will use the following manufacturing steps. Table 11 details the steps necessary in order to get ready for the assembly stages of the device. It should be noted that the process used for this project was for an adhesive layer attachment approach. It has been realized after testing this assembly process that other assembly methods exist and should be tested for the final product design. The challenges and recommendations for each assembly methods are further discussed in Table 12 and Section 8. The manufacturing process used for this prototype model follows the steps detailed in Table 11.

Table 11: Individual Layer Manufacturing Steps

1.	Verify that you have the following materials and tools before beginning this stage of the assembly process: • Box cutter • Cardboard (5x4 ft) • Long ruler (48 in) • Square ruler • Fabric (60" x 15 yds) • Neoprene (2" x 2") X 5 • Halkey-Roberts valves (5) • Hobby flat iron • Hair straightening iron • Masking Tape	

2.	Using the long ruler, square ruler, and box cutter, cut the cardboard pattern to the dimensions specified in Appendix I, drawing 21. This cardboard will be used as a template to cut out the fabric for the inflatable device so make sure the edges are as straight as possible.	
3.	Roll out the fabric onto a large, flat, clean surface.	
4.	Using the cardboard template, cut out 8 parts from the fabric. Additionally, cut two layers as per the dimensions in Drawing 22 that will later become the top layers. To ensure layers are perfect use a right angle and a straight edge to first scribe the cut lines then measure to ensure that they are correct prior to cutting.	
5.	For this version of the device we decided to test the feasibility of using epoxy to hold the layers together. If you are using epoxy it should be noted that the bare nylon fabric will not be enough to bond with the adhesives and that a polyurethane coating ('kiss-coating') will need to be applied by the Lamcotec fabric company.	
6.	Align the long edges of the cut fabric with the heat-sealable sides facing each other. Use masking tape or clamps to hold the fabric into place and then use the straightening iron to seal a 1" thick seam along **one** of the long edges of the fabric. NOTE: Feed rates will vary depending on the temperature and power of the iron. Use test samples to determine an appropriate feed rate that will allow the fabric to melt and seal together (at 410 F and 120 W we used a federate of 2.5 in/min)	
7.	After sealing one of the long edges of the layers open the fabric to expose the inside (heat sealable) side of the seam.	
8.	Using scrap fabric left from cutting out the fabric to act as a backing on the back side of the seam. This is where the valves will be installed into each layer. Each valve is aligned with the inner wall of the inflatable device.	
9.	Fold the fabric back so that the heat-sealable sides are facing each other (now with the patch folded in between). Use a thin piece of cardboard to push the patch as tight against the inside of the seal as possible. While holding the patch in place, use the flat iron to seal the patch to the fabric	

	NOTE: Be careful to only apply heat to the area with the patch so that you don't fuse the inflatable together	
10.	After verifying that the backing is sealed, install the valve directly into the seam with neoprene backing as per the manufacturer recommendations using a neoprene backing to help provide a seal on the valve.	
11.	Use the straightening iron to create a 1" seal along the rest of the fabric. Be careful to keep the edges alighted well to avoid any gathering and overlap of the fabric edges.	
12.	Use Silicon sealant around the outside of the valve to create an additional air-tight seal around the valve.	
13.	Inflate each layer to ensure they are fully sealed and working properly. Repeat steps 5-12 until you have 4 individual layers.	
14.	After making the main layers of the inflatable it is time for the top. Take both top layers and align them with the heat-sealing side facing each other. Mark off 2" wide bands that are spaced 5" apart as shown in Drawing 22.	
15.	Use the hobby flat iron to seal the bands together. You should heat the fabric on both sides by flipping the layer over. This will ensure that you have a good seal.	
16.	Install the valve with a neoprene backing in the location shown in Drawing 22 as per the manufacturer specifications.	
17.	Once the valve is installed, use the hair straightening iron to create a 1" seal around the rest of the inflatable top layer and fill to test for any leaks.	

After creating each individual layer of the inflatable device, the next step is to attach them all together and apply the final accessories. For this prototype model, an adhesive assembly approach was used as shown in Table 12. It should be noted however that it has been realized that without a proper coating on the fabric, adhesives are not always reliable and can cause issues in the assembly process. Additional assembly processes should be tested and are detailed below in Table 13 and further discussed in section 8.

Table 12: Bottom Layers Assembly Instructions

STEP	DESCRIPTION	
1.	Verify that you have the following materials and tools before beginning this stage of the assembly process: • Fully assembled layers • Clear RTV Silicon Epoxy • Extra 400D Nylon fabric for handles • Handle fabric (Webbing) • Masking Tape	
2.	Take each layer (main body and top) and mark a 2" wide, centered band. This will be where the layers will be glues together	
3.	Apply the epoxy to 1 layer at a time and be sure to follow the epoxy instructions and safety warnings.	
4.	Allow proper time for the epoxy to dry on each layer. Then test for strength and visually inspect to make sure the layers have been properly adhered together.	
5.	Inflate the entire device to test for any imperfections and make sure the assembly is secure.	
6.	For the handles, cut 8 pieces of fabric per Drawing 31. Additionally, cut 4 lengths of 1.5" wide webbing to 10". This will be the handle material.	
7.	Per Drawing 21, cut 2 slits 1" from the ends of 4 of the coupons. This is where the handle fabric will go.	
8.	Insert one end of the handle material through the slit with the non-heat-sealable side facing you. Sew in place.	

9.	Insert the other end of the handle material into the other slit and sew into place	
10.	Repeat steps 7-8 until you have 4 handles	
11.	Use the hair straightening iron to seal the other 4 unused coupons to the back side of the handles.	
12.	Epoxy the handle to the sides of the layers specified in Drawing 3	

The adhesive attachment process is desirable for manufacturing because it is more cost effective and much easier to manufacture. Additionally, by creating each layer individually this manufacturing process allows for constant leak testing and makes repairing the inflatable much easier. For the best results of the adhesive assembly method, the nylon fabric will need a polyurethane coating (supplied by Lamcotec fabrics) or you will need to use a vinyl fabric. If future testing proves that the adhesive methods are not suitable for a final product design, additional steps can be taken to heat seal or sew the fabric layers together. Although this manufacturing process has not been fully tested the process follows the steps shown in Table 11.

Table 13: No Adhesive Manufacturing Method

STEP	DESCRIPTION	
1.	After cutting each individual layer (Steps 1-4) of Table 9, mark off a 2" wide band in the middle of the layers. This is where the heat sealing and or sewing will be applied	
2.	If heat sealing: cut out the marked 2" band from step 1 and put two layers together (non-heat-sealing side facing each other). Use additional fabric cut-outs to sandwich the layers with the heat-sealing side facing each other. These cut-outs will be sealed together through the cut-out section.	

	If sewing: put two layers together (non-heat-sealing side facing each other). And sew in the marked 2" band region. Use an epoxy to fill holes created while sealing NOTE: the bonded fabrics will create the top of one layer and the bottom of another.	
3.	Repeat step 2 until there are 3 sets of the combined main body layers and 1 with the top and main body layer fused together	
4.	Use the hair straightening iron to fuse a 1" seam along one of the long edges of layers and install the valves following steps 6-10 in Table 9.	
5.	After installing the valves, use the hair straightening iron to seal the rest of the layers together with a 1" seal.	

6.4 Challenges and Future Considerations

The manufacturing phase presented lots of challenges. First, it is very important that when cutting the layers, you make sure to have clean consistent edges that all align. This helps to make sure you don't get any overlap or crimps when you seal the inflatable together. Another important step in the manufacturing process is to always test the seals that you make and make sure you are getting very even and consistent seals. This will help to make sure you don't have any leaks which might be hard to fix later. This also helps to ensure that your seals will not peel back during inflation. Any inconsistencies in the width of the heat-sealed seam can cause stress build-ups and can sometimes peel back giving you a slightly smaller seam than desired. Both the problems with the edges aligning and the consistent seams can be fixed by making sure you are going slow and being careful about how you are cutting and putting everything together.

One of the other challenges that we had when manufacturing this product was getting the adhesive to maintain a strong hold on between the layers. Through lots of testing and research, we found that adhesives have a very hard time curing to or bonding to nylon fabric. After further research, we found that Lamcotec offers a "kiss-coat" polyurethane backing that they can apply to the surface of the nylon fabric. This will, in turn, allow urethane-based adhesives to be able to bond to the fabric. Additionally, there are a couple of different techniques for assembling the inflatable device that does not require the use of adhesives. Such assembly methods are detailed out in Table 13. For future mockups and final design products, all the listed assembly methods should be tested in order to determine the strongest, safest, and most cost-effective solution. For the prototype model, we used a clear silicone adhesive that was able to provide a reliable bond to the nylon fabric for a prototype model without the polyurethane coating.

7 Design Verification Plan

To verify our design, we first start with reviewing the project statement as well by reviewing the initial wants and needs list for the product. Next, a list of tests designed to verify the design objectives laid in the objectives section (Section 3) has been created to further confirm the validity of the design. Table 14 shows the intended steps for the verification test plan as well as a description for each plan and if the criteria were met.

Table 14: Design Verification Test

Design Objectives	Test Description	Acceptance Criteria	Testing Verification	Pass/Fail
Reduced Strain	We intend on utilizing the NIOSH lifting equation to calculate ergonomic risk with and without the chair. We also plan on testing any lifting devices the fire station already has.	NIOSH lifting equation determines the lift is within the acceptable limits for all observed lifts performed with the chair at the fire station.	Although we were unable to perform actual lifting tests, the device can lift the patient to the design height which when used in the NIOSH lifting equation does, in fact, reduce the NIOSH number to a safe lifting load.	Based on the NIOSH lifting equation the device does reduce strain on EMS, however, further field testing is required.
Leak before burst condition	Verify through Instron testing that the fabric provides a safe "leak before burst" condition.	The inflated device must have a failure mode that confirms it will leak before bursting to ensure the safety of anyone on or near the inflatable.	Instron testing showed that at a heat-sealing feed rate of 2 - 8 in/min the heat-sealing material was stronger than the fabric and that the fabric ripping was the mode of failure. The test results showed that the fabric would slowly rip and continue to hold pressure as the device began to deflate. See Figure 18	Pass
Lifting Capacity	Incrementally increase the load from 450 – 700 lbs without fail.	The chair must successfully perform all lifts without fail up to 750 pounds. All seams will be checked afterward for leaking.	The final mock-up of the inflatable was not able to be fully tested as the material did not have the proper coating for the adhesives to work. Instead, each layer was tested individually to 800 lb and held up. It is safe to say that with the appropriate material the whole device can lift 700 lb however, further testing will need to be done to confirm this.	Pass-with further testing needed
Lifting Capacity Continued	At the maximum load, verify that the adhesive strength is enough to bond the layers and handles to the device.	The axial and "peal" strength of the adhesive should be stronger than any loads expected by the device.	The prototype version of the device used fabric unsuitable for adhesive purposes. The adhesive used was tested to a load of 40 lb. Further testing will need to be performed to confirm that the company's urethane coating will provide adequate adhesion to bond the layers.	Fail – further testing with appropriate material.

Size	Simple measurements of the chair's deflated size.	The chair must be roughly the same size as a large backpack. Or under the predetermined max allowable of 3.5 ft^3	The folded and measured device is confirmed to be within the allotted size requirements for the packed device.	Pass
Fill Speed	Calculations regarding fill rate are being performed but our fill speed will not match the rate expected from the manifold	Although the device is not used in an emergency where time is not critical, it is desired to maintain inflation time within +/- 2min of the leading Manger product.	The prototype version of the device did not have the proper connection to the SCBA tanks. For this version, a small 18 V air compressor was used to inflate the device. The air compressor was able to fully inflate the chair in 20 min. Simple calculations, however, show that at a higher pressure from the SCBA tank, the inflate time can be reduced to < 5 min	Further testing needed on the final product
Required Personnel	After internal testing this device will be brought to the fire station for dry runs.	Must be useable with a max weight individual with only 2 personnel.	Due to the unforeseen complications with the adhesion possess along with not being able to obtain permission to do live testing, the device was not tested for this scenario.	Needs further testing.
Weight	Measuring the deflated weight will be done on a scale.	Deflated weight must be under the allowable max of 20 lbs.	Measurements show that the final product weighs roughly 18 lb.	Pass
Washable	To determine ease of washing, we will contact Lamcotec to verify which detergents are safe to use on the fabric and test	Must be able to be cleaned with one readily available detergent.	Lamcotec fabric company confirmed that the fabric can be washed with standard household cleaning products which will not damage the fabric.	Pass
Comfortable	If possible, we would like to lift all members in the senior project class that volunteer to be lifted in our finished prototype and answer a yet to be determined survey	Not yet developed due to the unforeseen complications with the adhesion possess along with not being able to obtain permission to do live testing, the	Although no live testing was performed, members of the Air Chair team tested individual layers by laying on them and the product felt secure and comfortable.	Pass – Further testing and survey to be done

	regarding the comfort of the chair.	device was not tested for this scenario.		

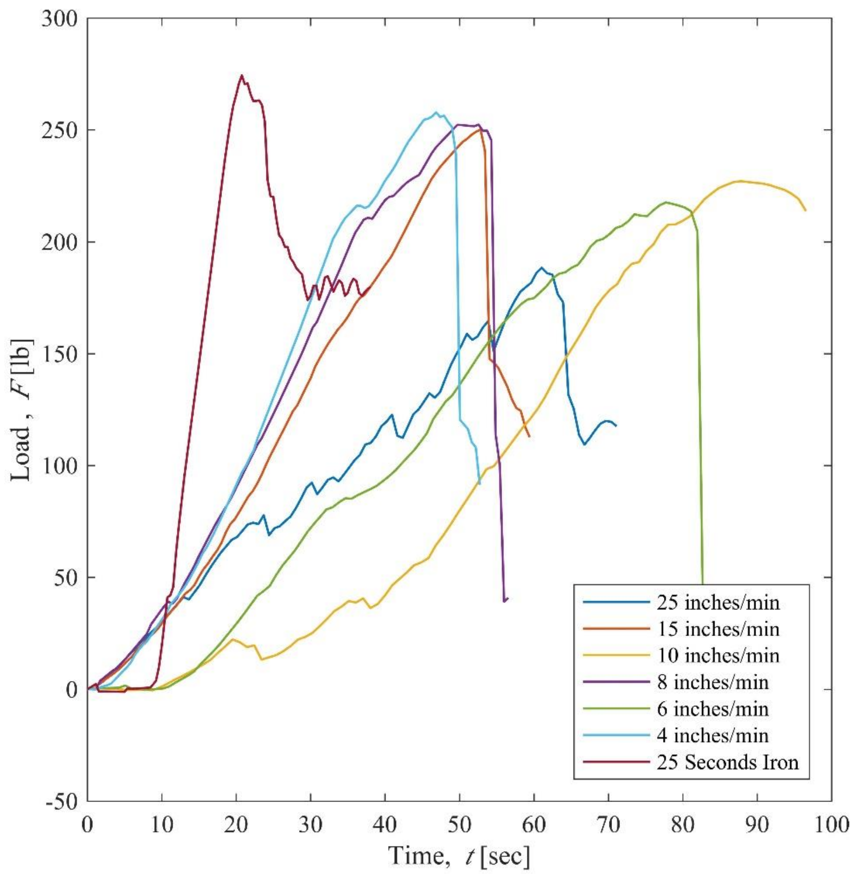


Figure 18: 400 Denier Seal Strength Instron Test

Testing the design is a big step in being able to improve on the functionality of the device. Appendix F and G show the design hazard checklist and the FMEA report. Although not everything on these reports can be tested, it is important to verify and test as many as possible. The biggest challenges for this project was being able to make sure the proper testing procedures could be set into place. With an un-foreseen issue of not being able to adhere directly to the bare Nylon fabric, the device was unable to be tested directly for weight, comfortability, and function-ability. Further development of the project would need to include all the tests that were unable to be met for this prototype version.

8 Project Management

As the completion of the project is finalized, there is value in recognizing what could have been done to improve the quality of specific aspects of this project. The intent of this section is to observe the project's path, identify areas in which the project could have used more attention, and consolidate what was learned from those experiences. Background knowledgeand research has allowed for a more fully designed project. However, failure through experience is an important stepping stone towards a successful project. This section of the paper will outline a qualitative completion of the project as well as outline further considerations and improvements for future project management.

8.1 Further Considerations

As part of any project, there are always aspects of the project's progression that could use improvement. Outlined in this section will be general considerations learned through oversight and what would could be done in the future to alleviate them.

When consulting a manufacturer about a new material, or part, that nobody in the project's team has experience handling, explain to the manufacturer every aspect of your project. Disclosing the purpose, requirements, and capacity for the need of any new material allows the manufacturer to best suit the team with the product they need. In hindsight, this was one of the largest components of the project's hindrances. While heat sealable nylon fabric was a great product that was within specification for most of our building material requirements, it came at an unforeseen cost. Nylon is a synthetic silky thermoplastic material that when woven creates an elastic, lightweight, high strength fabric that is water resistant; resulting in a naturally adhesive repellent surface. This untested quality of nylon caused a delay in build time and a haste to source an adhesive that could bond nylon fabric together. A call to a technical consultant at Lamcotec, a fabric manufacturer, revealed that nylon is, in fact, a difficult fabric to work with when trying to adhere two surfaces together. To alleviate this reoccurring problem, Lamcotec offers a polyurethane coating for these types of applications. If the fabric manufacturer had a better understanding of our needs, specifications, and requirements our delays and hindrances could have been avoided. Additionally, this blunder could have been resolved earlier in the project's timeline if the validity of the design decision, to use an adhesive between two nylon fabric surfaces, would have been tested and verified earlier.

Before committing to a final design decision, validate the decision through testing. Confirming final design decisions through small scale testing saves time and resources when the project is closer to the end of its completion. For the Atlas Air Chair project, the testing done was with respect to the fabric's tear and seam strength. During testing of manufacturability, the team tested for burst strength, failure modes, and manufacturing methods. However, testing for adhesive bonding between layers was never validated. Hence, the delay in build time and ultimately a delay on the completion date. This leads to the final general consideration learned through project management - keeping a schedule.

Keeping a project schedule, as detailed as possible with strict deadline, was a key component in keeping the team on schedule. The irony in creating a schedule for a project that is new to a team is trying to account for things that one has never encountered. The best way to approach this is to create a schedule with as much detail as possible and deal with the unknowns as they arrive.

8.2 Timeline and Deliverables

Moving forward from the final design the team has completed a functional prototype based on it project specifications and multiple design iterations. Through the manufacturing stage of the project, the team encountered unforeseen challenges with adhesives that hindered the design in this iteration. However, looking forward the application of the polyurethane coating, changing materials to PVC, or the redesign to heat-seal layers together would all alleviate this issue.

Table 2 can be used as a checklist to quantify if those specifications where met with the functional prototype. In Table 14: Design Verification Test, the categories in which the final design completed the targeted goals were in lifting capacity, packaging size, overall weight, water proof, and cost. Lifting capacity and packaging size are attributed to the nylon fabric of which the inflatable design was created. The heat-sealed seams were resilient enough to hold form and withstand pressure vessel loads. Additionally, the use of a nylon fabric allowed for a condensed packaging size when the device is not being used attributing to its relatively small packaging size. The device is still relatively easy to use; featuring a single input and output source. The cost of this functional prototype was kept below projected production cost through in-house manufacturing and low materials cost. The category in which the working prototype did not meet the requirements was time to inflate. Currently, the total time to inflate our working prototype is roughly around 5-6 minutes, which places the design out of target. This is due to having individual valves on each layer without having a central manifold from which all layers can be inflated simultaneously. Finally, while the design is waterproof and can be power washed, it is not advised to machine wash the device because of effect of heat on adhesives.

9 Conclusion & Recommendations

The goal of this design project is to create a prototype that can safely and quickly lift overweight individuals by emergency medical service personnel. A need was established through research showing that a significant majority of injuries EMS personnel receive is to the lifting of heavy objects, patients included. Further background research was done to show that the current project being used do not meet the needs or wants of the customer base and that there is indeed a place in the market for this product. After thorough background research, the team came up with a list of conceptual ideas that were further narrowed down by decision matrices. Through preliminary calculations and initial material testing the team narrowed down the design ideas list to a set of only two final ideas. These ideas were then refined and combined to create the final design. This design meets the wants and needs listed established in Appendix D and proved to be a strong design throughout the project. Prototyping of the product proved the feasibility of the design so that the team would be confident with moving forward. This report laid out the project goals set in place by the design team as well as the steps and process taken to establish a key idea that solves the problem statement. The report also contains a timeline for the project with key deliverables along the way. To ensure that the project has been completed a set of tests and key benchmarks were performed. Through iteration, a prototype was created based on a reexamination of the customer's expectations and a better understanding of the problem. The expectation for this prototype was to meet the goal of designing a product that could safely and quickly lift overweight individuals and that the design would be refined in later iterations for mass manufacturing.

This project was a success as far as designing and creating a functional prototype to meet our design goals is concerned. The design can hold/lift the desired weight (700 lb) with a factor of safety while also being collapsible to save space on the fire engines. According to Lamcotec the fabric is washable with an array of standard detergents and should have little to no wear when used appropriately, thought excessive strain applied to localized areas can jeopardize the fabric. This, however, is not a hazard as the test showed that even a rapid deflation of a loaded system would be caught by the subsequent parallel layers. Though we were unable to utilize a SCBA tank to fill the device based on calculations and test run we believe a full fill time under 5 minutes is easily accomplishable with a single fully pressurized tank. The device is also lightweight and can be very easily carried by EMS personnel. Finally, according to our simulations, using the NIOSH lifting equation, the device also greatly reduces the strain on EMS teams. For these reasons, the design team considers the Air Chair a successful first step in the process to bring a new product to market that could be utilized by emergency medical service districts across the nation.

In building the prototype the team was able to identify a few difficulties that inflatables pose to standard manufacturing processes. One of these difficulties includes how to most efficiently seal nylon pack cloth backed with Lamcotec's heat sealable laminate. Also, with the help of Lamcotec material information and our own testing, we were able to validate that this fabric is more than strong enough for our purposes.

Though the team worked hard not all issues could be resolved within the predetermined timeline. What was left undone and still needs to be completed includes getting a PE to sign the device is good to be used in real situations, redesign or material selection for the optimal way to attach layers, and how to create a valve manifold system that would work with the different firefighter SCBA connections.

The current prototype though capable of holding the weight in our tests is not a device that is ready for use in the field. Several steps are needed to make this possible and would likely require not only a professional engineer to sign off but several improved iterations on the current design. After these steps have been completed a fire marshal and the legal team of his department would also have to agree to accept any liability that comes with the device which means extensive testing is likely required to prove its functionality and reliability.

Another issue that the team faced was the fact that our design underestimated how nylon's adhesive resistant properties would affect the design. Due to its structure nylon does not bond well with most industrial adhesives and those that do work are often, though not always, weaker than their standard counterparts. Realizing this after already receiving the raw materials meant that the team could not change to another material but could find the best solution for the nylon fabric. This resulted in a close choice of hot glue and a silicone adhesive. The silicone adhesive was ultimately chosen due to creating a more repeatable bond than hot glue. After realizing this we contacted Lamcotec to ask if they had any solutions to nylons adhesion resistance. The notified us that, like their fire-retardant coating, they also have an option to put a polyurethane coating ('kiss-coating') on the outside of the nylon. This would effectively solve the issue as it fixes the nylons adhesion issues without altering the other material properties of the fabric. Another option would be to switch materials. Vinyl is the other fabric that is highly used in the inflatables industry and is often the stronger of the two. This comes at a higher cost been the difference between the nylon with the additional coating may be negligible when done on a large scale. Other options include changing the manufacturing method. We laid out plans as to how this could be accomplished earlier in Table 13 but ultimately believe that this overly complicates the manufacturing process and wouldn't recommend it.

Another weak point of the project is that the current prototype did not utilize firefighter valve fittings. With the end goal of filling the air chair with a firefighter SCBA tank through a regulated manifold system, the current filling method falls short. Following groups will need to create a manifold system with ideally off the shelf parts that can regulate the 4500 psi SCBA tank down to the ~20 psi for our device without overly restricting flow. Note if the user is attentive the regulator may not need to go so low but with raising this the possibility of overinflating now becomes a possibility. The ideal manifold system has been hypothesized earlier in the report where the device works similar to the current regulators and controllers that firefighters already use for their high-pressure airbags.

If we were to start this project over again there are some choices that the team would do differently. First the team would have been more thorough when talking to the material vendor about all processes we planned to perform with their material, had we had this foresight we may have been able to avoid the problems that were to come with the nylon pack cloth by either being recommended to get the surface coating mentioned earlier or possibly choosing an entirely different fabric based on which one fits the requirements better. Also, since small scale prototyping was entirely possible for the project it may have benefitted the team to create a ¼ scale model first. This would use less fabric and flush out all manufacturing questions prior to assembling the first full-scale parts saving time and materials. Note several test layers were created during the project to ensure that every layer could be reliably produced with little to no rework. These test layers, however, were never adhered to one another which would have been done had we created a ¼ scale complete test part.

Finally, the team fully believes that there is a need for this device in the market and would advise moving forward with its development. Next steps would include further iterations on the device targeting a new fabric choice and the filling manifold system. With the new choice in fabric also comes the need for a new adhesive but upon preliminary research, we found that there are many that fit the needs of this project. Thanks, and good luck to whoever takes this project over.

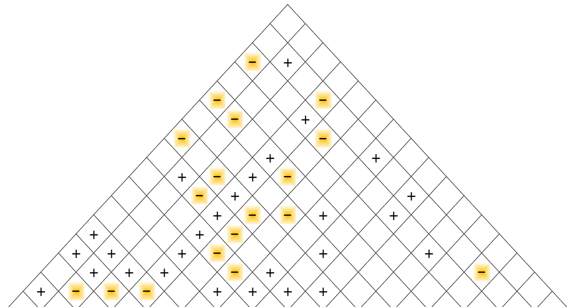
Appendix A - QFD

QFD: House of Quality
Project:
Revi 1
Date 4.19.18

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

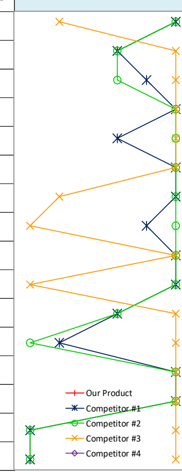


Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction of Improvement	▲	▼	◇	▼	▼	◇	▲	▲	▲	◇	◇	▲	◇			
HOW: Engineering Specifications	Max Load (lbs)	Lift time (minutes)	Packed Geometry (Volume)	Cost ($)	Weight (lbs)	Waterproof	Product life (uses/years)	Servicable	Ease of use	Portable	Manufacturablity	Use per charge (lift cycles)	Prior Patents	Usable on angled surfaces	Uses equipment already at firehouse	

WHO: Customers

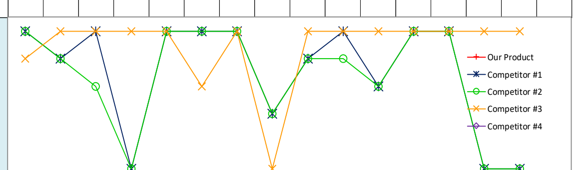
NOW: Current Product Assesment - Customer Requirements

Row #	Weight Chart	Relative Weight	Sponser	Manufacturer	Users	Designers'	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Our Current Product	Competitor #1: Manger Elk	Competitor #2: Manger Camel	Competitor #3: Doty	Competitor #4: *Product Name*	Row #
1		7%	10	0	10	10	9	Ability to lift 600+ lbs	●	○		○	▽		▽											5	5	1		1
2		5%	7	0	7	7	9	"Less than 2 minutes would be great"		●		●	▽							●						3	3	5		2
3		4%	5	0	5	5	9	"As big a a standard backpack"	▽		●	▽	○					●					●			4	3	5		3
4		4%	4	0	8	6	9	Lasts long						▽	●	●										5	5	5		4
5		6%	5	4	7	2	3	Color coded handels									○									3	5	5		5
6		6%	7	0	8	10	9	Useable by 2 or less people									●						▽			5	5	5		6
7		7%	8	0	10	10	9	Stable	○				○				●		○			●				5	5	1		7
8		5%	9	0	6	7	9	No lift by paramedics		▽		○					●		○							4	5	0		8
9		10%	8	7	8	5	9	machine washable				▽		●	○											5	5	5		9
10		10%	6	7	8	7	9	self powered	▽	●	○	○	○		▽	▽		●	○	●						5	5	0		10
11		9%	3	10	0	4	9	ease of manufactuability			▽	●		○	○	●			●							3	3	5		11
12		12%	8	8	10	8	9	cheap	●	●	●	●	▽	▽	○	▽	○	●	○	○						1	0	5		12
13		4%	10	0	5	3	9	ability to go to market	●	○	▽	●					●	●	●	○	●					5	5	5		13
14		3%	4	0	6	4	9	light enough for 1 person to carry				○	●				○									5	5	5		14
15		4%	6	0	8	3	9	Can be used in any terrain				○					●	○				●				0	0	5		15
16		5%	8	0	8	5	9	Uses as few "New" things as possible				●				●	●		●		●		●			0	0	5		16



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	700	3	2x2x3	1000 TBD	35 lb max	YES	10 years…	YES	Idiot proof	See weight and size	YES	2 to 5	NONE	0 - 45 Deg	Compatable with equipment	
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
Technical Importance Rating	240.22	277.54	179.51	411.42	113.42	129.89	145.53	182	340.75	275.11	260.18	180.88	81.908	95.162	82.158	0
Relative Weight	8%	9%	6%	14%	4%	4%	5%	6%	11%	9%	9%	6%	3%	3%	3%	0%
Weight Chart																
Our Product																
Competitor #1: Manger Elk	5	4	5	0	5	5	5	2	4	5	3	5	5	0	0	
Competitor #2: Manger Camel	5	4	3	0	5	5	5	2	4	4	3	5	5	0	0	
Competitor #3: Doty	4	5	5	5	5	3	5	0	5	5	5	5	5	5	5	

Current Product Assesment - Engineering Specifications



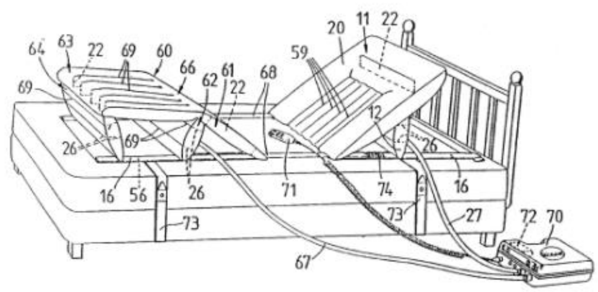
Column # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

APPENDINX B - EXISSTING PATENTS

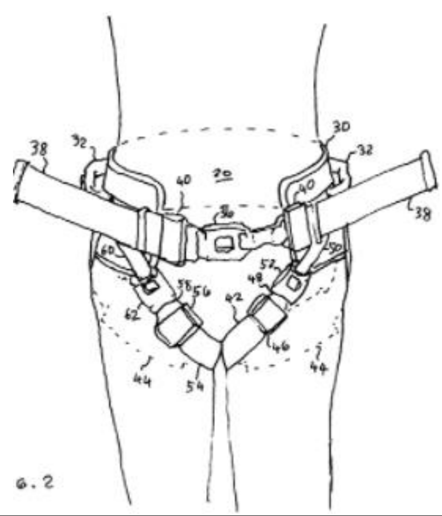
Patent No. 5970545
Description: This patent is assigned to Mangar Internation Ltd. This patent describes an inflatable apparatus bag structure that is comprised of two hollow limbs constructed and connected to assume a stable configuration when fully inflated.

Support apparatus for lift on beds, by D. E. T. Garman, R. E. Fletcher. (1995, May. 26). *US5970545*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US5970545A/en?oq=5970545+



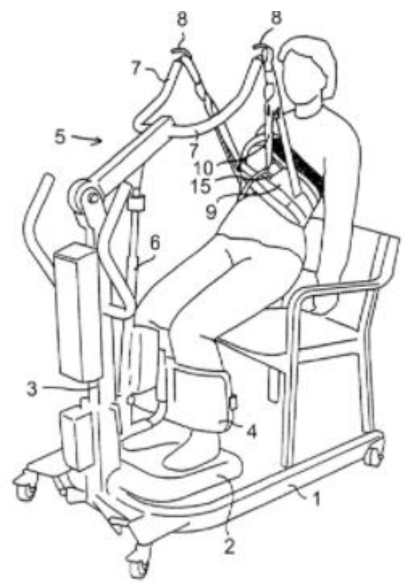
Patent No. US20090178194A1
Description: This patent is assigned to Delia Story. This patent describes a manual lifting pelvic harness for lifting or otherwise assisting debilitating patients has an adjustable belt, adjustable straps for encircling the thighs adjacent the buttocks, and fasteners such as tongues and buckles for securing the belt around the patient and securing the straps to the belt.

Manual Lifting Pelvic Harness, by D. Story. (2007, Dec. 11). *US20090178194A1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US20090178194A1/en?oq=US20090178194A1



Patent No. US6449785B1
Description: This patent is assigned to Liko Research and Development AB. The patent is an aid apparatus for raising a disabled person from a sitting position to a standing position including a wheeled base in the form of a U-shaped frame with a post, which surrounds at least partly the body of the person.

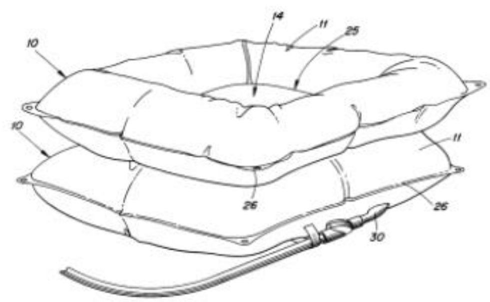
Aid for disabled persons to stand up, by G. Liljedahl. (1997, March. 12). *US6449785B1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6449785B1/en?oq=US6449785B1



Patent No. US6015471A
Description: This patent is assigned to Manger International Ltd. The patent describes an inflatable cushion made up of two welded segments in the shape of a ring. The cushions are joined together between a central chambers. An inlet fitting is attached to the bottom cushions for simultaneous inflation.

Inflatable Cushions, by R.M. Rimington and R.E. Fletcher. (1997, May. 15). *US6015471A*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6015471A/en?oq=US6015471A+

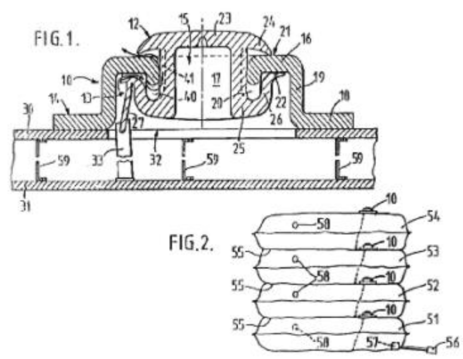
FIG. 2



Patent No. US6199827B1

Description: This patent is assigned to Manger International Ltd. This patent is for a valve assembly having a rigid mounting that allows fluid under pressure to flow past the flange of the first head accumulating fluid pressure in the opening behaving as a self-seal.

Expandable lifting device and valve assemblies for such lifting devices, by R.M. Rimington and R.E. Fletcher. (1996, May. 21). *US6199827B1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6199827B1/en?oq=US6199827B1+



teamgantt
Created with Free Edition

Appendix C - Gantt Chart

Spring Quarter

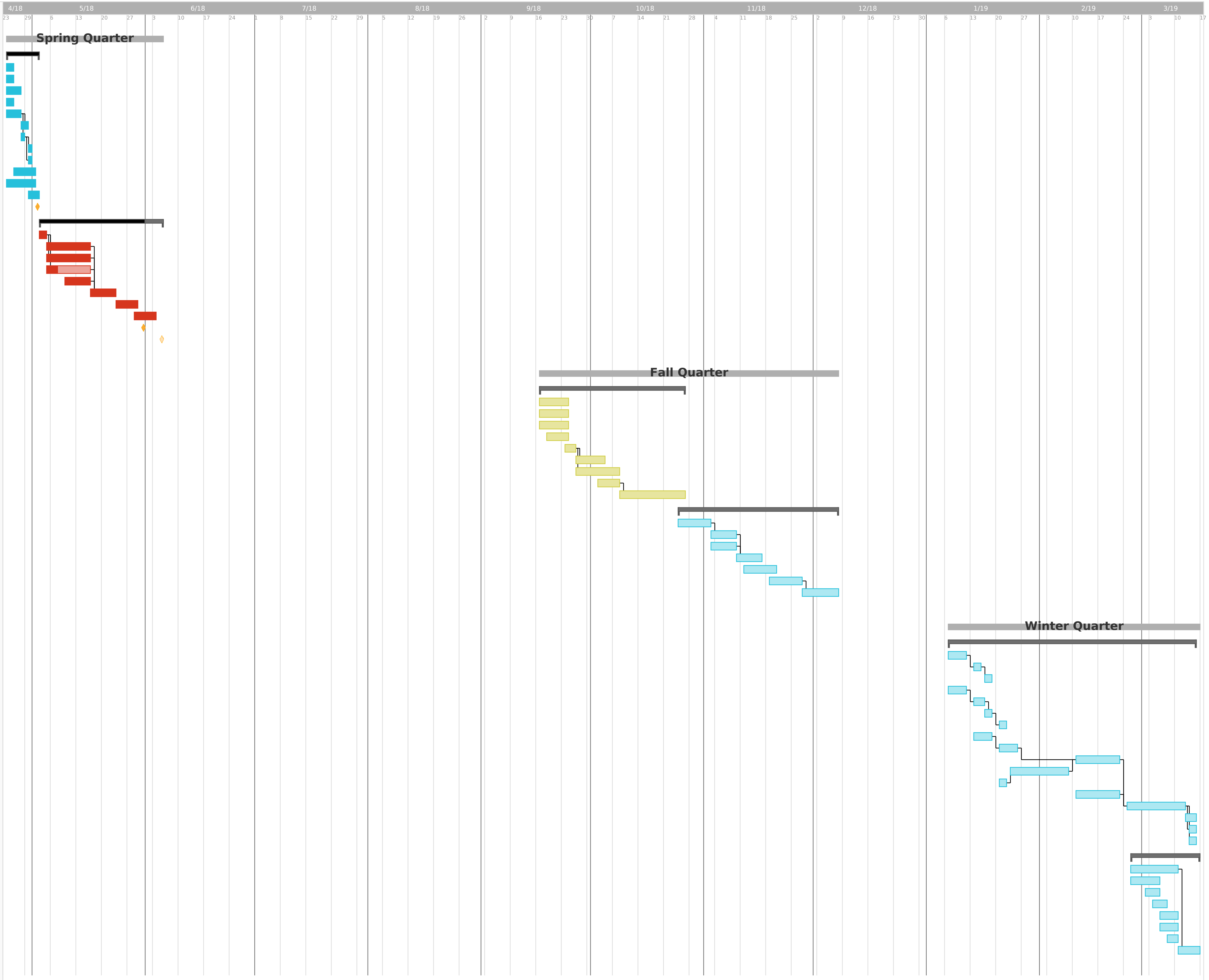
Task	start	end
Scope Of Work	**04/24/18**	**05/02/18**
Research Existing Products - Gio	04/24	04/25
Patent Search - Gio	04/24	04/25
Technical Literature and Review - Iz...	04/24	04/27
Research Need - Seb	04/24	04/25
Interviews -Seb	04/24	04/27
Needs/Wants list - TEAM	04/28	04/29
Problem Statement - TEAM	04/28	04/28
Initial Analysis of Problem - Tyler	04/30	04/30
Finalized QFD	04/30	04/30
Overall Design Process -TEAM	04/26	05/01
Works Cited Page	04/24	05/01
Compile Everything - TAM	04/30	05/02
Scope of Work Due	05/02	05/02
PDR	**05/03/18**	**06/05/18**
List Concepts	05/03	05/04
Quantitative Work for Concepts	05/05	05/16
Materials specifications	05/05	05/16
Manufacturing Specifications	05/05	05/16
Drawings / Layouts	05/10	05/16
Selection Process	05/17	05/23
Prototyping	05/24	05/29
Testing	05/29	06/03
Report Due	05/31	05/31
Presentation Due	06/05	06/05

Fall Quarter

Task	start	end
CDR	**09/17/18**	**10/26/18**
Further Product Design	09/17	09/24
Material Research	09/17	09/24
Manufacturing Research	09/17	09/24
Schedule	09/19	09/24
Selection	09/24	09/26
Drawings	09/27	10/04
Calculations	09/27	10/08
Analysis	10/03	10/08
Report	10/09	10/26
Prototyping and Testing	**10/25/18**	**12/07/18**
Test Seam Design and Build	10/25	11/02
Make Prototype	11/03	11/09
Make procedures	11/03	11/09
Test Prototype weight and pressure	11/10	11/16
Figure out how to pack it up	11/12	11/20
Implement changes	11/19	11/27
Final Prototype build	11/28	12/07

Winter Quarter

Task	start	end
Final Design Build	**01/07/19**	**03/15/19**
Cut and seal 1st layer	01/07	01/11
Test first layer	01/14	01/15
Redesign valve placements	01/17	01/18
Cut material for top layer prototype	01/07	01/11
Seal top layer prototype	01/14	01/16
Test top layer prototype	01/17	01/18
Redesign top layer prototype	01/21	01/22
List parts to order	01/14	01/18
Order components	01/21	01/25
Seal individual layers	02/11	02/22
Cut all material	01/24	02/08
Cut cardboard template	01/21	01/22
Test adhesives	02/11	02/22
Assemble final build	02/25	03/12
Design Verification	03/13	03/15
Internal Team Testing	03/14	03/15
Schedule time to test w/ Amanda	03/14	03/15
Final Design Report	**02/26/19**	**03/16/19**
Rough draft	02/26	03/10
Manufacturing plan	02/26	03/05
Edit final design	03/02	03/05
Project management	03/04	03/07
User manual	03/06	03/10
Add design verification	03/06	03/10
Add conclusion	03/08	03/10
Review	03/11	03/16



Appendix D – Full Wants and Needs List

Geometry:

Size

- Packaged Size: The packaged size will be about the size of an average carry backpack.
- Unpackaged size: The unpackaged size will be able to comfortably accommodate a variety of body size including the higher percentiles in height and weight.

Space requirements

- The product must be able to operate in tight quarters. Ie: small bathroom spaces.

Connection

- Possibility for modularity. Must package into one unit.

Motion/Kinematics:

Velocity

- Note: Leading brand can successfully operate "lift" in 3 minutes. The product must match or succeed on this value.

Forces/Torques:

Load

- Must be able to accommodate a range of weights to a maximum of 700 lb.

Deformation/stiffness

- Depends on material. However, must not fail under max load.

Material:

Materials

- Material in contact with patient must be an ergonomic polymer

Signals:

Input

- Remote Controlled (Ideally), manual or automatic actuation of valves is okay.

Displays

- If battery included. Available charge left/ charge needed notification. Pressure.

Safety:

Direct protection

- Overload fail safe in case too much load is applied
- Power loss fail safe in case power is lost to the device, it should not deflate automatically.
- Pressure Limit (if gasses used)

Operational safety

- Must be useable via two-person operation. (One preferred)
- Minimal to no lifting force required by operator, during lifting phase

Human Factors/Ergonomics:

Type of operation

- Remote Controlled or actuated valves

Sitting comfort

- Comfortable for patient in "sitting" or "laying down" positions

Shape compatibility

- Must comfortably accommodate a wide range of body types

Quality Control:

Possibilities of testing and measuring

- Max Loading
- Wear Testing
- First Hand Responder Operational Test

Application of special regulations and standards

- OSHA, NIOSH

Assembly:

Modularity

Wear

- Service checkup every quarter for pressure retention, valve fittings, surface wear
- Visual inspection after every use during cleaning

Destination conditions

- Must be operational in a variety of conditions. Ie. dirty, small, compact

Color

- Color coded handles for easy operational use

Maintenance:

- Maintainable/Serviceable in house with parts ordered from suppliers for chair
- Compressor should be sent out or replaced if failure occurs.

Service intervals

- Yearly service intervals

Exchange and repair

- Replaceable components

Cleaning

- Machine or Power Hose Washable

Costs:

Maximum permissible manufacturing costs

- Note: Average product cost is about $1000 - $2000

Cost of tools

-

Schedules:

End date of development

- End of Senior Project

Appendix E – Pugh Matrices

	datum	A	B	C	D	E	F	G	H	I
stable		-1	1	0	0	-1	0	0	0	0
Max Load (lbs)		0	0	0	0	0	0	-1	0	0
Lift time (minutes)		1	1	1	0	0	0	1	0	0
Packed Geometry (Volume)		0	0	0	0	0	0	0	0	0
Weight (lbs)		0	1	0	0	0	0	0	0	0
waterproof		0	0	0	0	0	0	0	0	0
product life		0	0	0	0	0	0	0	0	0
manufacturability		-1	-1	0	0	-1	0	1	0	0
use per charge		1	1	1	1	1	1	1	1	1
no patents		1	1	1	1	1	1	1	1	0
angular surfaces		1	1	1	1	0	0	0	0	0
raise to seated		0	0	0	0	1	0	-1	0	0
raise to standing		-1	0	-1	0	0	0	0	0	0
easy to use		0	0	0	0	0	0	0	0	0
self-powered		0	0	0	0	0	0	0	0	0
Totals		1	5	3	3	1	2	2	2	1

Appendix F – Design Hazard Checklist

Y N

☐ ✕ 1. Will the system include hazardous revolving, running, rolling, or mixing actions?

☐ ✕ 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?

☐ ✕ 3. Will any part of the design undergo high accelerations/decelerations?

✓ ☐ 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?

✓ ☐ 5. Could the system produce a projectile?

✓ ☐ 6. Could the system fall (due to gravity), creating injury?

☐ ✕ 7. Will a user be exposed to overhanging weights as part of the design?

☐ ✕ 8. Will the system have any burrs, sharp edges, shear points, or pinch points?

☐ ✕ 9. Will any part of the electrical systems not be grounded?

☐ ✕ 10. Will there be any large batteries (over 30 V)?

☐ ✕ 11. Will there be any exposed electrical connections in the system (over 40 V)?

☐ ✕ 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?

☐ ✕ 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?

☐ ✕ 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?

☐ ✕ 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?

☐ ✕ 16. Could the system generate high levels (>90 dBA) of noise?

☐ ✕ 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?

✓ ☐ 18. Is it possible for the system to be used in an unsafe manner?

☐ ✕ 19. For powered systems, is there an emergency stop button?

☐ ✕ 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The person being lifted in the chair is the mass	This is unavoidable so we will ensure that they do not fall due to tilting or sudden failure of the device		
In the event of sudden failure or being over pressurized if the valve broke off there is the possibility of it being launched due to the pressure inside the chamber	Ensure the strength of the valve attachment and design in a failure point that would not cause a projectile. Also use a valve that doesn't let the system exceed a designed pressure so this doesn't happen during the inflating phase.		
If for some reason the system became unstable and tilted the person would fall and be at risk for being injured	Design a system that helps center the mass or provide a way to prevent tilting i.e, tie downs or support.		
Yes if inflated in an unstable manner or in the wrong orientation it could cause the system to be unstable and fall	We will provide clear operating instruction and label the device so the orientation is clear at all times.		

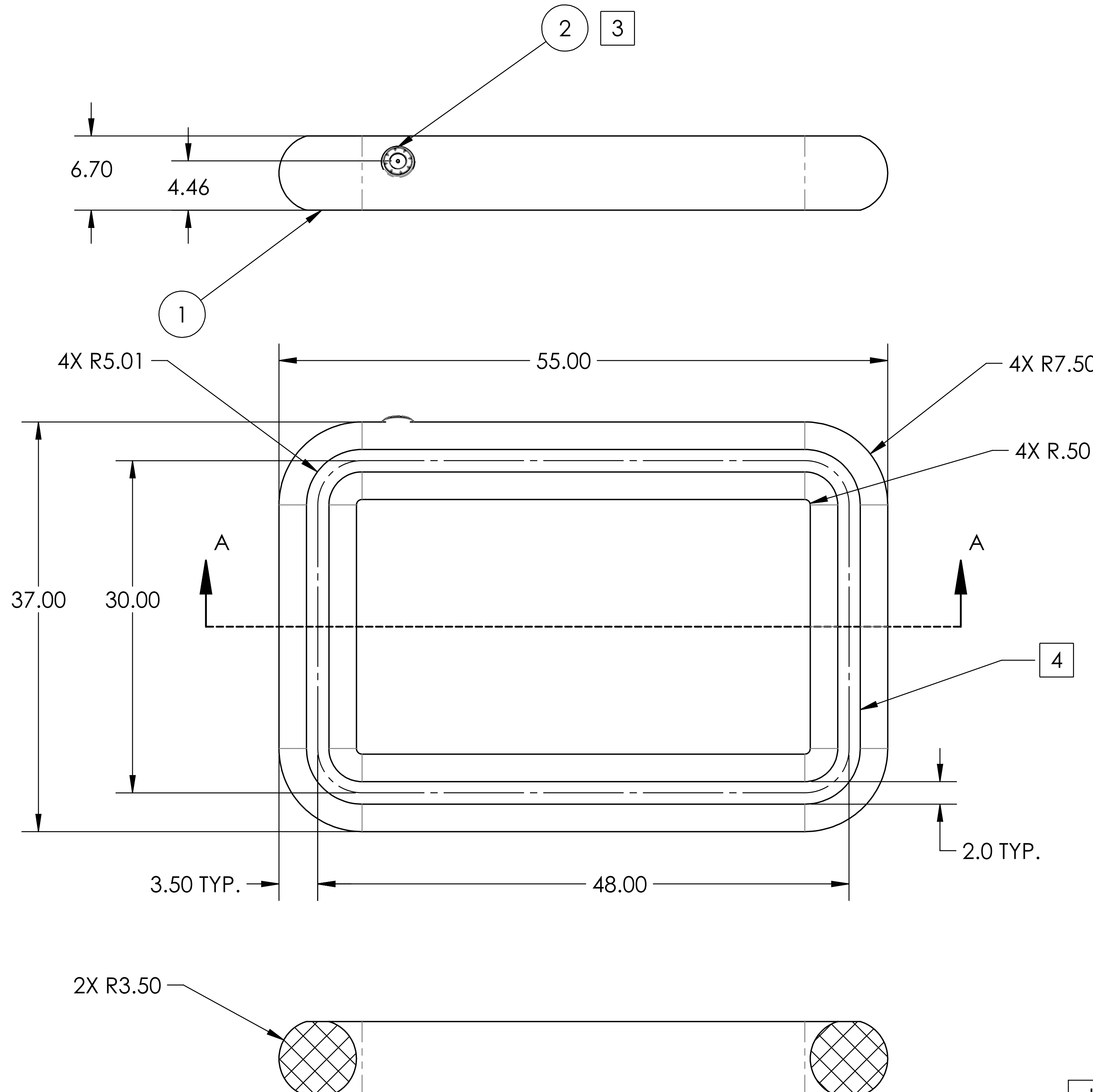
Appendix G – FMEA

System	Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Base	Structure and Stability	1) Structure is not stable 2) Part of structure collapses	1) EMS personnel do more work 2) Person falls 3) Person becomes uncomfortable	10	1) Shape is not good for height and weight of person 2) Not inflated enough 3) Inflates too much and becomes rounded on bottom 4) top heavy	1) Run tests on structure shape and stability with prototypes 2) make sure we can fill the vessle to a mix pressure to make the structure more rigid	2	1) test stability at various heigths and weight. 2) test dynimic stability as well during lifting	1	20	Fall Quarter Week 4	1) Dsign verified to support the given loads at the given pressures. 2) Further testing needs to be done on the prototype design for stabity of the top layer	2	2	6
	Hold pressure required to lift 700lb	1) Leaks 2) Pops 3) Cant maitian the pressure needed	1) Person falls 2) Person cant be lifted at all 3) Takes a long time to fill up	10	1) No good seals 2) Heat 3) cleaning degridation 4) person too large 5) tank pressure not enough	1) Test using 700+ lb the inflatable 2) add a pressure relief system	2	1) Test using 700+ lb the inflatable 2) Test till burst	1	20	Fall Quarter Week 2	Design and claclulations verified to hold the required pressure needed to lift 300 lb	1	1	7
	Washable	1) Not waterproof 2) Cleaning degrades the material 3) Material stains	1) User is uincomfortable 2) Clogs valves or other components 3) User becomes sick	6	1) Fabric not waterproof 2) Fabric degrades 3) fabric color is easy to stain	1) Make sure marterial properties ar waterproof 2) test corrothon of material	6	1) Test how easy it is to was the device using a hose	1	36	Fall Quarter Week 1 and Summer Research	Fabric confirmed to be cleanable by houshold detergants	0	0	1
	Air tight	1) Seams leak 2) Valve leaks	1) Becomes unstable 2) person may fall 3) Unsfae 4) long time to fill	10	1) Seals not made right 2) pressure to high 3) seal degridation	2) add pressure relief valve to protect seams 3) rienforce with epoxy	5	1) test at max weights and pressure and use wither water, soap, or smoke to see if there are leaks	8	400	Fall Quarter Week 7	The small pockets that have been tested are indeed air tite. Nee to prove this on the actual model	1	1	6
	Valve input	1) Not easy to use 2) Not adabtible to air bottle threads 3) bursts 4) clogs	1) Takes a long time to fill 2) user fall or become injured 3) cant use the device	7	1) Valve is too complicated 2) Valve not in a good spot 4) No addapter 6) Seal is too weak 7) Pressure was too high 8) Dirt glogging it	1) Research mutiple valve fittings 2) Find universal design and or adapters 3) add protective cap to keep contaminates out	10	Customer clinic	2	140	Fall Quarter Week 7	1) For this design we are using standard bick pump valves. 2) Research will go into what valves and addaptors would work best for the final design	3	2	4
	Pressure relief valve	1) Does not release at the right pressure 2) does not release at all	1) Injury to person/user 2) potential burst or leaking seams	7	1) Valve not calibrated to correct pressure 2) something blocking valve	1) Calibrate valve well below pressure limit	5	1) test by filling to releaf pressure multiple times to verify that it leaks out	3	105	Fall Quarter Week 7	1) Looked into 2 methods for this either adding relief valves on the inflatabel itself or one in-linr with the lifting hose	3	3	4
Platform	Support user	1) Falls 2) sinks in too much	1) User is injured 2) User has hard time getting out of the chair 3) User in uncomfortable	10	1) Not properly attached 2) Seams become weak 3) heavier object placed on the device	1) Reienforce seams with epoxy and stitching	10	Test at max weight and pressure	2	200	Fall Quarter Week 8	N/A	3	2	4
	Comfortable	Discomfort	Discomfort	5			5	physical test	1	25					
	Holds weigth	1) Falls 2) sinks in too much	1) User is injured 2) User has hard time getting out of the chair 3) User in uncomfortable	10	1) Not properly attached 2) Seams become weak 3) heavier object placed on the device	1) Reienforce seams with epoxy and stitching	10	Customer clinic	1	100	Fall Quarter Week 8	N/A	1	1	4
	Attatches to base	Attachment fails	Person Falls	6	1) not attached well or properly	1) Reienforce seams with epoxy and stitching	10	Phsical inspection	4	240	Fall Quarter Week 8	N/A	1	1	3

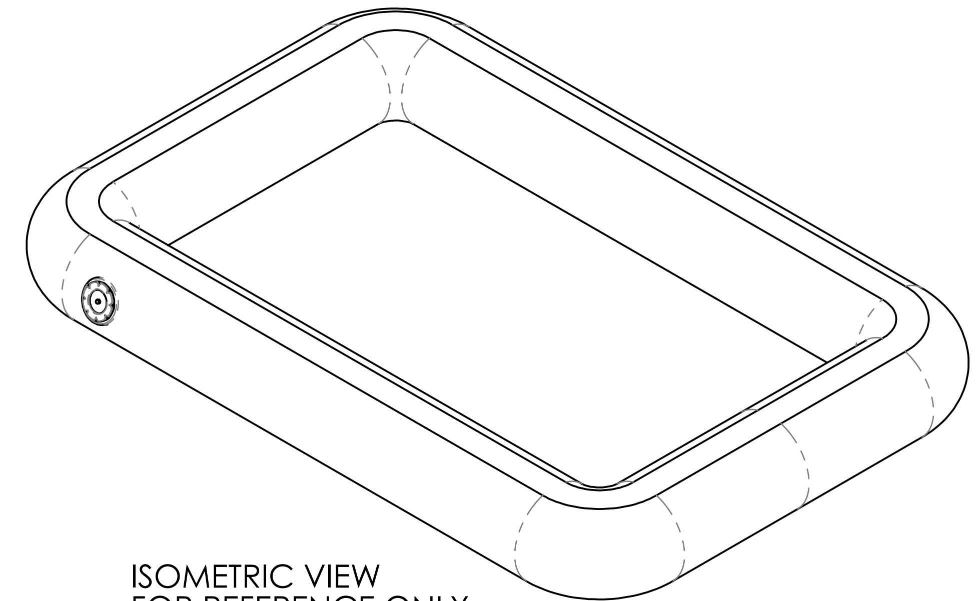
Appendix H - Purchased Parts Details

ITEM	DESCRIPTION	VENDOR	QTY	COST	Link
Heat Sealable Nylon	400D Ripstop (60” by QTY yards)	Lamcotec	15	$402.50	Lamcotec
Cardboard	60” x 48” - used as a template	Cal Poly Store	1	$8.00	
48” Ruler	48” Ruler	Home Depot	1	9.00	
Flat iron	2” wide hobby grade iron	Amazon	1	$22.47	Amazon
Square Ruler	90 Degree ruler	Home Depot	1	$8.00	
Valves/Wrench	HR Valves	NRS	5	$97.75	HR Valves HR Wrench
Handles	1.5” Wide Nylon webbing	N/A	4	$3.15	
Sealant	Loctite Boat sealant	Home Depot	1	$9.67	Loctite
Adhesive	RTV Silicone Adhesive	Harbor Freight	5	$15.42	
Adhesive	Test adhesives – Silicone, urethane, contact cement, sealant, hot glue	Harbor Freight	1	$34.56	
Adaptor	Schrader to HR valve	Amazon	1	$19.95	Adapter
Neoprene	Boot for valve to create seal	Amazon	1	$10.19	Neoprene
Pump	Used to inflate	N/A	1	$0.00	
Thread	Thread for seam	Beverly's	1	$3.00	Not Available
			Total	**$643.66**	

APPENDIX I - DRAWINGS



SECTION A-A



ISOMETRIC VIEW
FOR REFERENCE ONLY

NOTES:

1. ALL DIMENTIONS IN INCHES
2. TOLLERANCES
   .XX ± .50

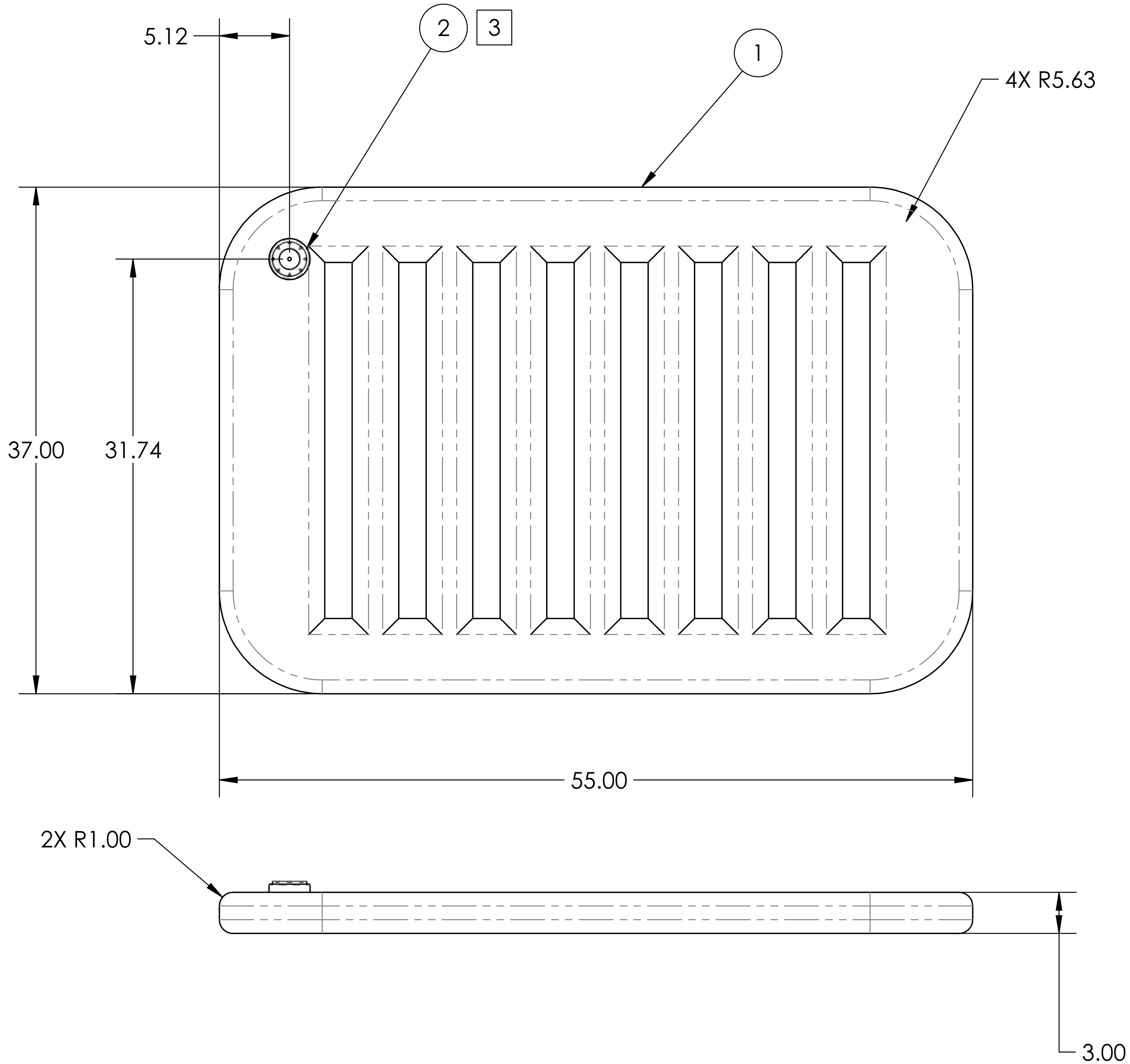
[3] INSTALL PER MANUFACTURER STANDARD

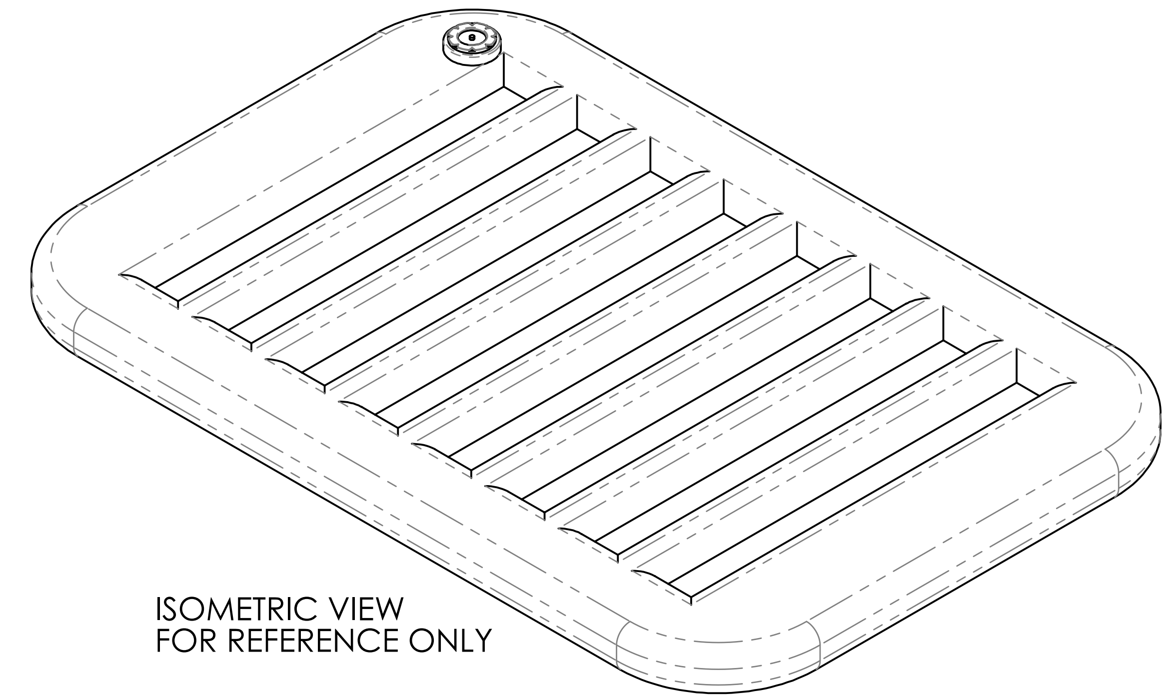
[4] APPLY ITEM -3 PER MANUFACTURER STANDARDS TO THE 2 INCH THICK REGION SHOWN ON THE INFLATABLE TO SECURE EACH LAYER TOGETHER

5. MATERIAL: 400 DENIER HEAT SEALABLE NYLON PACKCLOTH

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	AIRCHR001	AIR CHAIR LAYERS	1
2	38500.01	AIR CHAIR VALVES	1
3		LOCTITE BOAT EPOXY	-

Cal Poly Mechanical Engineering ME 429 - FALL 2018	Lab Section: 01	AIR CHAIR TEAM	Title: AIR CHAIR LAYERS		Drwn. By: SEBASTIAN GNAGY
	Dwg. #: 1	Nxt Asb:	Date: 10/16/18	Scale: 1:12	Chkd. By: AIR CHAIR TEAM





ISOMETRIC VIEW
FOR REFERENCE ONLY

NOTES:

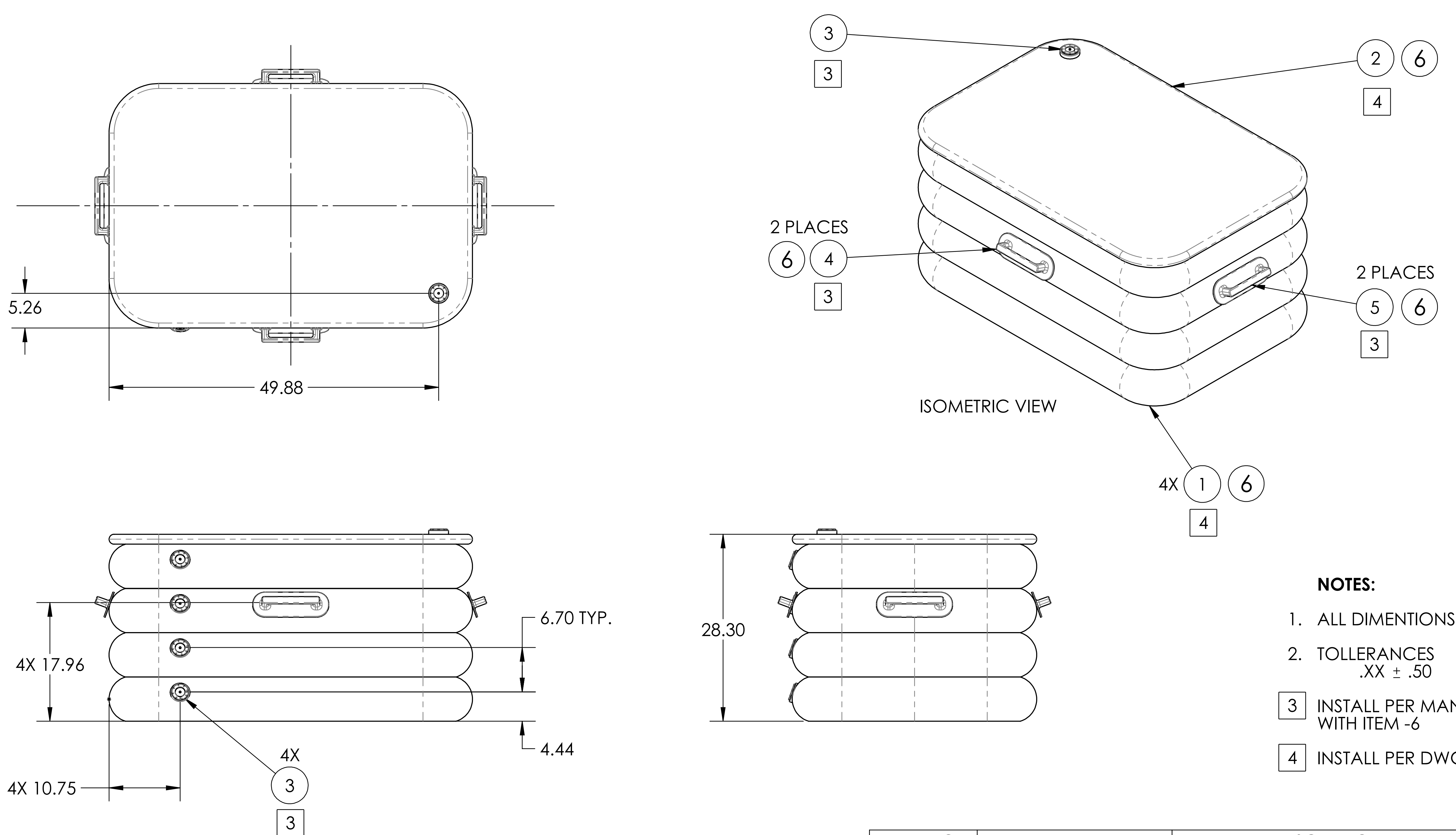
1. ALL DIMENTIONS IN INCHES
2. TOLLERANCES
   .XX ± .50

[3] INSTALL PER MANUFACTURER STANDARD

4. MATERIAL: 400 DENIER HEAT SEALABLE NYLON PACKCLOTH

ITEM NO.	PART NUMBER	DESCRIPTION	TOP/QTY.
1	AIRCHR002	AIR CHAIR TOP	1
2	38500.01	AIR CHAIR VALVES	1
3		LOCTITE BOAT EPOXY	-

Cal Poly Mechanical Engineering ME 429 - FALL 2018	Lab Section: 01	AIR CHAIR TEAM	Title: AIR CHAIR TOP LAYER		Drwn. By: SEBASTIAN GNAGY
	Dwg. #: 2	Nxt Asb:	Date: 10/16/18	Scale: 1:10	Chkd. By: AIR CHAIR TEAM



NOTES:

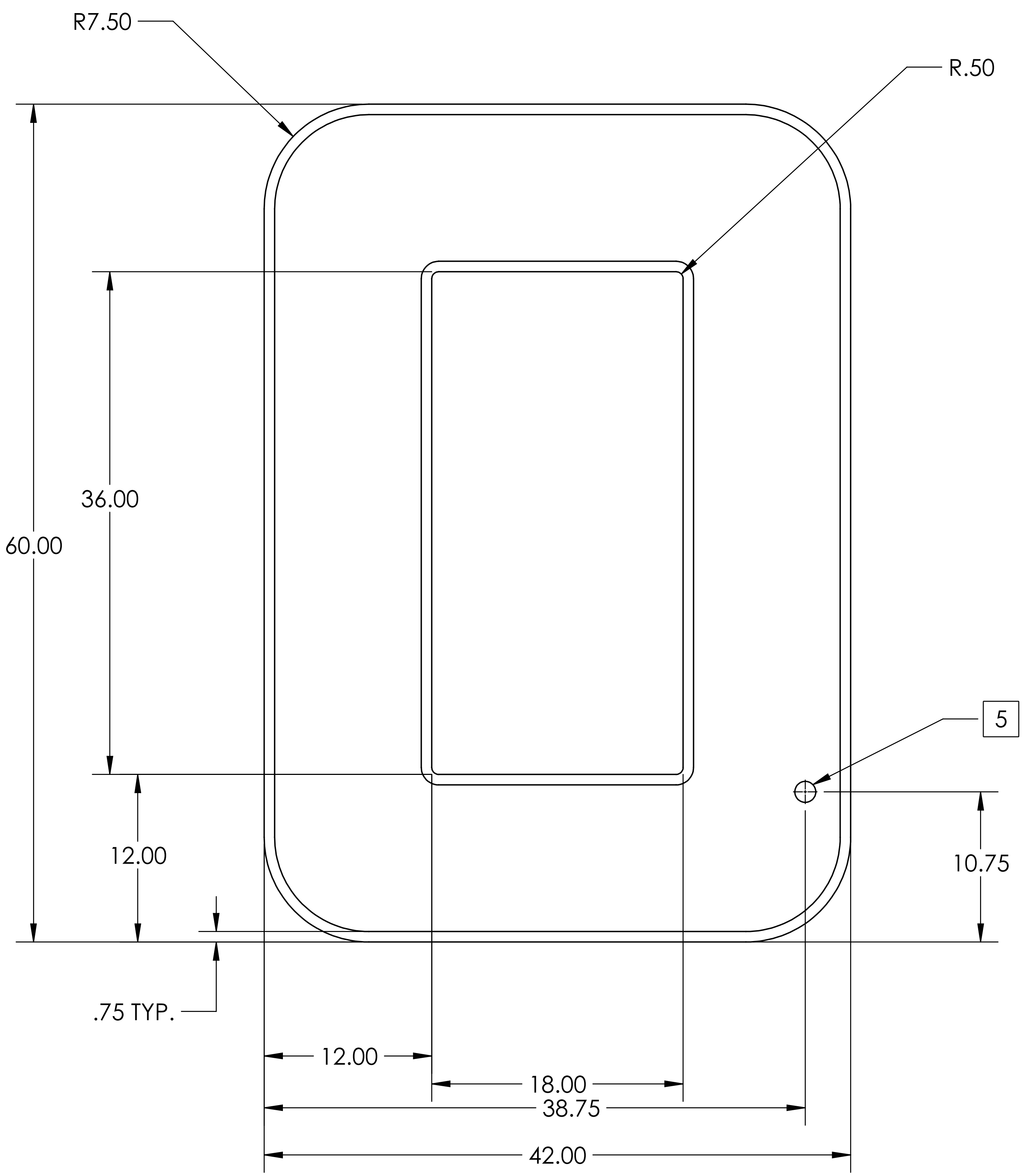
1. ALL DIMENTIONS IN INCHES
2. TOLLERANCES
   .XX ± .50

[3] INSTALL PER MANUFACTURER STANDARD WITH ITEM -6

[4] INSTALL PER DWG 10 WITH ATEM -6

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	AIRCHR001	AIR CHAIR LAYERS	4
2	AIRCHR002	AIR CHAIR TOP	1
3	38500.01	AIR CHAIR VALVES	5
4	AIRCHR004	AIR CHAIR HANDLES BLK	2
5	AIRCHR005	AIR CHAIR HANDLES WHT	2
6		LOCTITE BOAT EPOXY	-

Cal Poly Mechanical Engineering ME 429 - FALL 2018	Lab Section: 01	AIR CHAIR TEAM	Title: AIR CHAIR ASSEMBLY		Drwn. By: SEBASTIAN GNAGY
	Dwg. #: 3	Nxt Asb:	Date: 10/16/2018	Scale: 1:16	Chkd. By: AIR CHAIR TEAM

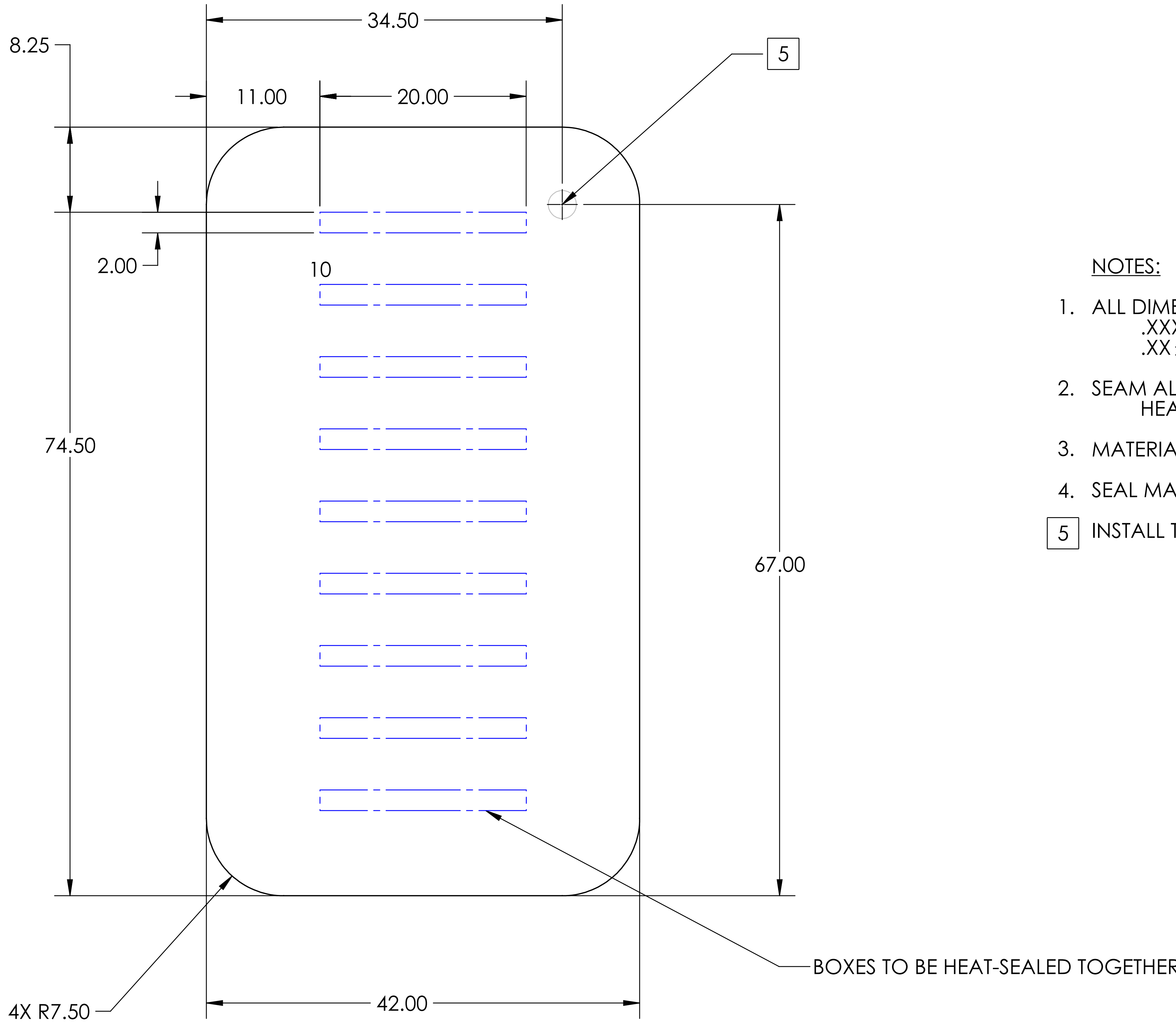


NOTES:

1. ALL DIMENSIONS IN INCHES
   .XXX ± .010
   .XX ± .10
2. SEAM ALLOWANCES:
   HEAT SEALABLE: 1.00"
3. MATERIAL: 400 DENIER HEAT SEALABLE NYLON PACKCLOTH
4. SEAL MATERIAL WITH A STANDARD HOUSEHOLD IRON ON THE HOTTEST SETTING

[5] INSTALL THE VALVE PER MANUFACTURER STANDARD WITH NEOPRENE PATCH

Cal Poly Mechanical Engineering	Lab Section: 01	AIR CHAIR TEAM	Title: LAYER FABRIC		Drwn. By: SEBASTIAN GNAGY
ME 429 - FALL 2018	Dwg. #: 21	Nxt Asb:	Date: 10/20/2018	Scale: 1:10	Chkd. By: AIR CHAIR TEAM



NOTES:

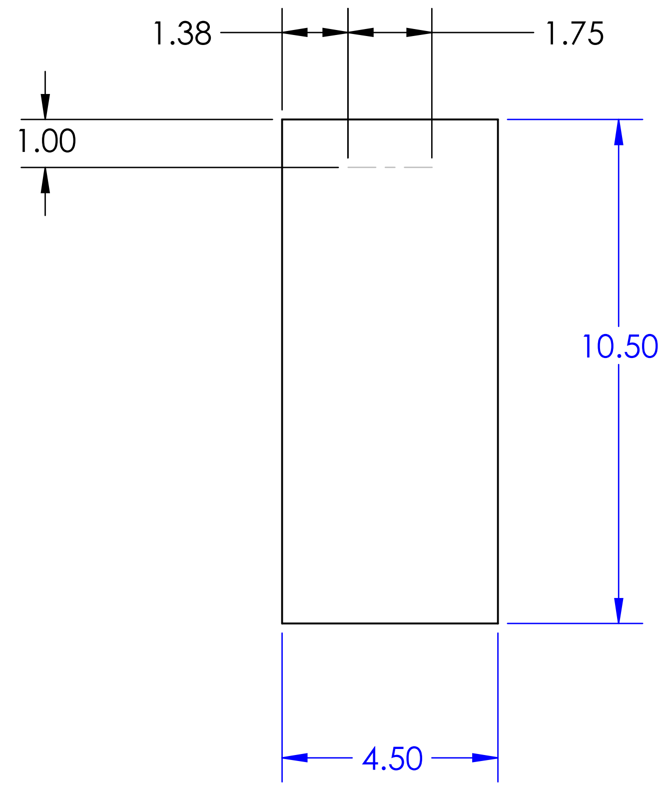
1. ALL DIMENSIONS IN INCHES
   .XXX ± .010
   .XX ± .10
2. SEAM ALLOWANCES:
   HEAT SEALABLE: 1.00"
3. MATERIAL: 400 DENIER HEAT SEALABLE NYLON PACKCLOTH
4. SEAL MATERIAL WITH A STANDARD HOUSEHOLD IRON ON THE HOTTEST SETTING

[5] INSTALL THE VALVE PER MANUFACTURER STANDARD WITH NEOPRENE PATCH

Cal Poly Mechanical Engineering ME 429 - FALL 2018	Lab Section: 01	AIR CHAIR TEAM	Title: AIR CHAIR TOP FABRIC	Drwn. By: SEBASTIAN GNAGY
	Dwg. #: 22	Nxt Asb:	Date: 10/25/18 Scale: 1:12	Chkd. By: AIR CHAIR TEAM

NOTES:

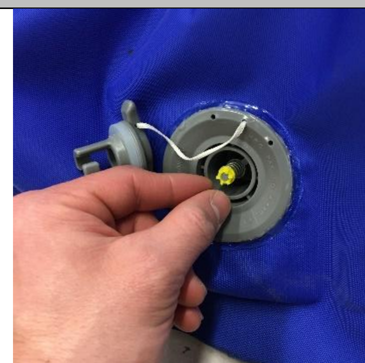
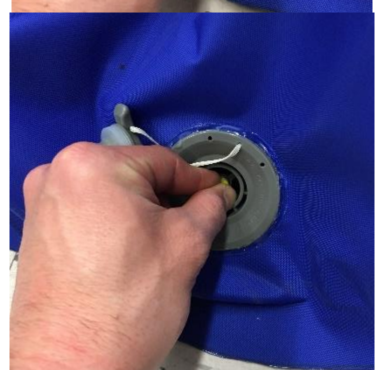
1. ALL DIMENSIONS IN INCHES
   .XXX ± .010
   .XX ± .10
2. SEAM ALLOWANCES:
   HEAT SEALABLE: 1.00"
3. MATERIAL: 400 DENIER HEAT SEALABLE NYLON PACKCLOTH
4. SEAL MATERIAL WITH A STANDARD HOUSEHOLD IRON ON THE HOTTEST SETTING



Cal Poly Mechanical Engineering	Lab Section: 01	AIR CHAIR TEAM	Title: HANDLE CUT-OUT	Drwn. By: SEBASTIAN GNAGY
ME 429 - FALL 2018	Dwg. #: 31	Nxt Asb:	Date: 3/12/2019 Scale: 1:4	Chkd. By: AIR CHAIR TEAM

Appendix J - Operator's Manual

How to Inflate the system		
STEP	DESCRIPTION	
1.	Open all valves by rotating the protective covers counter-clockwise.	
2.	Insert the Schrader bike valve adaptor (for the prototype version. For the final product you will use the SCBA tanks attached to a manifold system)	
3.	Inflate the top layer to ensure that the patient is fully secure on the inflatable device.	
4.	Inflate the main layers starting from the bottom most layer. Always Inflate slowly and watch the device to make sure the inflatable is inflating properly and is not being obstructed or pinched by any external objects.	

5.	Make sure each layer is fully inflated before moving on to the next layer.	
How to Deflate the System		
1.	With the prototype Halkey-Roberts Valves, press the center spring loaded tab inward and turn clockwise to lock the valve into an "open" position	 
2.	Starting at the opposite end of the device, push all the air from the inflatable working your way toward the open valve. If needed, you can roll the device up to help push out the air	

<table>
<tr><td>3.</td><td>Once all the air is out of the inflatable, close the valve by turning the center tab counter-clockwise until the tab springs back out.</td><td></td></tr>
<tr><td colspan="3">Packaging the device</td></tr>
<tr><td>1.</td><td>Before packaging the device, completely deflate all the layers so that the device lays completely flat.</td><td></td></tr>
<tr><td>2.</td><td>Orient the device so that the top layer face is exposed</td><td></td></tr>
</table>

3.	Tuck the top layers extra fabric so top layer folds in the middle.	
4.	Fold the end of the device that does not have the valves over the end that does so the valves are no longer visible, and the two ends meet.	
5.	Repeat the process until the you have successfully folded the device two more times.	

6.	Place the folded device into an appropriately sized storage pack so that the folded device is ready and available the next time it is needed.	 
Cleaning the device		
1.	Always clean the device after each use to remove any dirt or other potentially degrading compounds on the material.	
2.	Any standard household cleaners are okay to use on the fabric however, depending on the epoxy used, you should verify that the cleaning products won't weaken the adhesion strength.	
3.	The product is not machine washable however, we suggest adding a sacrificial, machine washable fabric to cover the device while in use.	
General Safety		
1.	Don't over fill the device	
2.	Any potential wear on the device should be treated and fixed before the next use	
3.	Don't leave out in dirt or sunlight	
4.	Always watch the device when in use and stand within reaching distance.	
5.	The handles should be used as quick positioning of the device only. They should not be used to lift the device while the patient is on the device unless safely tested and approved by an engineer to be strong enough)	
Repairs		
1.	Any repairs or replacements of the valves should follow the Halkey-Roberts recommended	

	procedures. Please reference their instructional videos on their website	

REFERENCES

[1] Audrey A. Reichard, Gamunu U. Wijetunge, Suzanne M. Marsh, Srinivas Konda. *5 Causes of High Injury Rates in EMS Providers.* NIOSH, NHTSA. Nov 6, 2017.

[2] National Fire Protection Association. *Reports. Fire Departmetnt Calls.* Fire department calls by type and year.

[3] Hoyer Lifts. 2018. Accessed on: May 2, 2018. [Online]http://www.hoyerlift.com/

[4] Binder Lift Product. 2018. Accessed on: May 2, 2018. [Online] http://www.binderlift.com/products/

[5] Doty Belt. 2018. Accessed on: May 2, 2018. [Online] http://www.dotybelt.com/

[6] Raizer – Raizer Lifitng Chair. 2018. Accessed on May 2, 2018. [Online] https://www.raizer.com/

[7] Manger USA | Inflatable Bath Pillow, Movement and Transport Aids. Accessed on: May 2, 2018. [Online] https://mangarhealth.com/us/

[8] T. Waters, V. P. Anderson, and A. Gerg, *Applications Manual for the Revised NIOSH Lifting Equation*. Cincinnati, OH: Division of Biomedical and Behavior Science, 1994.

[9] Health and Nutrition. (2011). [PDF] U.S. National Center for Health Statistics, p.135. Available at: https://www.cdc.gov/growthcharts/data/set2/chart-07.pdf [Accessed 30 Apr. 2018].

[10] "Anthropometric Data" University of Rhode Island, Kingston, RI, rep., 2017.

[11] A. T. Ozeren, *Human body dynamics classical mechanics and human movement*. New York: Springer, 2000.

[12] *NFPA 1901*. Dallas, TX: National Fire Protection Association, 2003.

[13] Support apparatus for lift on beds, by D. E. T. Garman, R. E. Fletcher. (1995, May. 26). *US5970545*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US5970545A/en?oq=5970545+

[14] Manual Lifting Pelvic Harness, by D. Story. (2007, Dec. 11). *US20090178194A1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US20090178194A1/en?oq=US20090178194A1

[15] Aid for disabled persons to stand up, by G. Liljedahl. (1997, March. 12). *US6449785B1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6449785B1/en?oq=US6449785B1

[16] Inflatable Cushions, by R.M. Rimington and R.E. Fletcher. (1997, May. 15). *US6015471A*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6015471A/en?oq=US6015471A+

[17] Expandable lifting device and valve assemblies for such lifting devices, by R.M. Rimington and R.E. Fletcher. (1996, May. 21). *US6199827B1*. Accessed on: March 24, 2018. [Online]: https://patents.google.com/patent/US6199827B1/en?oq=US6199827B1+

[18] Seattle Fabric Company. *Heat Sealable Fabric Sample Booklet.* Fabric supply company, Seattle WA. [online]: http://www.seattlefabrics.com/Heat-Sealable-Coated-Nylon-Sample-Pack_p_874.html

[19] C. J. Rothwell, Anthropometric *Reference Data for Children and Adults: United States, 2011-2014*, vol. 39. Hyattsville, MD: DHHS, 2016, pp. 10–25.